White Paper
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Vs. 0.4

Open Smart Home Framework

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1 Summary

The Open Smart Home Framework (OSF) is an architecture that is comprised of the components of the ZigBee (IEEE 802.15.4) standard family that are relevant for the home and the consumer. It combines these components into an architecture that allows for an easy to install, maintenance-free, reliable, secure and cost effective sense and control network implementation, without any visibility for the user of the different ZigBee network layers or other underlying components that are used.
The goal of the "Open Smart Home Framework" is to make ZigBee as successful, ubiquitous and easy to use as Wi-Fi is today.

2 Introduction Home Automation

What went wrong with Home Automation?

For decades, people have been promising the new smart home but little has changed. It is obvious that we have become significantly smarter after the last 40 years of explosive technology growth that has revolutionized communications and how we interact with our world. However, compared to where we thought we would be after 40 years of technology growth, we have made significantly less progress than we expected.
How come most homes are not much smarter today than they were 40 years ago? Our cars are smart – full of remote controls and monitors you can press a button and all your windows roll up. Why not that in your home? Press one button and all your car doors lock or unlock. Why can't our homes do that? You can now remotely start your car and warm it up. Soon your car will be able to automatically park itself and even drive itself down the street. Cars monitor the air pressure, fluid levels and even tell us when it is time to get them repaired. Why are our cars so smart and our homes so stupid?

The short and simple answer is that Home Automation is much more complex and more diverse than we thought. Maybe our expectations for Home Automation were too high. Maybe the tremendous waves of sophisticated technology development that we have experienced over the recent decades made us believe that Home Automations would be something simple to implement.
In all fairness though, in the last 40 years we have come a long way, and probably further than we think.
Our homes today are definitely more sophisticated than 40 years ago. Thermostats for heaters/air conditioners and remote monitored security systems are widespread. In our homes we have more and more sophisticated equipment considering the white goods (washing machines, refrigerators, ovens, etc.) and brown goods (TV and audio equipment, computers, games, etc.). On top of that: today there are 600 million homes connected to the internet and within each home, on average, probably five web connected devices. This means that 3 billion devices can share and exchange content, with the potential of profoundly changing our working and social lives. Despite these 3 billion connected devices in our homes, most of the equipment at home still operates in isolation from the internet, as the internet today is mainly focused on content sharing and distribution. The essential element that is still missing in today's Home Automation environment is the connectivity of this equipment, or even a step further, the understanding of useful applications that get enabled by such connectivity.

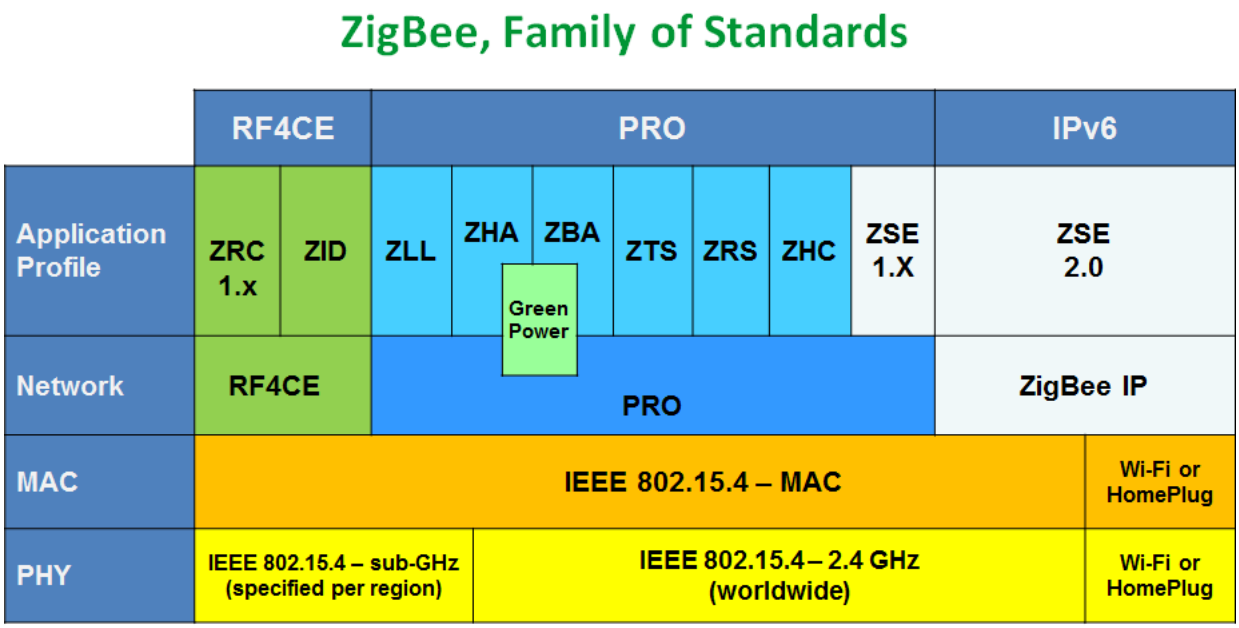
This white paper is about the architecture that will connect all the "other devices" in our homes: the Open Smart Home Framework (OSF). The purpose of this white paper is to explore how to most efficiently develop and build a solid and cost effective infrastructure (the plumbing) that will enable product builders to develop a plethora of new devices and applications for the smart home, as well as to develop a cost effective means for them to connect their existing in-home devices to web.

3 ZigBee

To understand the OSF and its options it is important to have a basic understanding of the ZigBee standard. ZigBee is a group of standards owned by the ZigBee Alliance, an organization with more than 400 (paying) members. This group of standards serves the standardization of sense and control networks in a wide variety of application domains (home/consumer, smart energy/grid, building automation, retail automation, and several others). All these standards have one element in common – they all use the same underlying radio technology and comply with worldwide radio certification rules. A ZigBee radio certified for use in the USA is also certified for use in Europe, China and the rest of the world.

There are many similarities between the ZigBee Alliance (addressing sense and control networks) with the Wi-Fi Alliance (addressing high speed content sharing and distribution networks). Both standards follow the ISO layered model and are based on open IEEE standards (defining the bottom two layers of the model). Both Wi-Fi and ZigBee offer similar ranges and the ability to transmit through furniture, walls and floors. Both use the 2.4 GHz spectrum. The main difference between the two is that Wi-Fi is building on the IETF for the network layers (TCP/IPv4/v6), where the ZigBee Alliance has taken the responsibility for standardization of the upper layers, up to the application level.

A complete overview of the ZigBee family of standards can be found in the picture below.



Legend

ZRC	ZigBee Remote Control	ZSE	ZigBee Smart Energy
ZID	ZigBee Input Devices	ZHA	ZigBee Home Automation
ZGP	ZigBee Pro Green Power feature	ZBA	ZigBee Building Automation
ZigBee IP	Internet Protocol	ZTS	ZigBee Telecom Services
MAC	Media Access Control	ZRS	ZigBee Retail Services
PHY	Physical Layer	ZHC	ZigBee Health Care
RF4CE	RF for Consumer Electronics	ZLL	ZigBee Light Link

As previously mentioned, the ZigBee MAC and PHY layers have been defined as part of the IEEE 802.15.4 work. The three network layers in ZigBee are RF4CE, PRO and Green Power, where Green Power essentially is a feature of PRO. A fourth network layer is under development: ZigBee IP (ZIP). These three existing layers are quite complementary.
RF4CE is intended for devices that require a lot of human interfaces (like keyboards, or remote controls), and low latency and low power are key characteristics. RF4CE also offers star-networking capabilities (point-to-multipoint).
PRO can be considered as “the backbone” network layer of ZigBee, where the key characteristic is mesh-networking with the capability to cover large areas with redundant connections and therefore reliable coverage.

Green Power is a feature of PRO and supports ultra-low power devices that are powered by energy harvesters or (non-replaceable) batteries. These devices are part of the network, but usually they are only included in network activity when they have to be, and otherwise they are completely shut down.

Another way to look at this is as follows: ZigBee PRO is defined as a backbone network for the sensors and actuators in the home. These sensors are often battery powered, while the actuators (HVAC systems, security alarms, kitchen appliances) tend to be mains powered. RF4CE handles the (mostly battery powered) human input devices, while for the most simple devices, Green Power does the job, even allowing these devices to work without batteries – on energy harvesters. These networking technologies have been shipping for several years now and in large volumes available from different sources: they have been "industry proven" and there are many chip suppliers offering hardware and software implementations of these technologies.

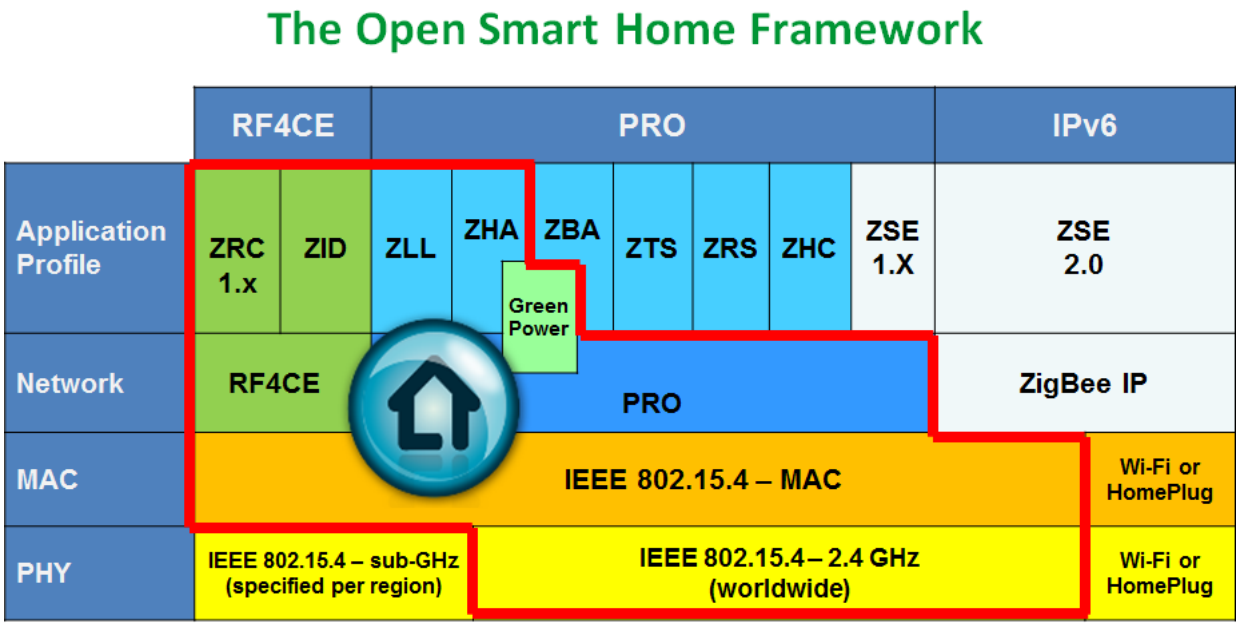
There are also hybrid/bridging technologies available, where one chip (node) can support all three network layers at the same time. One example of the many useful applications for such a chip is a set-top box that is controlled by a remote control (keyboard) for typical TV functions (channel selection, volume, etc.) and at the same time, is part of the home sense and control network, allowing the remote control to serve other equipment in the home as well (lights, curtains, heating/air-conditioning, etc.). This exists already as a proprietary solution from selected high-end brands, but standardizing this with ZigBee will make it mainstream and general accessible, as we are used to with Wi-Fi today. The set-top box is connected to the internet and can also act as the gateway to monitor and control all the devices on the sense and control network via smart phones, remotely from any place in the world.

As mentioned, the fourth network layer ZigBee IP is still a work in progress. Based on its success in the data world TCP/IPv4/v6, has been considered for ZigBee as well, but as the focus for TCP/IPv4/v6 is on massive data volumes (and high data rates), using this technology has so far been rejected as too costly and not economically feasible for the low-power sense and control networks. The jury is out on whether this ZIP will become a commercial success and how it will add to and differentiate from the existing three network layer solutions that exist today. In particular, the question is whether the additional cost for the incremental overhead to support high-speed data networks can be reduced enough to be practical for sense and control networks - the future will tell.

4 The Open Smart Home Framework

4.1 The OSF structure

The Open Smart Home Framework (OSF) is specifically defined for ZigBee based home management (sense and control) networks, with the goal of making ZigBee as easy to use as Wi-Fi is today. The focus of sense and control networks is not on high data rate (compared to Wi-Fi), but on availability: easy to install, maintenance-free, reliable, secure and cost effective.
The OSF is a subset of the ZigBee standards that specifically addresses those elements that are playing a role for the consumer in the home. Therefore, OSF is not a standard in itself, but is a framework that specifically addresses the needs and the coexistence of the different ZigBee standards within the home/consumer space.



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The OSF covers the communication between all the devices in the home that are not naturally related to content sharing or distribution. Wireless content sharing (internet, pictures, music, video, TV, VoIP, etc.) is the domain of Wi-Fi for which data rate requirements are dominant over any other requirements. OSF is for connecting all the other devices in the home that do not require high data rates. For example, low data rate devices and gadgets include everything from dishwasher controls to light switches, from motion sensors to door bells and from lights to thermostats. It is quite obvious that the dynamic range covered by these devices is of a different order compared to the devices covered by Wi-Fi. With ZigBee, we are usually talking about a limited number of bits to be transmitted at data rates of 250K bits per second, slow compared to Wi-Fi's data throughput of up to 600 Mbit/s, but very energy efficient!
With OSF, all these ZigBee connected gadgets and devices are brought together under one umbrella from which they can be reached from anywhere in the home, as well as from any place in the world.

4.2 The OSF Home Control Box

The centerpiece of Open Smart Home Framework is a Home Control Box (HCB), a (virtual) device that can be implemented on a Gateway, Set-Top Box, built into a TV set or any other device, as long as this HCB has a connection to the internet and makes every ZigBee device in the home accessible from any place in the world. This HCB also offers the function of network address translation (NAT). Contrary to common belief, not every node in the home will (have to) carry the burden of full IP addressing, as this would increase the cost of the end-nodes unnecessarily: see also the previous comments on ZigBee IP (ZIP).

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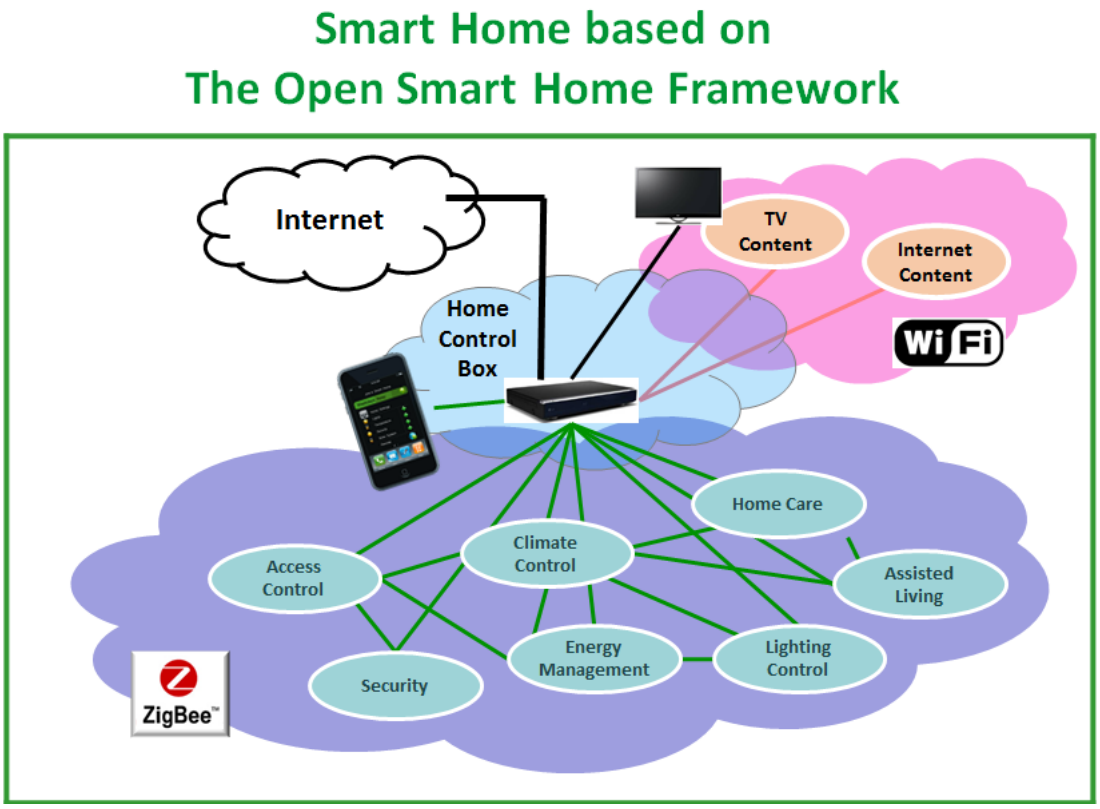

The next key element is that OSF assumes that the HCB, or the device(s) where the HCB is implemented on, is connected to (at least) a screen. In its most simple form, as it is already implemented today, is the connection from a set-top box to a TV screen. This element of OSF largely improves and simplifies the ease of installation, as well as the management of the home sense and control network. It is not necessary that the TV-screen has a ZigBee connection, as usually TV-screens are connected directly to the set-top box via HDMI, coax or video cables.

4.3 The OSF physical implementation

OSF is based on ZigBee in the 2.4 GHz band. The reason for this choice is that 2.4 GHz is the only open, worldwide standard frequency band that is available from multiple technology providers and that meets the requirements for indoor sense and control networks. This means that product providers will be able to offer single version of products that can be designed, certified and produced for the worldwide market, without requiring local hardware variants. By the way: the first Wi-Fi products were in the sub-GHz band but they never really caught on, because large (computer) companies wanted to avoid the logistics of multiple hardware products performing the same function, as that can make the difference between profit and loss.

It is well understood that the 2.4 GHz band is not dedicated for ZigBee alone and that in particular Wi-Fi has a strong presence in this band, which potentially could lead to interference or congestion. In this respect it is

important to recognize that Wi-Fi is significantly suffering from the congestion it is creating for itself, and that Wi-Fi developers are already moving significant amount of traffic to the also worldwide 5.2 GHz band. But the main thing is that the ZigBee traffic is so small compared to the Wi-Fi traffic that when considering it in the total occupation of bandwidth, ZigBee can be ignored.

4.4 The OSF networking

Because of the dynamic range of ZigBee home devices there are a variety of power requirements: AC mains power, battery power and energy harvesting, which have generated three networking layer implementations. OSF supports all three ZigBee networking layer implementations (RF4CE – battery/human interface, PRO – battery/AC mains and Green Power – energy harvesting). It is important to recognize that as a result of OSF handling of all the network layer interactions, the specific network layers that are used in a specific application are hidden from the end user. To the consumer, it is all ZigBee.
This is an essential feature of OSF, to meet the goal of making ZigBee as easy to use as Wi-Fi. In OSF the technology in the HCB (Home Control Box) takes care of the right interpretation of the message. The complexity for supporting the dynamic range of various ZigBee devices is hidden "under the hood" of the HCB. By knowing that all three layers can talk to each other, this enables product and system builders to make the most economic choices for the device's ZigBee communication technology.
Although ZigBee has mesh networking capabilities, these capabilities are not an essential part of OSF. As long as every node is within range of the Home Control Box, meshing should not even be required.
However, in certain situations (for instance in a large home), because ZigBee's innate meshing capabilities, OSF does not require any dedicated repeaters (like we sometimes see with Wi-Fi). When a node is outside the range of the Home Control Box, the meshing nodes in ZigBee will automatically function as a repeater. This way the meshing nodes function together as a wireless back-bone. However, in general use, as long as the range of the used RF technology in the nodes is of sufficient quality, meshing can be avoided and can be turned off, assuring proper latency of the total system.

4.5 The OSF supported applications

The OSF will support a selection of Application Profiles: ZRC (connecting Remote Controls), ZID (connecting other Input Devices: keyboards, mice, etc.), ZHA (Home Automation: supporting all other devices in the home) and ZLL (Light Link: for specific light controls). The main criteria for selecting these profiles were that these are the profiles that are currently connected to consumer applications. In the future, the OSF is open for including other profiles if they are supporting consumer devices in the home as well.
It is fair to admit that the ZigBee Alliance is still working to further harmonize the different vertical application profiles to generate the seamless ZigBee consumer experience. Significant steps are currently being made to have the standardization realities catch up with the simple expectations of how all the home devices can work in an integrated fashion with each other.
For obvious reason other domain application profiles like ZBA (Building Automation) and ZRS (Retail Services) are not included in OSF, as they are servicing different application domains. However, if need be, the OSF can be extended to these other domains as well.
It is important to note that ZSE (Smart Energy) is not part of the OSF. The reason is straightforward. Instead of being part of the consumer Home Automation, ZSE is an extension of the smart grid, a vehicle of the utilities to reduce their cost of generating energy, specifically to be able to spread the load of energy intensive equipment, like car rechargers, freezers and air conditioners. This has led for instance to very intensive security/privacy requirements for ZSE that have set it apart from other ZigBee home/consumer applications.
It is certainly feasible that ZSE output can be generated to be read into the OSF. However, the utilities currently only make energy consumption data available through their own web applications, using this as a customer retention mechanism. They have no incentive for make raw data available directly from the "smart meter" to the ZigBee home network.

5 Key Characteristics of OSF

Summarizing the key features of the OSF as described in the previous sections:

1 OSF is defined for one frequency band worldwide (2.4 GHz), allowing the development and production of world class products;
2 OSF assumes an input device (key board or remote control) and a display device (TV) as part of the network to primarily simplify the installation of the network;
3 OSF makes all the equipment in the home connect seamlessly and to operate in a way that one would expect;
4 OSF integrates the ZigBee home network with the internet and therefore makes each connected device controllable from any place in the home or from anywhere in the world;
5 OSF supports all the feasible networking stacks for battery-less, battery operated and mains power operated devices in a seamless way;
6 OSF provides full home coverage, if not directly, then via mesh networking, where mesh nodes function as repeaters.

These features lead to a set of key characteristics for the OSF meeting the Home Automation requirements as stated earlier.
In particular: OSF supports an architecture that makes make Home Automation systems very easy to install. In the last few years various simple device pairing mechanism have been developed, including proximity pairing, button-to-button pairing and button-less pairing that can all be easily monitored from a TV and controlled with a remote control. These mechanisms are highly secure and closed for outsiders, as they cannot be observed from outside the home, because they use state of the art standard AES encryption for all its data-communication.
A Home Automation system based on OSF is essentially maintenance free: either the networked devices are mains powered, or they carry batteries of which the battery life exceeds the life of the device, or they are battery free. At the same time the technologies used are highly reliable and robust. For example, a RF-based remote control is already significantly more reliable than the interference sensitive and line-of sight requiring IR-based remote controls.

Finally and probably most important: this open standard technology is very cost effective, leading back to the earlier discussions about why ZigBee in Home Automation is still waiting to become as common-place as Wi-Fi. As mentioned earlier, today there are 600 million homes connected to the internet. In each home there are probably 100 applications and/or devices just waiting to be connected, which means a stunning number of 60 billion devices that are expected to be connected to the internet within the next few years.

6 Summarizing

Looking forward is always a challenge. When we started with Wi-Fi, we only could dream of the average of five Wi-Fi devices per household that we find today. With ZigBee the world is going to change once again, and the OSF is defining the framework in which this change will take place.
It creates a context for which Cable and other Service Operators can equip their set-top boxes and other devices in such a way that they can build the connect points for the Smart Home, so they can extend their current portfolios with new service offerings like security services (alarm, access control), like energy management services (heating/air conditioning control or tracking consumption data) or home care (assisted living for an aging population). It encourages product builders to build products that leverage these entry points in the home and to build on it, creating a complete new retail and add-on business. It will also enable the development of new software applications that help turn our homes into really Smart Homes.

The Smart Home is becoming a reality, finally!