enocean® alliance

NO WIRES.
NO BATTERIES.
NO LIMITS.

DR DEAN ANTHONY GRATTON

Abstract

EnOcean's award-winning patented and battery-less, self-powered wireless sensor radio technology provides a robust, low cost and low power energy efficient solution for home, commercial building and industry environments.

'*Introducing the EnOcean ecosystem*' offers the reader a reflective and historical narrative covering the technology's relatively short and successful history, as well as introducing the benefits of EnOcean Alliance membership whilst sharing some of the attributes that succinctly characterises EnOcean's energy harvesting technology. What's more, we'll explore EnOcean's current product portfolio and discuss the technology's market scope. Likewise, we'll better understand how EnOcean fares with its competitors and examine several differentiators that uniquely distinguish EnOcean from its competition. Finally, we'll explore in some detail, the Dolphin hardware and software architectures, as well as the equipment profiles that provide EnOcean with its application-base.

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About this book

This document introduces the EnOcean ecosystem and its associated application scope and market landscape; its technical make-up, to include an overview of the EnOcean software protocol stack, its architecture and equipment profiles.

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- the page number and paragraph section where your feedback, suggestion and/or improvement applies;
- and finally, an explanation describing your feedback, suggestion and/or improvement

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INTRODUCING THE ENOCEAN ECOSYSTEM

TOWER 185 – FRANKFURT, GERMANY. The impressive skyscraper boasts 50 floors and 100,000 m^2 of rentable area. In all, 5,850 EnOcean energy harvesting devices are deployed throughout to realize an economically and strategically sustainable operation, making Tower 185 a next generation building. (Photo courtesy of Gregg Johnstun © 2015.)

1 Introduction

EnOcean is an *energy harvesting wireless* technology that is used primarily for building automation. However, the technology can also be applied across other industries to include transportation and smart homes (or domotics). EnOcean technology uses an energy harvesting technique, that is, the ability for a wireless sensor to derive energy from natural environmental surroundings using minor variations in the environment; for example, ambient light; the action of turning on or off a switch, or with the smallest change in temperature – are some of the harvesting techniques used to generate a sufficient amount of energy to not only power a device, but to store energy for sustained use. The technique is akin to *renewable energy* – something consumers and industries alike have become increasing aware of due to increased cost of energy and its supply. In Section 1.1, “What is renewable energy?”, we discuss how renewable energy is used to garner natural resources from nature to energise our increased consumption. With EnOcean utilising energy harvesting technology, it does not need to rely on batteries or other fixed power sources, in turn, reducing cost and the need for ancillary maintenance.

1.1 What is renewable energy?

Inescapably we are increasingly aware of the rise in cost of energy whether that’s electricity, gas or oil over the last few decades. With the demand on such resources with increased need and population growth, consumption on limited resources continues to rise and, alas, we’re abundantly aware that there isn’t an infinite supply. With this in mind, many, if not all, industries have been prompted to seek alternative energy solutions. Renewable energy is the ability to capture natural resources such as the wind, rain, sunlight and so on, and ultimately convert this natural energy into a sustainable and inexhaustible supply. The numerous low power wireless technologies that share the *Wireless Personal Area Networking* (WPAN) domain are, likewise, mindful of consumption and provide the

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consumer with the ability to use their products for longer and without the need to frequently recharge the batteries! Furthermore, innovators are equally responsible for offering consumers and the industry alternative energy source or provide more efficient transmission techniques which, in turn, extend battery life or reduce overall energy consumption. In essence, EnOcean's energy harvesting technology delivers an effective alternative, in turn, reducing its energy footprint with innovative techniques.

Figure 1-1: The EnOcean trademark and logo.

1.2 Siemens Research spin-off

EnOcean GmbH (enocean.com) has been venture funded and has its head office located in Oberhaching (near Munich), Germany. In Figure 1-1, we illustrate the company's trademark and logo. EnOcean also has offices in the United States and was established in 2001, as a spin-off from Siemens Research. EnOcean GmbH is the originator of its self-powered, patented energy harvesting wireless technology, which utilises numerous small energy convertors to gather variances in its surrounding environment to provide a device with sufficient energy to power itself. The company provides its technology and licenses for numerous patented features through the EnOcean Alliance, which we discuss shortly in the following section. EnOcean technology has been installed and integrated into over 350,000 buildings; has more than 1,500 interoperable products and has been chosen by a diverse and varied number of manufacturers across the world.

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1.3 Membership with the EnOcean Alliance

The EnOcean Alliance (enocean-alliance.org), a global consortium of companies, was established in 2008 and is responsible for the collective effort of the development and promotion of EnOcean technology across the world; in Figure 1-2 we illustrate the Alliance's trademark and logo. The Alliance, a non-profit consortium, undertakes standardisation effort of the technology itself, as well as promoting a set of interoperable wireless products for residential, commercial and industrial buildings. What's more, the Alliance likewise, encourages third-party developers to evangelise EnOcean technology within the wireless sensor market across the world.

Figure 1-2: The EnOcean Alliance trademark and logo.

The EnOcean Alliance currently has almost 400 companies that are wholly committed to advance the technology whilst boasting the largest and proven installed-base of wireless buildings automation networks in the world.

1.3.1 Membership structure

The EnOcean Alliance provides three levels of membership to prospective participants. The level of membership allows a participant to decide as to how they wish to participate within the Alliance. We summarise in Table 1-1 the three membership levels.

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Table 1-1: The EnOcean Alliance offers potential participants three levels of membership.

MEMBERSHIP	BENEFITS
Promoter	Promoter membership is the highest level available within the Alliance. It provides participants with the ability to define and drive the EnOcean Alliance itself and offers the participant company a seat on the Board of Directors.
Participant	Participant membership offers potential members the ability to create and utilise interoperable EnOcean profiles for a range of building environments. What's more, members may define new features and profiles through the *Technical Working Group* (TWG). Likewise, members can also use the user education programmes through the *Marketing Working Group* (MWG). Participant membership allows its members to use the Alliance wording and branding on their own documentation and products. *Original Equipment Manufacturers* (OEMs) typically have access to this membership level.
Associate	Associated membership provides potential members an entry level which, in turn, permits access to standards, EnOcean documentation and other information once available. Building professionals, academics and researchers/journalists typically have access to this membership level.

1.4 Charting EnOcean's history

In this section, we briefly summarise EnOcean's relatively short history from its inception to where the technology is today. In Figure 1-3 we provide an infographic charting EnOcean's history. Earlier, in Section 1.2, "Siemens Research spin-off," we touched upon how EnOcean technology was originally developed at Siemens Research, Munich, Germany. As such, during the mid-1990s, numerous patents covering energy harvesting were developed and, coinciding with the establishment of the Alliance in 2008 that the

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EnOcean Equipment Profiles (EEP) v2.0 specification emerged in early 2009. You will also note from our infographic that EnOcean products began entering the market in 2002 where subsequently EnOcean products were installed in buildings later in 2003.

1.4.1 A new wireless standard

The EEP v2.1 and v2.5 specifications included additional features, improvements, new telegrams (something we'll pick up on later) and other minor enhancements. In April 2012, the EnOcean wireless standard was ratified as the *International Organisation for Standardisation* (ISO) / *International Electrotechnical Commission* (IEC) 14543-3-10.[1] The standard covers layers one to three of the *Open Systems Interconnection* (OSI) model. The current version of the equipment profiles, namely EEP v2.6.4, will be released in December 2015 (latest version always available under: http://www.enocean-alliance.org/eep/) and likewise provides additional features and other enhancements. More specifically, the ISO/IEC is currently expanding the EnOcean standard to accommodate new frequencies, which now utilise the *Frequency-shift Keying* (FSK) modulation scheme. The new standard, currently available in draft format, will be named, ISO/IEC 14543-3-11 and is planned for full release December 2015. In fact, both 315MHz and 868MHz frequencies use *Amplitude-shift Keying* (ASK) modulation, which are covered by the existing ISO/IEC 14543-3-10 standard whereas, the 902MHz and 928MHz frequencies use the FSK modulation scheme and will be covered in the new -11 standard. The 902MHz frequency now replaces 315MHz for North America; 928MHz is positioned within Japan, whilst the 868MHz FSK frequency will be used in China and not for Europe.

[1] EnOcean Wireless Standard, https://www.enocean.com/en/enocean-wireless-standard/, 2015.

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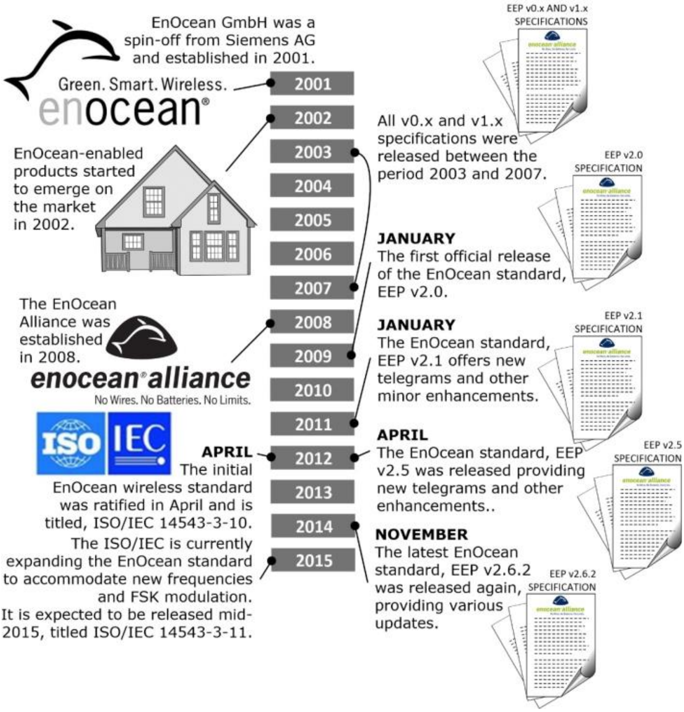

Figure 1-3: Charting EnOcean's relatively short history.

1.5 EnOcean certification programme

The EnOcean Alliance provides EnOcean device manufacturers a four-stage self-certification process to ensure interoperation of their devices with other like-enabled devices. In Figure 1-4, we illustrate this four-stage process. The certification programme provides guidance to device manufacturers aiding them in their self-certification process – this is akin to the European CE declaration. Interoperability, for EnOcean technology, requires that all layers of the software protocol stack performs as defined and are repeatable, such that:

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- the air-interface (at the physical layer) must be compliant with the EnOcean ISO/IEC 14543-3-10/11 standard, along with achieving a defined minimum transmission range;
- the scheduling and logical compliance at the communication layers must have defined communication flows;
- and finally, the correct coding and decoding of communication content at the application layer must adhere to defined schedules and processing of transmitted data.

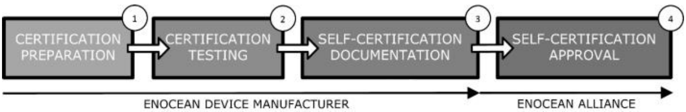

Figure 1-4: EnOcean Alliance's four-stage self-certification process.

What's more, EnOcean's self-powered technology must assure the ability to harvest energy from the ambient environment over a defined timeframe to ensure proper operation of the device over a defined period. In Table 1-2, we summarise the four-staged self-certification process milestones.

Table 1-2: Four-stage self-certification process milestones.

PROCESS	DESCRIPTION
1	Test cases;
	Device documentation (public).
2	Test procedures;
	Test coverage;
	Test results.
3	EnOcean self-certification documentation.
4	Quality marking "EnOcean certified".

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2 A Greener Philosophy

We have already touched upon a need to reduce our demand on natural resources and, in turn, the homes, commercial and industrial buildings that are architected today must be eco-friendly and for existing buildings they must at least be retrospectively geared towards a greener philosophy. Naturally, this has a long-term view on reducing our energy footprint, but it also helps with reducing cost to the consumer and business alike.

EnOcean is not alone in its endeavour in creating a greener world.

2.1 EnOcean's competition

EnOcean is presented with competitive technologies such as low power Wi-Fi, Bluetooth Smart, ZigBee and Z-Wave, which all compete in a similar or the same market sector. Nonetheless, EnOcean uniquely sets itself apart from its competition, insofar as, its energy harvesting patented technology bestows upon its wireless sensor the ability to capture the minutest changes in its environment to power the device sufficiently to transmit and receive data – this ability singularly sets EnOcean apart from its competitors. What's more, EnOcean's energy harvesting technology has some positive consequences, namely it removes the need for sensors to house batteries and almost eliminates the need to maintain sensors within an installation. The EnOcean Alliance continues to place EnOcean technology at the heart of and to establish the technology as the de facto low energy standard for sustainable buildings, in turn, embracing a greener philosophy.

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3 Architecting Sustainability

With consumers and industries becoming increasingly conscience of their growing energy consumption and, in turn, its exponential growth on demand, alternative energy resources are nowadays needed to help alleviate consumption of our limited natural resources. EnOcean is not alone in its endeavour to reduce our energy footprint. Wireless technologies such as Bluetooth Smart, ZigBee and Z-Wave are some of the technologies that are vying for a similar market to EnOcean. However, EnOcean GmbH provides a unique wireless sensor technology that's self-powered and affords homes, commercial and industry dwellings with an eco-friendly and environmentally responsible ecosystem that helps architect sustainability and paves the way to a greener, eco-conscience world.

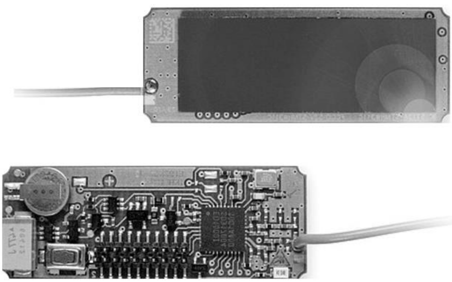

Figure 3-1: The STM 330/430 is a solar-based wireless sensor utilizing 315MHz, 868MHz, 902MHz or 928MHz frequencies.

EnOcean's battery-less, self-powered wireless sensor technology provides its users with an ecosystem where intelligence can be offered to such systems as lighting, heating and climate control, and ancillary building diagnosis and maintenance. An EnOcean ecosystem

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additionally negates the need to retrofit cabling, in turn, eliminating or reducing the cost of cabling whilst providing a reduced necessity to constantly maintain the installed equipment. What's more, EnOcean offers the ability to remote manage the ecosystem using a smartphone or over the Internet. Incidentally, a Feng-Shui approach can be adhered to for most EnOcean installations.

3.1 Small or low data rates

EnOcean's wireless sensors utilize small or low data rates whilst its energy harvesting techniques removes the need for batteries. The smallest ambient changes in a sensor's environment are sufficient to allow the sensor to transmit data. For example, variances such as a light switch being turned on or off; the minutest vibrations within a vehicle; energy derived from the motion of people or ambient luminosity or temperature changes can be used singularly or in combination to power a sensor. Furthermore, EnOcean provides third-party developers the *Dolphin* system architecture, which we discuss later in Section 6, "The Dolphin Platform". It empowers such third-parties the ability to create a wireless solution that uniquely satisfies their own residential and commercial building requirements. As such, EnOcean additionally provides a series of wireless sensor products that utilise the EnOcean standard, and in Figure 3-1, we provide an example of a self-powered wireless sensor product, which will help accelerate your development life-cycle. Alternatively, in Figure 3-2, we show a mechanical energy harvester (motion convertor) that is used alongside other products, which include the wireless sensor.

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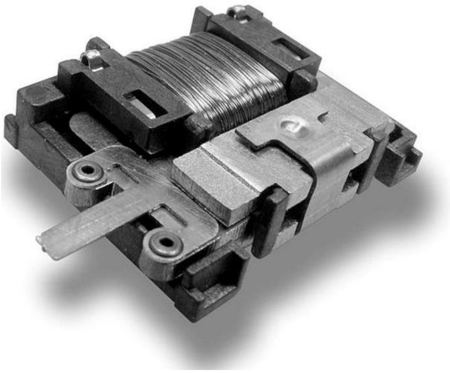

Figure 3-2: The ECO 200 is an energy harvester (motion convertor).

3.2 A typical EnOcean ecosystem

In this section, we provide an example of a typical EnOcean ecosystem, as shown in Figure 3-3 and, as such, we'll explore further how the technology is used in a real-world context to help us understand the numerous products and applications supported in such an ecosystem.

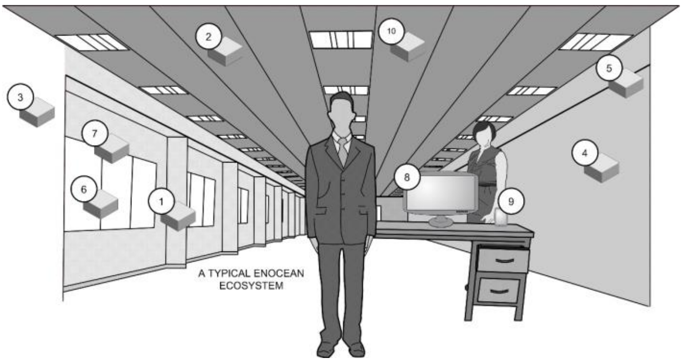

Figure 3-3: An EnOcean ecosystem where, in this example, lighting and HVAC systems are powered.

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EnOcean technology can be installed, mostly inhibited and undaunted by its location. As we have already mentioned, EnOcean has been installed in over 350,000 buildings and the company vaunts to have "the largest installed base of proven interoperable wireless building automation networks in the world.[2]"

3.2.1 An EnOcean ecosystem at work

EnOcean technology can be installed in locations such as residential homes, commercial and industry settings, hospitals, aircraft, historic buildings and yachts! If we refer back to our example installation in Figure 3-3, we depict an environment that manages lighting and *Heating, Ventilation and Air Conditioning* (HVAC) systems using a combination of wireless sensors, which is managed through a touch panel (**8**). The touch panel can be remote managed over the Internet or using a smartphone (**9**), as shown in our illustration. You will also notice a number of battery-less wireless sensors in our example ecosystem. As such, switches and blinds (**1**), occupancy detectors (**2**), and outdoor lighting (**3**) sensors, room temperature (**4**), as well as humidity (**5**) sensors; window handles (**6**) and contact (**7**) sensors. Finally, in (**10**) we have a line-powered gateway device. When a room is occupied, the occupancy sensors can detect such presence and turn the lights on; likewise, it can also control the room temperature. Conversely, when a room is unoccupied the lights are turned off and the ambient temperature can be reduced. Similarly, the heating and air conditioning systems are switched off where the window handles and contact sensors alert the system when a window is opened.

[2] Schneider, Andreas, "EnOcean Company Presentation", May 2010.

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4 Enabling the Internet of Things

The *Internet of Things* (IoT) has largely been touted and hyped across an industry always eager to launch the next big thing,[3] and EnOcean technology will ultimately play a part in creating an IoT ecosystem that will help shape the future of the technology. In Figure 4-1, we provide an image that's representative of today's vision of the IoT. Firstly, we need to better understand the differentiators that distinguish the Internet from the IoT, and further explore the original supposition used to explain the IoT. Finally, we'll discuss how EnOcean will help shape the future of the Internet of Things.

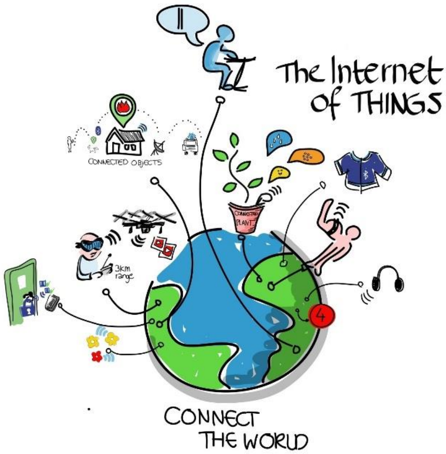

Figure 4-1: An image that is representative of the Internet of Things. [4]

[3] Gratton, D. A., "What is this Internet of Things, thing?", retrieved January 2015.

[4] Image credit: "Internet of Things" by Wilgengebroed on Flickr – cropped and sign removed from Internet of Things signed by the author.jpg. Licensed under Creative Commons Attribution 2.0 via [Wikimedia Commons](https://commons.wikimedia.org).

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4.1 The Internet versus the IoT

The Internet is a globally connected network, which is formed across many, multiple networks using either a wired or wireless interconnection; whereas, the IoT supposes the ability of a device, or 'thing' that can be tracked or identified within an IP or similar structure.[5] Nowadays, the IoT supposition has essentially been misunderstood and, as such, anything remotely having Internet capability is deemed to be integral within the IoT, and this is certainly not the case. IoT is representative of an ability to track and identify objects or things within an IP structure. These 'smart' objects, or things, hitherto have an ability to collate data which, as a consequence, has extended the original IoT supposition. To a greater extent, the Internet has been largely reliant on information provided by humans; however, with the IoT, we can empower[6] our smart objects with some intelligence to collate data or information, in turn, providing new and more accurate data since humans are constrained by time and often have limited accuracy. Such smart/intelligent devices have a representation5 of their world and, can share data or information that can be readily digested and consumed by humans. These smart objects are empowered to gather and share data with other like-minded objects and, of course, us! Hence, the notion of 'big data,' which is often used synonymously with the IoT.[3]

4.1.1 Install and forget

Typically, the notion of the IoT has been extensively overused to embrace numerous Internet-like trends which, in short, is due to the popularity of the Internet itself. The IoT has been moulded and shaped into various guises, which aptly suit a particular industry trend or phenomenon. Nonetheless, EnOcean's vision of the smart object would typically cost no more than a few dollars (or less),

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[5] Gratton, D. A., *The Handbook of Personal Area Networking Technologies and Protocols*, 2013.
[6] Ashton, K., "That 'Internet of Things' Thing", RFID Journal, June 2009.

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comprise a small foot print harnessing an 8-, 16- or 32-bit microcontroller with a modest memory of say several tens of kilobytes; would send and receive small data packets, and ultimately, would have the ability to connect to the Internet. Of course, EnOcean energy harvesting technology would negate the need for such devices to use batteries. It is anticipated that such smart objects would be inclusive within smart homes, industry and commercial automation, something that lends itself well to EnOcean's existing product portfolio. And finally, "The intelligence to make use of the data can and will be implemented anywhere, but the systems that collect the initial information need to be reliable and perpetual so that we can 'install and forget'; this is where energy harvesting wireless sensors come in: the 'things' in the IoT."[7]

[7] Siskens, W., "Energy harvesting will be big in 2015", ElectronicsWeekly.com, retrieved January 2015.

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5 Networking Topologies

In this section, we discuss several networking topologies that can be used within an EnOcean ecosystem and some of the devices that may form such an ecosystem. Firstly, EnOcean supports a *point-to-point*, *star* and *mesh* topologies, which we highlight in Figure 5-1. In particular, EnOcean primarily supports both a point-to-point and star topologies although, with the use of 'smart' repeaters, it is possible to achieve range extension or build a mesh topology.

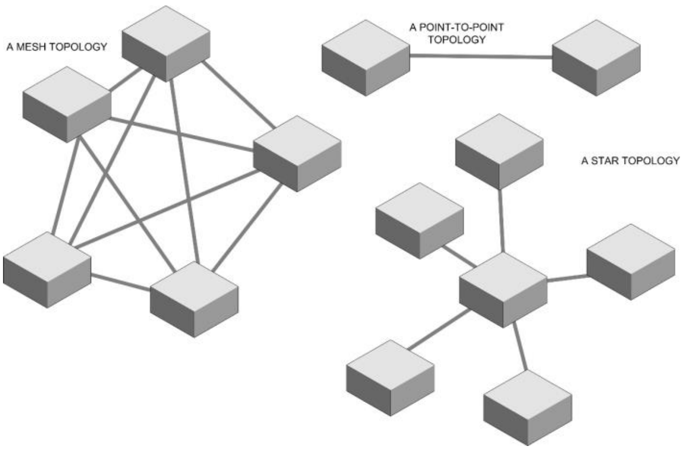

Figure 5-1: EnOcean supports three networking topologies, namely point-to-point, star and mesh.

Earlier, in Section 3.2, "A typical EnOcean ecosystem" we provided an example of an EnOcean ecosystem that managed lighting and HVAC system and discussed how some of the sensors were used to manage the installation. An EnOcean network may comprise further devices, which may include *energy harvesting switches* and *sensors*; *actuators* and *controllers*; a *gateway* and *building management system*, as well as other ancillary *wireless modules*, *sensors* and *repeaters*.

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5.1 Line-powered controllers

In Figure 5-2, we illustrate how, in this topology, a number of battery-less wireless sensors communicate with their respective line-powered controllers, which successfully manage the lighting, shading and HVAC systems.

5.2 Gateway device

Conversely, in Figure 5-3, we illustrate how, in this topology, a number of battery-less wireless sensors communicate with an EnOcean gateway device. In this instance, the gateway device uses a backend bus network that permits it to manage the lighting, shading and HVAC systems.

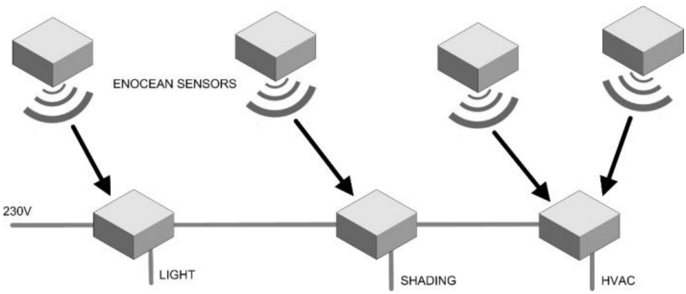

Figure 5-2: In this topology, a number of battery-less wireless sensors communicate with their respective line-powered controllers

The EnOcean gateway device supports both the *LonWorks*[8] (LON) and *Konnex*[9] (KNX)/*European Installation Bus* (EIB) protocols; however, the gateway may also support BACnet,[10] TCP/IP, *Digital*

[8] LonWork is a networking protocol that was developed and created by the Echelon Corporation.
[9] Konnex is a network communications protocol standard and is managed by the KNX Association.
[10] BACnet is a communications protocol used for intelligent buildings.

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Addressable Lighting Interface (DALI), Thread,[11] AllJoyn,[12] ZigBee, Bluetooth *Smart* and other building automation protocols. Essentially, the intelligent building or building automation concept is realised through the use of these protocols which, in turn, offer building automation standardisation for such systems as lighting and HVAC.

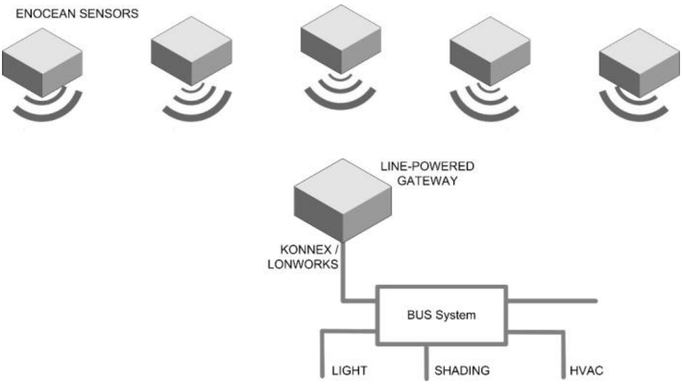

Figure 5-3: in this topology, a number of battery-less wireless sensors communicate with an EnOcean gateway device.

[11] Thread is an IPv6-based networking protocol primarily used for smart home device.

[12] AllJoyn is a system that provides devices the ability to advertise and share its capabilities with other devices that are in proximity.

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6 The Dolphin Platform

In this section, we'll begin to lift the lid on EnOcean's software and hardware architectures, as well as revealing components of the hardware and the associated developer environment that is provided by EnOcean. What's more, we will discuss the *EnOcean Radio Protocol* (ERP), later in Section 6.1, "Introducing the EnOcean Radio Protocol" and the layers that form the software stack architecture.

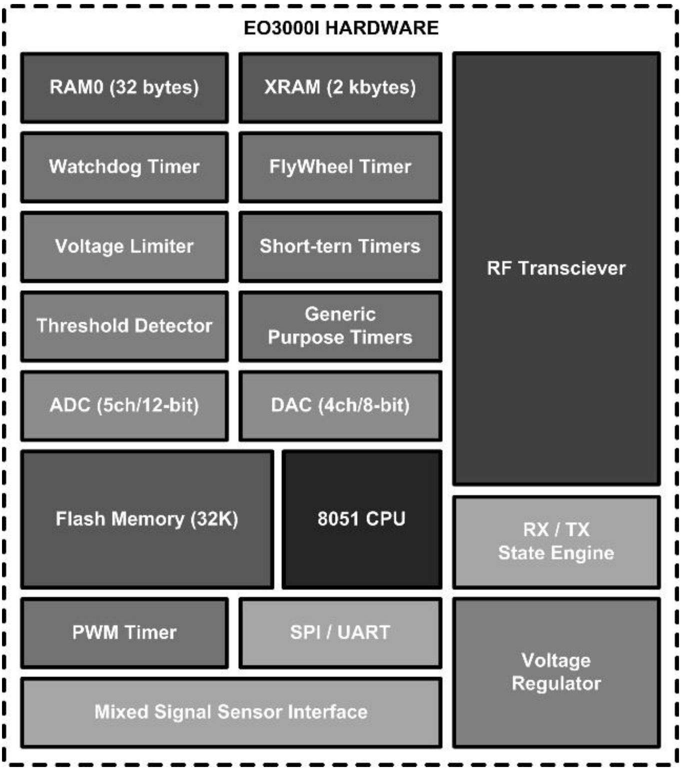

Figure 6-1: The EnOcean Dolphin EO3000I hardware platform that's used in the development and design of numerous products.

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The *Dolphin* platform is a *System-on-Chip* (SoC) transceiver providing a bi-directional *Ultra Low Power* (ULP) solution for various applications. It comprises a RF transceiver offering data rates of up to 125kbit/s with an 8051 microcontroller. The SoC is further supported with a number of peripherals and numerous ULP power management sections. In Figure 6-1, we illustrate the building blocks that comprise EnOcean's EO3000I hardware platform and offer a summary description in Table 6-1. The powerful SoC allows third-party developers to both design and develop a myriad of EnOcean-enabled products, such as switches, sensors, receivers and transceivers uniquely taking advantage of EnOcean's energy harvesting wireless technology for use within the home, commercial and automation industry. Likewise, the Dolphin platform can be used in line-powered receivers with either switched output or gateways, something we touched up on earlier in Section 5, "Networking Topologies".

Table 6-1: A snapshot of EnOcean's EO3000I hardware building blocks.

BLOCK	NAME	DESCRIPTION
ULP	Voltage limiter	The ULP building block limits voltage supply of the Dolphin system.
	Threshold detector	An ULP On/Off threshold detector.
Timers	Watchdog	The timer building block uses an internal oscillator for ULP timing.
RF	Transceiver and state Engine	EnOcean products use 315MHz, 868MHz, 902MHz, and 928MHz frequencies and, as such, can be configured. The integral state engine undertakes the transmission and receiving of telegrams, which is based on the ERP.
CPU and peripherals		Using an 8051 processor, along with a transceiver and state engine, the CPU is also accompanied with system timers, memory and a serial interface.

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Mixed signal sensor interface	The mixed signal sensor interface can support up to 10 configurable I/O lines.
Operating modes	The operating modes supported are, CPU mode", "OFF mode", "Deep sleep mode", "Flywheel sleep mode", "Short-term sleep mode" and "Standby mode".

The EnOcean Dolphin platform provides third-party developers a broad developer environment with a comprehensive *Application Programming Interface* (API) called the *DolphinAPI*. Using the DolphinAPI, developers can create their own specific firmware utilising the control, configuration and management features of the processor. Such features within the control of the receiving and transmission of radio telegrams are based on the ERP in addition to management of generic I/O and control of the power modes.

6.1 Introducing the EnOcean Radio Protocol 1

In this section, we describe ERP*1*, which is used across the United Kingdom and Europe. In Section 6.2, "Introducing the EnOcean Radio Protocol 2", we describe ERP*2*, which is used across both the United States and Japan. In Figure 6-2, we illustrate EnOcean's software building blocks, which are mapped against the *Open Systems Interconnection* (OSI) model. You will note that the session and transport layers are not used within the model and are not shown here.

6.1.1 Sub-telegrams

The ERP1 is a packet-based protocol and comprises three possible data unit types, namely a *frame*, a *sub-telegram* or a *telegram*, which are all hierarchal in nature. In the hierarchy, the lowest data unit is the frame and carries data relating to the physical layer such as the control and synchronization parameters of the receiver. The frame

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data unit is transmitted as a bit serial sequence. Moving up in the protocol hierarchy, the sub-telegram forms the next data unit, which we illustrate in Figure 6-3. The sub-telegram data unit carries data relating to the data link layer.

Figure 6-2: EnOcean's software building blocks mapped against the OSI model. You will note that the session and transport layers are not used within the architecture.

The EnOcean software architecture undertakes responsibility for the encoding/decoding process, where it provides the preamble padding, that is, *Start of Frame* (SoF), inverse bits and *End of Frame* (EoF) to assure quality in transmission. Naturally, the encoding process is initially undertaken prior to transmission at the physical layer. The receiving device decodes the data unit and discards the preamble padding.

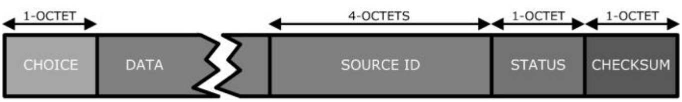

Figure 6-3: The structure of the sub-telegram data unit.

Essentially, ERP1 is a unidirectional protocol, but can offer bidirectional support especially with SmartACK, although we'll come back to this later. The protocol offers no handshaking, but reliability is assured with a repeating mechanism where three identical sub-telegrams are transmitted over a fixed period. In Table 6-2, we

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describe the fields that comprise the sub-telegram data unit. We discuss later, in Section 8, “EnOcean Equipment Profiles” the highest data unit in our hierarchy, that is, the telegram. Incidentally, for future reference, we should not that the sub-telegrams’ timings are grouped *ORG*anizationally (RORG).

Table 6-2: The fields that comprise the sub-telegram data unit.

FIELD	DESCRIPTION	BITS
Choice	The Choice field is 8-bits in length and sets the type of sub-telegram and corresponds with the RORG value of ERP1.	8
Data	The Data field is of variable length and carries the actual payload to be transmitted.	~
SourceID	The SourceID field is 32-bits (Japan 48-bits) in length and identifies the source transmitter.	32
Status	The Status field is 8-bits in length, and contains a value, which determines if the sub-telegram was transmitted from a repeater, as well as identifying the type of integrity control mechanism in use.	8
Checksum	The Checksum field is 8-bits in length and provides a data integrity check on the data transmitted.	8

6.1.2 Sub-telegram timings

The ERP1 is aware of telegram collisions over the air-interface and, as such, the management of sub-telegram timings is paramount. Therefore, a sub-telegram is transmitted at varying time intervals, which is determined by the *transmit* (TX) and *receive* (RX) *maturity*

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periods. In Table 6-3, we provide the associated timing windows for the maturity period in which all sub-telegrams have to be transmitted and received, respectively. For example, if a telegram uses three sub-telegrams, then each sub-telegram (from start to finish) shall not exceed the TX maturity period.

Table 6-3: The maturity windows for TX and RX periods.

MATURITY	DESCRIPTION
40ms	Maximum TX maturity period.
100ms	RX maturity period.

However, a repeater device uses an alternative timing method compared with the originating transmitting device. So, each sub-telegram (from start to finish) shall not exceed the RX maturity period. Furthermore, an effective scheduling mechanism is provided where the TX maturity period is divided into four windows; hence, a window now has 10, 1ms time slots, as we illustrate in Figure 6-4. As we mentioned earlier, the TX maturity period permits up to three sub-telegrams to be transmitted where the specific period is determined by a sequence corresponding to the current window in use. Collision avoidance is limited when using repeaters where the timing of the original versus the repeat telegram differs and, as such, we now demonstrate in Table 6-4 how the allocation of time slots for the various telegrams occur.

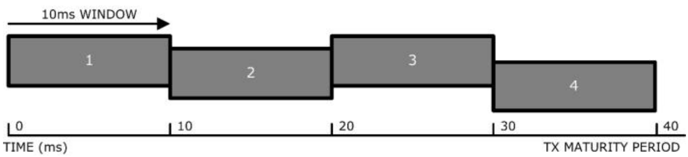

Figure 6-4: The TX maturity period is divided into four 10ms windows.

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Of course, all sub-telegrams are transmitted in sequence where a second or third sub-telegram may only start transmitting once the first sub-telegram has completed. In instances where a wireless channel is busy, the *Listen Before Talk* (LBT) mechanism can delay transmission until the end of the TX maturity period. We discuss LBT in the following section.

Table 6-4: The appropriate allocation of time slots to the corresponding telegram.

STATUS	1ST SUB-TELEGRAM	2ND SUB-TELEGRAM	3RD SUB-TELEGRAM
Original	0	1…9	20…39
Level 1 repeated	10…19	20…29	
Level 2 repeated	0…9	20…29	

6.1.3 Listen Before Talk

The LBT is an optional feature, although it is strongly recommended. It provides a collision avoidance technique, which is a common feature used within most wireless technologies. The mechanism simply determines if there is an ongoing transmission before a device begins transmission of its payload. More specifically, if an EnOcean device detects an ongoing transmission, it shall defer transmission for a random period. At the end of this period, the EnOcean device will again attempt to transmit its payload and if it's clear to do so, then the payload is sent.

6.1.4 Repeater behaviour

In an environment where wireless sensors need to be deployed over a large area and if it's not feasible to bring a sender and receiver device into proximity with each other, then a maximum of two

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repeater devices can be used to ensure seamless wireless communication. Akin to a relay race, a repeater device receives a payload from the sending device and relays it to the receiving device. In instances where a sub-telegram has been repeated, the Status field, as shown in Table 6-5, is modified to reflect the repetition sequence or if the sub-telegram is not to be repeated.

Table 6-5: The possible values of the Status field.

VALUE	DESCRIPTION
`0x00`	Original sender.
`0x01`	Sub-telegram was repeated once.
`0x02`	Sub-telegram was repeated twice.
`0x0F`	Sub-telegram shall not be repeated.

You will notice in Table 6-6 that two repeater levels are used to not only distinguish, but limit the repetition of sub-telegrams.

Table 6-6: The two repeater levels that assist with limiting repeated sub-telegrams.

LEVEL	DESCRIPTION
1	Repeat only received original sub-telegrams.
2	Repeat only received original sub-telegrams or once repeated sub-telegrams.

6.1.5 The ISO/IEC 14543-3-10 standard

In Section 1.4.1, “A new wireless standard”, we touched upon how the EnOcean standard had been ratified. In this section, we’ll explain a little further on the specifics of that standardization, namely ISO/IEC 14543-3-10 Information technology includes *Home Electronic Systems* (HES), Part 3-10 “*Wireless Short-packet* (WSP)

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protocol optimized for Energy Harvesting – Architecture and Layer Protocols".

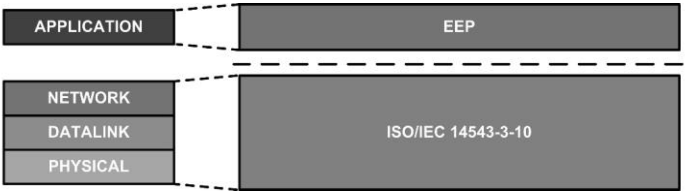

Figure 6-5: ISO/IEC 14543-3-10 now provides the physical, data link and network layers of the EnOcean software stack.

ISO/IEC 14543-3-10 provides the physical, data link and network layers of the EnOcean software stack, as shown in Figure 6-5. Both the 315MHz and 868MHz frequencies use the ASK modulation scheme, which are covered in this standard. What's more, it is the first and only wireless standard that is suitable for energy harvesting with a focus on optimized ultra-low energy consumption. This new standard when combined with the EnOcean EEP forms a holistic interoperable, open technology that can be used across the world.

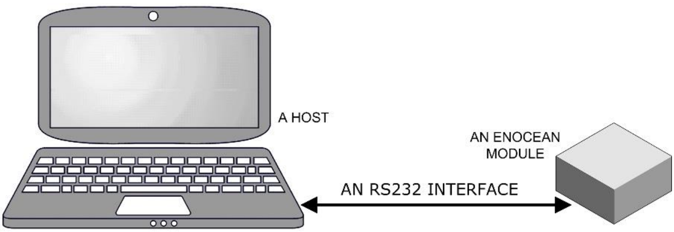

Figure 6-6: The host (in this example, a PC) interfaces with an EnOcean module over an RS232 serial interface.

6.1.6 The ISO/IEC 14543-3-11 standard

Likewise, in Section 1.4.1, "A new wireless standard", we discussed how EnOcean's initial 14543-3-10 standard is being extended to

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accommodate new frequencies, namely 902MHz and 928MHz, along with the FSK modulation scheme. The new standard is currently available in draft format and is planned for full release end-2015. Moreover, the 902MHz and 928MHz frequencies both use the FSK modulation scheme and will be covered in this new standard. The 902MHz frequency now replaces 315MHz for North America; 928MHz is positioned within Japan, whilst the 868MHz FSK frequency will be used as an option in China.

6.2 Introducing the EnOcean Radio Protocol 2

In this section, we describe ERP*2*, which is used across the United States and Japan. Earlier, in Section 6.1, "Introducing the EnOcean Radio Protocol 1", we described ERP*1*, which is used across both the United Kingdom and Europe. ERP2 was designed to improve performance and to extend implementation across a variety of RF transceiver architectures.

In the following list, we highlight several significant changes when compared with ERP1:

- the use of FSK modulation versus ASK in ERP1;
- the use of a longer preamble and longer sync-word (formerly known as SoF) to increase detection reliability; and
- changes in the telegram structure where the EoF field is used as a data length filed to allow variable length telegrams with minimal overhead.

In the following sections, we now describe the *physical*, *data link* and *network* layers, which are used in ERP2.

6.2.1 Physical layer

The electrical specification of the physical layer is open to any frequency, but two frequencies are currently specified. Nevertheless,

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subject to national regulatory requirements and new markets additional frequencies may be implemented.

In Table 6-7, we list key parameters that are used in ERP2.

Table 6-7: Key parameters that are used in ERP2.

PARAMETER	MIN	VALUE	MAX	UNIT
Frequency error	-18		-18	kHz
Modulation[13]		FSK		
Frequency deviation	±55.0	±62.5	±70.0	kHz
Data rate		125		kbps
Data rate tolerance[14]	-30		+30	ppm
PA ramp-on time			40	µs
PA ramp-off time			40	µs
Coding		NRZ		
Code for 1		+62.5		kHz
Code for 0		-62.5		kHz

6.2.1.1 902.875MHz

In Table 6-8, we show the parameter used in ERP2 at 902.875MHz, which is targeted toward the North American market.

[13] Permitted to use GFSK with various filters (BT) subject to national regulation requirements.

[14] This provides a 1µs time offset between RX and TX after 256 bytes. A transmitter may feature higher tolerances since the time offset between RX and TX does not exceed 1µs following the maximum number of bytes actually transmitted.

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Table 6-8: ERP2 at 902.875MHz for North America.

PARAMETER	MIN	VALUE	MAX	UNIT
Nominal frequency		902.875		MHz

6.2.1.2 928.35MHz

In Table 6-9, we show the parameter used in ERP2 at 928.35MHz, which is targeted toward the Japanese market.

Table 6-9: ERP2 at 928.35MHz for Japan.

PARAMETER	MIN	VALUE	MAX	UNIT
Nominal frequency		928.35		MHz

6.2.1.3 Other frequencies

ERP2 was specifically designed to be frequency independent. However, other frequencies may be introduced as and when new markets and requirements emerge.

6.2.1.4 Frame structure

At the physical layer, data is transmitted in *frames*, as we illustrate Figure 6-7 – in Table 6-10, we describe the fields that make up the physical frame structure.

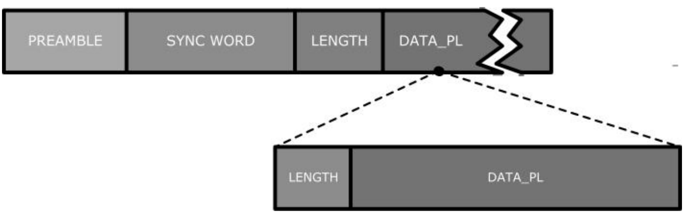

Figure 6-7: The ERP2 physical frame structure.

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Table 6-10: The fields that comprise the ERP2 physical frame structure.

FIELD	DESCRIPTION	BITS
Preamble	The preamble field is 16-bits in length and is used to provide bit synchronisation.	16
Sync-word	The Sync-word field is 16-bits in length and is used to enable the receiver to synchronise to the data bytes.	16
Length	The Length field is 8-bits in length and indicates the number of bytes in the Data_PL field.	8
Data_PL	The Data_PL (*physical layer*) field is of variable length and carries the actual payload.	

In Figure 6-7, we also show the physical layer to data link layer conversion where the length followed by the Data_PL is transferred to the data link layer.

6.2.2 Data link layer

At the data link layer sub-telegrams are transmitted, which we discussed earlier in Section 6.1.1, "Sub-telegrams". Sub-telegram *timings* aim to avoid telegram collisions from different transmitters whilst LBT is a technique used to ascertains in its environment whether other devices are transmitting prior to transmitting its payload.[15]

15 EnOcean GmbH, "Specification: EnOcean Equipment Profiles 2", v1.0, September 2013.

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6.2.2.1 Frame structure

The frame structure at the data link layer differs depending on its size. Telegrams that are six bytes or less have a fixed structure for special payloads such as acknowledge, keep alive and errors messages, as we show in Figure 6-8. We describe these fields in Table 6-11.

Figure 6-8: The frame structure for the data link layer with six bytes or less.

Further information can be obtained from EnOcean's ERP2 specification.

Table 6-11: The fields that comprise the data link layer frame structure.

FIELD	DESCRIPTION	BITS
Length	The length field is 8-bits in length and indicates the number of bytes in the Data_DL field.	8
Originator ID	The Originator ID field is variable in length and indicates the originating device.	8, 16, 24, 32
Data_DL	The Data_DL (*data layer*) field is of variable length and carries the actual payload.	

6.2.3 Network layer

The network layer specifies access to the transmission media, as well as providing guidance for redundancy in transmission such as

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repeating or acknowledge. At this layer, routing, repeating and sub-telegram timing is taken from ERP1.

6.2.3.1 Redundancy

As a default, redundant transmission is used, if no other technique to successfully acknowledge transmissions is available. A transmission shall be repeated at least once and up to a maximum of two. Furthermore, there is a maximum pause of 12ms between the first and subsequent transmission. Typically, this technique will be applied to devices that are unable to receive (that is, pure transmitters) but can also be applied to transceivers.

6.2.3.2 Repeating

Only level 1 repeating is permitted and will remain the same as specified in ERP1.

6.2.3.3 Local requirements dependent specifications

There are no specific requirements for the US and Canada (902.875MHz); however, redundant transmissions shall be finished within 50ms for Japan (928.35MHz). In other words, following the last transmission no further transmissions are permitted for 50ns.

6.3 Introducing the EnOcean Serial Protocol

The *EnOcean Serial Protocol* (ESP) allows developers with an EnOcean module to establish serial communication with, for example, a host, that is a microcontroller or PC and, as we demonstrate in Figure 6-6. The connection established between a host and the module is based on an RS232 serial interface; more specially, a 2-Wire *Universal Asynchronous Receiver/Transmitter* (UART) connection, comprising receive, transmit and ground, as well as software handshake and full-duplex. The ESP uses a point-to-point topology as shown in Figure 6-6 and uses the data structure illustrated in Figure 6-9; the data structure is made up of the user data, command,

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response and event messages. Moreover, Figure 6-9, illustrates the packet structure, which comprises a header, length, packet type, data and an optional data payload, as well as a sync-byte (indicating start of frame). In Table 6-12, we explain the fields that comprise the ESP packet structure.

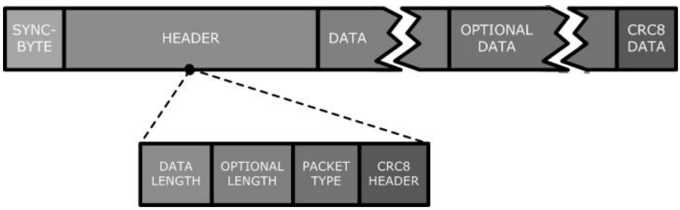

Figure 6-9: The ESP packet structure.

Table 6-12: The fields that comprise the ESP frame structure.

FIELD	DESCRIPTION	BITS
Sync-byte	The Sync-byte field is 8-bits in length and provides the serial connection with a synchronisation mechanism and is always set to `0x55`.	8
Data length	The Data length field is 16-bits in length and indicates the number of bytes that need to be addressed in the Data field.	16
Optional length	The Optional length field is 8-bits in length and the number of bytes that need to be addressed in the Optional data field.	8
Packet type	The Packet type field is 8-bits in length and indicates the packet type contained within the data and optional data fields. In Table 6-13, we show the possible	8

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	packet types that are available.	
CRC8H	The CRC8H (header) field is 8-bits in length and contains the checksum for data and optional data, and packet type.	8
Data	The Data field is variable in length and contains the payload.	~
Optional data	The Optional data field is variable in length and contains the optional pay-load.	~
CRC8D	The CRC9D (data) field is 8-bits in length and contains the checksum for data and optional data fields.	8

Table 6-13: The possible Packet types and value.

VALUE	DESCRIPTION
0x00	Reserved.
0x01	Radio telegram.
0x02	Response to any packet.
0x03	Radio sub-telegram.
0x04	Event message.
0x05	Common command.
0x06	SmartACK command.
0x07	Remote management command.
0x08-0x7F	Reserved (EnOcean use only).
0x80-0xFF	Manufacturer-specific command and message.

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6.3.1 Synchronization

In Figure 6-10, we illustrate a Sync-byte value (`0x55`) initiates the start of frame where the data and optional length, packet type that all follow, are validated against the CRC8H (header) field. If there is no match, then the Sync-byte does not correspond with a new payload and the process is repeated. Conversely, if there is a match, then the payload is processed and moved along.

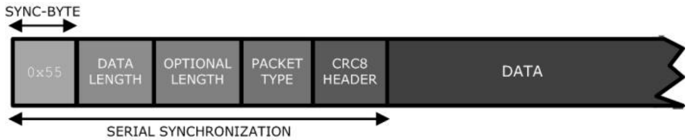

Figure 6-10: The Sync-byte is used to denote the start of a new payload.

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7 The Dolphin Architecture

In Figure 7-1, we illustrate the high-level view of EnOcean's software stack architecture where each layer uniquely provides a set of functions and parameters. As such, each layer or module is wholly independent and provides an interface, which can be directly accessed by an application. Each module further provides two types of interface, that is, *initialisation* and *functional*. The function interface offers reliable access as to whether or not a function was executed successfully. Moreover, the function interface provides the ability to share parameters and offers a reason, if the function was not executed successfully. You should note that not all software modules are accessible from the application layer, such as scheduling and interrupt handlers, as we illustrate in Figure 7-2.

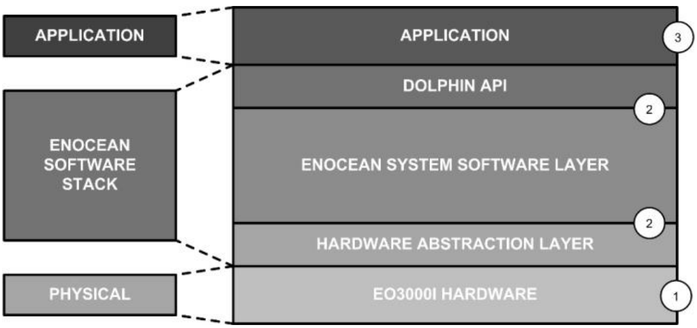

Figure 7-1: A top-level view of the Dolphin system architecture that make up the EnOcean software stack.

In Figure 7-1, the block labelled (**1**) represent both the *Media Access Control* (MAC) and *Physical* (PHY) layers, which we discussed earlier in Section 6, "The Dolphin Platform"; block labelled (**2**) forms the center of the EnOcean architecture, which includes the DolphinAPI (see Section 7.1, "Introducing the DolphinAPI"), the *EnOcean System Software Layer* (ESSL) and the *Hardware Abstraction Layer* (HAL); and finally, block (**3**) permits third-party

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developers to create their own applications using either the EEP (see 8, "EnOcean Equipment Profiles") or Generic Profiles (see Section 9 "Generic Profiles").

7.1 Introducing the DolphinAPI

The DolphinAPI offers developers an interface to create two application types, namely *Line Powered* and *Self-powered ULP*. The former application type is typically used for modules that require a fixed power feed such as controllers, repeaters and gateways whereas the latter application type is used for modules that are powered using the energy harvesting technique, such as sensors and actuators. A line powered module remains on and does not enter a sleep state (only standby), where on the other hand, the self-powered ULP module is normally switched off or is in a deep sleep state periodically awakening.

7.1.1 Line-powered vs. Self-powered ULP

Naturally, line-powered and self-powered ULP differ insofar as their respective APIs offer varying methods in functionality for energy optimisation. More specifically, whilst a line-powered device is typically energy efficient, it can be a little relaxed with its energy consumption where a telegram can be transmitted using the *scheduler* (see Section 7.2.1, "Scheduler") regardless of the lapsed time. Alternatively, a self-powered ULP device remains more moderate in its energy consumption where telegram transmissions have to be optimised and completed quickly.

7.2 Introducing the EnOcean System Software Layer

In Figure 7-2, we show a series of blocks that are shown horizontally – these represent several software modules that comprise the ESSL. In our illustration looking from left to right, we see the RadioULP, several timer modules, a *Serial Peripheral Interface* (SPI) and a *Universal Asynchronous Receiver/Transmitter* (UART);

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Smack (see Section 7.3, "Smart Acknowledge"), generic I/O, power management (PWR) and miscellaneous software module resources. Some modules are not able to be accessed from the application layer, but interact with each other. The ESSL likewise houses the scheduler, power management, the serial and radio protocol stacks and other miscellaneous compounds. Incidentally, the Dolphin architecture does not adopt a user/kernel topology and, instead, the DolphinAPI and other libraries are all linked to the application during compilation. Similarly, memory management is also allocated during compilation.

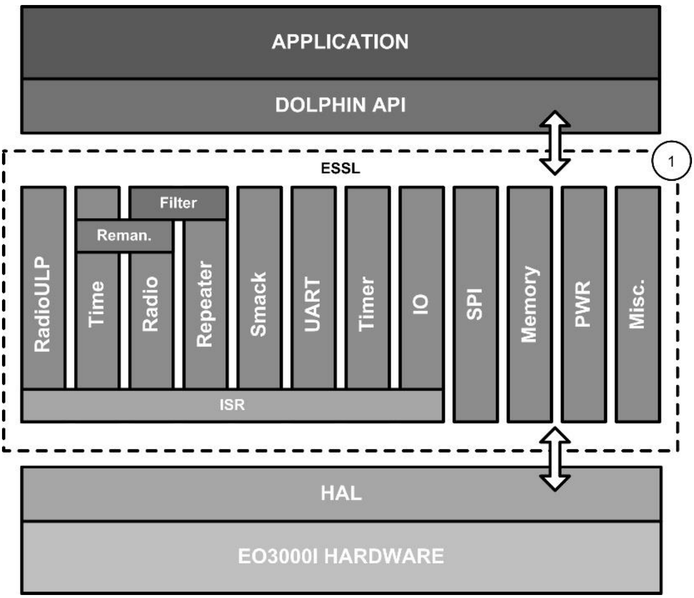

Figure 7-2: A number of interactive modules comprise the ESSL that's located within the Dolphin architecture. Security options may now also be added here.

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7.2.1 Scheduler

We summarise in Table 7-1 the scheduler functionality where tasks can be executed concurrently within the EnOcean system. The DolphinAPI supports both single application and multiple system tasks, as well as pre-emptive priority scheduling at the system level. Most system tasks execute to completion and cannot be interrupted by other system tasks, although the UART system task has a higher priority and, as such, has the ability to pre-empt system tasks.

Table 7-1: Functionality offered by the scheduler.

SCHEDULER FUNCTIONALITY
Transmit and receive telegrams.
Offer levels 1 and 2 repeating.
SmartACK postmaster functionality.
LBT
Software timing.
Remote management.

The scheduler is executed using a round robin technique where the application task is provided a 1ms opportunity to be interrupted. *Synchronous system tasks* are executed consecutively and are triggered by the timer hardware interrupt – the average duration for a synchronous task to complete is around 50 to 150µs. A synchronous task may take longer than 1ms to complete where other active functionality, radio buffers, traffic load and the actual length of a sub-telegram may be factors that extend a system task's execution.

7.3 Smart Acknowledge

Smart Acknowledgement (SmartACK) is a bidirectional communications protocol where communication happens between two *actuators*, that is, an energy autarkic sensor and a line-powered controller. Primarily, SmartACK is used to provide efficient data transmission

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and its reception within an EnOcean ecosystem. When a sensor is in receive mode, it results in unnecessary energy consumption – SmartACK uses message synchronisation to reduce receiver on time, in turn, message flow is undertaken in a predefined interval: that is, *actual reclaim period*. As soon as a sensor sends its telegram, it expects an immediate reply and, as such, the receiver on time is only available for a short period. If the sensor doesn't receive the response in time, then it can *reclaim* it from a *mailbox* located on the controller device. Line powered devices are considered postmasters and can act as a controller or repeater. In some instances, a repeater may cause some delay, which disrupts synchronisation. As such, mailboxes are used within line powered devices, which have direct access with the autarkic device.

The SmartACK protocol uses three actuators, namely a sensor, repeater and a controller – these are *actual* devices within an EnOcean ecosystem. A repeater and a controller device may adopt the role of a postmaster, which houses a sensor's mailbox. In fact, the functionality within these devices is similar, yet controllers are capable of *learning*. Likewise, a repeater may also provide additional functionality such as a light actuator. A SmartACK sensor is a self-sufficient device also capable of learning; as such, the controller and sensor are both aware of each other's existence.

7.3.1 Mailboxes

A mailbox can retain only one telegram whereas a postmaster may retain one of two types of mailbox, that is, *temporary* or *normal*, as we describe in Table 7-2. A postmaster notifies a sensor if its mailbox doesn't exist or if it's empty. A controller can hold multiple mailboxes for as many connections it has with other sensors within the ecosystem.

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Table 7-2: The two types of mailbox.

TYPE	SCHEDULER FUNCTIONALITY
Temporary	A temporary mailbox is used when learning.
Normal	A normal mailbox is used during standard operation.

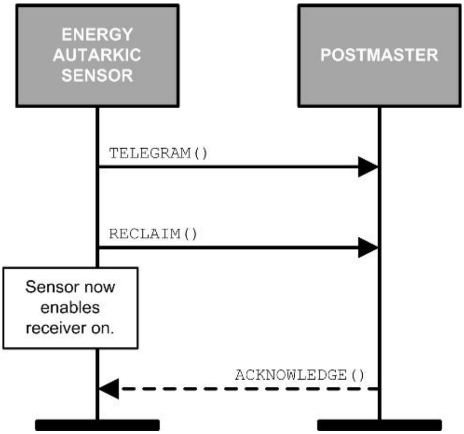

Figure 7-3: The radio is switched on whilst the sensor awaits a reply within the reclaim period.

7.3.2 Reclaiming

The reclaim process is the ability to reduce the need for radio on time, hence time synchronisation established between the sensor and postmaster is enabled for the duration of the transfer. If a reclaim has failed, then the sensor can retry up to three times where the period between is set by the length of a sub-telegram (see Section 6.1.2, “Sub-telegram timings”). For additional clarity, we illustrate in Figure 7-3, a message sequence chart showing when the sensor transmits a reclaim telegram and switches the radio on. The radio is

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switched on once the sensor receives the reclaim request and then the radio is switched off following the reclaim period. The ‘acknowledge’ in this sequence forms the conceptualization, *smart acknowledge*.

7.3.3 Normal operation and learning behavior

A distinction should be made between normal operation and learning behaviour and, as such, in Table 7-3 we note the SmartACK telegram differences. Normal operation is the typical data transfer that is undertaken between two devices; Figure 7-4 illustrates the message sequence for an operation showing a sensor and a postmaster, which are in direct contact with each other.

Table 7-3: The different types used during normal vs. learning operations.

TELEGRAM	NORMAL OPERATION	LEARNING BEHAVIOUR
Initial	Data	Learn request
Reply	Data reply	Learn reply
Reclaim	Data reclaim	Learn reclaim
Acknowledge	Data acknowledge	Learn acknowledge

In Figure 7-5 we show an alternate sequence where the sensor has no radio contact with the other device. In this message sequence, you can see from the illustration that a repeater is used. You should also note that in both sequence charts, an acknowledgement is optional.

The learning ability actually refers to a sensor’s unique functionality to understand more about neighbouring sensors. This process is achieved through the exchange of information resulting in *learning out* or *learning in*. An autarkic sensor enters learning mode by

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submitting a learn request, as we illustrate in Figure 7-6 and Figure 7-7 – we depict here a complex scenario since a repeater is involved due to the sensor not being in radio contact.

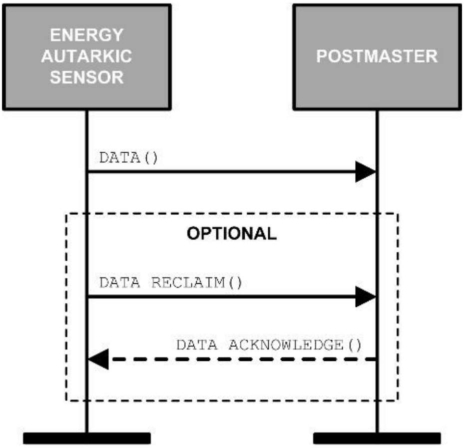

Figure 7-4: Normal operation request where the sensor is in direct contact with its peer device.

When a sensor issues a learn request telegram, a *Radio Signal Strength Index* (RSSI) value is used to denote if the signal strength is acceptable. As such, if the value offered is significant, then the device is considered to be within direct radio contact.

We have already touched upon how a SmartACK controller or repeater is capable of retaining a sensor's mailbox. A sensor discovers the nearest device where a postmaster is then chosen; the controller or repeater will then decide if the learning is 'in' or 'out'. For the normal operation and learning behaviour process, the best scenario is to ascertain a simple mode where the sensor, that is for either normal or learning, is in direct radio contact.

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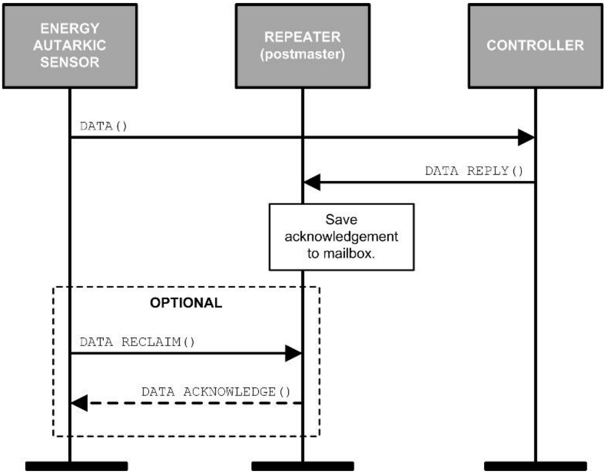

Figure 7-5: Normal operation request where the sensor is not in direct contact with the corresponding device.

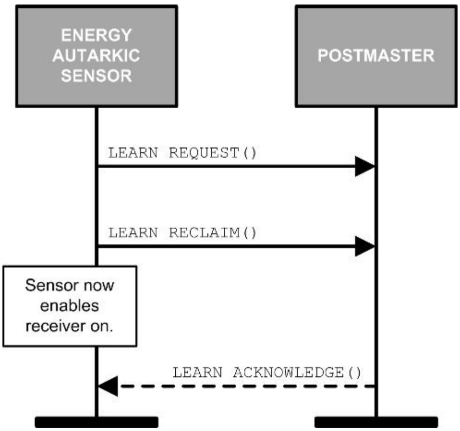

Figure 7-6: The learning behavior where the sensor is in radio contact.

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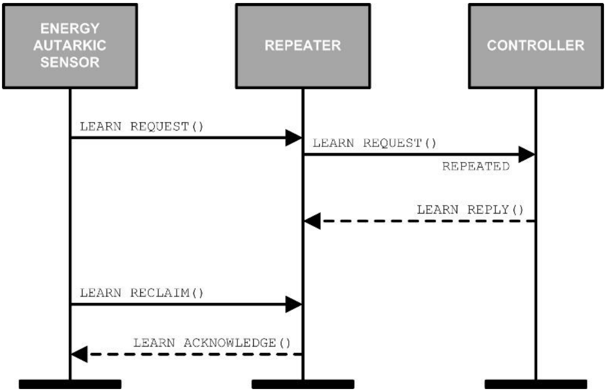

Figure 7-7: The learning behavior where the sensor is not in radio contact and a repeater is used.

7.3.3.1 Learn in and learn out

'Learn in' is a requirement for a controller to sustain a relationship with its sensor; 'learn out' is the need for a controller to cease the relationship. A 'relationship' can be understood, if the controller is already aware of an existing relationship or if the controller accepts EEP telegrams from neighbouring sensors.

7.4 Introducing the Hardware Abstraction Layer

The HAL is the lowest layer within the EnOcean software stack, as shown earlier in Figure 7-1 and Figure 7-2; it provides hardware independence and abstraction for the underlying Dolphin platform.

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8 EnOcean Equipment Profiles

The equipment profiles essentially form the application layer, as we earlier illustrated in Section 7, “The Dolphin Architecture”. The ERP describes the radio telegram where the transmission window is typically under 1ms and it uses little power to transmit data. Due to infrequent transmission, the likelihood of data is reduced which suits itself well to a more reliable transport mechanism. We discuss in this section the EEP telegram structures that, in turn, offer interoperability across manufacturers. What’s more, the EnOcean Alliance provides three profile elements, which we illustrate in Table 8-1 – these profile elements are common to all equipment profiles.

Table 8-1: The three common profile elements used in the payload.

	DESCRIPTION
1	The ERP radio telegram type, ‘RORG’.
2	Basic functionality of the data content, ‘FUNC’.
3	Type of device, ‘TYPE’.

In Section 6.1.1, “Sub-telegrams”, we discussed how the RORG value actually corresponded to ‘CHOICE’, which is represented at the radio telegram level. As such, in Table 8-2, we describe the telegram types that are used at the EEP layer.

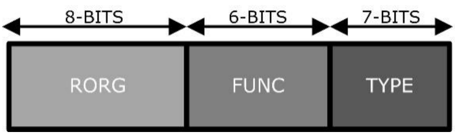

Figure 8-1: The three common elements that comprise all EnOcean devices.

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Table 8-2: The telegram types that are used within the EEP.

RORG	TELEGRAM	DEFINITION
0xF6	RPS	Repeated Switch Communication.
0xD5	1BS	1-byte Communication.
0xA5	4BS	4-byte Communication.
0xD2	VLD	Variable Length Data.
0xD1	MSC	Manufacturer-specific Communication.
0xA6	ADT	Addressing Destination Telegram.

8.1 The RBS and 1BS telegram types

Both the RBS and 1BS telegrams provide a one-byte data payload where the frame structures are comparable to each other, as we illustrate in Figure 8-2. However, the use of the LRN-bit in the data field, distinguishes the two telegram types.

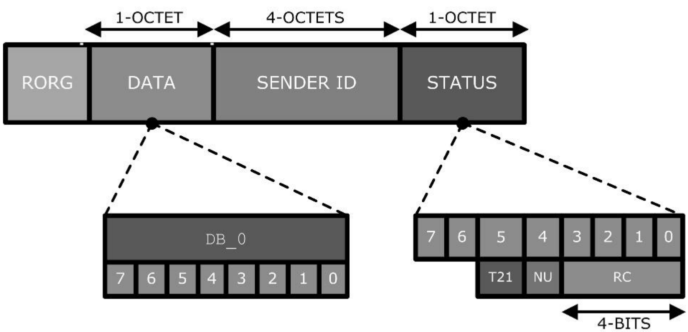

Figure 8-2: The RBS and 1BS telegram frames are comparable with the exception of the LRN-bit.

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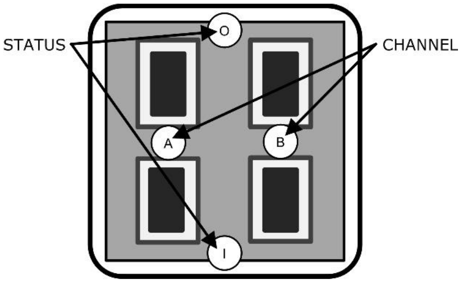

Figure 8-3: An example EnOcean mechanical energy harvester wireless sensor based on the PTM 210 transmitter.

In Figure 8-3, we illustrate an example EnOcean device, which is based on the PTM 210 transmitter module – a mechanical energy harvester wireless sensor utilising 315MHz, 868MHz, 902MHz, 928MHz (or 2.4GHz) frequencies. Our example image shows a 'State' and a 'Channel' setting which, in turn, influences the functionality within the status field. Furthermore, two types of messages are used, namely *N*-message and *U*-message, which are further denoted in the status field; see Figure 8-2. The data telegram not only includes the data type, but the T21 and NU bits in the status field are used to distinguish the state and channel setting. The status field also includes a *Repeater Count* (RC). In Table 8-3 and Table 8-4, we describe the numerous application sets that are used for both RPS and 1BS telegrams.

Table 8-3: An example list of application types that use the RPS telegram.

RORG	FUNC	DESCRIPTION	TYPE	DESCRIPTION
0xF6	0x02	Rocker switch, 2 rockers.	0x01	Light and blind control, style 1.
	0x02	Rocker switch, 2 rockers.	0x02	Light and blind control, style 2.

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0x03	Rocker switch, 4 rockers.	0x01	Light and blind control, style 1.
0x03	Rocker switch, 4 rockers.	0x02	Light and blind control, style 2.
0x04	Position switch, home and office application.	0x01	Key card activation switch.
0x10	Mechanical handle.	0x00	Window handle.

Table 8-4: An example list of application types that use the RPS telegram.

RORG	FUNC	DESCRIPTION	TYPE	DESCRIPTION
0xD6	0x10	Contact and switches.	0x07	Single input contact.

8.2 The 4BS telegram type

The 4BS telegram offers a four-byte payload and we illustrate its structure in Figure 8-4. Our payload, in this instance, shows a 10-bit temperature profile that showcases how a range from 0 to 1023 can be addressed. Finally, in Table 8-5, we describe the set of applications used for the 4BS telegram type.

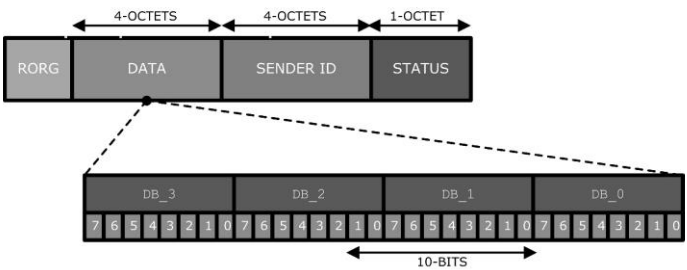

Figure 8-4: The 4BS frame structure.

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Table 8-5: An example list of application types that use the 4BS telegram.

RORG	FUNC	DESCRIPTION	TYPE	DESCRIPTION
0xA5	0x02	Temperature sensors.	0x01 – 0x1B	Variable temperature ranges.
	0x04	Temperature and humidity sensors.	0x01	Range 0°C to 40°C and 0 to 100%.
	0x06	Light sensor.	0x01	Range 300lx to 60.000lx.
	0x06	Light sensor	0x02	Range 0lx to 1.020lx.
	0x07	Occupancy sensor.	0x01	Occupancy.
	0x08	Light, temperature and occupancy sensor (ceiling).	0x01	Range 0lx to 510lx; 0°C to 51°C and occupancy.
	0x08	Light, temperature and occupancy sensor (wall).	0x02	Range 0lx to 1020lx; 0°C to 51°C and occupancy.
	0x08	Light, temperature and occupancy sensor (outdoor).	0x03	Range 0lx to 1530lx; -30°C to 50°C and occupancy.
	0x09	Gas sensor.	0x01	CO sensor.
	0x09	Gas sensor.	0x04	CO_2 sensor.
	0x10	Room operating panel.	0x01 – 0x1E	Various voltage monitor, temperature sensor, set point and fan speed control; humidity and occupancy control.

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0x11	Controller status.	`0x01`	Lighting controller.
0x11	Controller status.	`0x02`	Temperature controller output.
0x12	*Automated meter reading* (AMR).	`0x00` – `0x03`	Counter: electricity, gas and water.
0x13	Environmental applications.	`0x01` – `0x06`	Weather station; sun intensity, northern hemisphere; data exchange; time and day exchange; direction exchange and geographic position exchange.
0x20	HVAC components.	`0x01` – `0x03`	Battery powered, basic and line powered actuators.
0x20	HVAC components.	`0x10`	Generic HVAC interface.
0x20	HVAC components.	`0x11`	Generic HVAC interface (error control).
0x20	HVAC components.	`0x12`	Temperature controller input.
0x37	Energy management.	`0x01`	Demand response.
0x38	Central command.	`0x08`	PHC gateway.
0x3F	Universal.	`0x00`	Radio link test.

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8.3 The VLD telegram

The VLD telegram type provides a variable data payload that varies between one to 14-bytes. In Figure 8-5, we show the VLD frame structure and in Table 8-6, we describe the range of application sets that is used for the VLD telegram type. You may notice, the application type shown, in this instance, uses the SmartACK protocol; something we discussed earlier in Section 7.3, “Smart Acknowledge”.

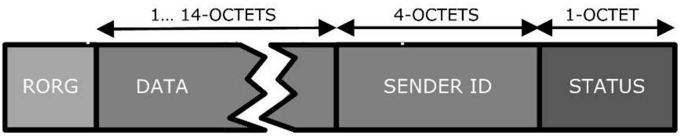

Figure 8-5: The VLD data structure.

Table 8-6: An example list of application types that use the VLD telegram.

RORG	FUNC	DESCRIPTION	TYPE	DESCRIPTION
0x02	0x00	*Room Control Panel* (RPC).	0x01	RCP with temperature measurement and display.

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9 Generic Profiles

The EnOcean Alliance TWG is responsible for ensuring interoperability across the EnOcean product portfolio, along with supporting multiple manufacturers that deploy, integrate and develop using EnOcean products. As such, the working group originally provided a series of equipment profiles, something we discussed earlier in Section 8, “EnOcean Equipment Profiles”, which not only complements the new *Generic Profiles*, but also offers an alternate profile set such that new and existing manufacturers have every opportunity to create and extend their ecosystems with a new generation of EnOcean profiles or applications. The EnOcean Alliance continues to support legacy products that have been successfully used over the last twelve years or so, as well as architecting new profiles that accommodate a new generation of consumer expectations and requirements whilst being mindful of a need to accelerate the time-to-market.

> “With Generic Profiles, the EnOcean Alliance has further developed the standardized interoperable communication of energy harvesting wireless solutions. It allows multi-functional products that flexibly adapt to a variety of applications.”
>
> — Marian Hönsch, Technical Working Group, EnOcean Alliance

What’s more, the EnOcean Alliance has selected an architecture that minimises development overhead for product designers, as well as providing sufficient flexibility in product design to assure product longevity.

9.1 The communication layers

In Table 9-1, we describe the abstraction layers and services that are used for the *Generic Profiles* (GP), which are mapped against the OSI model. Using this approach, as depicted in Table 9-1, offers

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software independence from the radio, serial or any other communication type to exchange GP messages. In other words, any radio medium can be used to deliver content over the air-interface using the EnOcean software protocol.

Table 9-1: The layer model for Generic Profiles.

LAYER	SERVICE
Application	Product-/manufacturer-specific software application/GP message generation.
Presentation	Radio telegram processing.
Session	Not used.
Transport	Not used.
Network	Addressing telegrams/RORG/Status processing.

9.1.1 Message types

The GP provides four message types, as we describe in Table 9-2, where each message is assigned to a destination *Identifier* (ID) that is, *Addressing Destination Telegram* (ADT).

Table 9-2: The four message types for Generic Profiles.

TYPE	PROPERTIES	RESTRICTION
Teach-in request	GP teach-in request.	512 bytes in length
Teach-in response	GP teach-in response (bi-directional only).	512 bytes in length
Complete data	Complete (measurement) data.	512 bytes in length
Selective data	Selected parts (measurement) data.	512 bytes in length

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9.1.2 Radio communication

In Table 9-3, we describe the layers and services that are used for GP during radio communication. Incidentally, the application layer at the GP API shown in our table, the RORG radio telegram shall be selected subject to the message type. However, if the message exceeds the restricted length, as shown in Table 9-2, then the telegram shall be split across a number of telegrams.

Table 9-3: The layer model for Generic Profiles during radio communication.

LAYER	SERVICE
Application	Generates GP messages as a bit stream and ascertains message type.
GP API	Selects RORG and translates messages to one or more radio telegrams.
Dolphin API	Transmits radio telegram(s).
Dolphin chip	The physical radio telegram transceiver.

9.1.2.1 Telegram chaining

As we mentioned, in instances where the GP telegram payload exceeds the restricted length (see TAB), chained radio telegrams are used where the payload is split into the number of messages required by the EnOcean radio stack. For instance, ERP *1*, the maximum payload is 13 bytes or nine bytes, if it is an ADT message. [16][17][18]

[16] EnOcean Alliance, "System Specification: Generic Profiles", v1.0, April 2014.

[17] DolphinAPI User Manual, http://www.enocean.com/fileadmin/redaktion/pdf/download/EO3000I_API_user_manual.zip

[18] EnOcean Radio Protocol (1) Specification, http://www.enocean.com/fileadmin/redaktion/pdf/tec_docs/EnOceanRadioProtocol.pdf.

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9.1.3 Other communication

With the EnOcean Alliance TWG creating generic messages instead of defining specific telegrams, provides the opportunity for manufacturers and developers to use other communication types and, as such, we describe in Table 9-4 the available layers that could perhaps be expanded for future use; for example, serial communication and so on.

Table 9-4: The layer model for Generic Profiles during serial communication.

LAYER	SERVICE
Application	Generates GP messages as a bit stream and ascertains message type.
GP API (with serial support)	Creates serial message(s).
Dolphin API	Transmits radio telegram(s) via ESP3, for example.
Dolphin chip	The physical serial transceiver.

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10 Remote Commissioning

The EnOcean Alliance has defined a standardized process to pave the way forward for remote commissioning of EnOcean-based devices in building automation networks. As such, installers and system integrators can now remotely connect battery-less wireless devices using a central tool. What's more, EnOcean's standard permits such networks to be adaptable, such that existing installations can easily be expanded or modified.

Remote commissioning defines an ordered and interoperable process to manage EnOcean devices when establishing a new ecosystem or installation. Furthermore, this process offers a standard interface, ensuring ease of use for commissioning and maintaining an EnOcean network. Utilising remote commissioning with an EnOcean device reduces installation complexity; removes the need to physically access a device to configure it and allows simpler replacement of devices. More specifically, remote management allows EnOcean devices to be accessed and configured remotely using a basic set of standardised and mandatory commands called *Remote Management Control Commands* (RMCC) which, in turn, provide the abstract structure of a *Remote Procedure Call* (RPC).

The *Technical Working Group* (TWG) of the EnOcean Alliance has developed a complete process for remote commissioning that includes initial set-up, parameterization, control, maintenance and documentation of battery-less wireless devices. Our objective is to define a uniform approach for all of the listed procedures as a next level of interoperability.

10.1 Common rules

Remote commissioning defines the communication between the commissioned and the target device. Our specification expands the existing EnOcean standardized profiles and offers enhanced interoperability which, in turn, defines abstract structure of commands and

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basic rules for remote access, configuration and a uniform procedure of parameterizing EnOcean-based devices. The communication is based on the Generic Profiles data description language; the grammatical rules for all options of data encoding for ultra-low power and energy harvesting radio communication. These also specify how a managing device – a smart phone for example, talks with the target device.

10.2 Consistent device description

In addition to the commissioning process, the TWG has introduced a standardized *file* for device description that describes the device and its functionalities in detail in a pre-defined electronic data sheet. It comes along with a uniform device label, which comprises the EnOcean ID (communication basis) and the product ID (reference to manufacturer's specific end-application). All this information is available on a central data base. Installers or system operators can use a device ID to locate the detailed electronic data sheet. As such, installers or system operators have immediate access to all the specifics of the product, including the application profiles in use, that is, EEPs, operational modes and the requirements of parameterization. This significantly simplifies set-up and maintenance of an EnOcean network.

The specification has an open character so that manufacturers and service providers can develop tools such as 'apps' and web interfaces that include all functionalities of the remote commissioning. This will provide installers and system operators with user-friendly solutions to configure, control and maintain automation systems.

10.3 One specification for several tasks

The standardized interface and process of remote commissioning are intended to further optimize the control and configuration of building automation networks by using software that automates the support for EnOcean-based devices.

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In the following list, we describe several remote commissioning tasks:

- In a network, devices can be identified by their unique EnOcean ID, radio and device label;
- The connection between devices (network structure) can be fully documented and modified (add/change/delete);
- The device's operating parameters can be commissioned and documented;
- A device that replaces a previous device, for example, due to a malfunction, can be remotely configured using commissioning to match the functionality of the replaced device;
- A device can either be commissioned in the field or pre-commissioned on- and off-site of the installation;
- All functionalities of the installed device are still configurable after the installation has been completed;
- A factory reset to defaults is available;
- The radio link/range can be remotely tested using the commissioning tool;
- A device that supports remote commissioning can be remotely commissioned without physical access to the device.

10.4 Different use case scenarios

The functionalities of remote commissioning provide benefits in several scenarios. First of all, they help to centralize and record the *teach-in* process. Likewise, they enable system planners to reproduce an implementation at any time, even after several years. As such, planners can adapt a process or change it for a new device or if

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the network structure needs to be modified. When a new network is installed, all parameterization can be completed using one central commissioning tool. The user just needs to scan the device and transmit this information to the actuator. All necessary information including IDs and functionalities are transformed with one single step and stored centrally for configuration purposes.

10.5 Adjustments of an existing network

In an existing network, devices can be commissioned retrospectively. This is particularly relevant for areas where rooms have a similar design like a hotel, for example. Here, the same commissioning procedure can be repeated several times for different target devices. Another scenario is the change of control parameters of intelligent actuators, for example thresholds and timers in local HVAC equipment, or if the room structure in office buildings has been changed. The complete process of re-configuration can be undertaken during operation via remote control without physically touching a single device. Nevertheless, this might affect the configuration of the application or of the entire system, which can also be completed with the remote commissioning tool.

10.6 Service and maintenance

The comprehensive documentation as a vital part of the remote commissioning process can also be used to set-up a comprehensive monitoring application to visualize and actively control a live network. More so, visualization tools provide an overview of the documented system structure (plans, drawings, descriptions, tables and so on) that, for example, allow users to identify and solve potential problems in context. The same functionality can also help to determine malfunctions and the affected devices very quickly. Additionally, the specifics of remote commissioning simplify the replacement of the non-functioning device. For a simpler replacement process, a new device should support the same application profiles (that is, EEP) as the previous device. Installers can find this information

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in the product labeling, which they can access in the central data base. Moreover, the application configuration needs to be restored in the new hardware. As such, the new device can be commissioned in accordance with the documented and previously stored link tables and application configuration of the old device. This guarantees a seamless product exchange without any system failure.

In summary, the EnOcean Alliance's remote commissioning standard has defined new procedures for the set-up and operation of intelligently automated buildings. This significantly eases the work of planners, installers and system integrators. Similarly, it strengthens the interoperability of EnOcean-based devices as the installer doesn't need to concern themselves with specifics. Today, manufacturers can integrate the standardized specification in their devices and develop tools for central control, configuration and troubleshooting – bringing the intelligence of a smart building to the next level.

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11 Security Options

EnOcean's energy harvesting wireless solution provides several enhanced security mechanisms to prevent replay or eavesdropping attacks. If these are included, a battery-less wireless node 'counts' all incoming and outgoing data packets continuously and thus ensures the authenticity of the telegrams. A 16- or 24-bit *Rolling Code* (RC) incremented with each telegram is added as a constantly changing, that is, 'rolling' security mechanism. So, the telegram header, telegram data and current rolling code are used to calculate a 24- or 32-bit *Cypher-based Message Authentication Code* (CMAC). The CMAC counting is also protected by an *Advanced Encryption Standard* (AES) 128-bit encryption algorithm. The receiver system can then validate the data packet on the basis of the code. More specifically, this functionality protects networks against reply attacks – additionally, another mechanism is used to encrypt the data packets from the transmitter. The data is encrypted using the AES algorithm with a 128-bit key, in turn, negating eavesdropper attacks.

11.1 Introducing four new RORGs

With these new security mechanisms[19] in mind, EnOcean have introduced four new RORGs, which we describe in Table 11-1.

Table 11-1: Four new RORGs, which bolster EnOcean's security.

RORG	DESCRIPTION
`0x30`	Secure telegram. This message was not created from a non-secure counterpart. A message with this RORG was created by the secure application and the data may be interpreted by a teach-in-process outside of this specification; for example, EEP or GP.

[19] Further information can be found in, "Security of EnOcean's Radio Networks," https://www.enocean.com/en/security-specification/.

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`0x31`	A secure message that transports the original RORG non-secure code.
`0x32`	A non-secure message type that results from the decryption of a secure message with RORG `0x30`.
`0x35`	Secure teach-in telegram transmits private key and rolling to the communication partner.

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A Glossary

1BS	1-byte Communication
4BS	4-byte Communication
ADC	Analog-to-Digital Converter
ADT	Addressing Destination Telegram
AES	Advanced Encryption Standard
AP	Access Point
API	Application Programming Interface
ASK	Amplitude-shift Keying
CDM	Chained Data Message
CPU	Central Processing Unit
CMAC	Cypher-based Message Authentication Code
CRC	Cyclic Redundancy Check
DALI	Digital Addressable Lighting Interface
EEP	EnOcean Equipment Profiles
EIB	European Installation Bus
EoF	End of Frame
ERP	EnOcean Radio Protocol
ESP	EnOcean Serial Protocol
ESSL	EnOcean System Software Layer
FCC	Federal Communications Commission
FCS	Frame Check Sequence
FSK	Frequency-shift Keying
FW	Firmware

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GP	Generic Profiles
HA	Home Automation
HAL	Hardware Abstraction Layer
HAN	Home Area Network
HES	Home Electronic Systems
HVAC	Heating, Ventilation and Air Conditioning
ID	Identifier
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IoT	(the) Internet of Things
IP	Internet Protocol
ISM	Industrial, Scientific and Medical
ISO	International Organization for Standardization
ITU	International Telecommunications Union
KNX	Konnex
LAN	Local Area Network
LE	(Bluetooth) Low Energy
LBT	Listen Before Talk
LON	LonWorks
LSB	Least Significant Bit
M2M	Machine-to-Machine
MAC	Media Access Control
MAN	Metropolitan Area Network
MSB	Most Significant Bit
MSC	Manufacturer-specific Communication

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MWG	Marketing Working Group
OEM	Original Equipment Manufacturer
OSI	Open Systems Interconnection
PAN	Personal Area Network(ing)
PC	Personal Computer
PCB	Printed Circuit Board
PDU	Protocol Data Unit
PHY	Physical (layer)
QoS	Quality of Service
RC	Repeater Count
RC	Rolling Code
RCP	Room Control Panel
RF	Radio Frequency
RMCC	Remote Management Control Command
RORG	Radio (telegrams) ORGanizationally
RPC	Remote Procedure Call
RPS	Repeated Switch Communication
RSSI	Receive Signal Strength Indicator
RX	Receive
SmartACK	Smart Acknowledgement
SoC	System-on-Chip
SoF	Start of Frame
TCP	Transmission Control Protocol
TWG	Technical Working Group
TX	Transmit

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UART	Universal Asynchronous Receiver/Transmitter
UDP	User Datagram Protocol
ULP	Ultra Low Power
VLD	Variable Length Data
WPAN	Wireless Personal Area Network(ing)
WSP	Wireless Short-packet

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B References & Bibliography

EnOcean GmbH, “Dolphin Core Description” v2.1, December 2014.

EnOcean GmbH, “EnOcean Certification: Quality Seal for Reliable Interoperability”, retrieved, February 2015.

EnOcean GmbH, “Generic language for EnOcean networks”, retrieved, January 2015.

EnOcean GmbH, “Specification: EnOcean Serial Protocol 3 (ESP3)”, v1.27, July 2014.

EnOcean GmbH, “Specification: EnOcean Equipment Profiles”, v2.6.2, November 2014.

EnOcean GmbH, “Specification: EnOcean Equipment Profiles 2”, v1.0, September 2013.

EnOcean GmbH, “Security of EnOcean’s Radio Networks,” v1.9, July 2013.

EnOcean GmbH, “System Specification: Generic Profiles”, v1.0, April 2014.

EnOcean GmbH, “System Specification: Remote Commissioning”, March 2014.

EnOcean GmbH, “System Specification: Smart Acknowledge”, v1.6, July 2014.

EnOcean GmbH, “The Dolphin API”, v2.6.1.0, September 2014.

EnOcean Wireless Standard, https://www.enocean.com/en/enocean-wireless-standard/, retrieved, January 2015.

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Gratton, D. A., The Handbook of Personal Area Networking Technologies and Protocols, First Edition, Cambridge University Press, United Kingdom, 2013.

Gratton, D. A., "What is this Internet of Things, thing?", Telecoms.com, July 2014.

Schneider, Andreas, "EnOcean Company Presentation", EnOcean Alliance, May 2010.

Siskens, W., "Energy harvesting will be big in 2015", ElectronicsWeekly.com, retrieved, January 2015.

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