Energy Harvesting Wireless Power for the Internet of Things

Everybody is talking about the Internet of Things (IoT). In a few years only, it is predicted that there will be 25 billion of permanently connected things1, some years later 10 trillion connected sensors2. The possibilities of such a connected world are huge and will make data collection and processing the next big gold rush. The IoT provides a wealth of information and enables new forms of automation to make our lives easier and safer. However, in that vision, there remains a key question: how will billions of communicating devices be powered? The answer is energy harvesting wireless technology.

Data becomes a precious asset

The IoT will radically alter our world through "smart" connectivity, save time and resources, and provide opportunities for innovation and economic growth. In a cold chain monitoring system, for example, temperature data from food containers could be used to alert someone when temperatures approach thresholds and investigation or maintenance of the cooler is required. This data, collected from thousands of containers, can be consolidated to find potential gaps in the temperature-controlled supply chain for optimized logistic processing. In addition, if a drop in temperature is detected, an alarm is immediately sent to a central control or the smart phone of a person in charge, which enables the user to react in time before the cold chain is interrupted. Thus, continuously collected data in the supply chain could improve food quality and significantly reduce the loss at an estimated rate of something between 25 and 50 percent.

Sensors build the foundation

Such scenarios can only come true with wireless sensors as the tools needed to capture and transmit the first data bit in an IoT system. In contrast to line-powered actuators, which transform information into an activity, sensors don't process data but collect it. Thus, the IoT's sensory organs can be cheap, tiny and placed everywhere indoors and outdoors, even on the body. The more sensor data is available the better the insight into the application and system status. This allows for a more efficient decision-making process considering a broader range of criteria. Examples where this is true include industrial process control and automation, structural monitoring and agriculture or health care.

Unlike the standard approach of one or more sensors being connected to one central control unit, an Internet of Things allows the sharing and reuse of available information between different partners. **Thus, distributed sensors collect data only once but the processing intelligence makes use of the information for several applications.**

From local approach to a global Internet

Current control systems are usually local; for example sensors, control unit and actuators are often in close proximity and directly connected with each other, wired or wirelessly. An Internet of Things no longer requires such proximity. It allows centralized, or even outsourced computing resources, such as cloud-based computing, thus driving down infrastructure cost. Cloud-based computing resources could be used, for example, to combine local temperature sensor data with an external weather forecast to compute the exact amount of water required for agricultural irrigation. This information would then be sent to a remote actuator controlling the water flow.

Besides this, the IoT allows a dynamic creation of control networks. The networks can be formed or dissolved dynamically based on time, location or other parameters. **All the necessary base technologies for forming such networks already exist today – sensors, actuators, local or cloud-based control units and IPv6 providing an address space of more than 280 billion to connect all of them together.**

Requirements for a connected world

Computing power for such applications is readily available both locally or cloud-based. The main challenge now is how to deploy large numbers of sensor and actuator nodes and connect them in a suitable way.

Five key parameters must be addressed in order to enable such deployment:

- Installation effort – large numbers of new sensor and actuator nodes need to be deployed, often in existing infrastructure, while at the same time keeping the installation complexity at a minimum and allowing a gradual up-scaling in the number of deployed units.
- Service and maintenance effort – required by individual nodes has to be minimal when creating large scale networks. The vast majority of nodes in such networks needs to be maintenance-free. In addition, communication between all parties involved has to be rolled out.
- IPv6 communication – a true Internet of Things can only be formed if all of its nodes can be accessed via Internet Protocol (IP). However, it is not required that the nodes themselves physically communicate via IPv6 as long as the translation between the node's protocol and IPv6 is transparent.
- Reliability – reliable data exchange is a key consideration when sensor information and actuator commands are exchanged over the Internet.
- Total cost of ownership – cost is almost always a limiting factor. Thus, the total cost of ownership such as unit cost, installation cost, operation cost and maintenance cost, must be low.

The environmental impact

Energy waste is another challenge. Even in low power mode, the 14 billion network enabled devices, which are currently in use worldwide, waste 400 TWh (terawatt-hour) of electricity. With 50 billion devices in 2020, the consumption will increase by factor 3.5 to over 1,400 TWh[3]. **Energy waste presents a global issue for the IoT and is opposed to its resource-saving benefits.**

In addition, if all of these devices were to be powered by batteries, people would need to dispose of hundreds of tons of hazardous waste every year – an irresponsible environmental impact and anything but future-proof. Even battery recycling is no alternative as it takes 6 to 10 times more energy to reclaim metals from some recycled batteries than it does to produce it through other means, including mining[4].

The "things" in the Internet of Things

However, there is an energy and resource saving alternative: energy harvesting wireless technology. All requirements of an IoT listed above can be met by wireless (ease of installation and scaling), self-powered (maintenance-free, zero cost of operation) sensor and actuator nodes that can be accessed via IPv6 protocol. Energy harvesting wireless sensor nodes that use ambient energy as a power source enable unlimited processing and monitoring applications where cables or batteries fail. **Energy harvesting wireless sensors are needed to collect and transmit the first data bit and will be the "things" in the Internet of Things.**

The Internet of Things is the ideal environment to demonstrate the unique benefits of EnOcean energy harvesting wireless technology. It provides a great solution for bridging the last meters for wireless network applications to the Internet. IoT networks benefit from self-powered technology because it eliminates the need for battery replacement, making devices maintenance-free, which is especially beneficial for inaccessible areas and the deployment of billions of connected devices. In addition, energy harvesting sensors give IoT a green angle, bridging between the automation world and the mobile world with the added benefit of being eco-friendly.

Energy-efficient system design

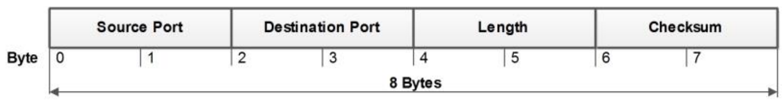
The specific characteristics of the EnOcean sensor protocol allow highly energy-efficient communication. **Due to a radio technology that only needs very little amounts of energy, wireless sensors can be powered by energy converters using motion, light or temperature differences as their energy source.**

Since most energy harvesters deliver only very small amounts of power, it is necessary to accumulate it over time while the system is sleeping and to lose only a small fraction of it in the process. Therefore, they have an extremely low idle current. This means that only a very tiny amount of energy is consumed while the system is sleeping. Standard consumer electronics devices today have a standby current in the range of a few milliamperes (mA), whereas power-optimized embedded designs typically achieve standby currents in the range of a few microamperes (uA), an improvement of factor 1,000. In comparison, the latest generation of EnOcean energy harvesting wireless sensors requires standby currents of 100 nanoamperes (nA) or less, an improvement of more than factor 10,000.

Energy-optimized protocol

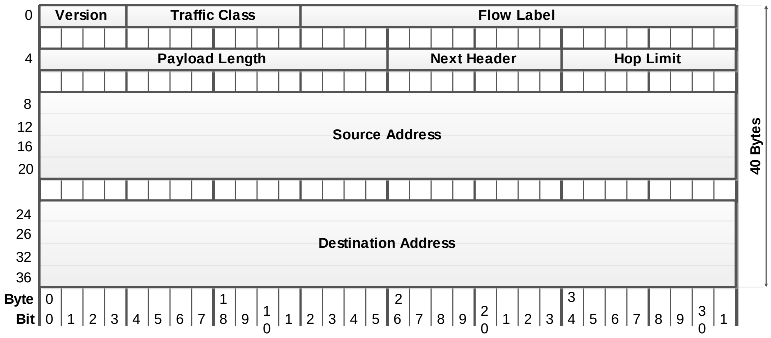
Achieving this level of performance requires very advanced design techniques and extensive optimization of each individual component. **The second requirement is that the accumulated energy has to be used as efficiently as possible when the system is in active mode.**

This is difficult to achieve while using IPv6 as communication protocol, as it incurs significant overhead, since the IPv6 header alone requires 40 bytes of protocol data. In addition, UDP (User Datagram Protocol), probably the simplest communication protocol on top of IPv6, would require an additional 8 bytes of protocol data.



The UDP header structure

Based on the IPv6 and UDP header structure, the transmission of 1 byte sensor data would require an additional 48 bytes of low level protocol data. IPv6/UDP is therefore not well suited for energy-efficient communication on sensor level in a network.



The IPv6 header structure

In comparison, the industry-leading EnOcean protocol for energy harvesting wireless applications in accordance with ISO/IEC 14543-3-1X and ultra-low power specifications of IEEE 802.15.4 use only 7 bytes of protocol overhead for the transmission of 1 byte of sensor data. This protocol length is sufficient for the wireless transmission of a measured value while it needs very low pow-er only. This meets the requirements and capabilities for wireless sensors and enables simple deployment of maintenance-free, intelligent nodes.

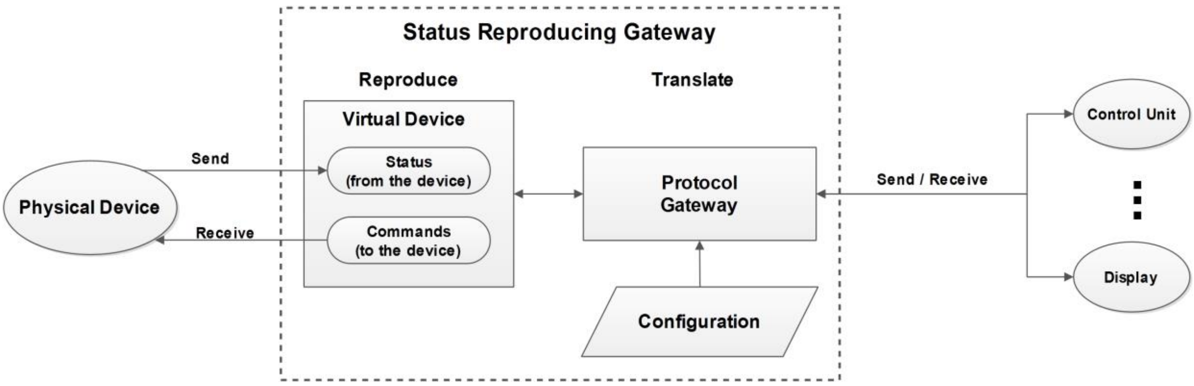
RORG	DATA	SOURCE ID	STATUS	HASH
1 Byte	1 Byte	4 Byte	1 Byte	1 Byte
8 Bytes				

ISO/IEC 14543-3-1X protocol structure

Status reproducing gateways

Dedicated IP gateways provide the translation between the energy-efficient EnOcean sensor protocol and IPv6 for intelligent data processing. They represent the state of each connected sensor node and act as their representative within the IPv6 network. These gateways reproduce each physical device as a virtual one. Such a virtual device represents all information that could be sent by the physical device. It also stores all of the commands that may be sent to the physical device. Each time the physical device, e.g. a temperature sensor, wakes up and sends new information, for example the current temperature, the corresponding parameter in the virtual device is adjusted accordingly. Similarly, each time a command is received for the device, e.g. a change in the data transmission frequency, it is buffered so that the sensor can access the data at a later time.

The actual gateway that handles the protocol conversion, only communicates with the virtual device. Thus, it can always access the physical device, even though that it is only possible in a fraction of the time.



Foundation for the next technological revolution

This integrated approach of protocol translation enables all parties to communicate with energy harvesting wireless sensor and actuator networks via IPv6. Thus, a protocol such as ISO/IEC 14543-3-1X, which is optimized for ultra-low power and energy harvesting wireless applications, can be used for the communication between the sensor and the gateway. This allows the deployment of a broad range of maintenance-free and cost-effective devices which are wirelessly connected. **In conjunction with IPv6 gateways, these self-powered wireless nodes are the foundation for the Internet of Things.**

Examples for a connected world with EnOcean's energy harvesting wireless technology

Based on the EnOcean technology, there is already a strong ecosystem of nearly 400 companies established with a significant footprint in building automation: the EnOcean Alliance. With the EnOcean technology's progress and the enhanced abilities of IPv6, several additional IoT application fields for energy harvesting wireless communication came up, including consumer and outdoor use cases:

- **Monitoring and control**

Wireless and battery-less technology simplifies monitoring and control significantly with only little intervention into the existing systems, requiring no reconstruction and no maintenance. Today, building automation systems already benefit of these characteristics. This is also applicable for smart home and any other kind of connected systems where data is needed for control over the Internet. An example for such a flexible automation system is HVAC control. Here, a thermostat, VAV (Variable Air Volume) or fan coil controller receives information related to occupancy, temperature, humidity, window position or CO_2 from the respective battery-less sensors and controls the opening and closing of valve actuators for radiators, or dampers for VAV systems. At the same time, the controller sends status information to a central building automation system, and receives control messages from the BAS system.

- **Structural health monitoring**

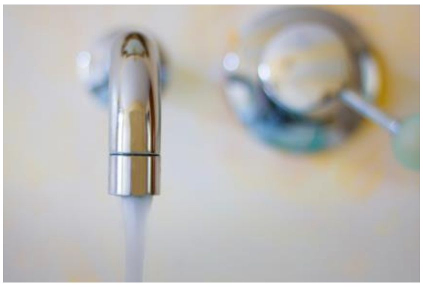
Large structures such as bridges, tunnels, dams or drilling platforms have to resist extreme forces created by weather, earthquakes or traffic. Radio sensors, powered by light, temperature changes or vibrations, that permanently monitor critical parameters, can warn against non-conformance and prevent break downs. A similar functionality can provide an alarm notice in the event of an avalanche or rock fall. Pilot installations in these fields already approved the solutions' successful functionality and pave the way for a market introduction in the near future.

➢ Agriculture and environment

Cloud-based computing resources can be used to combine local temperature data provided from battery-less sensors with an external weather forecast to compute the exact amount of water required for agricultural irrigation. This information is then sent to a remote actuator controlling the water flow. Similar sensors could measure the degree of humidity or soil nutrients for an optimal supply of water and care for plants. Current pilot projects already deliver data on the positive impact of such an installation for a resource-saving agriculture.

➢ Transportation

By 2030, 60% of all people will live in a city (source: World Health Organization), representing almost six billion people. Intelligent control will be needed to coordinate people's daily lives and prevent a city from collapsing. This includes automated control of traffic, street lights, energy supply or transportation of goods as well as waste disposal. This can only be realized with millions of energy-autonomous sensor nodes collecting and delivering the necessary data. In the London Eco-Routemaster hybrid buses, energy harvesting wireless technology allows passengers to activate stop signals with their bodies as a source of energy using. This saves up to 100 meters of cabling in the bus, saves installation effort and avoids the time-consuming effort to replace defective cables.



➢ Performing tasks

Alarm systems are a second field, which battery-less wireless technology is opening up, due to its specific features. Here, the reliability requirements are a lot more stringent than those required for lighting controls, for example. A system failure not only means a malfunction but can cause much more serious consequences for other systems that depend upon the equipment being monitored. It's a fact that more malfunctions are caused by battery failures than by the electronics, especially in large systems. Energy harvesting overcomes this issue with maintenance-free sensors monitoring water, oil or gas leaks, for example.

There are already various battery-less wireless water detectors using miniaturized solar cells or motion energy converters to power wireless signals that report water leaks in areas such as washing machines, under the bathtub, in the kitchen or in the bathroom. The EnOcean wireless signal immediately sends the leakage information to a gateway controller or directly to a valve, causing that the main water pipeline or the affected supply line to be shut off. A notification is sent to the user's smart phone or smart pad at the same time to inform them about the incident.

Sources:
[1] Gartner "Predicts 2015: The Internet of Things", January 2015
[2] TSensor Summit, Fairchild Semiconductor "Emergence of Trillion Sensors Movement", January 2014
[3] International Energy Agency, iea "Energy Efficiency Policy Brief", August 2014
[4] Battery University, April 2015