6LoWPAN Working Group	E. Kim	
Internet-Draft	ETRI	
Expires: January 15, 2009	N. Chevrollier	
	TNO	
	D. Kaspar	
	Simula Research Laboratory	
	JP. Vasseur	
	Cisco Systems, Inc	
	July 14, 2008	

TOC

Design and Application Spaces for 6LoWPANs
draft-ekim-6lowpan-scenarios-03

Status of this Memo

Abstract

This document investigates potential application scenarios and use cases for low-power wireless personal area networks (LoWPANs).

Table of Contents

---

1. Introduction

TOC

LoWPANs are inexpensive, low-performance, wireless communication networks, and are formed by devices complying with the IEEE 802.15.4 standard [3] (IEEE Computer Society, “IEEE Std. 802.15.4-2006,” October 2003.). Their typical characteristics can be summarized as follows:

*Low power: depending on country regulations and used frequency band, the maximum transmit power levels can be up to 1000 mW [3] (IEEE Computer Society, “IEEE Std. 802.15.4-2006,” October 2003.). However, typical wireless radios for LoWPANs are battery-operated and consume between 10 mW and 20 mW [4] (Bulusu, N. and S. Jha, “Wireless Sensor Networks,” July 2005.).

*Short range: The Personal Operating Space (POS) defined by IEEE 802.15.4 implies a range of 10 meters. For real implementations, the range of LoWPAN radios is typically measured in tens of

meters, but can go far beyond that in line-of-sight situations [4] (Bulusu, N. and S. Jha, “Wireless Sensor Networks,” July 2005.).

*Low bit rate: the IEEE 802.15.4 standard defines a maximum over-the-air rate of 250 kb/s, as well as lower data rates of 40 kb/s and 20 kb/s for each of the currently defined physical layers (2.4 GHz, 915 MHz and 868 MHz, respectively).

*Small memory capacity: common RAM sizes for LoWPAN devices consist of a few kilobytes, such as 4 KB.

*Limited processing capability: current LoWPAN nodes usually have 8-bit processors with clock rates around 10 MHz.

The IEEE 802.15.4 standard distinguishes between two types of nodes, reduced-function devices (RFDs) and full-function devices (FFDs). Through their inability to transmit MAC layer beacons, RFDs can only communicate with FFDs in a resulting "master/slave" star topology. FFDs are able to communicate with peer FFDs and with RFDs in the aforementioned relation. FFDs can therefore assume arbitrary network topologies, such as multi-hop meshes.
LoWPANs do not necessarily comprise of sensor nodes only, but may also consist of actuators. For instance, in an agricultural environment, sensor nodes might detect low soil humidity and then send commands to activate the sprinkler system.
A LoWPAN network can be seen as a network of small star-networks, each consisting of a single FFD connected to zero or more RFDs. The FFDs themselves act as packet forwarders or routers and connect the entire LoWPAN in a multi-hop fashion. A LoWPAN domain is defined by the number of devices controlled by the LoWPAN coordinator. Each LoWPAN has a single coordinator, which must be of FFD type and it is responsible for address allocation. A LoWPAN coordinator is responsible for a single LoWPAN.

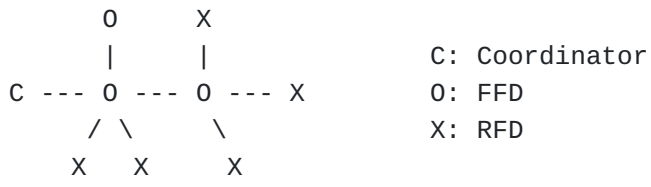

Figure 1: Example of a simple LoWPAN

Furthermore, communication to corresponding nodes outside of the LoWPAN is becoming increasingly important. The distinction between RFDs and

FFDs and the introduction of additional functional elements, such as gateways or border routers, increase the complexity on how basic network functionality (e.g., routing and mobility) can be designed for LoWPANs.
After describing the characteristics of a LoWPAN, this draft provides a list of use cases and market domains that may benefit and motivate the work currently done in the 6LoWPAN WG.

---

2. Design Space

TOC

Inspired by [5] (Roemer, K. and F. Mattern, “The Design Space of Wireless Sensor Networks,” December 2004.), this section describes the potential dimensions that could be used to describe the design space of wireless sensor networks in the context of the 6LoWPAN WG. The design space is already limited by the unique characteristics of a 6LoWPAN (e.g., low-power, short range, low-bit rate) as described in [2] (Kushalnagar, N., Montenegro, G., and C. Schumacher, “IPv6 over Low-Power Wireless Personal Area Networks (6LoWPANs): Overview, Assumptions, Problem Statement, and Goals,” August 2007.). The possible dimensions for scenario categorization used in this draft are described as follows:

*Deployment: In a LoWPAN, sensor nodes can be scattered randomly or they may be deployed in an organized manner. The deployment can occur at once, or as an iterative process. The selected type of deployment has an impact on node density and location. This feature affects how to organize (manually or automatically) the sensor network, and how to allocate addresses in the network.

*Mobility: Inherent to the wireless characteristics of LoWPANs, sensor nodes could move or be moved around. Mobility can be an induced factor (e.g., sensors in an automobile), hence not predictable, or a controlled characteristic (e.g., pre-planned movement in a supply chain).

*Network Size: The network size takes into account nodes that provide the intended network capability (i.e., FFD). The number of nodes involved in a LoWPAN could be small (10 nodes), moderate (several 100s), or large (over a 1000).

*Power Source: Whether the sensor nodes are battery-powered or mains-powered influences the network design. A hybrid solution is also possible where only part of the network (e.g., FFDs) is mains-powered.

*Security Level: sensor networks may carry sensitive information and require high-level security support where the availability, integrity, and confidentiality of the information are primordial. This high level of security may be needed in case of structural monitoring of key infrastructure or health monitoring of patients.

*Routing: The routing factor highlights the number of hops that has to be traversed to reach the edge of the network or a destination node within it. A single hop may be needed for simple star-topologies or a multi-hop communication scheme for more elaborate topologies, such as meshes or trees. From previous work on LoWPANs from academia and industry, various routing mechanisms have been introduced, such as data-centric, event-driven, address-centric, localization-based, or geographical routing. We do not use such a fine granularity in our draft but rather use topologies and single/multi-hop communication when referring to the routing categorization.

*Connectivity: Nodes within a LoWPAN are considered "always connected" when there is a network connection between any two given nodes. However, due to external factors (e.g., extreme environment, mobility) or programmed disconnections (e.g., sleeping mode), the network connectivity can be from "intermittent" (i.e., regular disconnection) to "sporadic" (i.e., almost always disconnected network).

*Quality of Service (QoS): for mission-critical applications, support of QoS is mandatory in resource-constrained LoWPANs.

*Traffic Pattern: several traffic patterns may be used in sensor networks. To name a few, Point-to-Multi-Point (P2MP), Multi-Point-to-Point (MP2P) and Point-to-Point (P2P).

---

3. Application Scenarios

TOC

This section lists a fundamental set of LoWPAN application scenarios in terms of system design. A complete list of practical use cases is not the goal of this draft. The intention is to define a minimal set of LoWPAN configurations to which any other scenario can be abstracted to. Also, the characteristics of the scenarios described in this section do not reflect the characteristics that every LoWPAN must have in a particular environment (e.g., healthcare).

3.1. Industrial Monitoring

TOC

3.1.1. Application Features

TOC

Sensor network applications for industrial monitoring can be associated with a broad range of methods to increase productivity, energy efficiency, and safety of industrial operations in engineering facilities and manufacturing plants. Many companies currently use time-consuming and expensive manual monitoring to predict failures and to schedule maintenance or replacements in order to avoid costly manufacturing downtime. Deploying wireless sensor networks, which can be installed inexpensively and provide more frequent and more reliable data, can reduce equipment downtime and eliminate costly manual equipment monitoring. Additionally, data analysis functionality can be placed into the network, eliminating the need for manual data transfer and analysis.
Industrial monitoring can be largely split into the following application fields:

*Process Monitoring and Control: combining advanced energy metering and sub-metering technologies with wireless sensor networking in order to optimize factory operations, reduce peak demand, and ultimately lower costs for energy.

Manufacturing plants and engineering facilities, such as product assembly lines and engine rooms, can be drastically optimized using wireless sensor technology in order to ensure product quality, control energy consumption, avoid machine downtimes, and increase operation safety. In industrial settings, sensors such as vibration detectors can be used to continuously monitor equipment and predict equipment failure and to detect the need for maintenance, with far greater precision. This allows companies to avoid costly equipment failures or shutdowns of production lines and therefore increase their productivity.

Greater access to process parameters gives engineers better visibility and ultimately better decision making power. Various sensor measurements, such as gas pressure, the flow of liquids and gases, room temperature and humidity, or tank charging levels may be used together with controllers and actuators to improve a plant's productivity in a continuous self-controlling loop, in which instruments can be upgraded, calibrated, and reconfigured as needed via the wireless channel.

A plant's monitoring boundary often does not cover the entire facility but only those areas considered critical to the process. Easy to install wireless connectivity extends this line to include peripheral areas and process measurements that were previously infeasible or impractical to reach with wired connections.

*Machine Surveillance: ensuring product quality and efficient and safe equipment operation. Critical equipment parameters such as vibration, temperature, and electrical signature are analyzed for abnormalities that are suggestive of impending equipment failure (see Section 3.2 (Structural Monitoring)).

*Supply Chain Management and Asset Tracking: with the retail industry being legally responsible for the quality of sold goods, early detection of inadequate storage conditions with respect to temperature will reduce risk and cost to remove products from the sales channel. Examples include container shipping, product identification, cargo monitoring, distribution and logistics.

Global supply chain and transportation applications increasingly require real-time sensor and location information about their supplies and assets. Wireless sensor networks meet these requirements efficiently with low installation and management costs, providing benefits such as reduced inventory, increased asset utilization, and precise location tracking of containers, goods, and mobile equipment. Clients can be provided with an early warning of possible chain ruptures, for example by using call centers or conveniently accessing comprehensive on-line reports and data management systems. Such reports could include monitoring of current states, the history of goods with critical conservation conditions, and in critical areas the monitoring status of oil containers, or verification of chemical gas substance concentration.

For instance, thousands of cargo ships loaded with millions of containers are sailing the oceans today. However, supply and demand are not equally distributed around the world, which results in high costs for shipping empty containers. Sophisticated IT systems try to circumnavigate this problem and precision planning is critical in any case: the customer always expects containers to arrive just in time. Wireless sensor networks have a great potential of making this growing market even more efficient by allowing more reliable tracking and identification of containers, and cargo monitoring for hazardous freight detection or identification of illegal shipment.

Also, the process of loading and unloading can be implemented more efficiently. For example, after a crane operator has lifted

a container from the deck, its content is identified and taken to the corresponding warehouse -- on a driverless truck whose movements are controlled at centimeter precision by transponders under the asphalt.

*Storage Monitoring: sensory systems designed to prevent releases of regulated substances to ground water, surface water and soil. This application field may also include theft/tampering prevention systems for storage facilities or other infrastructure, such as pipelines.

3.1.2. A Use Case and its Requirements

TOC

Storage Monitoring (Hospital Storage Rooms)
In a hospital, maintenance of the right temperature in storage rooms is very critical. Red blood cells need to be stored at 2 to 6 degrees Celsius, blood platelets at 20 to 24 C, and blood plasma below -18 C. For anti-cancer medicine, maintaining a humidity of 45% to 55% is required. Storage rooms have temperature sensors and humidity sensors every 25m to 100m, based on the floor plan and the location of shelves, as indoor obstacles distort the radio signals. At each blood pack a sensor tag can be installed to track the temperature during delivery. A sensor node is installed in each container of a set of blood packs. In this case, highly dense networks must be managed.
All nodes are statically deployed and manually configured with either a single- or multi-hop connection to the coordinator. FFD and RFD nodes are configured based on the topology.
All sensor nodes do not move unless the blood packs or a container of block packs is moved. Moving nodes get connected by logical attachment to a new coordinator. Placement of coordinators differs between various service scenarios.
The network configuration and routing tables are not changed in the storage room unless node failure occurs.
This type of application works based on both periodic and event-driven notifications. Periodic data is used for monitoring the right temperature and humidity in the storage rooms. The data over or under a pre-defined threshold is meaningful to report. Blood cannot be used if it is exposed to the wrong environment for about 30 minutes. Thus, event-driven data sensed on abnormal occurrences is time-critical and requires secure and reliable transmission.
Due to the time-critical sensing data, reliable and secure data transmission is highly important.
Dominant parameters in industrial monitoring scenarios:

*Deployment: pre-planned, manually attached

*Mobility: no (except for the asset tracking case)

*Network Size: medium to large size, high node density

*Power Source: all battery-operated

*Security Level: business-critical. Secure and reliable transmission must be guaranteed. An extra key mechanism can be used.

*Routing: single- to multi-hop. Routing tables are merely changed after configuration, except in the asset tracking case. Node failure or indoor obstacles will cause the changes.

*Connectivity: always on for crucial processes, otherwise intermittent

*QoS: important for time-critical event-driven data

*Traffic Pattern: P2P (actuator control), MP2P (data collection)

*Other Issues: Sensor network management

3.1.3. 6LoWPAN Applicability

TOC

The network configuration of the above use-case can differ substantially by system design. The simplest way is to build up a star topology inside of the storage rooms, and connect the storage rooms with one link. In this case the sensor nodes in the container can be either FFDs or RFDs.
The PAN coordinators, C1, C2 and C3 are also 6LoWPAN routers. Each sensor node builds up its link-local address and may get a prefix from its default router by ND procedure (Mesh-under based ND optimization is on-going work in the WG [7] (Chakrabarti, S. and E. Nordmark, “LoWPAN Neighbor Discovery Extensions, draft-chakrabarti-6lowpan-ipv6-nd-04 (work in progress),” November 2007.), and route-over based ND optimization will be handled as well). Inside of the storage room, the each node does not need to get a globally unique IPv6 address. However, the container can be moved inside or outside of the hospital, so that globally unique addresses may be needed depending on the purpose of the system. Address auto-configuration is explained in Chapter 6 of RFC 4944. When the system only uses link-local scope, 16-bit addresses can be utilized, but 64-bit addresses are recommended for globally unique addressing.

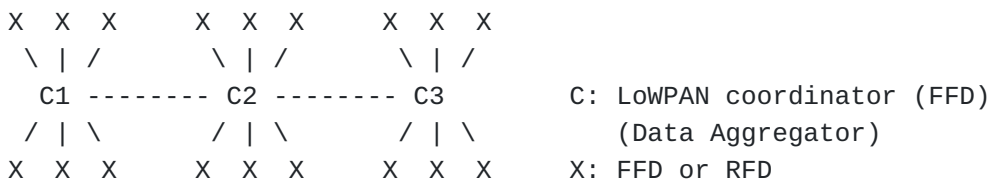

Figure 2: Storage rooms with simple star topology

The data volume is usually not so big in this case, but it is sensitive for delay. Data aggregators can be installed for each storage room, or just one data aggregator can collect all data. To make a light transmission, UDP (encapsulated in 6LoWPAN header or as it is) will be chosen, but secure transmission and security mechanism should be added. To increase security, MAC layer mechanisms or additional security mechanisms can be used.
Because a failure of a sensor node can critically affect the storage of the blood packs, network management is important here. SNMP-lite should be provided for the management.
When the container is moved out from the storage room, and connected to the hospital system (if the hospital buildings are fully or partly covered with 6LoWPANs), it should rebind to a new parent and a 6LoWPAN router. ND will support this procedure. In case that it is moved by an ambulance, it will be connected to the vehicle gateway or router.

3.2. Structural Monitoring

TOC

3.2.1. Application Features

TOC

Intelligent monitoring in facility management can make safety checks and periodic monitoring of the architecture status highly efficient. Mains-powered nodes can be included in the design phase of a construction or battery-equipped nodes can be added afterwards.

3.2.2. A Use Case and its Requirements

TOC

Bridge Safety Monitoring

A 1000m long bridge with 10 pillars is described. Each pillar and the bridge body contain 5 sensors to measure the water level, and 5 vibration sensors are used to monitor its structural health. The sensor nodes are deployed to have 100m line-of-sight distance from each other. All nodes are placed statically and manually configured with a single-hop connection to the coordinator. All sensor nodes do not move while the service is provided. The network configuration and routing tables are changed only in case of node failure. Except from the pillars, there are no special obstacles of attenuation to the sensor signals, but careful configuration is needed to prevent signal interference between sensors.
The network configuration and routing tables are changed only in case of node failure. On the top part of each pillar, an "infrastructure" FFD sink node is placed to collect the sensed data. The FFD is the LoWPAN coordinator of the sensors for each pillar which can be either FFDs or RFDs.
A logical entity of data gathering can lie with each LoWPAN coordinator. Communication schedules must be set up between leaf nodes and their LoWPAN coordinator to efficiently gather the different types of sensed data. Each data packet may include meta-information about its data, or the type of sensors could be encoded in its address during the address allocation. The data gathering entity can be programmed to trigger actuators installed in the infrastructure, when a certain threshold value has been reached. This type of application works based on both periodic and event-driven notifications. The data over or under a pre-defined threshold is meaningful to report. The event-driven data sensed on abnormal occurrences is time-critical and requires secure and reliable transmission. For energy conservation, all sensors could have periodic and long sleep modes but wake up on certain events.
The LoWPAN coordinators can play the role of a gateway, so that a third party with internet access can check the status of the specific pillar. Due to the contents of the data, only authenticated users should be allowed to access the data.
This use case can be extended to medium or large size sensor networks to monitor a building or for instance the safety status of highways and tunnels. Larger networks of the same kind still have similar characteristics such as static nodes, manual deployment, and mostly star (or multi-level of star) topologies, and periodic and event-driven real-time data gathering.
Dominant parameters in structural monitoring applications:

*Deployment: static, organized, pre-planned

*Mobility: none

*Network Size: small (dozens of nodes) to large, low density

*Power Source: mostly battery powered (except LoWPAN coordinators)

*Security Level: safety-critical. Secure transmission must be guaranteed. Only authenticated users should be able to access and handle the data. Lightweight key mechanisms can be used.

*Routing: star-topology (potentially hierarchical) In case of hierarchical case, reorganization of routing tree may be the issue. However, routing table may merely be changed after configuration. Node failure or indoor obstacles will cause the changes.

*Connectivity: always connected or intermittent by sleeping mode scheduling.

*QoS: Emergency notification (fire, over-threshold vibrations, water level, etc) is required to have priority of delivery and must be transmitted in a highly reliable manner.

*Traffic Pattern: MP2P (data collection), P2P (localized querying)

*Other Issues: accurate sensing and reliable transmission are important. In addition, sensor status reports may be needed to maintain a reliable monitoring system.

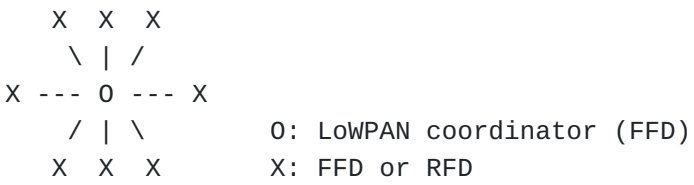

Figure 3: A LoWPAN with a simple star topology.

3.2.3. 6LoWPAN Applicability

TOC

TOC

3.3. Healthcare

3.3.1. Application Features

TOC

LoWPANs are envisioned to be heavily used in healthcare environments. They would ease the deployment of new services by getting rid of cumbersome wires and ease the patient care and life in hospitals and for home care. In this environment, delay or lost information may be a matter of life or death.
Various systems ranging from simple wearable remote controls for tele-assistance or intermediate systems with wearable sensors monitoring various metrics to more complex systems for studying life dynamics can be supported by the LoWPAN. In this latter category, a large amount of data from various sensors can be collected: movement pattern observation, checks that medicaments have been taken, object tracking, and more. An example of such a deployment is described in [6] (den Hartog, F., Schmidt, J., and A. de Vries, “On the Potential of Personal Networks for Hospitals,” May 2006.) using the concept of Personal Networks.

3.3.2. A Use Case and its Requirements

TOC

Healthcare at Home by Tele-Assistance
An old citizen who lives alone wears one to few wearable sensors to measure heartbeat, pulse rate, etc. Dozens of sensor nodes are densely installed at home for movement detection. A LoWPAN home gateway will send the sensing data to the connected healthcare center. Portable base stations with LCDs may be used to check the data at home, as well. The different roles of devices have different duty-cycles, which affect node management.
Multipath interference may often occur due to the patients' mobility at home, where there are many walls and obstacles. Even during sleeping, the change of the body position will affect the radio propagation.
Data is gathered both periodically and event-driven. In this application, event-driven data can be very time-critical. Thus, real-time and reliable transmission must be guaranteed.
Privacy also becomes an issue in this case, as the sensing data is very personal data. In addition, different data will be provided to the hospital system than what is given to a patient's family members. Role-based access control is needed to support such services, thus support of authorization and authentication is important here.

Dominant parameters in healthcare applications:

*Deployment: pre-planned

*Mobility: moderate (patient's mobility)

*Network Size: small, high node density

*Power Source: hybrid

*Security Level: Data privacy and security must be provided. Encryption is required. Role based access control is required to be support by proper authentication mechanism

*Routing: multihop for homecare devices, star topology on patients body. Multipath interference due to walls and obstacles at home must be considered.

*Connectivity: always on

*QoS: high level of support (life and death implication), role-based

*Traffic Pattern: MP2P/P2MP (data collection), P2P (local diagnostic)

*Other issues: Plug-and-play configuration is required for mainly non-technical end-users. Real-time data acquisition and analysis are important. Efficient data management is needed for various devices which have different duty-cycles, and for role-based data control. Reliability and robustness of the network are also essential.

3.3.3. 6LoWPAN Applicability

TOC

In this use-case, the network size is rather small (less than 10s of nodes). The home system is static with multi-hop paths, and the patient’s body network can be built on single-hop. The home gateway will be the sink node in the routing path. A 6LoWPAN router is logically or physically combined with it. A plug-and-play configuration is required. Each home system node will get a link-local IPv6 address following the auto-configuration described in RFC 4944. As the communication of the system is limited to the home, both 16-bit and 64-bit can be used to create their IPv6 link-local addresses.
Multi-hop communication can be achieved by either mesh-under or route-over routing mechanisms. In case the mesh-under mechanism is provided,

the 6LoWPAN router becomes the only router, and ND is done as [7] (Chakrabarti, S. and E. Nordmark, “LoWPAN Neighbor Discovery Extensions, draft-chakrabarti-6lowpan-ipv6-nd-04 (work in progress),” November 2007.) describes. The mesh-under based ND is still on-going work, and the routing mechanism is in study. When route-over is used, some FFDs will play role in 6lowpan routers and the network will build up one IPv6 link. IP-based routing is now chartered at the ROLL WG.
The patient’s body network can be simply configured by a single-hop. [7] (Chakrabarti, S. and E. Nordmark, “LoWPAN Neighbor Discovery Extensions, draft-chakrabarti-6lowpan-ipv6-nd-04 (work in progress),” November 2007.) is used in there, but RA may need to be optimized as it is sent to the FFD (or in other name, coordinator) by unicast, and the coordinator forward it to his neighbor nodes.
The mobility of the patient's body area network is caused by the patient’s movement within the home. If there are not many obstacles to block or distort the signal, it may not need additional mobility support. If not, additional mobility support must be provided. Currently there is no mobility work is handled by the 6LoWPAN WG.

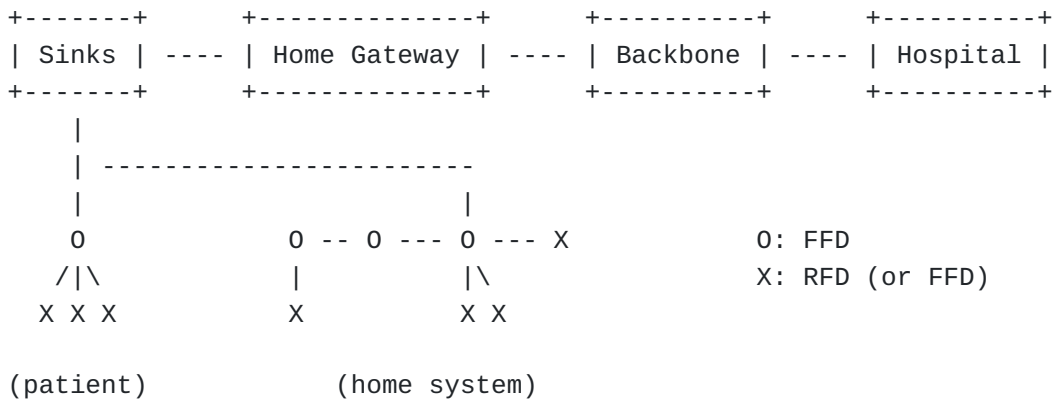

Figure 4: A mobile healthcare scenario.

3.4. Connected Home

TOC

The "Connected" Home or "Smart" home is with no doubt an area where LoWPANs can be used to support an increasing number of services:

*Home safety/security

*Home Automation and Control

*Healthcare (see above section)

*Smart appliances and home entertainment systems

In home environments LoWPAN networks typically comprise a few dozen and probably in the near future a few hundreds of nodes of various nature: sensors, actuators and connected objects.
[Example]: Home Automation
In terms of home safety and security, the LoWPAN is made of motion, audio, door/window sensors, video cameras to which additional sensors can be added for security (gas, water, CO, Radon, smoke detection). The LoWPAN typically comprises a few dozen of nodes forming a ad-hoc network with multi-hop routing since the nodes may not be in direct range. In its most simple form all nodes are static and communicate with a central control module but more sophisticated scenarios may also involve inter-device communication. For example, a motion/presence sensor may send a multicast message to a group of lights to be switched on, a video camera will be activated sending a video stream to a gateway that can be received on a cell phone.
The Home automation and control system LoWPAN offers a wide range of services: local or remote access from the Internet (via a secured gateway) to monitor the home (temperature, humidity, activation of remote video surveillance, status of the doors (locked),...) but also for home control (activate the air conditioning/heating, door locks, sprinkler systems, ...). Fairly sophisticated systems can also optimize the level of energy consumption thanks to a wide range of input from various sensors connected to the LoWPAN: light sensors, presence detection, temperature, ... in order to control electric window shades, chillers, air flow control, air conditioning and heating with the objective to optimize energy consumption.
Ergonomics in Connected Homes is key and the LoWPAN must be self-managed and easy to install. Traffic patterns may greatly vary depending on the applicability and so does the level of reliability and QoS expected from the LoWPAN. Humidity sensing is typically not critical and requires no immediate action whereas tele-assistance or gas leak detection is critical and requires a high degree of reliability. Furthermore, although some actions may not involve critical data, still the response time and network delays must be on the order of a few hundreds of milliseconds to preserve the user experience (e.g. use a remote control to switch a light on). A minority of nodes are mobile (with slow motion). Connected Home LowPAN usually do not require multi-topology or QoS routing and fairly simple QoS mechanisms must be supported by the LoWPAN (the number of Class of Services is usually limited).
Dominant parameters for home automation applications:

*Deployment: multi-hop topologies

*Mobility: small degree of mobility

*Network Size: medium number of nodes, potentially high density

*Power Source: mix of battery and AC powered devices

*Security Level: authentication and encryption required

*Routing: no requirement for multi-topology or QoS routing

*Connectivity: intermittent (usage-dependent sleep modes)

*QoS: support of limited QoS (small number of Class of Service)

*Traffic Pattern: P2P (inter-device), P2MP and MP2P (polling)

3.5. Vehicle Telematics

TOC

LoWPANs play an important role in intelligent transportation systems. Incorporated in roads and/or, they contribute to the improvement of safety of transporting systems. Through traffic or air-quality monitoring, they increase the possibilities in terms of traffic flow optimization and help reducing road congestion.
[Example]: Telematics
Scattered sensors are included in roads during their construction for motion monitoring. When a car passes over of these sensors, the possibility is then given to track the trajectory and velocity of the car for safety purposes. The lifetime of sensor devices incorporated into roads is expected to be as long as the life time of the roads (10 years). Multihop communication is possible between sensors, and the network should be able to cope with the deterioration over time of the node density due to power failure. Sinks placed at the road side are mains-powered, sensor nodes in the roads run on battery. Power savings schemes might intermittently disconnect sensors nodes. A rough estimate of 4 sensors per square meter is needed. Other applications may involve car-to-car communication for increased road safety.
Dominant parameters in vehicle telematics applications:

*Deployment: scattered, pre-planned

*Mobility: high

*Network Size: large

*Power Source: mostly battery powered

*Security Level: low

*Routing: multi-hop

*Connectivity: intermittent

*QoS: support of limited QoS

*Traffic Pattern: mostly Multi-Point-to-Point (MP2P)

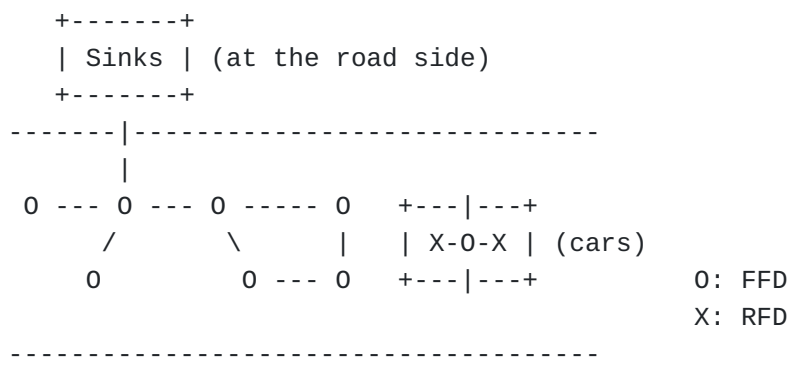

Figure 5: Multi-hop LoWPAN combined with mobile star LoWPAN.

3.6. Agricultural Monitoring

TOC

Accurate temporal and spatial monitoring can significantly increase agricultural productivity. Due to natural limitations, such as a farmers' inability to check the crop at all times of day or inadequate measurement tools, luck often plays a too large role in the success of harvests. Using a network of strategically placed sensors, indicators such as temperature, humidity, soil condition, can be automatically monitored without labor intensive field measurements. For example, sensor networks could provide precise information about crops in real time, enabling businesses to reduce water, energy, and pesticide usage and enhancing environment protection. The sensing data can be used to find optimal environments for the plants. In addition, the data on the planting condition can be saved by sensor tags, which can be used in supply chain management.
[Example]: Automated Vineyard

In a vineyard with medium to large geographical size, a number of 50 to 100 FFDs nodes are manually deployed in order to provide full signal coverage over the study area. These FFD nodes support a multi-hop routing scheme to enable data forwarding to a sink node at the edge of the vineyard. An additional number of 100 to 1000 (possibly different) specialized RFD sensors (i.e., humidity, temperature, soil condition, sunlight) are attached to the FFDs in local wireless star topologies, periodically reporting measurements to the associated master FFD. For example, in a 20-acres vineyard with 8 parcels of land, 10 sensors are placed within each parcel to provide readings on temperature and soil moisture. Each of the 8 parcels contains 1 FFD sink to collect the sensor data. 10 intermediate FFD "routers" are used to connect the sinks to the main gateway.
Sensor nodes may send event-driven notifications when readings exceed certain thresholds, such as low soil humidity; which may automatically trigger a water sprinkler in the local environment. For increased energy efficiency, all sensors are in periodic sleep state. However, FDD nodes need to be aware of sudden events from RFDs. Their sleep periods should therefore be set to shorter intervals. Communication schedules must be set up between RFDs and FFDs and global time synchronization is needed to account for clock drift.
Sensor localization is important for geographical routing, for pinning down where an event occurred, and for combining gathered data with their actual position. Using manual deployment, device addresses can be used. For randomly deployed nodes, a localization algorithm needs to be applied.
There might be various types of sensor devices deployed in a single LoWPAN, each providing raw data with different semantics. Thus, an additional method is required to correctly interpret sensor readings. Each data packet may include meta-information about its data, or a type of a sensor could be encoded in its address during address allocation.
Dominant parameters in agricultural monitoring:

*Deployment: pre-planned

The sensor nodes are installed outdoors or in a greenhouse with high exposure to water, soil, dust, in dynamic environments of moving people and machinery, with growing crop and foliage. Sensor nodes can be deployed in a pre-defined manner, considering the harsh environment.

*Mobility: all static

*Network Size: medium to large, low to medium density

*Power Source: all nodes are battery-powered, except the sink

*Security Level: business-critical. Light-weight security or a global key management can be used depending on the business purpose.

*Routing: mesh topology with local star connections. Routing table is merely changed after configuration. Node failure or indoor obstacles will cause the changes.

*Connectivity: intermittent (many sleeping nodes)

*QoS: not critical

*Traffic Pattern: Mainly MP2P/P2MP. P2P for Gateway communication or actuator triggering.

*Other issues: Time synchronization among sensors are required, but the traffic interval may not be frequent (e.g. once in 30 minutes to 1 hour).

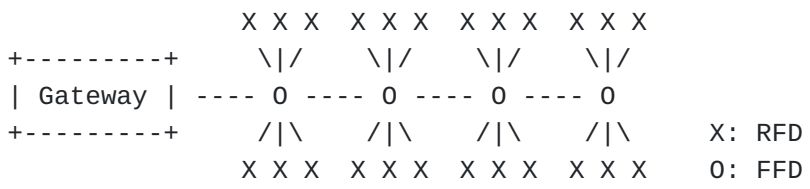

Figure 6: An aligned multi-hop LoWPAN.

4. Security Considerations

TOC

To be defined.

5. Acknowledgements

TOC

Thanks to David Cypher for giving more insight on the IEEE 802.15.4 standard and to Irene Fernandez for her review and valuable comments.

6. References

TOC

6.1. Normative References

TOC

[1]	Bradner, S., “Key words for use in RFCs to Indicate Requirement Levels,” BCP 14, RFC 2119, March 1997 (TXT, HTML, XML).
[2]	Kushalnagar, N., Montenegro, G., and C. Schumacher, “IPv6 over Low-Power Wireless Personal Area Networks (6LoWPANs): Overview, Assumptions, Problem Statement, and Goals,” RFC 4919, August 2007 (TXT).
[3]	IEEE Computer Society, “IEEE Std. 802.15.4-2006,” October 2003.

6.2. Informative References

TOC

[4]	Bulusu, N. and S. Jha, “Wireless Sensor Networks,” July 2005.
[5]	Roemer, K. and F. Mattern, “The Design Space of Wireless Sensor Networks,” December 2004.
[6]	den Hartog, F., Schmidt, J., and A. de Vries, “On the Potential of Personal Networks for Hospitals,” May 2006.
[7]	Chakrabarti, S. and E. Nordmark, “LoWPAN Neighbor Discovery Extensions, draft-chakrabarti-6lowpan-ipv6-nd-04 (work in progress),” November 2007.

Authors' Addresses

TOC

	Eunsook Kim
	ETRI
	161 Gajeong-dong
	Yuseong-gu
	Daejeon 305-700
	Korea
Phone:	+82-42-860-6124
Email:	eunah.ietf@gmail.com
	Nicolas G. Chevrollier
	TNO
	Brassersplein 2
	P.O. Box 5050
	Delft 2600
	The Netherlands
Phone:	+31-15-285-7354

Email:	nicolas.chevrollier@tno.nl
	Dominik Kaspar
	Simula Research Laboratory
	Martin Linges v 17
	Snaroya 1367
	Norway
Phone:	+47-4748-9307
Email:	dokaspar.ietf@gmail.com
	JP Vasseur
	Cisco Systems, Inc
	1414 Massachusetts Avenue
	Boxborough MA 01719
	USA
Phone:	
Email:	jpv@cisco.com

Full Copyright Statement

TOC

Intellectual Property

can be obtained from the IETF on-line IPR repository at http://www.ietf.org/ipr.
The IETF invites any interested party to bring to its attention any copyrights, patents or patent applications, or other proprietary rights that may cover technology that may be required to implement this standard. Please address the information to the IETF at ietf-ipr@ietf.org.