Opportunities of Emerging Technologies for Smart Houses – City-wide Energy, Gas and Water Measurement Networks

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Abstract: Due to the improvements in wireless sensor technology, an increased number of companies are using it for a wide range of purposes (monitor and automate home, building, industrial and agricultural systems, including thermostats and security products, automated meter reading). In order to achieve technological and marketplace success, the low power, inexpensive sensor networks need an economical, low-latency, robust, energy-efficient, wireless connectivity infrastructure. With this in mind, we are proposing a wireless network architecture for automated energy, gas and water meter reading based on ZigBee technology.

Keywords: smart houses, automated metering, telemetry, domotics, wireless networks, Zigbee

1 Introduction

"Smart home" technology or domotics has become the popular name for the integration of telematics into the electrical installation of the home. Products such as switches, dimmers, thermostats have incorporated microchips for a longer time. In the current smart home technology a large number of sensors and actuators are connected to each other, and by connecting also meters of different utilities such as energy, gas and water, will make the home look like being more intelligent. This intelligence could be of great assistance also to the end user, who could enjoy the comfort and benefit of energy saving and automatic cost calculation of a smart home, but also to the distribution company in sense that it will make easier the billing services.

For the last few years, a great expansion of remote control devices can be witnessed in our day-to-day life. A few years ago, infrared (IR) remotes for the television were the only such devices in our homes. But now the number of remotely controlled and monitored devices hopefully will increase. In order to interact with all these remotely controlled devices, there was a need to put them under a single standardized control interface that can interconnect them into a wireless network, specifically a home-area network or even a city-wide network. One of the most promising home-area network protocols is ZigBee, a software layer based on the IEEE 802.15.4 standard.

ZigBee has been created to satisfy the need of the market for a standard-based and cost-effective, wireless network that is able to support low data rates and power consumption, and still be able to provide security, and reliability. In order to address this need, the ZigBee Alliance, an industry working group (www.zigbee.org), has developed a standardized application software using the IEEE 802.15.4 wireless standard.

ZigBee's network layer supports three networking topologies [1]: star, mesh, and cluster tree. Star networks are common and provide for very long battery life operation. Mesh, or peer-to-peer, networks enable high levels of reliability and scalability by providing more than one path through the network. Cluster-tree networks use a hybrid star/mesh topology that combines the benefits of both for high levels of reliability and support for battery-powered nodes.

Energy, water and gas meters could benefit of such networks, meaning that they could integrate in the home-area network and by some gateways they can wirelessly send measurement data also to the energy, water and gas distribution companies through a city-wide wireless network.

During the last few years, new wireless local area networks such as Wi-Fi and Bluetooth became available. Table 1 shows the strengths and applications of these different systems:

Standard	***Bandwith***	***Power consumption***	***Stack size***	***Stronghold***	***Applications***
Wi-Fi	Upto 54 Mbps	400+mA TX, standby 20mA	100+KB	High data rate	Internet browsing, PC networking, file transfers
Bluetooth	1 Mbps	40mA TX, standby 0.2mA	~100+KB	Interoperability, cable replacement	Wireless USB, handset, headset
Zigbee	250 kbps	30mA TX, standby 0.1 mA	4.32KB	Long battery life, low cost	Remote control, battery-operated products, sensor

Table 1

Wireless technology comparison chart

There is also a new implementation called Wireless USB N:1, that aims to be a wire-replacement technology, predominantly for event-driven, low-duty-cycle applications in which multiple nodes reporting to a central point. The topology is of a star network. The maximum bandwidth is 1 Mbps, but maximum throughput is 62.5 kbps. As with other standards in this domain, W-USB operates in the 2.4-GHz band, using direct-sequence-spread-spectrum (DSSS) radio technology on 79 channels. Range reaches 50m, and the radio design detects occupied channels and avoids them in its automatic channel selection to minimise the effects of interference. W-USB N:1 aims at the lowest cost and power. The chip uses less than 0.25 μA in sleep mode; in a typical application, it spends most of its time in this mode (external events awaken it), reporting a measurement and closing down again. Designers can therefore expect years of battery life for such nodes, Cypress says. The host microcontroller needs to be only of 8-bit type, and the code for a W-USB node occupies less than 4 kbytes.

Analyzing the type of data that circulates within a network of sensors, actuators and meters, reveals that most of it is small packets that control devices or obtain their status and parameters. For many applications, such as energy, gas and water meters, the device mostly stays in deep-sleep mode and only sends a short burst of information at a fixed interval. The main requirements for devices in such types of networks are:

- extremely low power consumption
- the ability to sleep for a long time
- simplicity
- low cost.

A home network should also support different configurations, such as a star or mesh network, to effectively cover a household area of 30 to 70 meters, this range will also allow measurement data transmission from meters to a city-wide network.

ZigBee-compliant products operate in unlicensed bands worldwide, including 2.4GHz (global), 902 to 928MHz (Americas), and 868MHz (Europe). Raw data throughput rates of 250Kbps can be achieved at 2.4GHz (16 channels), 40Kbps at 915MHz (10 channels), and 20Kbps at 868MHz (1 channel). The transmission distance is expected to range from 10 to 75m, depending on power output and environmental characteristics. Like Wi-Fi, ZigBee uses direct-sequence spread spectrum in the 2.4GHz band, with offset-quadrature phase-shift keying modulation. The 868 and 900MHz bands also use direct-sequence spread spectrum but with binary-phase-shift keying modulation. ZigBee networks use three device types:

- The *network coordinator* maintains overall network knowledge. It's the most sophisticated of the three types and requires the most memory and computing power.

- The *full function device (FFD)* supports all 802.15.4 functions and features specified by the standard. It can function as a network coordinator. Additional memory and computing power make it ideal for network router functions or it could be used in network-edge devices (where the network touches the real world).
- The *reduced function device (RFD)* carries limited (as specified by the standard) functionality to lower cost and complexity. It's generally found in network-edge devices.

The ZigBee coordinator initializes a network, manages network nodes, and stores network node information. The ZigBee router participates in the network by routing messages between paired nodes. The ZigBee end device acts as a leaf node in the network and can be an RFD or FFD.

ZigBee networks consist of multiple traffic types with their own unique characteristics, including periodic data, intermittent data, and repetitive low latency data. The characteristics of each are as follows:

- Periodic data is usually defined by the application such as a wireless sensor or meter.
- Intermittent data is either application- or external stimulus-defined, such as a wireless light switch.
- Repetitive low latency data uses time slot allocations, such as a security system; these applications may use the guaranteed time slot (GTS) capability.

ZigBee networks are primarily designed for low duty cycle sensor networks (<1%). They may recognize new network nodes and associate them in about 30 ms. Waking up a sleeping node takes about 15 ms, as does accessing a channel and transmitting data. ZigBee applications benefit from the ability to quickly attach information, detach, and go to deep sleep, which results in low power consumption and extended battery life.

2 Present and Future Advantages of Wireless Systems

Concerning wireless communication, the advantage is obvious: there is no need for the installation of cables which would cause trouble if the household is inhabited and which is, therefore, disturbing for the inhabitants. A wireless medium allows a high flexibility for connecting devices and there is no problem to add more of them.

Also, it is now widely acknowledged that standards, such as Bluetooth and WLAN, are not suited for low-power applications, due to the fact that these standards' high node costs as well as power hungry radio frequency ICs and complex protocols. For system developers it is much more cost effective to design their applications based on a common standardized ZigBee platform than creating a new proprietary solution from scratch each time.

From the above advantages of ZigBee are obvious:

- It allows broad-based deployment of reliable wireless networks with low costs.
- Various types of equipment from any number of vendors can be integrated.
- These types of networks are typically used for monitoring and control purposes.
- Require very little power, which means they can run for years on inexpensive batteries.

The key feature of ZigBee-based networks is the ability to support robust, self-forming and self-healing mesh networking technologies. Such mesh networks can contain thousands of nodes, and the mesh networking topology means messages can choose a number of routes to get from one node to another (data and control messages can pass from one node to other node via multiple paths), making a reliable network not dependent on any particular individual node to function.

This extends the range of the network and improves data reliability. Peer-to-peer capability can be used to build large, geographically dispersed networks where smaller networks link together to form a cluster-tree network.

Anyhow according to [4] there will be several important developments and applications. Generally speaking, the following can be expected:

- a new generation of control systems/procedures, hardware, buses and protocols,
- convergence of control and communication functions,
- services such as monitoring, metering and localization,
- the introduction of intelligent systems like wearable computers and smart clothes,
- increase of the capability of the environment to adapt to the user (“ambient intelligence”).

3 Building a City-wide Wireless Network

The motivation for wireless connectivity of different meters (energy, gas and water) in Romania, or in Europe, is the comfort of the consumer and on the other hand the automation of such readings which will lead to better services. For example, the human operator that reads out the meters has a limited program, typically from 8:00 AM to 4:00 AM, in that time range the consumers are not at home, so they have to make themselves the readouts and communicate them to the distribution companies so that the billing activities can be made before the required deadlines. Mesh networking aids such unattended operation cycle and allows automatic readouts from ZigBee powered sensors to be transmitted even on alternative paths; routing of data to the target device (distribution company of energy, gas or water) is transparent to the end-user (consumer). To provide low cost, the system requirements for ZigBee are much less than Bluetooth and other wireless protocols. Also, ZigBee's bandwidth is lower than Bluetooth, but the range is greater and the number of nodes is much greater. The larger node capability means that a large number of nodes can be initially established in a network or added as technology and system requirements change [2].

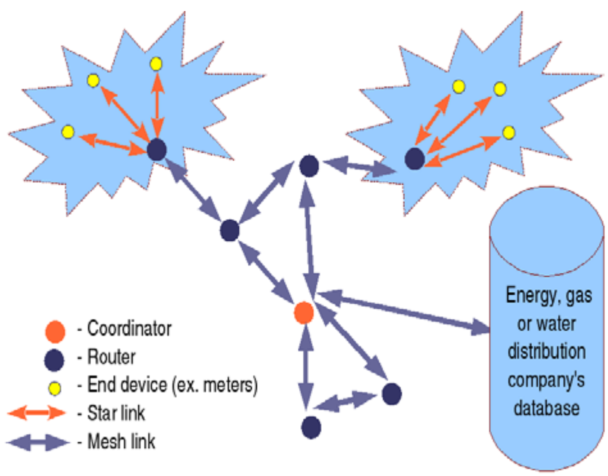

Figure 1
ZigBee network topology

The network layer of ZigBee protocol associates or dissociates devices using the network coordinator, implements security, and routes frames to their intended destination. In addition, the layer of the network coordinator is responsible for starting a new network and assigning an address to newly associated devices and supports multiple network topologies including star, cluster tree, and mesh, all of which are shown in Figure 1.

In a star topology, one of the FFD-type devices assumes the role of network coordinator and is responsible for initiating and maintaining the devices on the network. All other devices, known as end devices, directly communicate with the coordinator. In our context the end devices can be seen as ZigBee enabled energy, gas and water meters which communicates to the network coordinator the current readouts to be transmitted to the distribution company's database. The transmitted data can follow any available route in order to certainly arrive in the distribution database.

In a mesh topology, the ZigBee coordinator is responsible for starting the network and for choosing key network parameters, but the network may be extended through the use of ZigBee routers. The routing algorithm uses a request-response protocol to eliminate sub-optimal routing. Using local addressing, simple networks of more than 65,000 (2^{16}) nodes can be configured, thereby reducing address overhead.

The ZigBee stack can be considered small in comparison to other wireless standards. For network-edge devices with limited capabilities, the stack can be implemented in about 4Kb of the memory. Full implementation of the protocol stack takes less than 32Kb of memory. Only the network coordinator takes up extra resources (RAM) for the node devices database and for transaction and pairing tables.

A typical ZigBee enabled architecture is presented in Figure 2; due to the compact footprint, the architecture can be simply implemented on a 8 bit microcontroller core (such as PIC, 8051 etc.) and an RF IC:

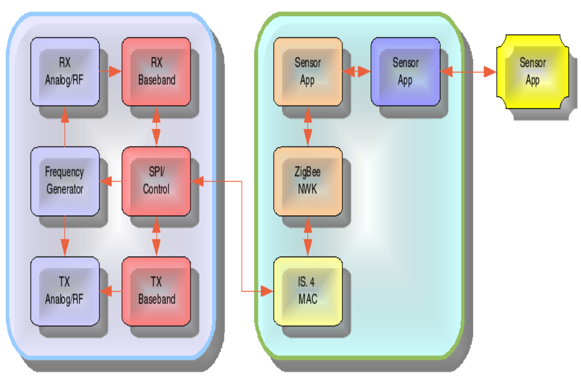

Figure 2
Typical ZigBee architecture

The ZigBee-enabled device consists in a radio frequency integrated circuit (RF IC) with a partially implemented physical layer connected to a low-power, low-voltage 8-bit microcontroller with peripherals, connected to the application sensor that is measuring the energy, gas or water consumption. The protocol stack and application firmware reside in on-chip flash memory. Therefore, the entire ZigBee device can be compact and cost efficient.

For this kind of applications (automated meter readings) also security is a big issue, but security alongside with integrity are the key benefits of the ZigBee technology. ZigBee leverages the security model of the IEEE 802.15.4 MAC sublayer which specifies four security services:

- access control - the device maintains a list of trusted devices within the network,
- data encryption - uses symmetric key 128-bit advanced encryption standard,
- frame integrity - protects data from being modified by parties without cryptographic keys,
- sequential freshness - rejects data frames that have been replayed (the network controller compares the freshness value with the last known value from the device and rejects it if the freshness value has not been updated to a new value).

Automated metering systems could play a very important role in smart home applications. Embedded devices that can communicate with the network infrastructure (home, office, city-wide) can be very helpful in increasing the comfortability of the user's environment and to help the user whenever this is required. As an example, alarms could be fired when one of the meter parameters are out of range or when they are meeting any errors, and a support center could be messaged if necessary. These are just very simple examples of what city-wide network could provide.

However, the systems, existing so far, are very often too complicated or not reliable enough. Frequently the bottleneck lies in the scheduling of the data communication between the nodes. But this can be avoided using proper scheduling and just-in-time delivery of the readings in order to meet the required deadlines for starting the automated billing services.

For example ZigBee can support up to 65,536 nodes. However, supporting this many nodes makes network administration unmanageable. To avoid this problem ZigBee networks should have no more than 3,000 nodes. For situations requiring more nodes, multiple subnets would work better than trying to make a single large network even bigger.

Introduction of wireless home, city-wide networks and smart home technology in normal housing has not taken place yet. High costs could be one of the key factors in the past, but also lack of standardization and lack of information to the end user were of big influence [6]. However, costs have been reduced considerably in recent years.

In order to provide flexibility both web based (end-user or consumer interface to the system) and desktop based monitoring application and automated billing services (server application that are hosted on the server computers of the distribution companies) have to be implemented for use in data centers of the distribution companies. The application has to be designed to monitor thousands of individual branch circuits of energy, gas and water meters. Among other things, the data logging could be designed to provide one year of min/max/mean measurement data.

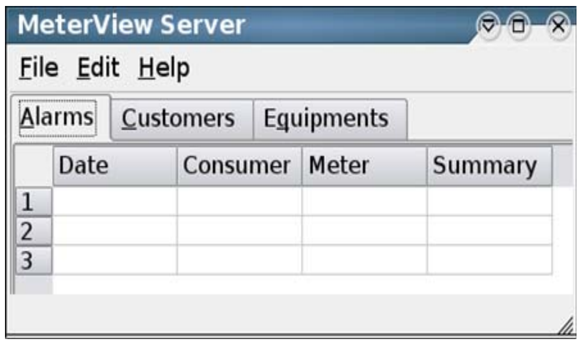

Figure 3
Scratch version of a dispatch server

The above screen shows a history of alarms. If the operator expands the alarm he will be able to see a summary of the alarm along with the consumer who it is impacted, and which equipment was potentially affected. Since the consumer can create notification groups against equipment as well as circuits, owners of the equipment are notified automatically. Even the exact location of the consumers house can be modeled as it shown in Figure 4. At the moment these screens are mostly just testing and presentation purposes. However all the major stuff in here could be put there. For example, all energy, gas and water meters have a plates with identification data. This would come in handy for reverse lookups (ie. finding the correct meter type by the service team) instead of calling the consumer and/or lookup from other different sources.

The proposed software will be intended for usage in ISP's and large data centers to monitor thousands of individual energy, gas or water meters. Each meter have to be sampled at rates that would meaningful information could be calculated and stored in a database. The system has to be able to maintain this resolution of data for every meter at least for a year providing a very detailed history for every part of the city-wide network.

The user-side software has to be web based. That will allow the user to login to a web server which launches for example a Java applet or a .Net servlet, with various functionalities, like custom floor maps to be uploaded; so that the tool could be used to place meters on the drafts so that alarms can be tied to physical locations (ie. the user's home).

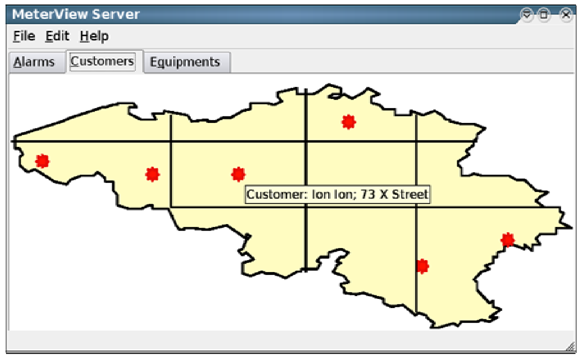

Figure 4
Map view of consumer alarms

That is, the ISP's of the distribution companies can create individual logins for their customers and assign individual meters to customers. This will allow customers to login and see just their part of the electrical, gas or water network consumption. Also they could populate meters lists and alarm notification groups based on their specific equipments and trigger various events etc... They could get their own alarm logs, alarm settings, notification groups, equipment lists, etc. Maybe this is not particularly useful for the monitoring company, if nothing else, it helps explain why some of the bills are not accurate...

Furthermore ZigBee could enable sensor networks to undertake such advanced and promising applications as automated metering or checking environmental conditions in large residential complexes, tracking agricultural parameters such as soil moisture and temperature, overseeing wastewater processing etc.

Conclusions

Thus, IEEE 802.15.4 is a new standard that still needs to pass through the circles of rigorous technology critics and establish its own place in the industry, but the predictions for the future of ZigBee-enabled devices are a popular topic for a plenty of market-research companies and also for a numerous scientific articles. Through this article we wanted to show that ZigBee has the potential to unify methods of data communication for sensors, meters, actuators, and appliances. First is the fact that it offers means for building, reliable and yet affordable, network structures and second takes advantage of battery-operated devices with a low data rate and duty cycle. Therefore ZigBee can be used in industrial automation, utility metering, and building control applications. This cost-effective and easy-to-use home network, as well as, city-wide network potentially creates a whole new ecosystem of interconnected home appliances, light and climate control systems, security and sensor subnetworks and different kind of utility meters (energy, gas and water). Very small embedded computers are essential to the development of a flexible smart home infrastructure. Good examples of this necessity can be found in the ISTAG report “Scenarios for Ambient Intelligence in 2010” which currently inspires several ideas behind the EU 6th framework program, where Smart homes are a part of the concept of ambient intelligence, that program is extended by the EU 7th framework program.

Probably only one type of network will not be enough to provide solutions for all the needs, making necessary the coexistence of diverse technologies. This must encourage the development of bridges in order to guarantee the interoperation of heterogeneous networks and/or even wired (high/low data transfer rates) and wireless (high/low data transfer rates) networks.

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