Role of Bluetooth LE Wireless Sensors for Smart Buildings

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Topics

- Characteristics of smart sensors
- Wireless sensor network options
- Sensors for smart buildings, smart grid and IoT
- Bluetooth sensor configurations
- Application examples
  - Seminar intended for those with technical backgrounds
Smart Sensor Characteristics

- Sensor Classes
  - Basic Sensors
  - Smart Sensors
  - Networked Sensors

Basic Sensor Electronics Block Diagram

- Physical to Electrical
  - (e.g. Temperature)
  - (e.g. Resistor)

- Electrical to Voltage
  - Sensor Element
  - Signal Conditioner

- Calibrated in Engineering Units
  - Analog Read out
  - (e.g. °C)

- DVM Option
  - 1.999
### Partial List of Measured Parameters and Sensor Technologies

- Acceleration/vibration
- Level & leak
- Acoustic/ultrasound
- Machine vision
- Chemical/gas*
- Motion/velocity/displacement
- Electric/magnetic*
- Position/presence/proximity
- Flow
- Pressure
- Force/strain/torque
- Temperature*
- Humidity/moisture*

**Technologies**

- Resistance
- Capacitance
- Inductance & magnetics
- Optical & fiber optic
- Voltage & piezoelectric
- Ultrasonic
- RF/microwave

* Used by Smart Grid

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**Sensors (and sensor industry) are subdivided (fragmented) by:**

1. Parameter measured
2. Technology
3. Application area

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### Analog Signal Conditioners

-- an example --

- Amplifier for piezoelectric motion sensor with demodulated signal is shown below:
- Amplifier is very low power so digital section can be in sleep mode

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![Analog Signal Conditioner Diagram](image-url)
Sensors with Digital I/O

- More sensors with digital outputs (but with internal analog signal conditioners and a/d) becoming available.
- Output format is usually I2C or SPI and thus requires further reformatting – not a smart sensor in itself.
- Example: temperature sensor (LM74)
  (SPI 12-Bit plus sign, +/- 0.0625

Smart Sensor Block Diagram
Smart (Digital) Sensor Features

- Analog/Digital Converter
  Typically 10-14 bits, usually internal
- Microcontroller (embedded)
  PIC or similar 8-bit (or 16-bit) micro with appropriate features
- Sensor Identification (serial # etc)
- Calibration information
  Compensation for sensor variations; conversion to engineering units
- Data logging and real-time clock (optional)

Connection of Non-networked Smart Sensors to Computers

- Serial Data Lines: USB (best for PCs) or RS232 (best for Instruments)
- One line and port per sensor (a problem with large systems)
- Data is digital but format is often not standardized
- Not a common configuration – most smart sensors are now networked
**Networked Sensor Block Diagram**

*Local network or bus*

Parameter in

- **Sensor Element** → **Signal Conditioner** → **A/D** → **Micro Computer**
- **ID**
- **Calibration**
- **Tx**
- **SMART SENSOR**

From Smart Sensor

- **Network Interface** → **Network** → **PC or Server** → **Internet**

Multi-level Data Protocols

- **Data formats**: How commands and transducer data are encoded (e.g. units, data type). Must be standard format for machine readability (M-to-M).
- **Communication formats**: How digital data is transmitted over network (e.g. IEEE 802.15.2g WiFi). Associated with physical (hardware) layer.
- **Multi-level** often has encapsulated data of form:
  - Header(Subheader(data)subfooter)footer
- **On Internet TCP/IP data** often uses XML format
- **Narrow application sensor network protocols** sometimes combine data and communication formats
- **Numerous sensors formats and standard in use (unfortunately)**
Busses and Networks Overview
-- Wired and Wireless

- Analog (Industrial)
  - 0-5v
  - 4-20 ma loop
- Wired (digital)
  - Ethernet
  - RS232/RS485
  - USB
  - PLC
- Wireless
  - Next slides

Wireless Data Transmission Classes

- Licensed
  - high power, long distance and high cost
- Unlicensed ISM Band (Industrial, Scientific and Medical)
  - low power, short range, low cost
  - Normally used for wireless sensor networks
- Cellular
  - 4G
  - Satellite phone
Non-networked Wireless Sensors
(not covered here)

- Smart sensors are usually networked
- **Observation**: low-cost sensors are not networked and non-networked sensors are not low cost (at least up to now)
- Some simple (and cheap) non-networked wireless consumer products and toys are shown below

ISM Frequency Bands
for sensor networks

**Main Bands (USA)**
- 433 Mhz
- 915 Mhz
- 2.4 Ghz <= most popular

**Sometimes used**
- Lower: 24, 40, 315 Mhz
- Higher: 5.8, 24 GHz
Wireless Sensor Popular Options
in ISM band

- WiFi
  - IEEE 802.11b,g
- Bluetooth
  - Older is 2.0, newer is 4.0 low energy -- LE has better range, connects easily but low bandwidth – good for sensors
- Mesh using IEEE 802.15.4 technology
  - Mesh networks provides data hopping
  - Includes Zigbee, 6LoWPAN, ISA100 and Wireless HART
- SubGHz
  - Lowest cost and power
  - Often transmit-only

Wireless Comparisons

<table>
<thead>
<tr>
<th>Technology</th>
<th>Range</th>
<th>Bandwidth</th>
<th>Transmit Power</th>
<th>Internet Access</th>
<th>Power Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>WiFi</td>
<td>100 ft</td>
<td>Hi/med*</td>
<td>Med</td>
<td>Router usually available</td>
<td>High*</td>
</tr>
<tr>
<td>Bluetooth</td>
<td>50/200 ft</td>
<td>Med/low*</td>
<td>Med</td>
<td>Smart phone, note 1</td>
<td>Med/low</td>
</tr>
<tr>
<td>Mesh (Zigbee, etc)</td>
<td>100/1000 ft</td>
<td>Med</td>
<td>Med/hi**</td>
<td>Special Gateway</td>
<td>Low</td>
</tr>
<tr>
<td>SubGHz</td>
<td>50/200 ft</td>
<td>Low</td>
<td>Low</td>
<td>Special Gateway</td>
<td>Very low</td>
</tr>
<tr>
<td>Cellular</td>
<td>Very wide</td>
<td>High</td>
<td>High</td>
<td>Provided</td>
<td>High</td>
</tr>
</tbody>
</table>

Note 1: A Bluetooth gateway is needed

*Low power version
**High power version (mesh has data hopping)
Wireless Star Network
for Buildings or Local Area

- Data transferred from each sensor to gateway directly
- Example: WiFi

Wireless Mesh Network
for Buildings or Local Areas

- Data hops from node to node
- Optimum data transfer varies with technology
- Example: Zigbee
Low Power Wireless Networks

- Goal: years of battery life (< 100 µA @ 3V)
- Analog/sensor section and microcontroller circuits must be low power
- Sleep mode used extensively to reduce average current draw
- Transmitter/receiver activated infrequently and briefly
- WiFi, Bluetooth and Zigbee/mesh have low power modes. We like Bluetooth LE
- Energy harvesting may be employed (no battery)

Transmit-only Sensors

- Sensors with just wireless transmitters are simpler
- Normally event driven (e.g. motion)
- May have a periodic beacon or heartbeat
- Typically low-power battery or energy harvest supply
- Lowest cost wireless sensor
- Often reporting to another, two-way wireless sensor
Conventional Bluetooth Sensor Network

- Bluetooth talks to smart phones and tables
- Smart phones display data as Apps
- Sensors usually provide personal information
  - Examples: heart rate, air quality
- Internet access, if needed, is via cellular link
  - But no access if smart phone is not in vicinity

Fixed Location Bluetooth Sensors

- For smart buildings monitoring and controls
- Low energy (LE) or 4.0 has better distance and lower power
- Gateway to Internet needed
- Expect mix of battery and line powered sensors
- For longer range, wireless relays or repeaters needed
  - Zigbee or 6LoWPAN convenient
Bluetooth LE Gateway
-- a proposed solution

- Bluetooth sensors for smart building (or smart grid) require Internet access via a gateway – few available
- Gateway functions similar to WiFi router
- Gateway also has sensor conditioning and translation software (APIs)
- Application example
  - Point of load power meter which is accessed by Browser to monitor energy usage
- Esensors wishes to find funding to develop this gateway
- Link: gateway page

Specialized Dashboards
-- examples of proprietary displays --

- Iconics Energyanalytix
- Google Powermeter
- Esensors PM31 monitor
Main Areas of Application
for Bluetooth sensors

- Internet of Things (IoT)
- Smart Grid
- Smart Buildings
- Medical/personal

Smart sensors for IoT

- Internet of Things (IoT) concept is interconnection of all digital devices or objects via the “cloud”
- Sensors are a major part of the IoT – could be billions
- Related to Machine-to-Machine (MtoM) compatibility
- Sensor data format is fixed, unambiguous and not require human intervention
- A series of standards are required, including IEEE 21451-1-4
Smart Grid Concepts

- The electrical grid upgraded by two-way digital communication for greatly enhanced monitoring and control
- Saves energy, reduces costs and increases reliability
- Involves national grid as well as local micro-grid ---
  - power generation, transmission, distribution and users
- Real-time (smart) metering of consumer loads is a key feature
- Phasor network another key feature (Phasor Measurement Unit, PMU)
- Uses integrated communication (requires standards)
- Includes advanced features (e.g., energy storage, solar power)
- Requires multiple power meters and other sensors, specially at loads
  - All networked

Smart Building Sensing Goals

- Integration of HVAC, fire, security and other building services
- Reduce energy use
- Automation of operations
- Interaction with outside service providers (e.g. utilities)
- Three main wired standards:
  - BACnet, Lonworks and Modbus
- Popular wireless standards:
  - WiFi, Zigbee (but Bluetooth, 4G, proprietary gaining acceptance)
- Two smart building organizations
  - ASRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers)
  - Remote Site & Equipment Management
Relationship of IoT Sensors to Smart Grid and Smart Buildings

- IoT aims to cover all sensors on the Internet
- Many electrical devices (e.g. lighting, motors) are part of both smart grid and smart building areas
- Many smart sensors are used for both
- Sensor networks are the same or similar for both

IP Based Networks

- Internet Protocol (IP) based networks are used for data communication involving the smart grid and most smart buildings
- Acts as bridge between application and underlying sensor/control networks
- Used by both private (dedicated) and public networks
- Used also by local wireless networks
- Need to interface (via translators) with popular and legacy networks such as Modbus, BACnet, DALI and Lonworks
Internet Protocols

- Smart Grid uses Internet Protocol (IP) for all data communications
- Specific protocols are:
  - HTTP
    - The most basic for data transfer
  - XML
    - Widely used because of self-identifying format
  - SNMP
    - Message protocol popular within data centers
  - SOAP
    - XML-based protocol for cross platform communication

Smart Building Applications
for Smart Sensors

- HVAC
- Environmental and comfort
- Lighting control
- Energy monitoring
HVAC Sensors
(Heating, Ventilation and Air Conditioning)

- Temperature
- Humidity
- Air Flow
- Air quality (gases: CO₂, CO, VOC)
- Also Actuators (control of heating, ventilation, AC)

Smart building communication choices
with connection to Internet

- Ethernet
  - Lowest cost to Internet
  - Installed base but often not at sensor site
- Other wired*
  - USB, RS232, RS485, Lonworks, DALI
- WiFi
  - Mobile and convenient (if router * already present)
- Local wireless (LAN)*
  - Mesh: Zigbee, 6LoWPAN, Wireless HART, ISA100
- Bluetooth
  - Pending gateway development
- Powerline*
  - Attractive concept but both narrowband and wideband not fully proven
- Cell phone
  - SMS, G4 modems available but costly (and requires higher power)
  - Highly mobile and convenient
* Requires gateway to reach Internet
Energy Conservation

- Smart meters (at Microgrid level) provide information needed to analyze energy usage and thus allow energy minimization algorithms to be implemented
- Real time data, best at individual loads
- Control programs by utilities or private companies

New ZigBee Smart Energy Version 1.1 Now Available

Smart Sensor Locations in an Auditorium
-- Bluetooth examples --

- Sensors are distributed within room
- Gateway within range of sensors
- Gateway connects to Internet
Smart Sensor Locations in a Building
-- example --

- Sensors are distributed within building
- Gateway connects to Internet
- Wireless repeater (relay) extends distance
- Power metering and HVAC/lighting controls included

Personal Monitoring with a Building
- assisted living home example -

- Sensors located in individual rooms and common areas
- Multiple types
  - Motion
  - Location
  - Door open/close
  - Alarm
- Can handle hundreds/thousands of sensors – local and Internet alerts
Standards and Interoperability

- TCP/IP is only the communication protocol used (at least on the Internet)
- Data carried as payload will be formatted by specific standards
- Over 100 Standards referenced in NIST Guidelines for smart grid – also many for IoT
- We support the IEEE/IEC 21451 set of standard for sensor data formatting

IEEE 1451 – the Universal Transducer Language
-- new name IEEE/ISO 21451-x series

- Problem: too many network protocols in common use
  - Narrow solutions and borrowed protocols have not worked
  - Sensor engineers in the fragmented sensor industry need a simple method of implementation

- How can it be done?
  - We need something like USB, except for sensors
  - Solution: the IEEE 1451 Smart Transducer Protocol open standard is the best universal solution
  - Supported by NIST, IEEE and many Federal agencies

- More information available
  - Link: http://www.eesensors.com/ieee-1451/
Summary of Topics Covered

- Characteristics of smart sensors
- Wireless sensor network options
- Sensors for smart buildings and smart grid
- Bluetooth sensor configurations
- Application examples

Contact: designer@eesensors.com
Sensor/Transducer Networks

- A network connects more than one addressed sensor (or actuator) to a digital wired or wireless network
- Both network and sensor digital data protocols are needed
- Standard data networks can be used but are far from optimum
- Numerous (>100) incompatible sensor networks are currently in use – each speaking a different language

The Tower of Babel

Status of Various Parts of IEEE 1451
Parts not developed in order

- **1451.0** – Basic data/TEDS format Done (2007)
- 1451.1 – NCAP/Computer Interface Done (1999) note 1
- **1451.2** – Serial Revised (2013) note 2
- [1451.3 – Wired Multi-drop Done (2002) note 3
- 1451.4 – TEDS Only Done (2005)
- 1451.5 – Wireless (WiFi, Zigbee, etc) Done (2007)
- 1451.7 – RFID Done (2010)

Note 1: Being revised
Note 2: Original Dot 2 in 1997 – being rebaloted as ISO standard
Note 3: Obsolete (hardware unavailable)
IEEE 1451 Command/Response

- Command format:
  - Header (6 bytes), Command (variable)
- Response Format:
  - Header (3 bytes), Data (variable)
- Command Examples (from NCAP to TIM)
  - TIM Discovery (to see which TIMs are available)
  - Channel Discovery (to see which Transducers are available)
  - Read TEDS (individually) – mostly binary
- Data Return Examples (from TIM to NCAP)
  - Data from Chan. 1 (# bytes and data type, e.g. 16-bit integer, set by TEDS)
  - Data from Chan 2
  - Commands and responses same for all types of sensors and physical layers on Network (Internet) side -- suitable for M2M & web networks
  - About 37 commands, many specialized (e.g. trigger, sleep, configure)
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Network side (NCAP) options (wired)

- Internet/Ethernet
- PC Readout
- Industrial network

All use Dot 0 protocol
Demonstration NCAP and TIM  
For Dot 2, Dot 4 and Dot 5

System Block Diagram

Manual:  

Wireless Sensors  
(Uses RF transceivers for short-range in unlicensed band)

- **Significant power available**  
  - Line-powered or laptop sized battery  
  - E.g. WiFi (IEEE 802.11b, 2.4 GHz)  
  - Variation of TCP/IP protocol, mostly non-standard  

- **Medium low power**  
  - Re-chargeable batteries or shorter life applications  
  - Cellular (GSM, 4G) – especially outside buildings  

- **Very low power** (long life operation -years)  
  - Batteries or energy harvesting  
  - Low bandwidth, sleep mode  
  - Sensor signal conditions must be low power
Prospects for Smart Appliances

- Examples: smart refrigerator, smart dryer
- Two-way communication via Internet
- Logical extension of smart grid/buildings
- Technically possible for years but ...
  - Hardware costs high
  - Installation may be complex (best plug & play)
  - Standards lacking
- Will disconnect feature be implemented?
- Privacy concerns high
- Benefits unclear
- Futuristic discussion mostly

All Whirlpool Appliances to be ‘Smart’ by 2015

If a couple of conditions are met by the private and public sectors, the company will build only products that can communicate with a smart power grid.

Whirlpool is on a mission to smarten up its appliances.

By 2015, the company will “make all the electronically controlled appliances it produces — everywhere in the world — capable of receiving and responding to signals from smart grids,” says Braden Darrell, president of Whirlpool Europe.

A smart grid is the wired version of the old-fashioned electrical grid that powers this and other countries.

Power Line Communication (PLC)

- Narrow-band (NB) Devices
  - Low frequency operation (e.g. 10 to 500 kHz)
  - Low data rate but good match for most sensors
  - Typically aimed at home (120v) — but also some high voltage applications
  - “X10” is the oldest protocol (pulses at zero-crossing)
  - Noise/interference and phase-to-phase loss are significant problems
  - Various new protocols and ICs have been developed – next slide
  - Usually more costly than wireless

- Broad-band devices
  - HomePlug HomePNA) AV (IEEE 1901) becoming used (carries Internet)
  - Frequency range: 4.5 to 20.7 MHz
  - Speed of 500 Mb/s (up to 100 MHz)
  - Interference a continuing problem (notching required by FCC)
DALI -- lighting

- Digital Addressable Lighting Interface (DALI) was developed for remote lighting control (e.g. dimmers)
- Rugged bus (64 devices, data & power on 2-wire bus)
- Asynchronous, half-duplex, serial protocol at 1200 Baud
- Requires controller (master) or gateway
- More popular in Europe
- Sensor bus based on DALI available

DALI – for sensors

- DALI extended to general purpose sensor bus (sensor is slave)
- Advantage of power and data on same 2-wire bus
- Higher data rate (9600 baud)
- Allows mix of standard and sensor DALI format on bus
- Allows TEDS and standard formats for sensors
- Actuators also
Time Sync via Ethernet (Internet)

- Time in µs available from NIST via Internet in several formats (widely used). -- Accuracy typically 0.1 sec.
- For local synchronization a master clock on one Ethernet node is used which is synchronized to other nodes via IEEE 1588 Precision Clock Synchronization Protocol.
  - Relative precision typically 0.05 µs between local nodes.
  - Wireless precision to 1-10 µs (over IEEE 802.15.4).
- NTP format -- 64-bit timestamp containing the time in UTC sec since EPOCH (Jan 1, 1900), resolved to 0.2 µs.
  - Upper 32 bits: number of seconds since EPOCH.
  - Lower 32 bits: binary fraction of second.

Air Quality Sensors for smart buildings

- Main gases:
  - Carbon Dioxide (CO2)
    - CO2 buildup in rooms when people present – signal for increased ventilation.
  - Volatile Organic Compounds (VOC) and Carbon monoxide (CO)
    - Potentially harmful gases (possibly toxic also).
- Signal Conditioners
  - Requires both analog and digital.
  - Multiple sensor technologies complicates design.
Energy Conservation Sensors

- Temperature
- Illumination
- Occupancy sensors
- Wireless room controls (e.g. lighting)
- Remote access (Smart grid, Internet)

Building Control Networks
(HVAC, lighting)

- Modbus (RS232/serial originally)
- BACnet - building automation and controls network (originally RS485)
- LonWorks (2-wire proprietary)
- All have TCP/IP (Ethernet) extensions, now commonly used
- Wireless versions (WiFi, Zigbee, 6LoWPAN)
- Some command examples (BACnet)
  - Read Property
  - Write Property
  - Device Communication Control
  - ReinitializeDevice
  - Time Synchronization
Mod-bus

- Monitoring and control for HVAC and industrial applications
- Simple format and limited functions, developed for PLCs
- Originally RS232 and RS485 (serial)
- Industrial Ethernet (TCP/IP) version popular

<table>
<thead>
<tr>
<th>Name</th>
<th>Length</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transaction Identifier</td>
<td>2 bytes</td>
<td>For synchronization between messages of server &amp; client</td>
</tr>
<tr>
<td>Protocol Identifier</td>
<td>2 bytes</td>
<td>Zero for MODBUS/TCP</td>
</tr>
<tr>
<td>Length Field</td>
<td>2 bytes</td>
<td>Number of remaining bytes in this frame</td>
</tr>
<tr>
<td>Unit Identifier</td>
<td>1 byte</td>
<td>Slave Address (255 if not used)</td>
</tr>
<tr>
<td>Function code</td>
<td>1 byte</td>
<td>Function codes as in other variants</td>
</tr>
<tr>
<td>Data bytes</td>
<td>n bytes</td>
<td>Data as response or command</td>
</tr>
</tbody>
</table>

SCADA and PMU Standards

- **Supervisory Control and Data Acquisition** is current control system which has these parts:
  - **Human-Machine Interface** (HMI)
  - **Remote Terminal Units (RTUs)** – converts sensor signals to digital data (alternative: Programmable Logic Controller)
  - **Communication** infrastructure connects to the supervisory system
- Uses Modbus and other sensor networks (also TCP/IP extensions)
- Phasor Measurement Unit protocol uses cycle by cycle phase measurements plus SCADA and other information via dedicated network
Automatic meter reading (AMR)

- Improved is Advanced Metering Infrastructure (AMI) or Smart meters (2-way)
- Used for revenue
- Wireless based
  - Many proprietary
  - Moderate range, drive-by reading
  - Mesh (Zigbee) and WiFi sometimes
  - Usually not Internet connected
- About 50M AMR/AMI installed (USA)
- Suggested standard: ANSI C12.18

Energy Conservation -- 2

- Energy usage monitoring websites
- Power use vs time ($ calculated)
- Google Powermeter and MS Hohm discontinued
- Others available – eMonitor, Tendril, Wattvision, PowerCost Monitor
- 5% to 30% (12% avr) savings reported in usage studies
Demand/Response

- Electrical load reduction (load shedding) in response to high demand on the grid (utilities issue alert)
- Purpose is to shave peak demand and reduce reserve power requirements (and build fewer power plants)
- Large rate increases during peak demand discourage consumption
- Implemented by utilities or third parties through contract (shed load when requested in return for lower rates)
- Requires smart meter at customer site