Role of Bluetooth LE Wireless Sensors for Smart Buildings

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Niagara Technology and Security Forum

Topics

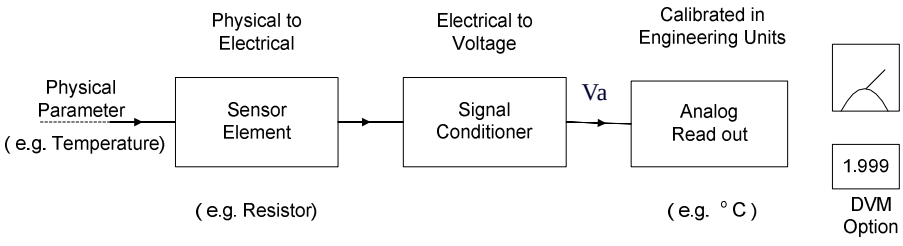
- Characteristics of smart sensors
- Wireless sensor network options
- Sensors for smart buildings, smart grid and IoT
- Bluetooth sensor configurations
- Application examples

Seminar intended for those with technical backgrounds

Smart Sensor Characteristics

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

Basic Sensor Electronics Block Diagram



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*

* Used by Smart Grid

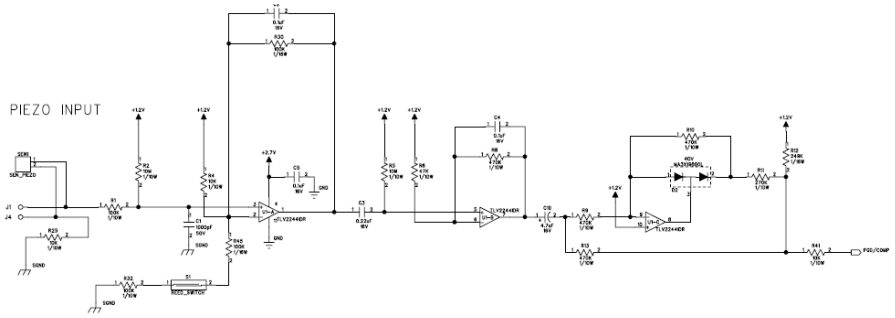
Technologies

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

Sensors (and sensor industry) are subdivided (fragmented) by:
1. Parameter measured
2. Technology
3. Application area

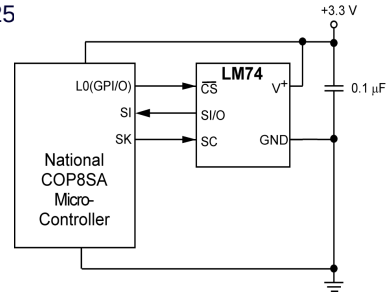
Analog Signal Conditioners
-- an example --

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

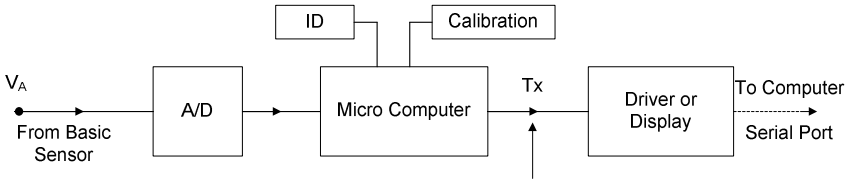


Sensors with Digital I/O

- 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)

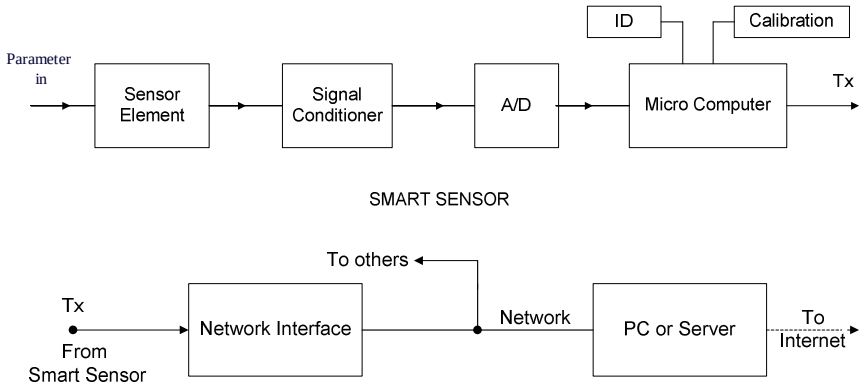
  PIC or similar 8-bit (or 16-bit) micro with appropriate features
- Sensor Identification (serial # etc)
- Calibration information

  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)



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

Technology	Range	Bandwidth	Transmit Power	Internet Access	Power Requirements
WiFi	100 ft	Hi/med*	Med	Router usually avail	Hi/low*
Bluetooth	50/200* ft	Med/low*	Med	Smart phone, note 1	Med/low
Mesh (Zigbee, etc)	100/1000** ft	Med	Med/hi**	Special Gateway	Low
SubGhz	50/200* ft	Low	Low	Special Gateway	Very low
Cellular	Very wide	High	High	Provided	High

* Low power version ** High power version (mesh has data hopping)

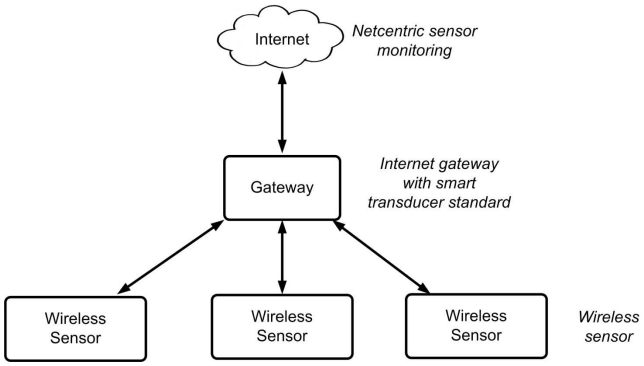
Note 1: A Bluetooth gateway is needed

- XXX

Wireless Star Network

for Buildings or Local Area

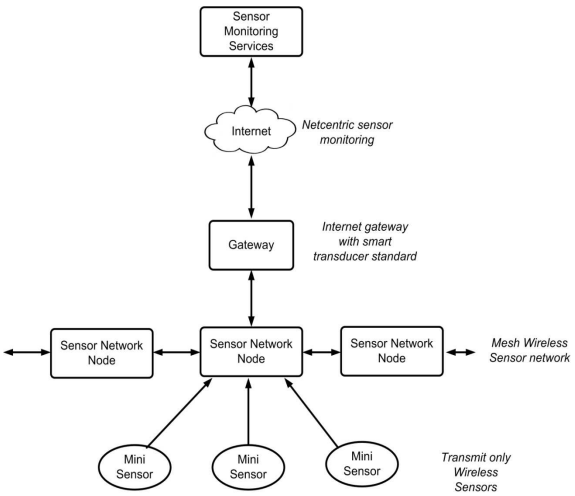
- Data transferred from each sensor to gateway directly
- Example: WiFi



Wireless Mesh Network

for Buildings or Local Areas

- Data hops from node to node
- Optimum data transfer varies with technology
- Example: Zigbee

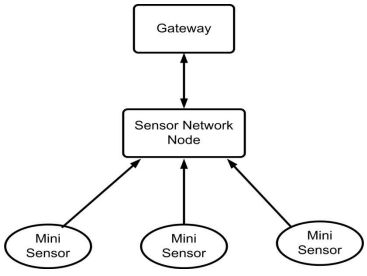


Low Power Wireless Networks

- 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)

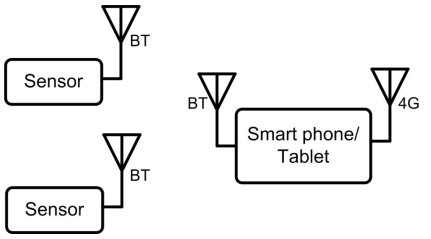
Transmit-only Sensors

- 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

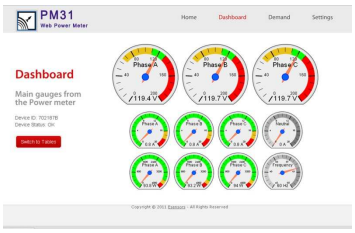
- For smart buildings monitoring and controls
- Low energy (LE) or 4.0 has better distance and lower power
- Gateway to Internet needed
- Expect mix of battery and line powered sensors
- For longer range, wireless relays or repeaters needed
  - Zigbee or 6LoWPAN convenient

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 Brower 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
- Poplar 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: CO_2, CO, VOC)
- Also Actuators (control of heating, ventilation, AC)

Smart building communication choices
with connection to Internet

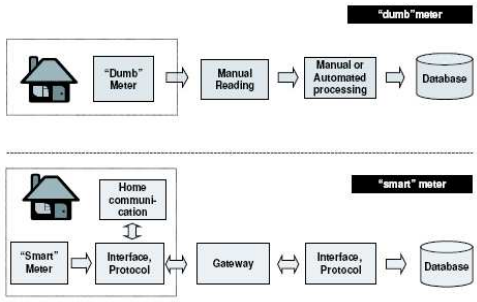
- Ethernet
  - Lowest cost to Internet
  - Installed base but often not at sensor site
- Other wired*
  - USB, RS232, RS485, Lonworks, DALI
- WiFi
  - Mobile and convenient (if router * already present)
- Local wireless (LAN)*
  - Mesh: Zigbee, 6LoWPAN, Wireless HART, ISA100
- Bluetooth
  - Pending gateway 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

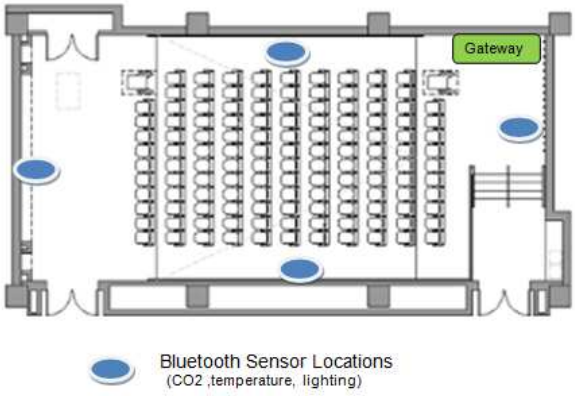
New ZigBee Smart Energy Version 1.1 Now Available



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 --

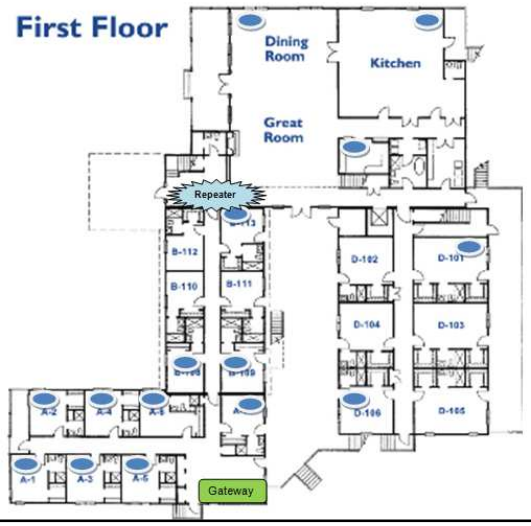
- Sensors are distributed within building
- Gateway connects to Internet Gateway
- Wireless repeater (relay) extends distance
- Power metering and HVAC/lighting controls included

Bluetooth Sensor Locations
(CO2, temperature, humidity, load power)

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

End

- Backup Slides Follow

www.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

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Bluetooth Sensor Networks

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) note1
1451.2 – Serial	Revised (2013) note 2
[1451.3 – Wired Multi-drop	Done (2002) note3
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 reballoted as ISO standard

Note 3: Obsolete (hardware unavailable)

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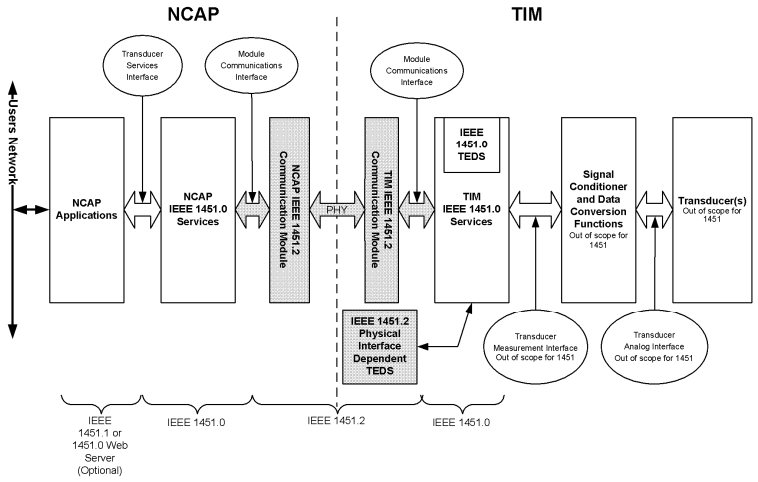
Dot 2 Description

Dot 2 Block Diagram



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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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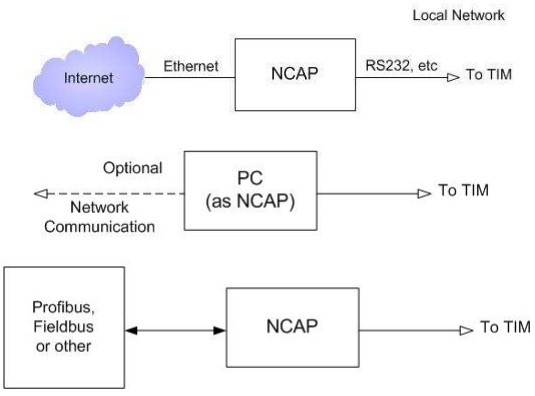
Network side (NCAP) options (wired)

- Internet/Ethernet
- PC Readout
- Industrial network

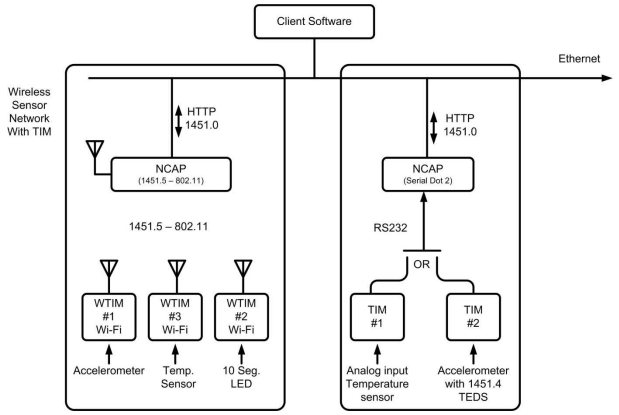


All use Dot 0 protocol

Demonstration NCAP and TIM

For Dot 2, Dot 4 and Dot 5

Open
Access
Downloads
Available



System Block Diagram

Manual:
http://www.eesensors.com/media/wysiwyg/pdf/1451_manual.pdf

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 Bracken Darrell, president of Whirlpool Europe.
A smart grid is the wiser version of the old-fashioned electrical grid that powers this and other countries.

Power Line Communication (PLC)

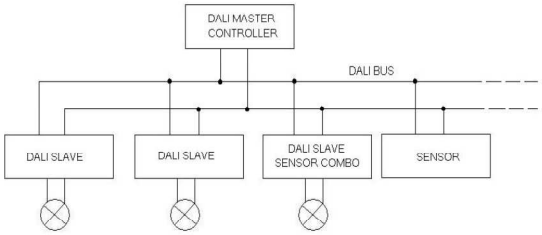
- Narrow-band (NB) Devices
  - Low frequency operation (e.g. 10 to 500 kHz)
  - Low data rate but good match for most sensors
  - Typically aimed at home (120v) – but also some high voltage applications
  - "X10" is the oldest protocol (pulses at zero-crossing)
  - Noise/interference and phase-to-phase 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 Mbits/sec (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

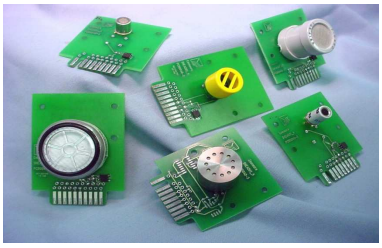


Time Sync via Ethernet (Internet)

- 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 (CO_2)
    CO_2 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

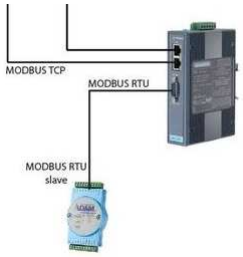
- Temperature
- Illumination
- Occupancy sensors
- Wireless room controls (e.g. lighting)
- Remote access (Smart grid, Internet)

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

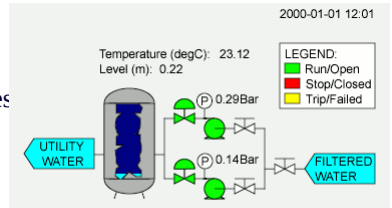
- Monitoring and control for HVAC and industrial applications
- Simple format and limited functions, developed for PLCs
- Originally RS232 and RS485 (serial)
- Industrial Ethernet (TCP/IP) version popular



Modbus TCP Frame Format		
Name	**Length**	**Function**
Transaction Identifier	2 bytes	*For synchronization between messages of server & client*
Protocol Identifier	2 bytes	*Zero for MODBUS/TCP*
Length Field	2 bytes	*Number of remaining bytes in this frame*
Unit Identifier	1 byte	*Slave Address (255 if not used)*
Function code	1 byte	*Function codes as in other variants*
Data bytes	n bytes	*Data as response or commands*

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



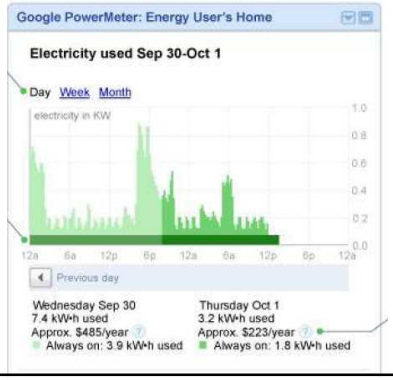
Human-Machine Interface (from Wikipedia)

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

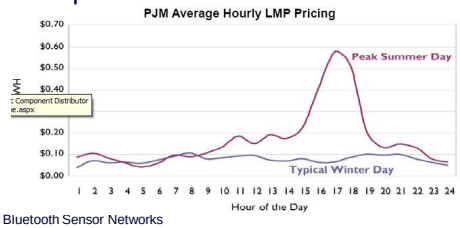
Energy Conservation -- 2

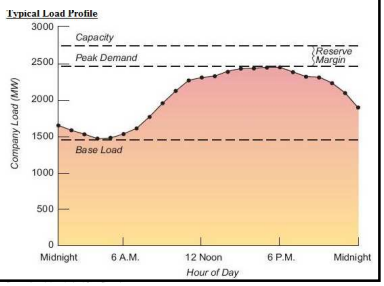
- Energy usage monitoring websites
- Power use vs time ($ calculated)
- Google Powermeter and MS Hohm discontinued
- Others available – eMonitor, Tendril, Wattvision, PowerCost Monitor
- 5% to 30% (12% avr) savings reported in usage studies



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





Bluetooth Sensor Networks