

IEEE 1451-- A Universal Transducer Protocol Standard

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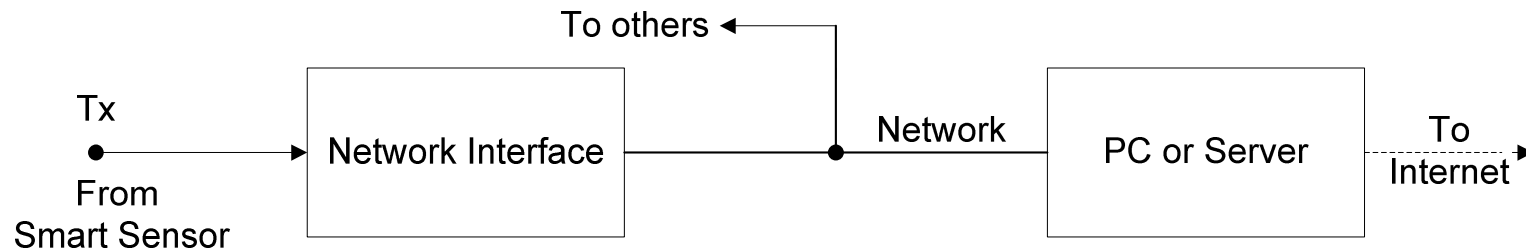
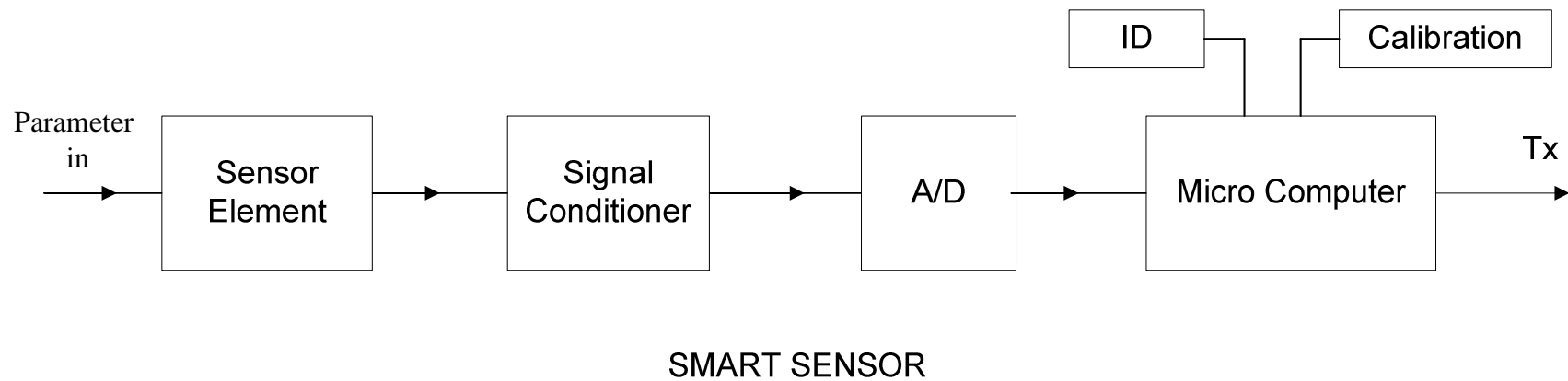


Goals

To describe ---

- Relationship of smart sensor and sensor networks
- IEEE 1451 Concepts and History
- Role of 1451 compilers
- Wireless 1451 NCAPs and TIM examples
- Relationship to sensor standards harmonization

Networked Sensor Block Diagram





Network Sensor Applications

- ❑ Automatic testing
- ❑ Plug and play
- ❑ Multiple sensors on one network or bus
- ❑ Machine to Machine (M2M) sensor data communications
- ❑ Wide area (Nationwide) data collection ability

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

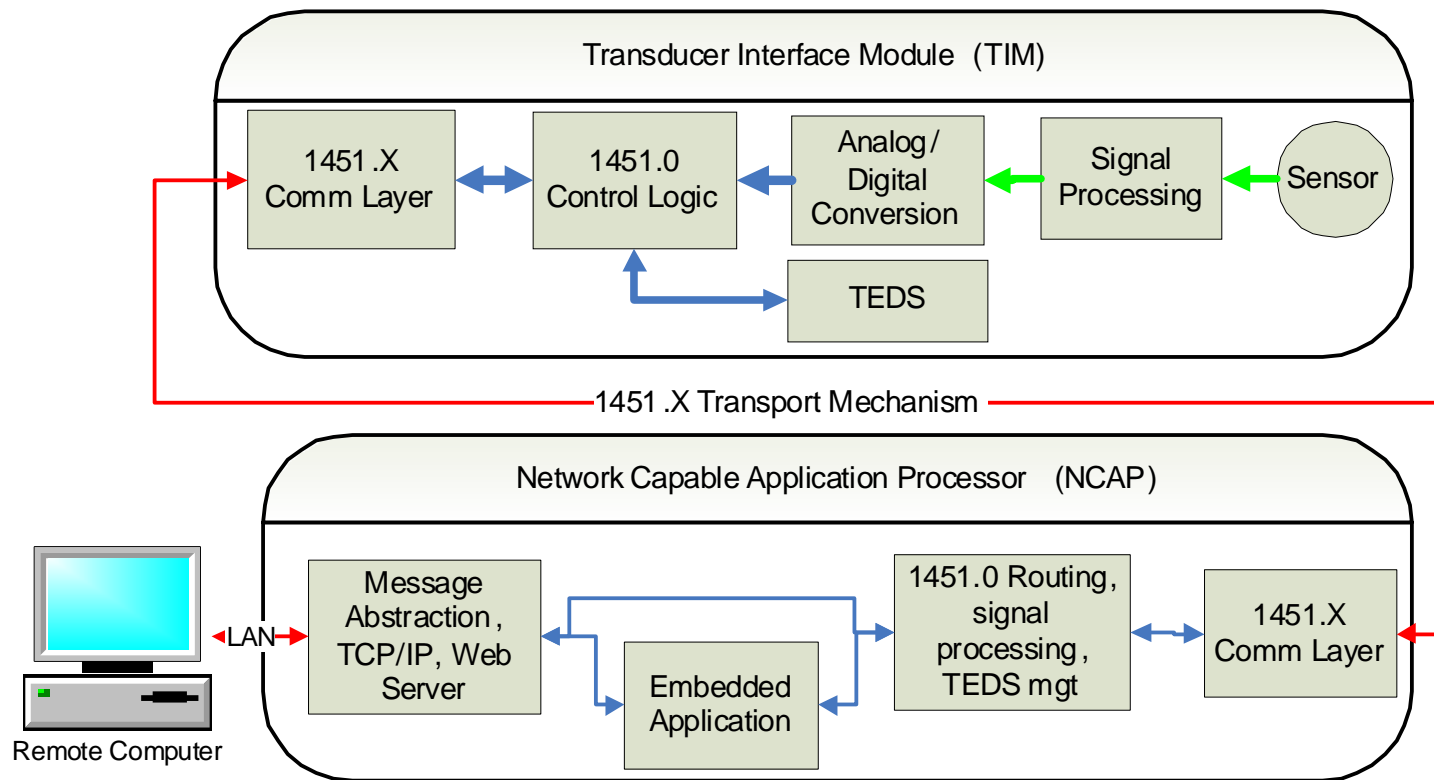


IEEE 1451 – the Universal Transducer Language

- ❑ 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

A review of the IEEE 1451 Smart Transducer Concept



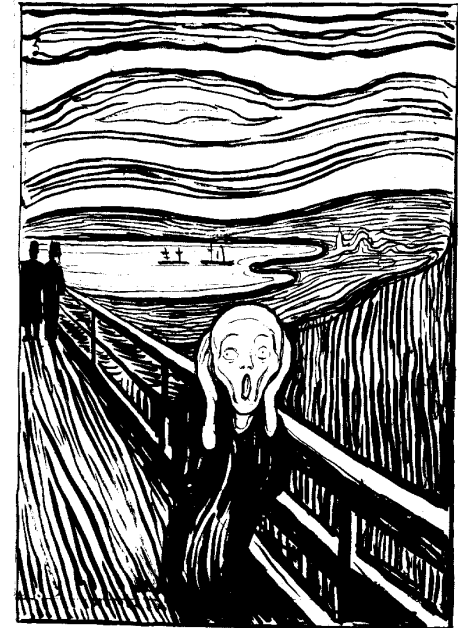


IEEE 1451 Advantages

- ❑ Comprehensive enough to cover nearly all sensors and actuators in use today (not 20/80% approach)
- ❑ Many operating modes
(buffered, no-buffer, grouped sensors, timestamps, timed data, streaming ...)
- ❑ Extensive units, linearization and calibration options
- ❑ Multiple timing and data block size constraints handled.
- ❑ Compatible with most wired and wireless sensor buses and networks (point-to-point, mesh, TIM-to-TIM, mixed networks).
- ❑ Efficient binary protocol (especially suitable for wireless)
- ❑ Standard is 400+ pages for basic part, over 1500 page total

But the Complexity!

- ❑ A comprehensive standard is necessarily complex
- ❑ There was little adoption of the original IEEE 1451.2 (TII) standard because of its perceived complexity
- ❑ Manual preparation of the TEDS is not practical -- A TEDS compiler is needed
- ❑ A compliance test procedure is also desirable to prove that a design is correct



Munch –The scream

Status of Various Parts of IEEE 1451

- | | | | |
|---|--|--------------------|-----------|
| □ | 1451.0 – Basic data/TEDS format | Done (2007) | |
| □ | 1451.1 – NCAP/Computer Interface | Done (1999)* | |
| □ | 1451.2 – RS-232 | Done (1997)* | |
| □ | 1451.3 – Wired Multi-drop | Done (2002)* | |
| □ | 1451.4 – TEDS Only | Done (2005) | ← |
| □ | 1451.5 – Wireless (WiFi, Zigbee, etc) | Done (2007) | Most used |
| □ | 1451.6 – CAN Bus | In process | |
| □ | 1451.7 – RFID | In process | |

* Needs revision



IEEE 1451.0 (Dot 0) TEDS Format

- Required TEDS [Memory block with defined format]
 - MetaTEDS
 - Channel TEDS
 - Calibration TEDS (unless SI units)
 - Xdr-name TEDS
 - Phy TEDS
 - Also optional TEDS

- Data Transmission [specific octet format]
 - TEDS/Status requests
 - Triggering and configuration
 - Sensor read commands and data return
 - Actuator write commands and data sending

TEDS Format

- General format for each TEDS section:

Field	Description	Data Type	Number of Bytes
-----	TEDS Length	UInt32	4 bytes
1 to N	Data Block	Variable	Variable
-----	Checksum	UInt16	2 bytes

- Binary TEDS Tuple format for each data block:

Type-Length-value (TLV)

Example: 01 02 A3 04

Field type is 1, Length is 2 bytes, field value is “A304” hex

- Field example: Meta-TEDS (TEDS # 1)

13: Number of Implemented Transducer Channels (default=1)

IEEE1451 Standard Description

TEDS Compiler

- Part of Ph. D. thesis of Wai Liu (Univ. at Buffalo)

The screenshot displays the TEDS Compiler software interface, which is a web-based application. The main window is titled "CHANNEL TEDS" and is part of the "IEEE 1451 TE" suite. The interface is divided into two main sections: a left sidebar and a main configuration area.

Left Sidebar (IEEE 1451 TE):

- META TEDS
- META ID TEDS
- CHANNEL CALIBRATION TEDS
- CHANNEL ID TEDS
- CALIBRATION ID TEDS
- Video NME TEDS

Main Configuration Area (CHANNEL TEDS):

Access Code 3

Change Default Value as Desired

Channel: [1]

Sensor Type: [Temperature Sens]

Units: [Celsius]

Zero/Minimum Value: [0.0]

Full Scale Value: [100.0]

OEError/Uncertainty: [0.1]

Chose Data Format:

- Integer
- Floating Point
- Other

Features:

- Self-Test/Multi-Range: [NO]
- Sampling/Buffer: [NO]
- Not Default Timing: [NO]

Next: [NEXT]

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TEDS Sections Implemented

- Meta TEDS
- Meta ID TEDS
- Transducer Channel TEDS
- Transducer Channel ID TEDS
- Calibration TEDS
- Calibration ID TEDS
- XdrcName TEDS

Referenced by TEDS section/access code (e.g. #1 for Meta-TEDS)
IEEE1451 Standard Description

Standard Transducer Units

(binary format)

SI Based Units

Base Quantity	Name	Unit Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	Kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

Field	Description	Data Type	Number of octets
1	Physical units interpretation	UInt8	1
2	$(2 * \text{<exponent of radians>}) + 128$	UInt8	1
3	$(2 * \text{<exponent of steradians>}) + 128$	UInt8	1
4	$(2 * \text{<exponent of meters>}) + 128$	UInt8	1
5	$(2 * \text{<exponent of kilograms>}) + 128$	UInt8	1
6	$(2 * \text{<exponent of seconds>}) + 128$	UInt8	1
7	$(2 * \text{<exponent of amperes>}) + 128$	UInt8	1
8	$(2 * \text{<exponent of kelvins>}) + 128$	UInt8	1
9	$(2 * \text{<exponent of moles>}) + 128$	UInt8	1
10	$(2 * \text{<exponent of candelas>}) + 128$	UInt8	1

Dot 0 Command/Response Structure

Byte Number	Description
1	Destination Transducer Channel Number (Most significant byte)
2	Destination Transducer Channel Number (Least significant byte)
3	Command Class
4	Command Function
5	Length (Most significant byte)
6	Length (Least significant byte)
7-N	Command dependent bytes

NCAP Command Message Structure

Byte Number	Description
1	Success/Fail Flag
2	Length (Most significant byte)
3	Length (Least significant byte)
4-N	Reply dependent bytes

TIM Reply Message Structure

Meta-TEDS Writer Screen

University at Buffalo The State University of New York

Access Code 1

META TEDS

Change Default Value as Desired

Enter ZIPCODE For UUID

Number of Implemented Transducer Channels

Operational Time-Out (Sec)

Slow Access Time-Out (Sec)

Self-Test Time (Sec)

Using Control/Vector/Proxy Groups

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University at Buffalo The State University of New York

IEEE 1451 TE

COPY

Channel/Calibration TEDS (for linear sensors)

The screenshot shows a web-based configuration interface for TEDS (Technical Electronic Data Sheet) for linear sensors. The interface is titled "CHANNEL TEDS" and includes an "Access Code 3" field. The main configuration area contains several fields and options:

- Channel:** A text input field.
- Sensor Type:** A dropdown menu set to "Temperature Sens".
- Units:** A dropdown menu set to "Celsius".
- Zero/Minimum Value:** A text input field set to "0.0".
- Full Scale Value:** A text input field set to "100.0".
- OError/Uncertainty:** A text input field set to "0.1".
- Chose Data Format:** Radio buttons for "Integer", "Floating Point" (selected), and "Other".
- Features:** Three dropdown menus for "Self-Test/Multi-Range", "Sampling/Buffer", and "Not Default Timing", all set to "NO".

A sidebar on the left contains navigation buttons: "META TEDS", "META ID TEDS", "CHANNEL/CALIBRATION TEDS" (highlighted), "CHANNEL ID TEDS", "CALIBRATION ID TEDS", and "Xdcr NAME TEDS". The sidebar also includes the University at Buffalo logo and a decorative image of flowers. A "NEXT" button is located at the bottom right of the main configuration area.

TEDS Reader

The image shows a screenshot of the TEDS Reader software interface. The main window, titled "University at Buffalo The State University of New York", displays "Access Code 3" and "CHANNEL TEDS". Below this, it shows the "TEDS Analysis Result:" section. This section contains two entries:

- TEDS HEADER: Calibration key (Header Field: 10)**
Number of Bytes: 1
DATA: 01
- TEDS HEADER: TransducerChannel type key (Header Field: 11)**
Number of Bytes: 1

Below these entries, there are several other header fields listed, including "Header Field: 3)", "Header Field: 12)", "80 80", "Lower range limit (Header Field: 13)", "Upper range limit (Header Field: 14)", and "ty (Header Field: 15)". A "SAVE REPORT" button is visible at the bottom right of the main window.

Overlaid on the bottom left is a "Save As" dialog box. The "Save in:" field is set to "NEW VOLUME (D:)", and the file name is "doc1". The dialog shows a list of folders and files, including "0", "1", "2", "3", "3Dbasis", "5", "6", "appformom", "Banana International", "Bewitched, T.C.XviD-ASTERIODS", "BitComet", "buildingconstructionanddesign", "CIE527", "CIE557", "CIE593", "CIE625", "civilengineering", "courses", "Data", "dell drivers", "Downloads", "earthquake Engineering", "Favorites", "FEMA 368", "FEMA 369", "Film", "geotechnicalearthquakeengineeringha", "ham", "LiveUpdt", and "lyrics".

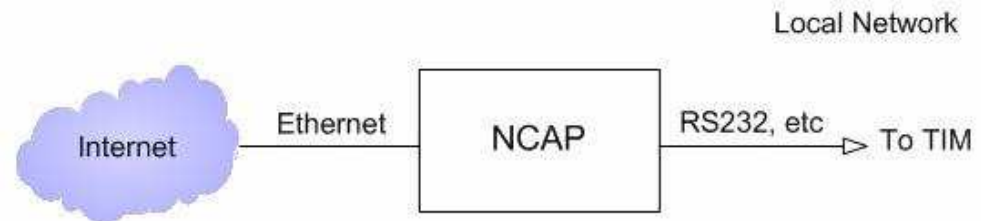


IEEE 451 TIM Compliance Tester

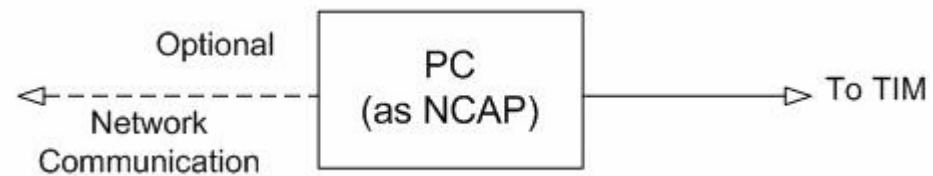
- ❑ TIM (Transducer Interface Module) is most complex and done by sensor design engineers
 - (TIM tester can be used by the few NCAP designers)
- ❑ Tester verifies compliance of a TIM to IEEE 1451.0 (Dot 0) protocol
- ❑ Focus is on TEDS checking and data transfer format
- ❑ Physical device compliance not checked (part of other standards, e.g. RS485, Bluetooth)
- ❑ Tester uses serial bus (RS232)
- ❑ Testing may be done by Internet

Network side (NCAP) options (wired)

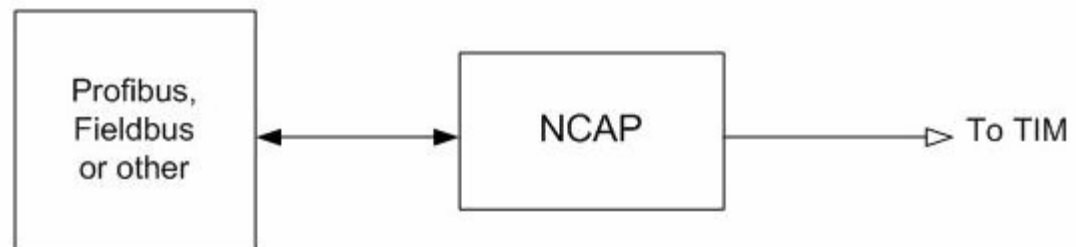
- Internet/Ethernet



- PC Readout



- Industrial network



All use Dot 0 protocol IEEE1451 Standard Description

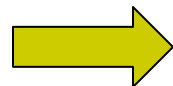


Data Readout Examples (via Internet)

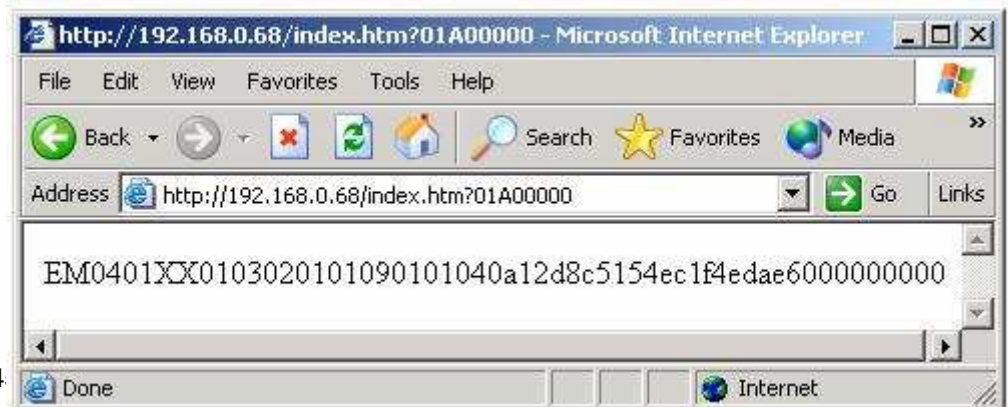
- Sensor data converted to ASCII for display



- TEDS data is displayed in hexadecimal form

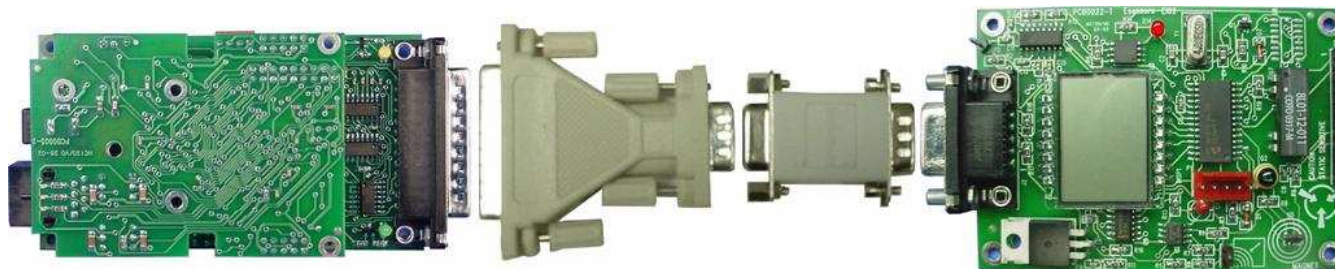
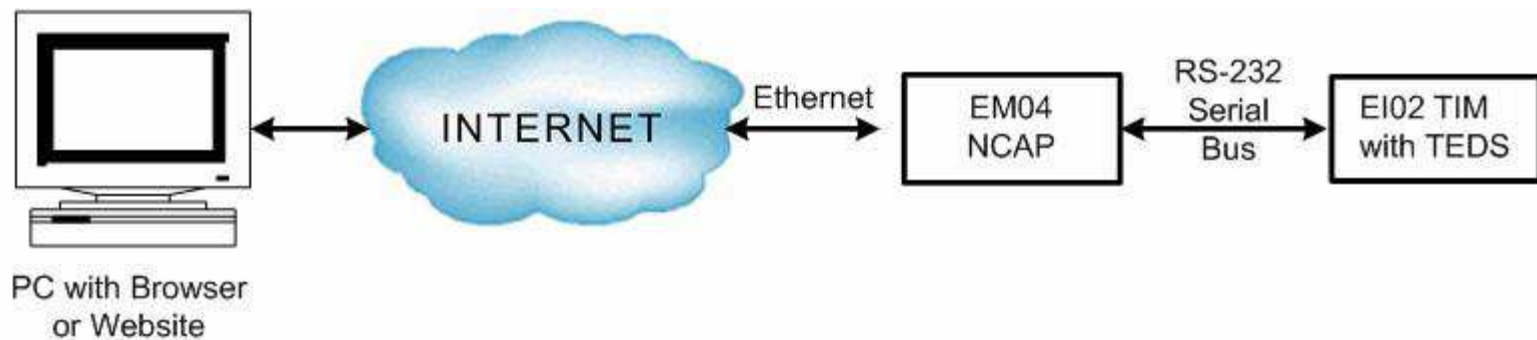


IEEE14

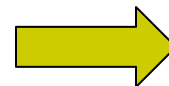


Prototype TIM and NCAP

- NCAP interfaces to Internet via Ethernet



IEEE1451 Standard Description





Serial Bus Format and Relation to other Networks

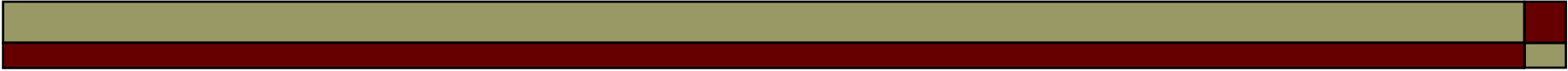
- ❑ Tester uses RS232 serial bus only but...
- ❑ Interfaces to other physical devices (USB, RS485, Bluetooth, Zigbee,) available.
- ❑ TEDS retrieval is one feature
- ❑ Sensor data read (protocol check) for each channel:
 - Idle mode* – full scale value of sensor reading
(Checked against TEDS, error flag is not correct)
 - Operating mode* – actual sensor reading
(Must be within sensor range)



Wireless Sensors

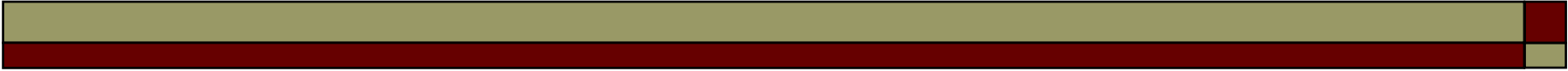
for short-range, unlicensed band

- A. Significant power available
 - line-powered or laptop size battery
- B. Medium low power
 - re-chargeable batteries or shorter life applications
- C. Very low power
 - Long life operation (years)



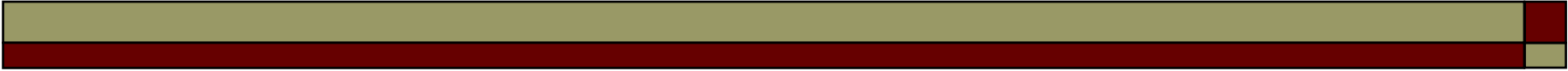
Wireless sensors – significant power available

- Line-powered or laptop sized battery
- Uses transceiver
- Popular choice: WiFi (IEEE 802.11b), 2.4 GHz
 - Components widely available (moderate cost)
 - Good bandwidth
- Variation of TCP/IP protocol, mostly non-standard



Wireless sensors – medium low power

- Re-chargeable battery
- Uses transceiver
- Popular choices: Bluetooth (IEEE 802.15.1)
 - Low cost components (production scale)
 - Hard to interface to sensors on prototype scale
 - Moderate bandwidth
- Zigbee (IEEE 802.11.5)
 - Low bandwidth
 - Intermittent communication (sleep mode)
 - Star or Mesh



Wireless sensors – Very low power

- Coin size battery, non-rechargeable, lifetime of years
- Transmit only
- Popular choice: TI/Chipcon (433 MHz and 2.4 GHz)

RF modules and microcontrollers available

Low bandwidth

Intermittent transmission (sleep mode)

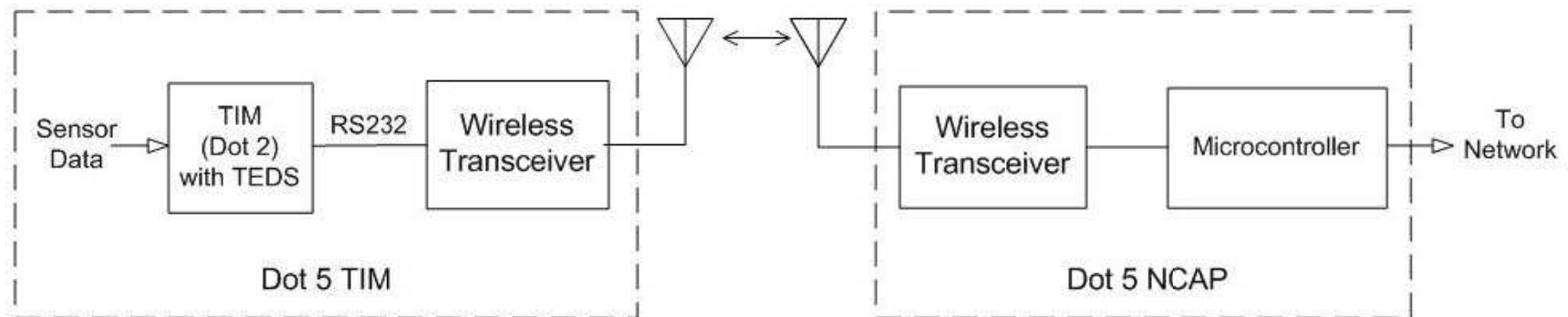


Wireless (Dot 5) Options

- IEEE 1451.5 protocols are based on existing wireless protocols used for sensor networking (mostly additions to the OSI Application Layer)
- NCAP (gateway) Network (e.g. Internet) format uses Dot 0
- Current options are:
 - WiFi (IEEE 802.11)
 - Bluetooth (IEEE 802.15.1)
 - Zigbee (IEEE 802.15.4)
 - 6LoWPAN (IEEE 802.15.4, IPv6)
- Named TIM or WTIM (Wireless Transducer Interface Module)
- Many options, including TIM to TIM com. via NCAP

Example – Wireless Connection

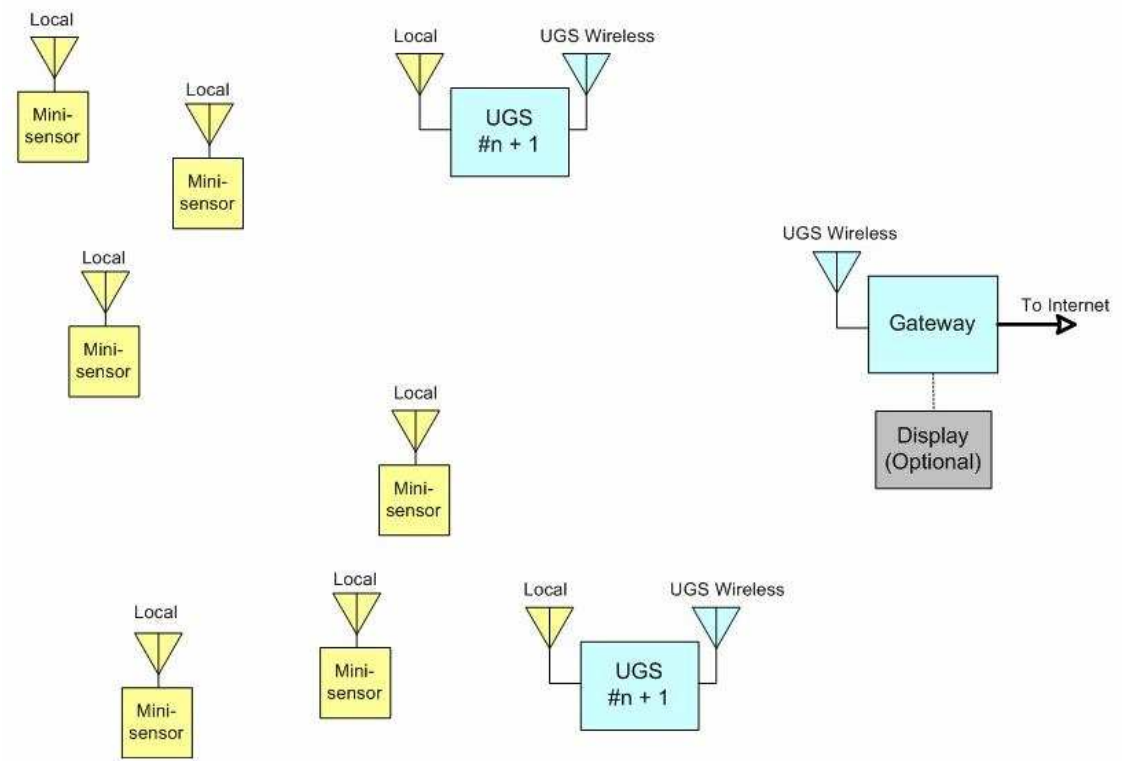
- Wireless modules with RS232 I/O when connected to Dot 2 TIMS are similar to IEEE 1451.5 TIMs (wireless version of IEEE 1451).
- Data format and TEDS are the same (both follow the Dot 0 standard)..

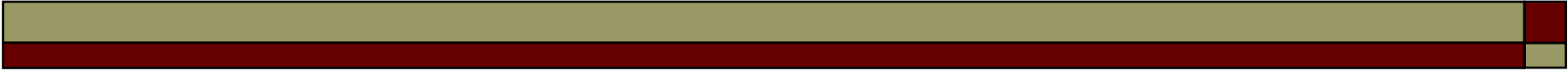


Dot 5 TIM built from a Dot 2 TIM and wireless transceiver

Zigbee Mesh Network System

- One of many sensor networks available.





Transducer Electronic Data Sheet

Dot 4 TEDS -- TEDS only

- **UUID (Universal **U**nique Identifier)**
Supplied by EEPROM (DS2433) manufacturer (6 bytes)
- **Basic TEDS (8 bytes)**
 - Model Number (15 bits)
 - Version Letter (5 bits, A-Z)
 - Version Number (6 bits)
 - Manufacturer ID (14 bits)
 - Serial Number (6 bits)
- **IEEE Template or Manufacturer's TEDS**
Sensor type and calibration parameters (32 bytes)

Conversion to Dot 0 TEDS possible (but not unique)

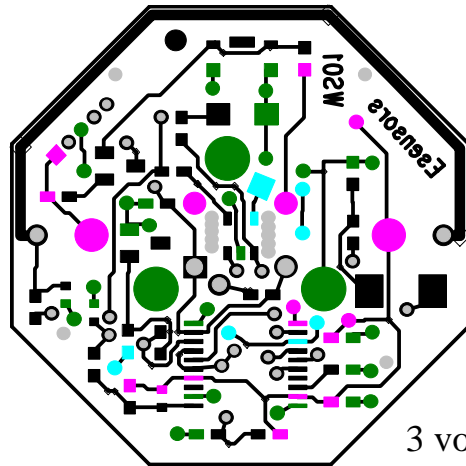
IEEE1451 Standard Description

Dot 4

Wireless Sensor Example

(low cost, long life, short messages)

- ❑ WS01 wireless temperature (and other) sensors
- ❑ 433 MHz FSK – range 10 to 100 meters, transmit only
- ❑ SNAP data protocol (header, data, crc)—8 to 12 bytes
- ❑ Dot 4 TEDS send periodically



3 volt coin battery
(back)

Printed Circuit Board (back)

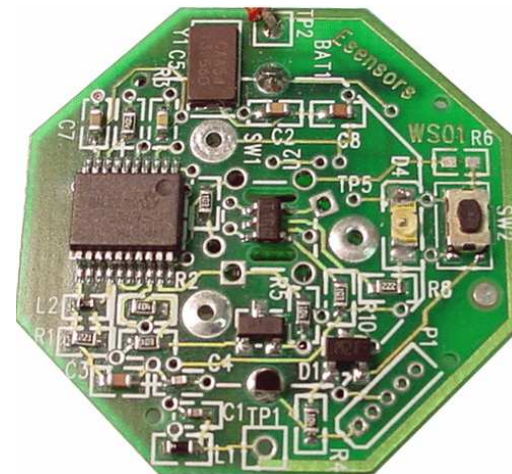


Photo (front)



RFID with Sensors (Dot 7)

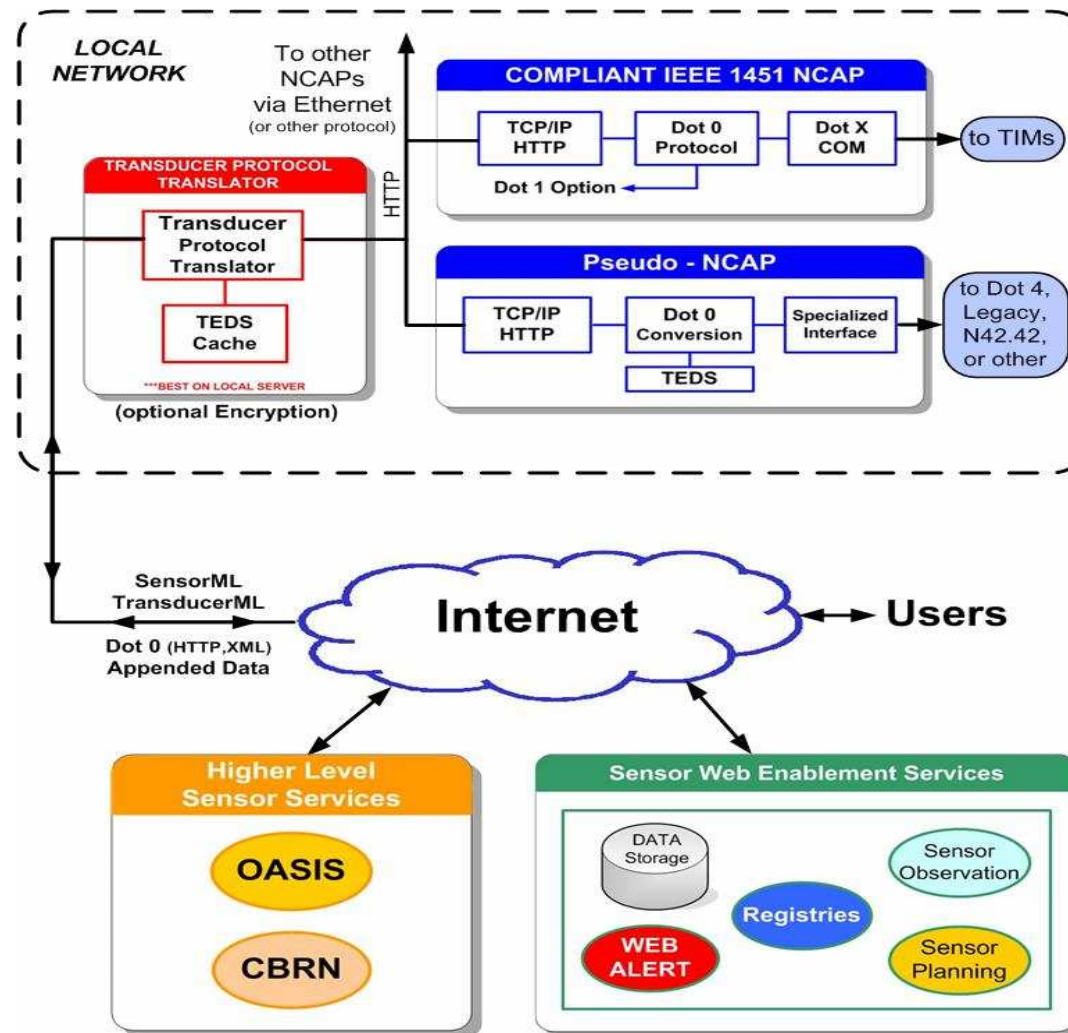
- ❑ Combines Radio Frequency IDentification with sensors
- ❑ Uses standard (ISO/IEC) RFID communication/format with additional sensor memory section
- ❑ Sensor format is based in IEEE 1451 protocol
- ❑ Typical application is tracking and monitoring perishable shipments (temperature, shock/vibration)



IEEE 1451 as a Universal Digital Sensor Base Format

- Specialized networks can handle only a limited number of sensor types or uses non-compact format
 - 1451 is much superior at the sensor end
- Most applications require individualized displays or graphical user interfaces – 1451 is a fixed format and poorly suited at the user end
- Network oriented applications prefer XML or similar formats which are convenient, but are too verbose at the sensor end
- 1451 at the sensor end (Sensor Fusion level 0) combined with translators is the best solution.

Harmonization of IEEE 1451 with Internet sensor standards





Future Prospects for IEEE 1451

- ❑ There has been little interest in previous parts of IEEE 1451 (Dots 2, 1 & 3), except for Dot 4 in certain areas.
- ❑ The basic Dot 0 (and Dot 5) are more carefully composed and thus likely to be accepted.
- ❑ The compiler may answer the complexity issue but still implementation of any full-featured standard will be difficult.
- ❑ The US government may mandate a sensor data standard and the NIST-supported IEEE 1451 is the most recognized candidate.
- ❑ The sensor industry, especially the wireless network sector, must recognize the business advantages of a single sensor data standard.



Summary

- ❑ IEEE 1451.0 (Dot 0) and Dot 5, the key parts of the standard, have recently been adopted.
- ❑ Features, advantages and complexity were described
- ❑ Use of a compiler advocated
- ❑ Several examples of TIMs and NCAPs given
- ❑ Sensor harmonization issue mentioned.

Contact: designer@eesensors.com

End

- Backup Slides Follow



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Harmonization Meeting Summary

(Held at NIST in June, next in Oct)

- ❑ 25 attendees, mostly government
- ❑ DOD, DHS, DJ, DS represented (also NASA subcontractor)
- ❑ All working under directives to implement standards
- ❑ DHS new directive requires new sensors to use existing open standards if available (not proprietary or invent new)
- ❑ DOD joint task group working on standards and expects to support test bed. Possible FY' 10 requirement.
- ❑ Several test beds involving IEEE 1451 started (Esensors has some part in all).



Wireless Sensor Networks

- ❑ Currently fashionable in academic and VC circles
- ❑ Recently available low-cost, high performance RF transceiver chips greatly simplify design
- ❑ Improvements in embedded microcomputers and smart sensor design also make wireless sensors much more practical now
- ❑ Can be lower cost and easier to use than wired sensors
- ❑ Point-to-point and mesh protocols available.
- ❑ Specialized sensor networks (e.g. Zigbee) much more efficient for wireless sensors, especially battery operated.
- ❑ Lack of standards inhibiting growth of industry.



Future of Networked Sensors

- ❑ Computer-based monitoring and control applications are increasing in commercial, industrial and military sectors.
- ❑ Networked, and often wireless, sensors offer performance and cost advantages over traditional methods.
- ❑ Wider use of networked sensors is inhibited by lack of standards (especially National scale networks, wireless and multi-vendor, long-term installations).
- ❑ I expect sensor standard and harmonization efforts to succeed within 2 to 5 years and Federal Agencies (DHS, DOD; NASA) to favor IEEE 1451.

Dot 4 TEDS Writer and Reader (PC Screens)

The screenshot shows the TEDS WRITER interface. At the top, it displays the Esensors Inc logo and the text "IEEE 1451.4 Minimal NCAP Module TEDS WRITER". Below this, there are five input fields for metadata: "Serial Number [24 BITS]" with the value "11010101010101010101010101010101", "Version Number [6 BITS]" with "1111000", "Version Letter [5 BITS]" with "01010", "Model Number [15 BITS]" with "110011001100111", and "Manufacturer ID [14 BITS]" with "00110011001100". Below these fields is a row of eight buttons labeled "MSB" and "LSB" with values: AA, AA, AA, E1, 99, 99, CC, CC. A status window shows "STATUS: 2:15:58 PM" and a list of test results: "Reset... Passed", "Verified... Passed", "Programmed... Passed", and "TEDS OK... failed". At the bottom, there are five buttons: CONVERT, VERIFY, PROGRAM (highlighted), RESET, and BACK.

Writer

The screenshot shows the TEDS READER interface. At the top, it displays the Esensors Inc logo and the text "IEEE 1451.4 Minimal NCAP Module TEDS READER". Below this, there are three input fields: "Family Code" with "14", "Unique Serial Code" with "22D534010000", and "CRC" with "B6". A "BASIC TEDS:" section contains a text box with the following data: "SERIAL NO --101", "VERSION NUMBER --1", "VERSION LETTER --E", "MODEL NO --6", and "MANUFACTURER ID --34". A status window shows "STATUS: 4 2:51:12 PM" and a list of test results: "RESET...Passed", "TEDS READ...Passed", and "CRC TEST...Passed". At the bottom, there are three buttons: READ, RESET (highlighted), and BACK.

Reader

TIM Tester – Data retrieval

