IEEE 1451-- A Universal Transducer Protocol Standard

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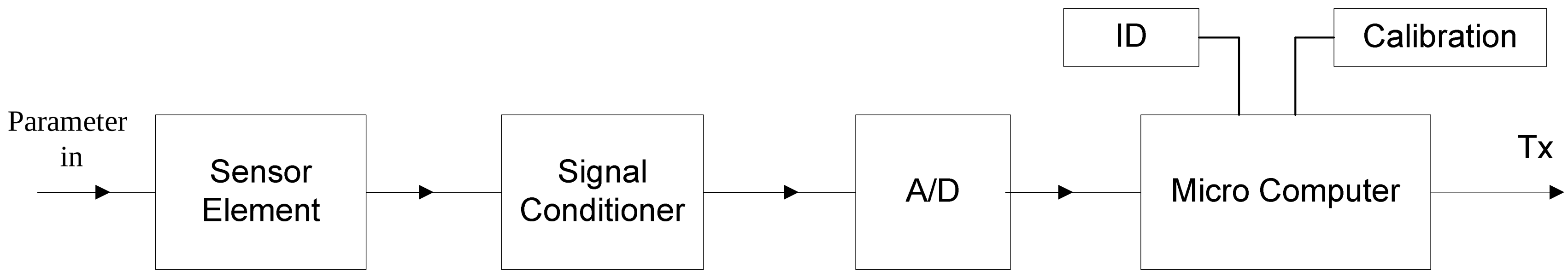
Goals

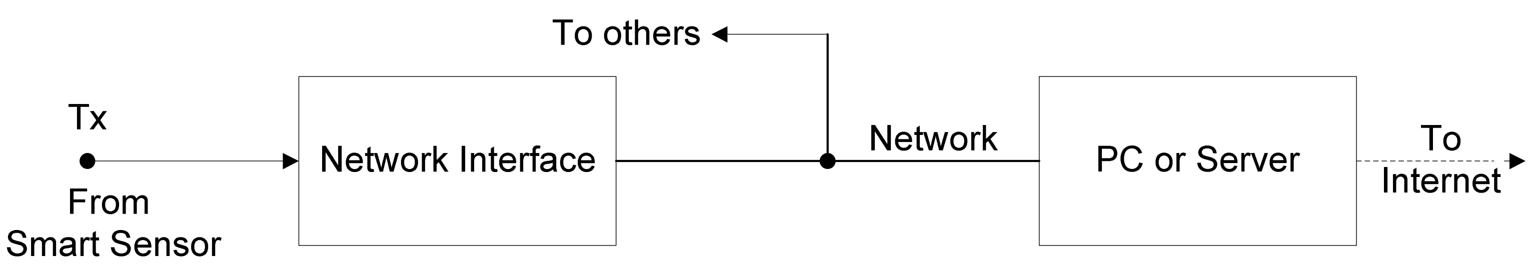
To describe ---

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

Networked Sensor Block Diagram



SMART SENSOR



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

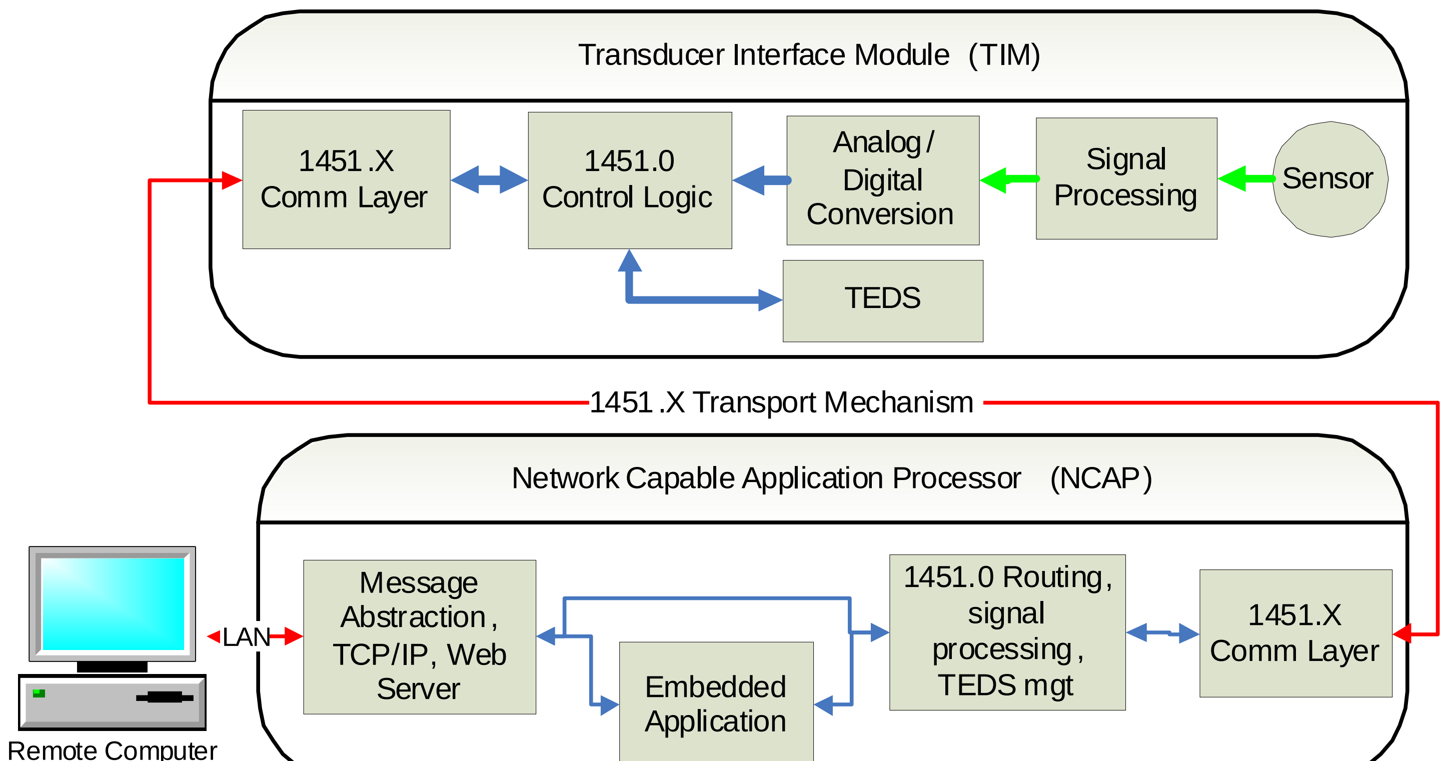
The Tower of Babel

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

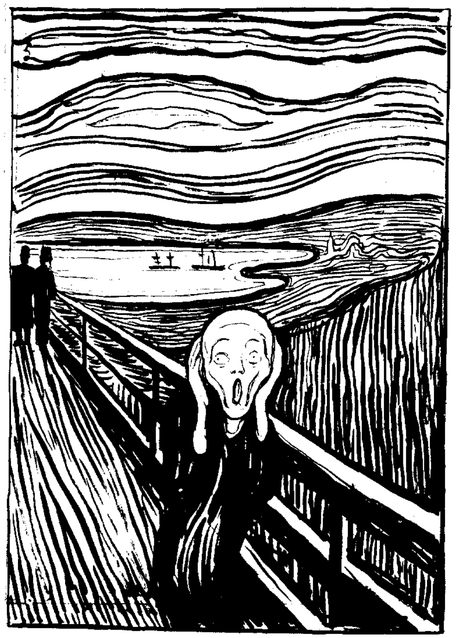


IEEE 1451 Advantages

- 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)
1451.6 – CAN Bus	In process
1451.7 – RFID	In process

Most used

* 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

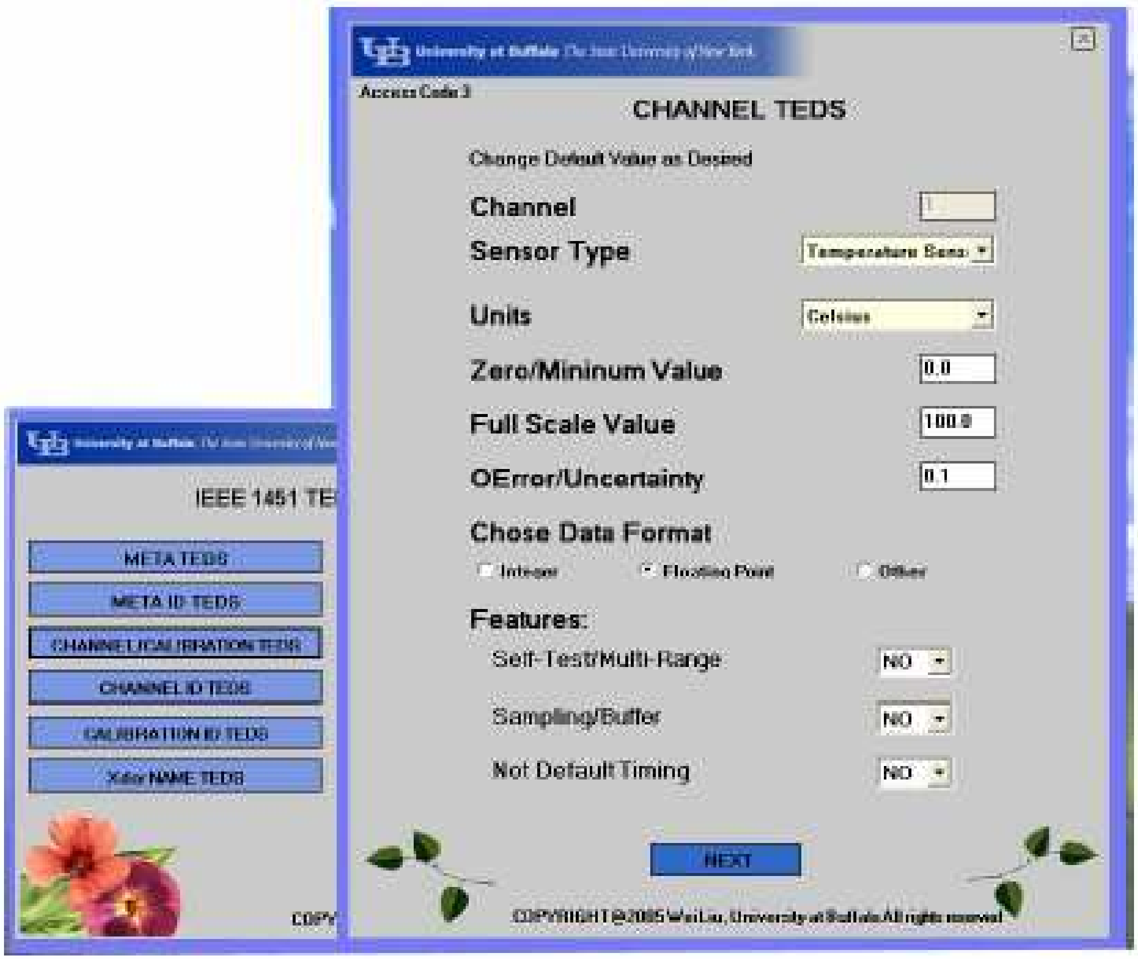
    Field type is 1, Length is 2 bytes, field value is “A304” hex

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

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

TEDS Compiler

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



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)

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 * <exponent of radians>) + 128	UInt8	1
3	(2 * <exponent of steradians>) + 128	UInt8	1
4	(2 * <exponent of meters>) + 128	UInt8	1
5	(2 * <exponent of kilograms>) + 128	UInt8	1
6	(2 * <exponent of seconds>) + 128	UInt8	1
7	(2 * <exponent of amperes>) + 128	UInt8	1
8	(2 * <exponent of kelvins>) + 128	UInt8	1
9	(2 * <exponent of moles>) + 128	UInt8	1
10	(2 * <exponent of candelas>) + 128	UInt8	1

Dot 0 Command/Response Structure

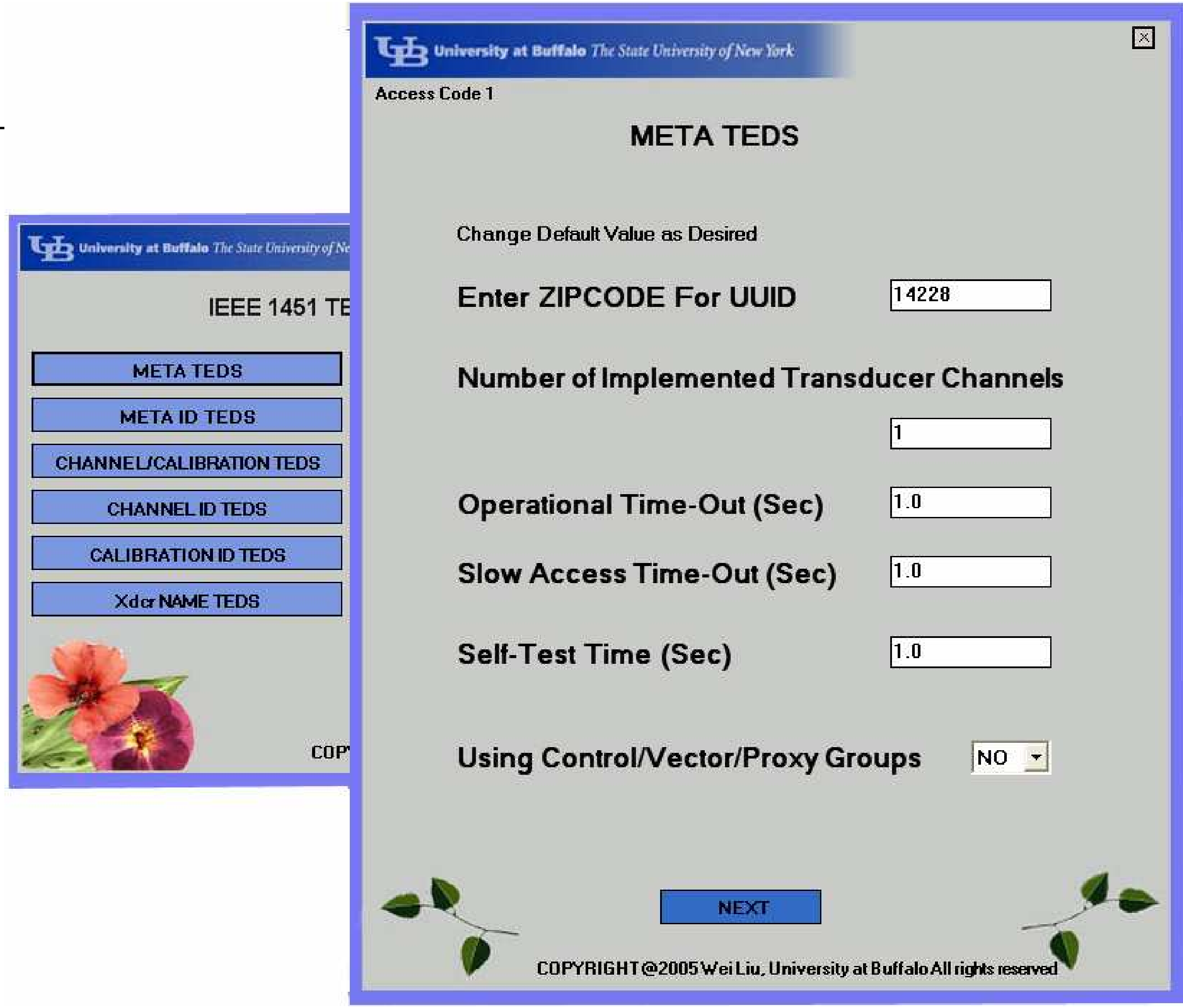
Byte Number	Description
1	Destination Transducer Channel Number (Most significant byte)
2	Destination Transducer Channel Number (Least significant byte)
3	Command Class
4	Command Function
5	Length (Most significant byte)
6	Length (Least significant byte)
7-N	Command dependent bytes

NCAP Command Message Structure

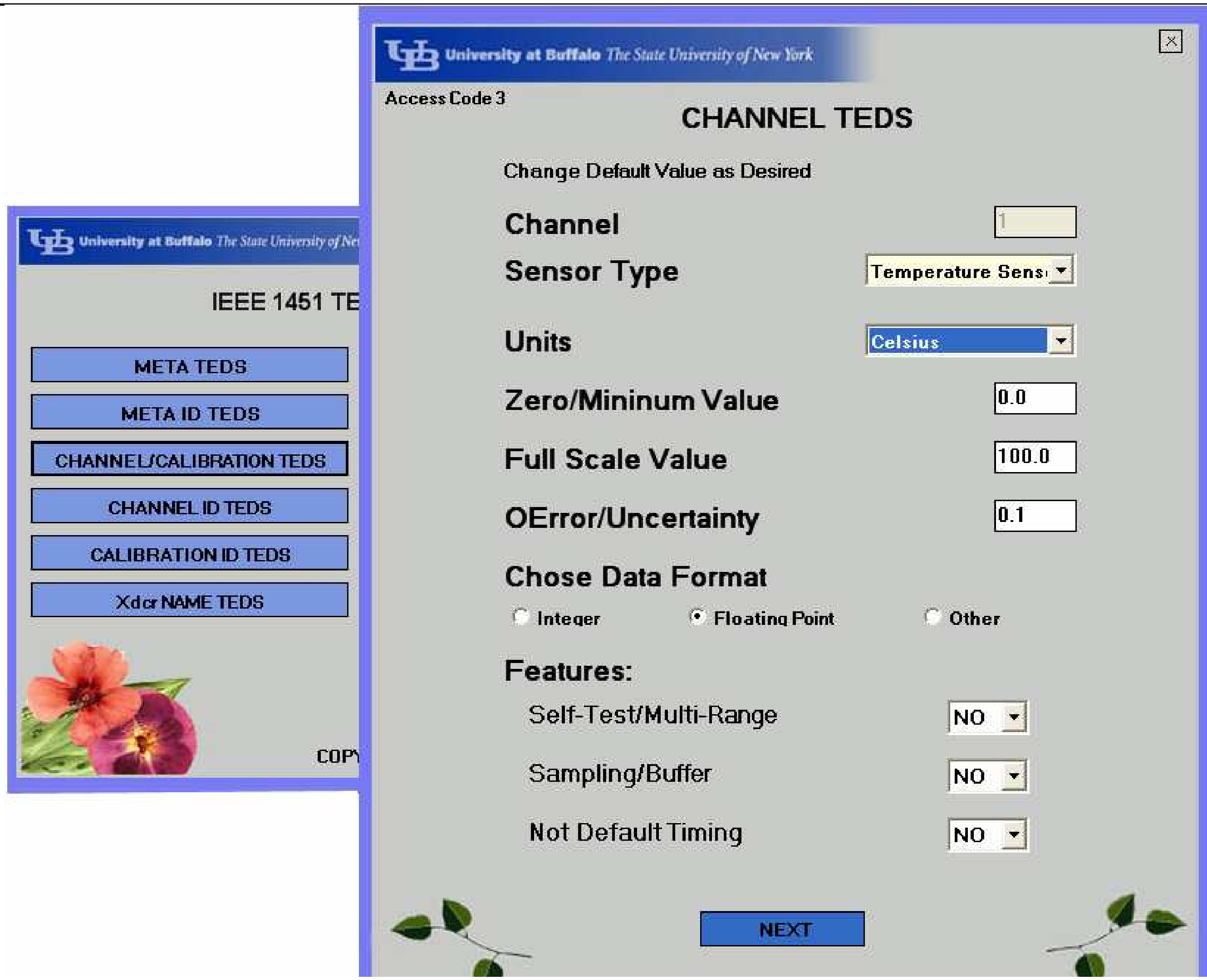
Byte Number	Description
1	Success/Fail Flag
2	Length (Most significant byte)
3	Length (Least significant byte)
4-N	Reply dependent bytes

TIM Reply Message Structure

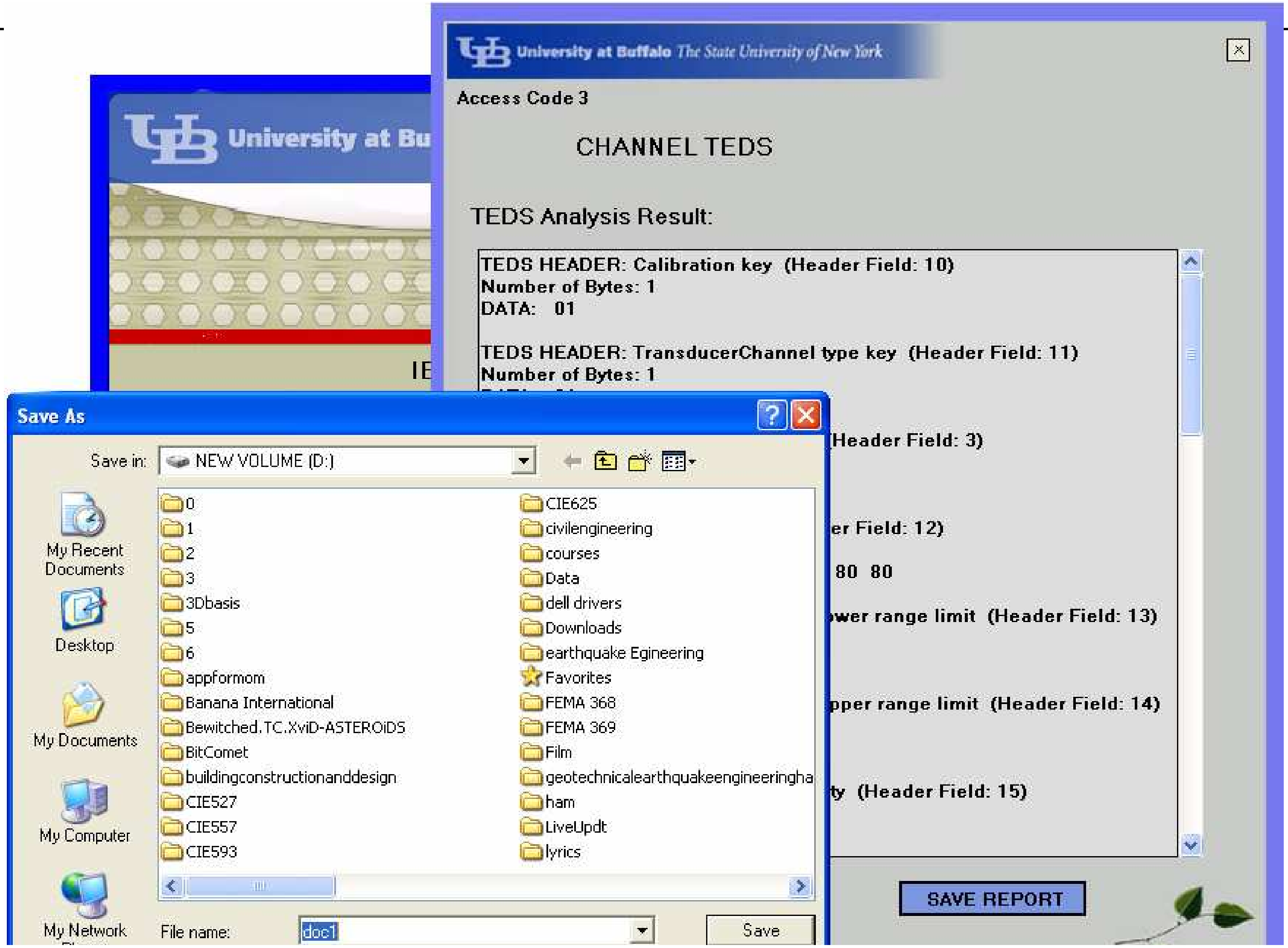
Meta-TEDS Writer Screen



Channel/Calibration TEDS (for linear sensors)



TEDS Reader


University at Buffalo The State University of New York
Access Code 3
CHANNEL TEDS
TEDS Analysis Result:
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
SAVE REPORT
Save As
Save in: NEW VOLUME (D:)
My Recent Documents
Desktop
My Documents
My Computer
0
1
2
3
3Dbasis
5
6
appformom
Banana International
Bewitched.TC.XviD-ASTEROiDS
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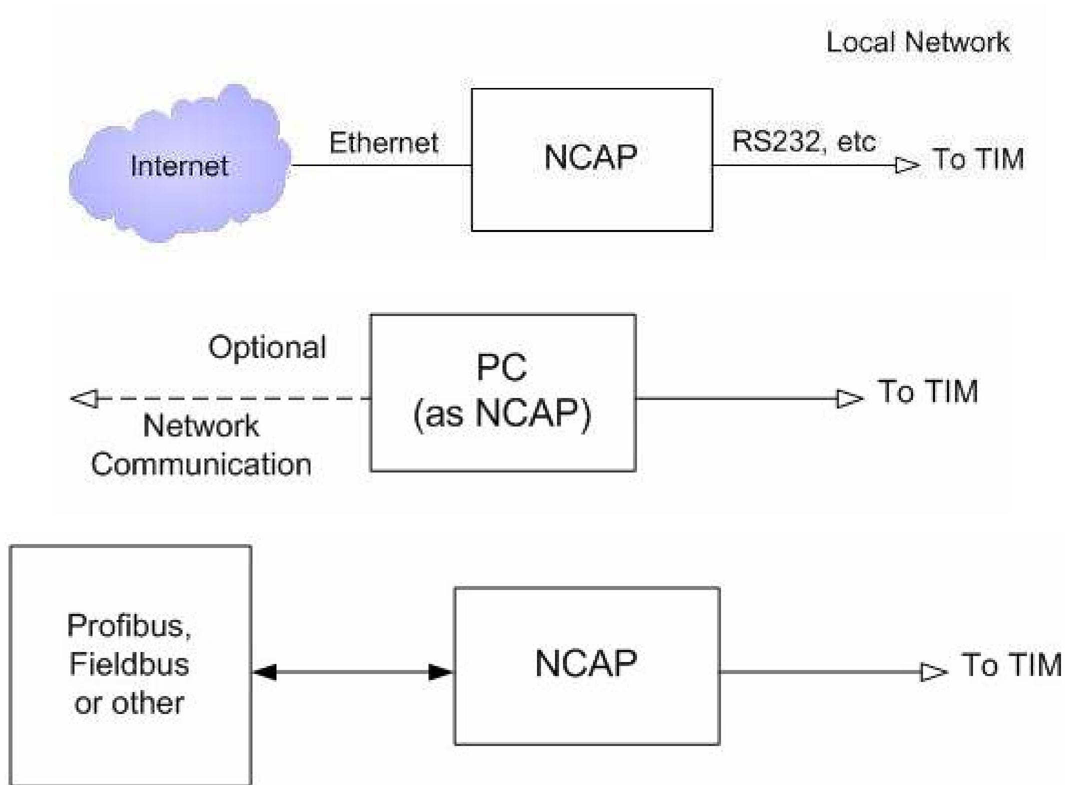
IEEE 451 TIM Compliance Tester

- 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

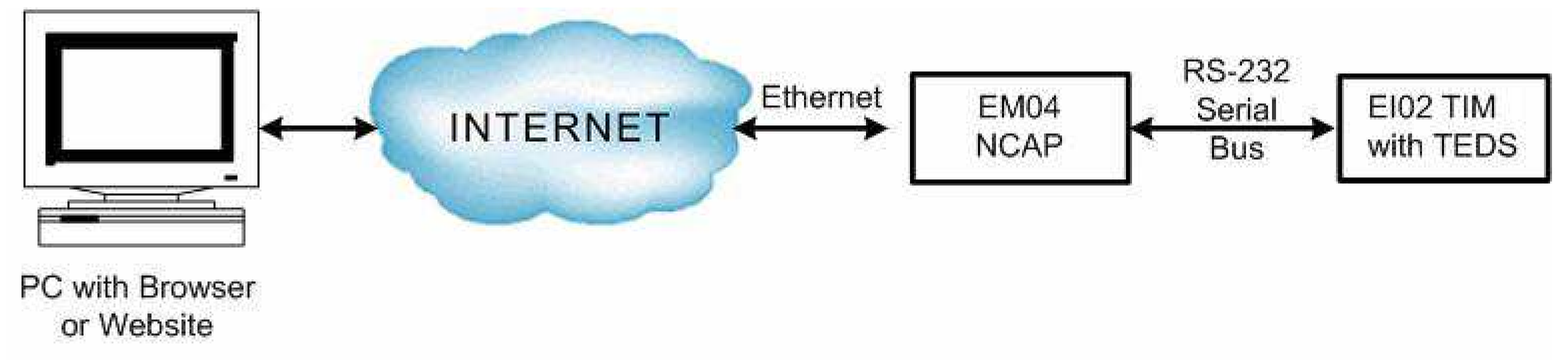
Data Readout Examples
(via Internet)

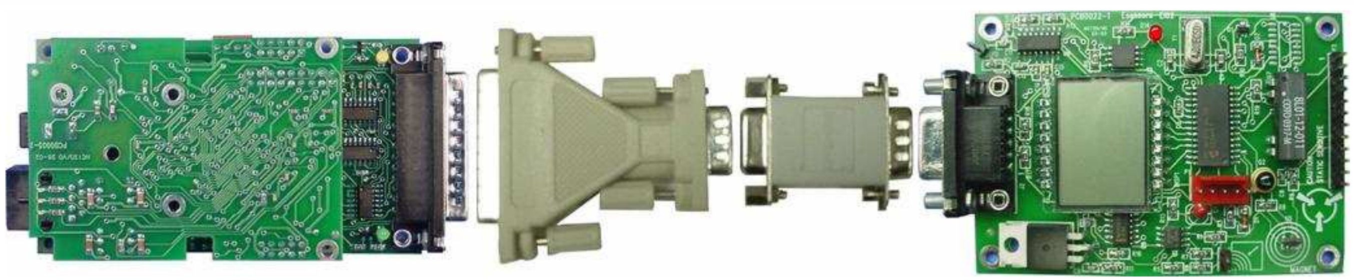
- Sensor data converted to ASCII for display

- TEDS data is displayed in hexadecimal form

Prototype TIM and NCAP

- NCAP interfaces to Internet via Ethernet





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

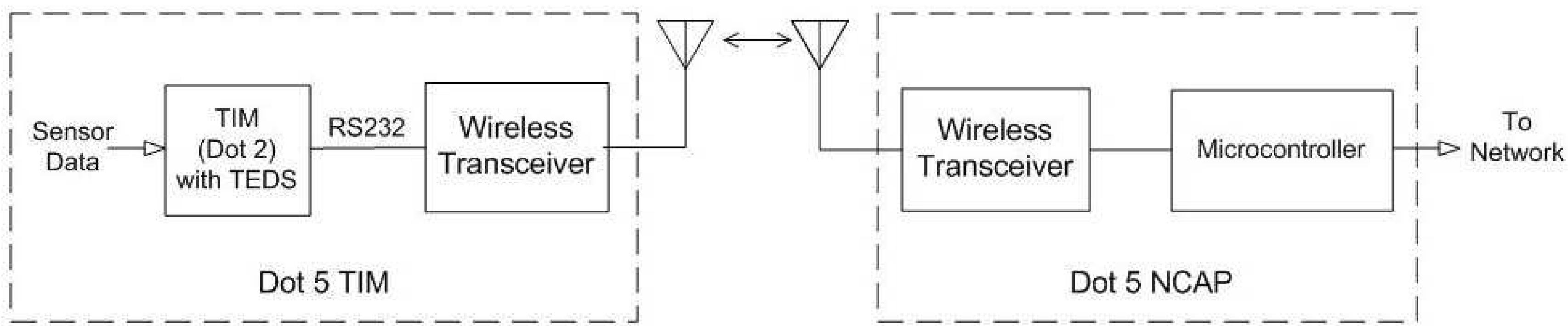
  Intermittent transmission (sleep mode)

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

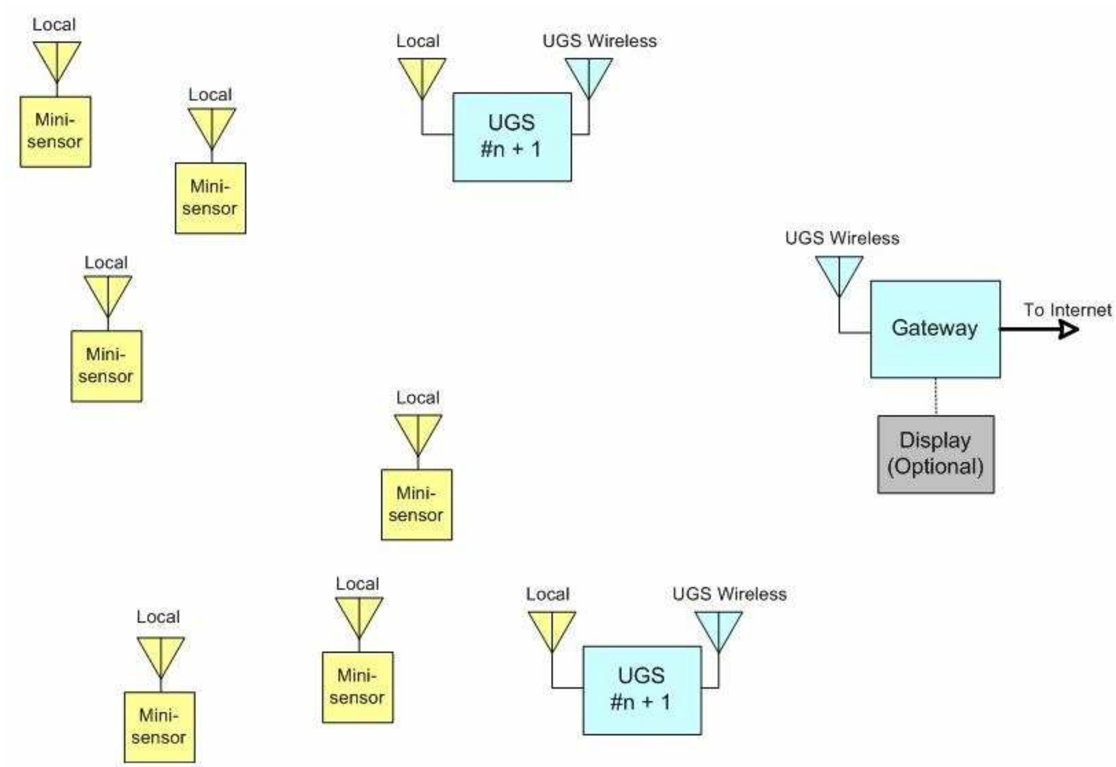
- Wireless modules with RS232 I/O when connected to Dot 2 TIMS are similar to IEEE 1451.5 TIMs (wireless version of IEEE 1451).
- Data format and TEDS are the same (both follow the Dot 0 standard)..



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

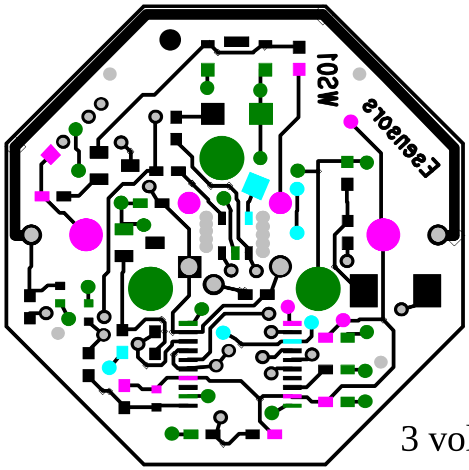
- UUID (Universal **Unique** Identifier)
  Supplied by EEPROM (DS2433) manufacturer (6 bytes)
- Basic TEDS (8 bytes)
  - Model Number (15 bits)
  - Version Letter (5 bits, A-Z)
  - Version Number (6 bits)
  - Manufacturer ID (14 bits)
  - Serial Number (6 bits)
- IEEE Template or Manufacturer's TEDS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

Dot 4

Conversion to Dot 0 TEDS possible (but not unique)

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)

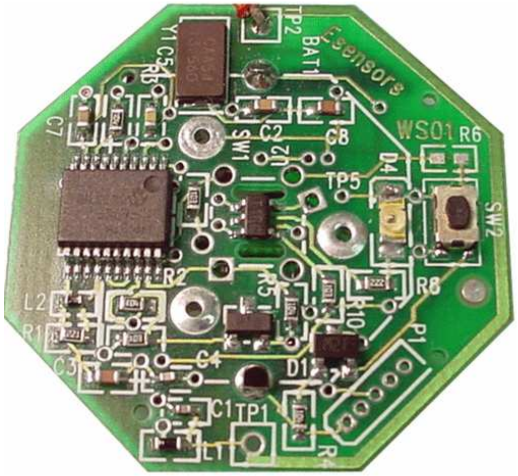


Photo (front)

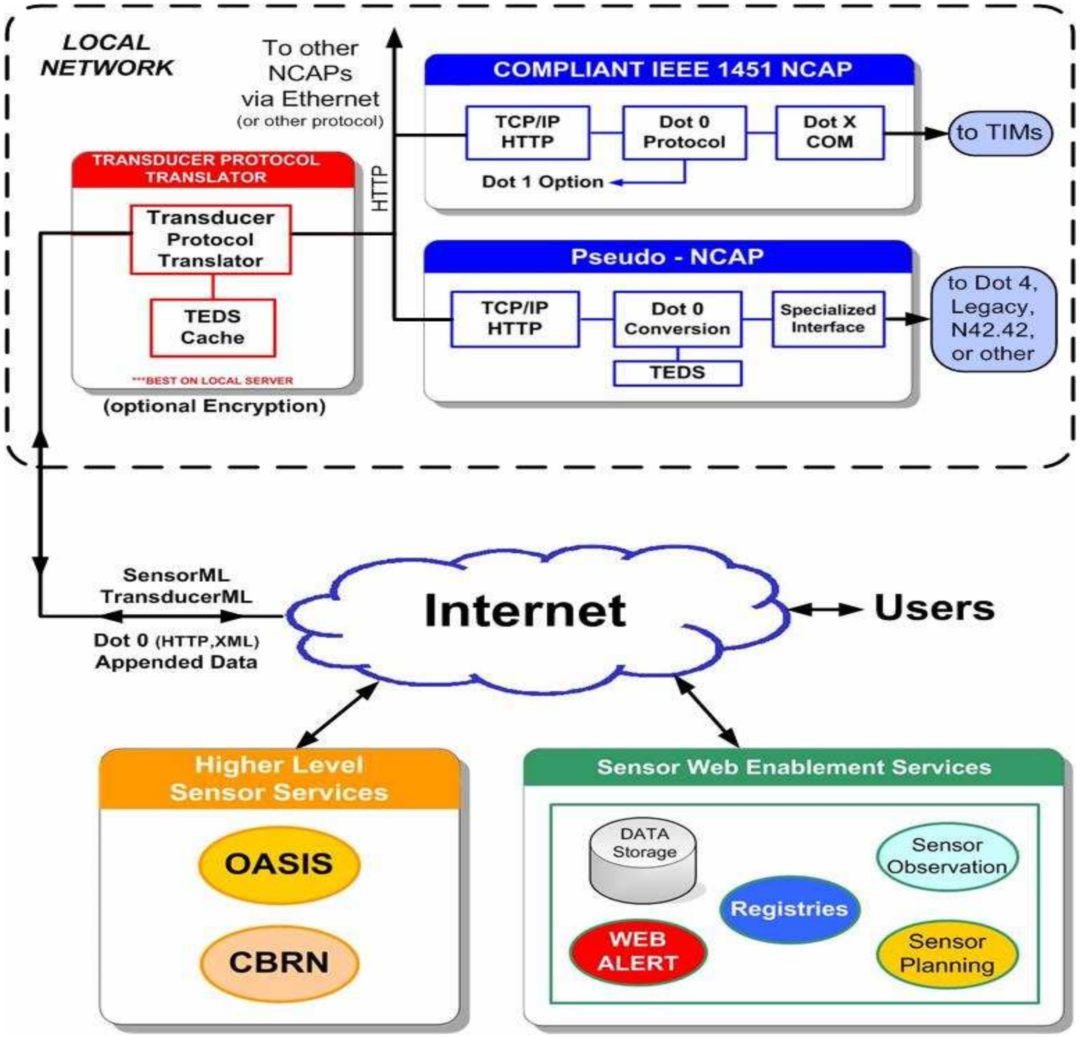
RFID with Sensors (Dot 7)

- 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.

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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.

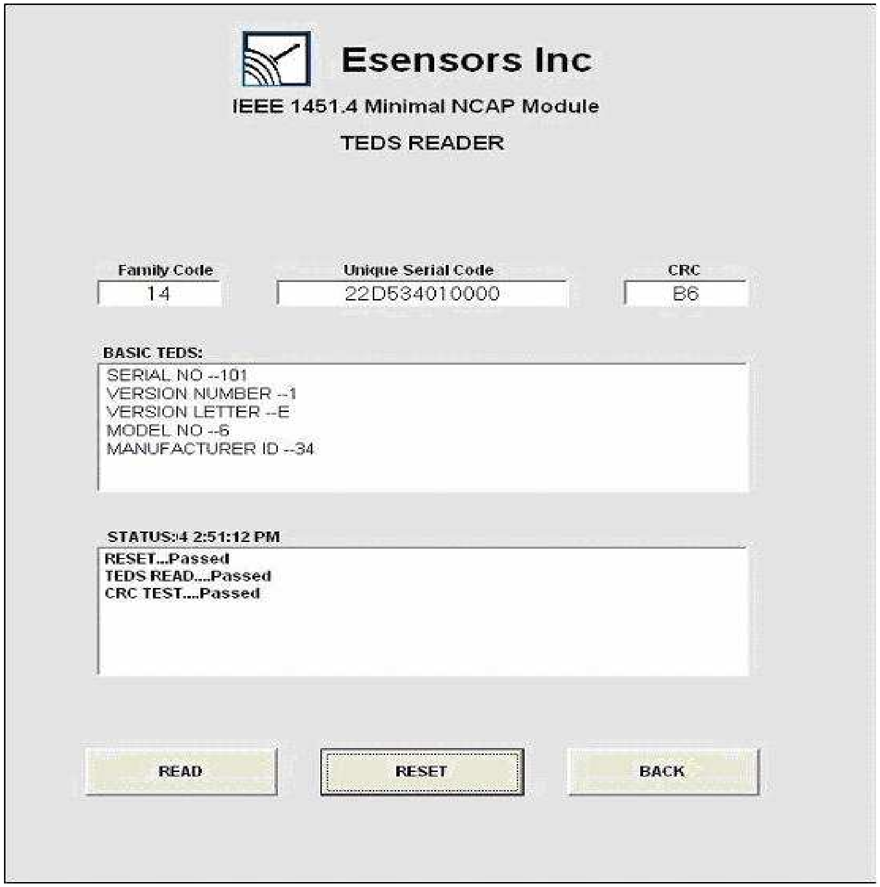
Future of Networked Sensors

- 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)

Writer



Reader

TIM Tester – Data retrieval