Low-Power Wireless Sensor with SNAP and IEEE 1451 Protocol

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and

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Goals

To describe ---

- Low-power wireless sensor requirements
- Advantages of compact SNAP protocol
- Need for IEEE 1451 smart transducer standard
- Wireless temperature sensor example

SAS -- Wireless with SNAP/1451

Network Sensor Features and Applications

Features

- Automatic testing
- Plug and play
- Multiple sensors on one network or bus

Applications

- Machine to Machine (M2M) sensor data communications
- Wide area (Nationwide) data collection ability

Wireless Sensors
for short-range, unlicensed band

Grouped by Power Requirements

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 operation (years) on small battery

Wireless sensors –
A. 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 –
B. 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 Configurations

New device: Low-power WiFi (GainSpan)

Wireless sensors –
C. Very low power

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

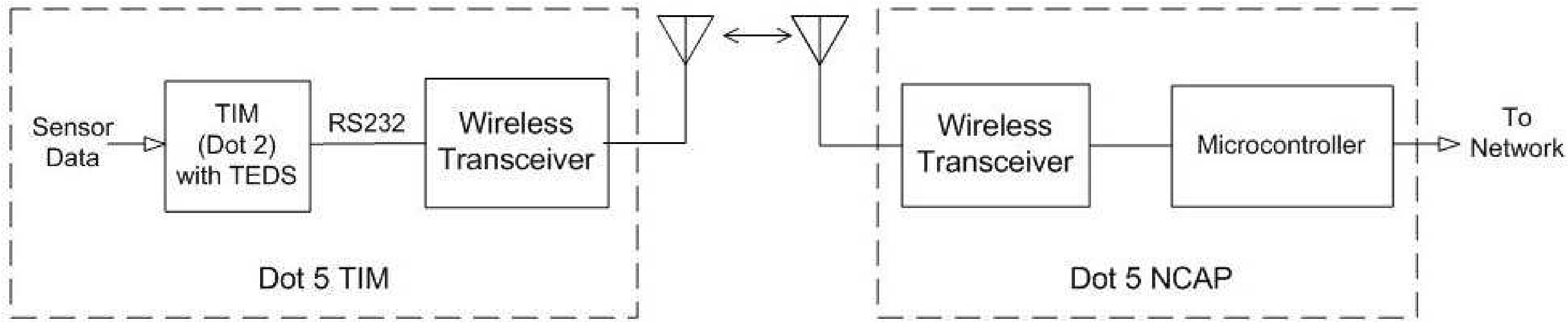
RF modules and microcontrollers available

Low bandwidth

Intermittent transmission (sleep mode)

Example –
Wireless Serial Connection

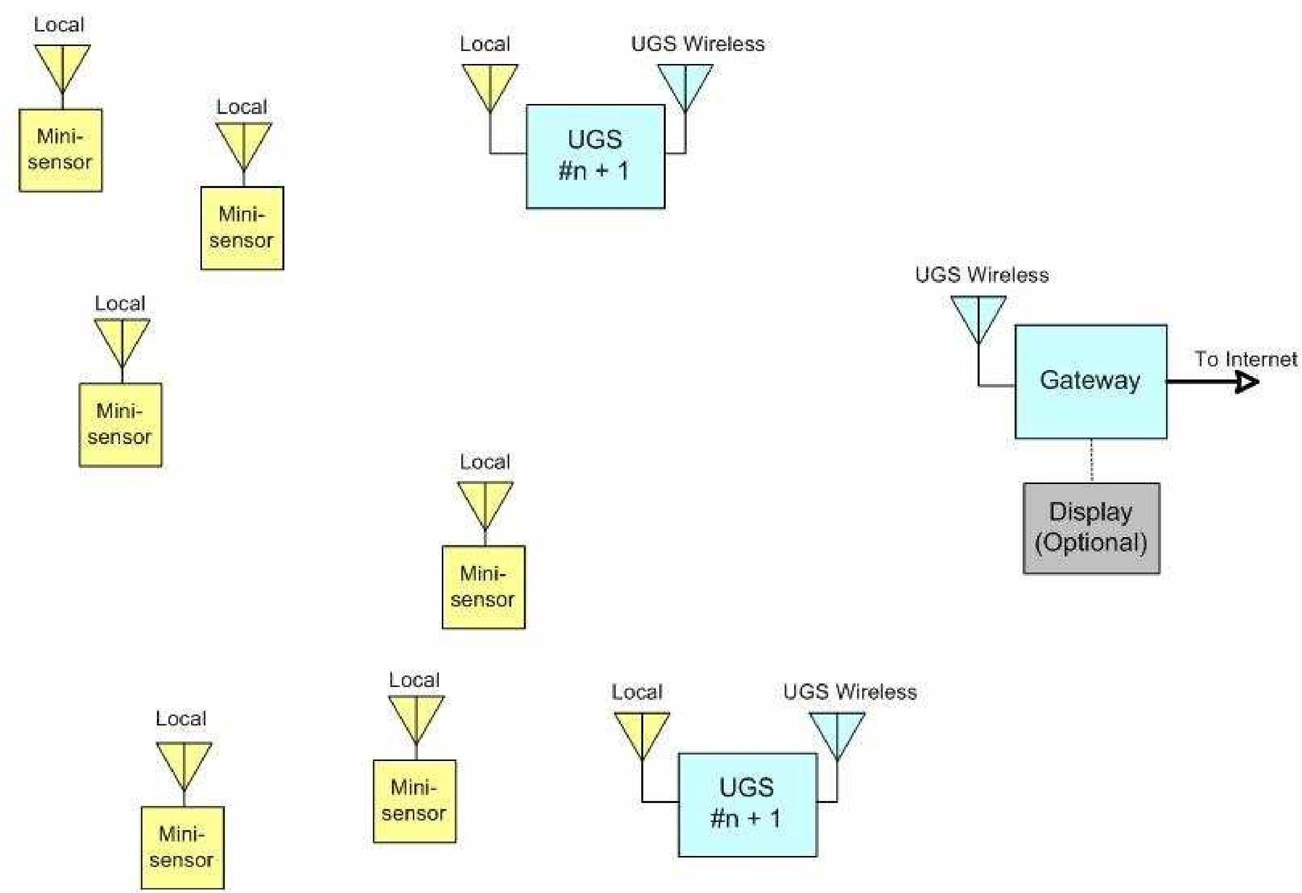
- Wireless modules with RS232 I/O when connected to Dot 2 TIMS are similar to IEEE 1451.5 TIMs (wireless version of IEEE 1451).
- Data format and TEDS are the same (both follow the Dot 0 standard)..



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

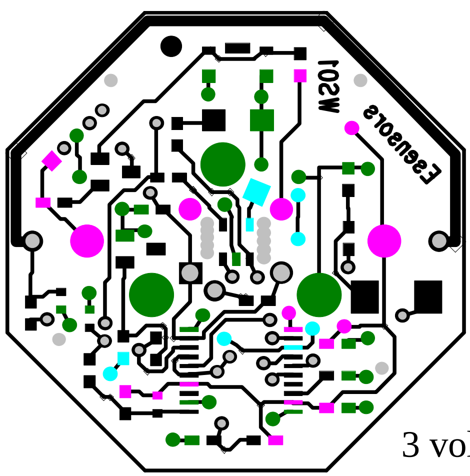
Zigbee Mesh Network System

- One of many sensor networks available.



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)

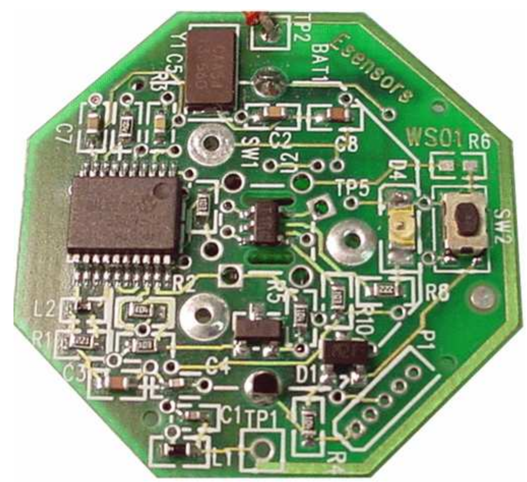
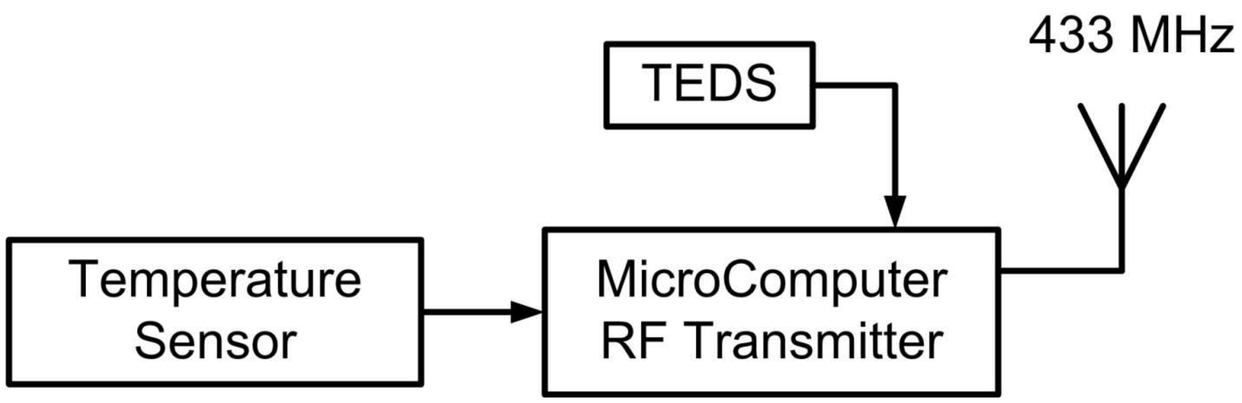
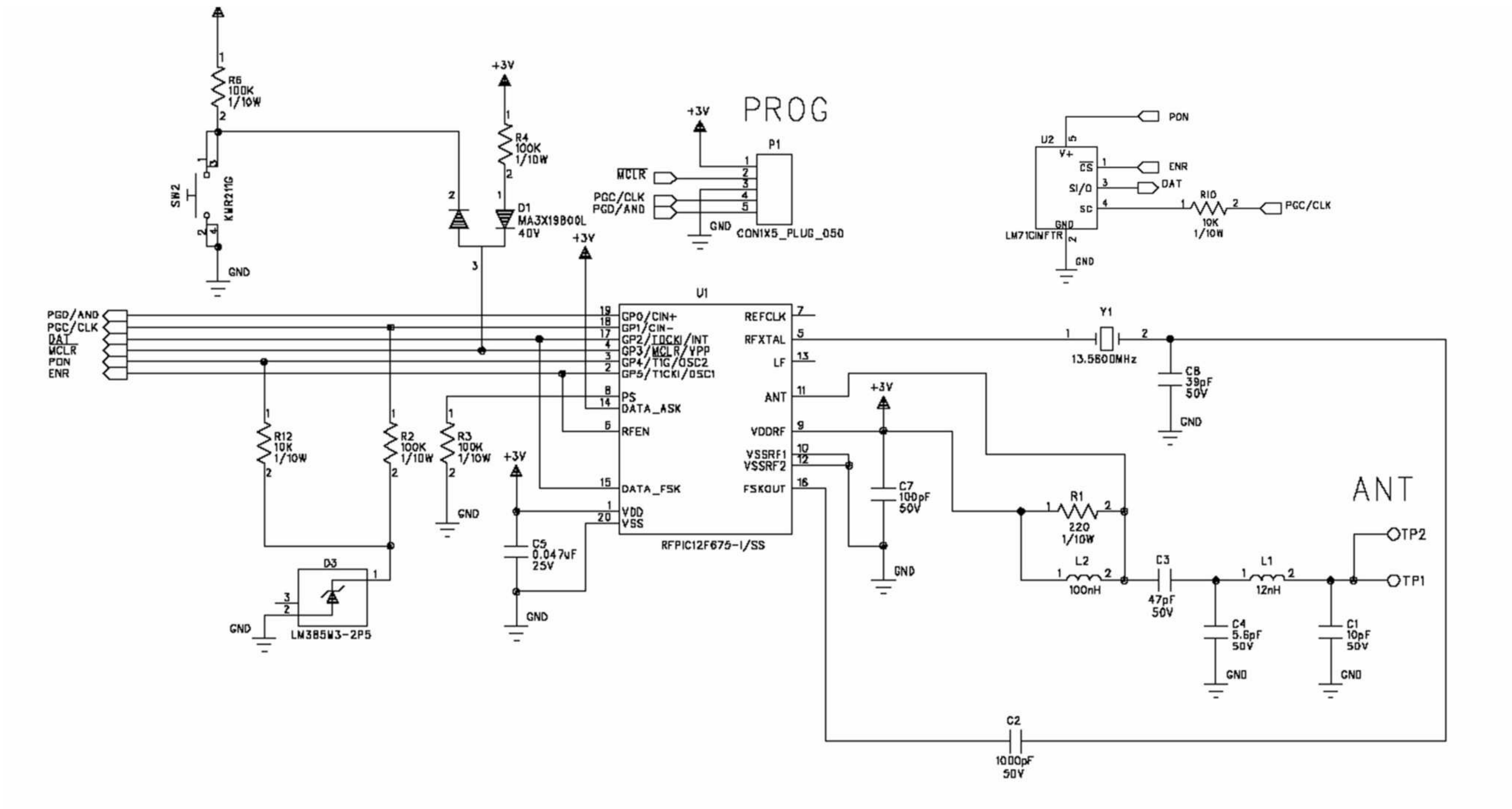


Photo (front)

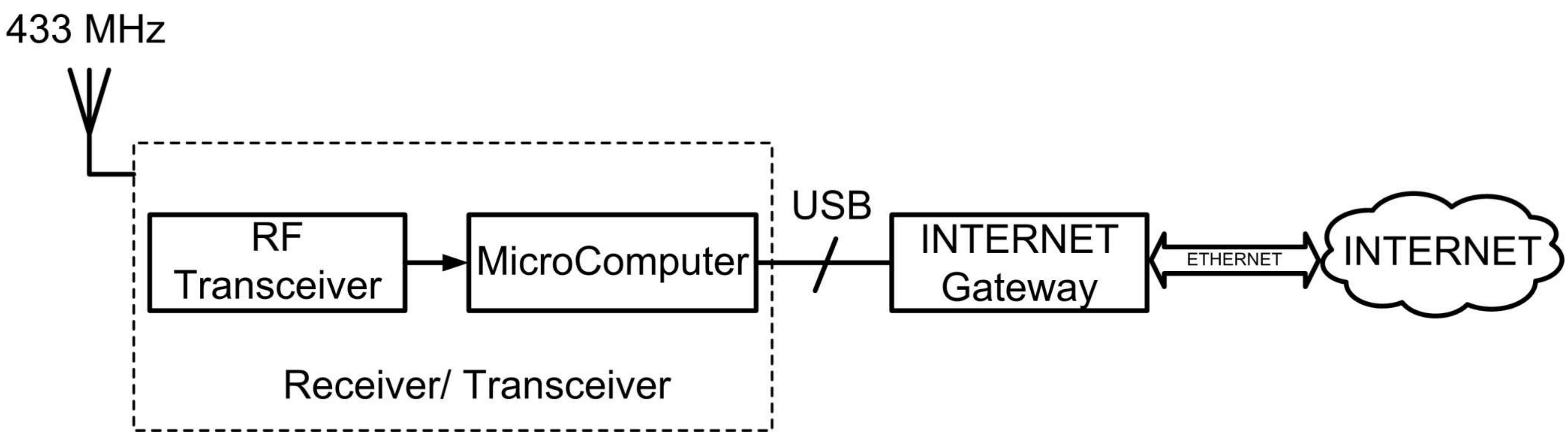
Wireless Temperature Sensor Block Diagram



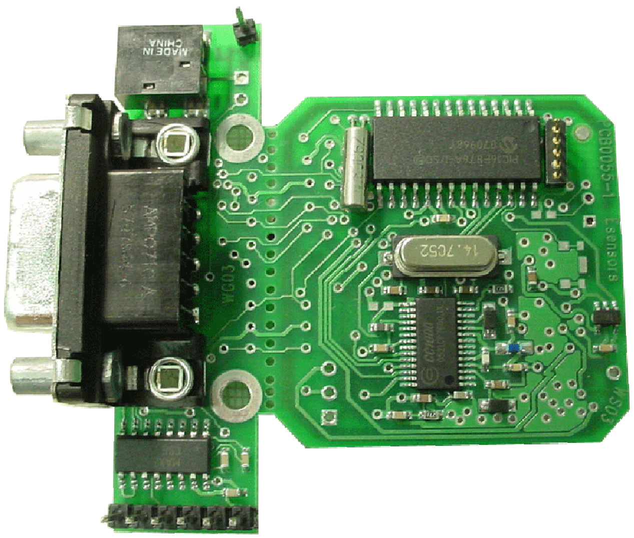
Wireless Temperature Sensor Circuit Diagram

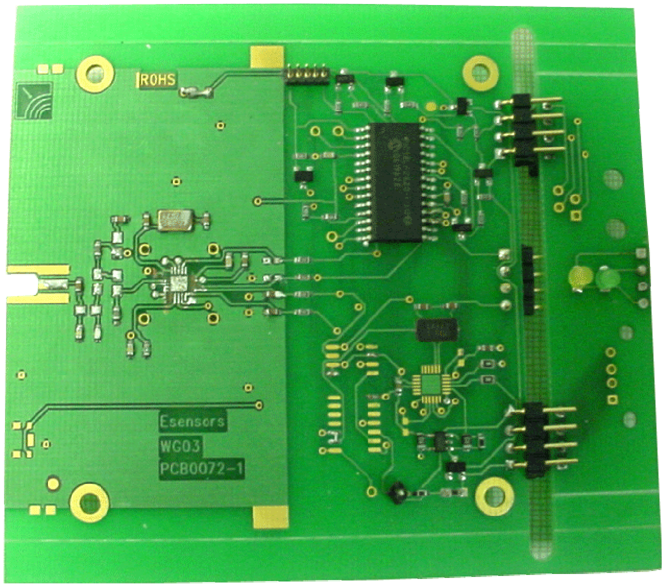


Wireless Sensor Receiver Block Diagram



Circuit Boards for Wireless Receivers



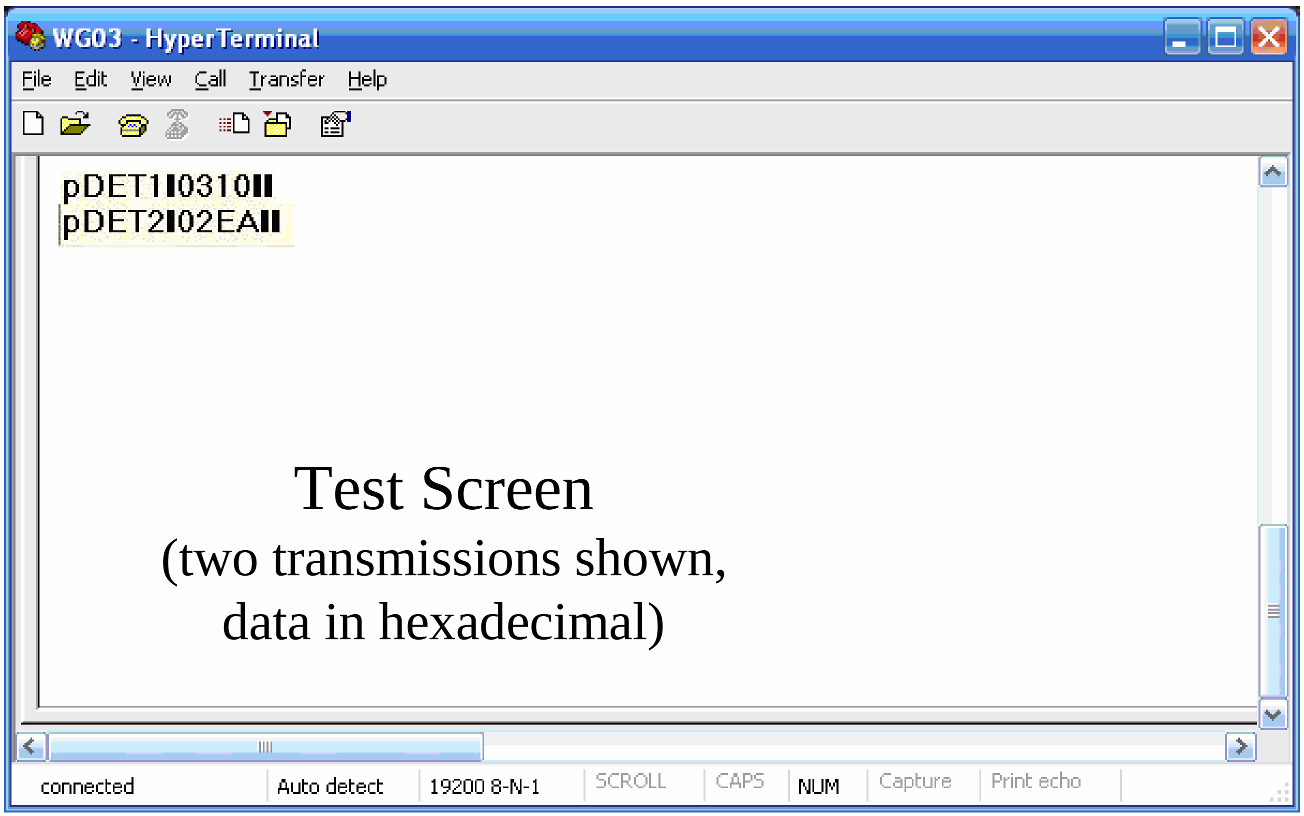


SNAP Data Transmission Protocol

<table>
<tr><td colspan="2">Header</td><td colspan="3">Address Field</td><td>Data Field</td><td>CRC field</td></tr>
<tr><td>SYNC
(1-byte)</td><td rowspan="2">Header Composition
(2 bytes)</td><td rowspan="2">Destination address
(1 byte)</td><td colspan="2">Source Address
(3 bytes)</td><td rowspan="2">data
(1-8 bytes)</td><td>CRC
(1 byte)</td></tr>
<tr><td></td><td>ID
(2 bytes)</td><td>Data Type
(1- byte)</td><td></td></tr>
</table>

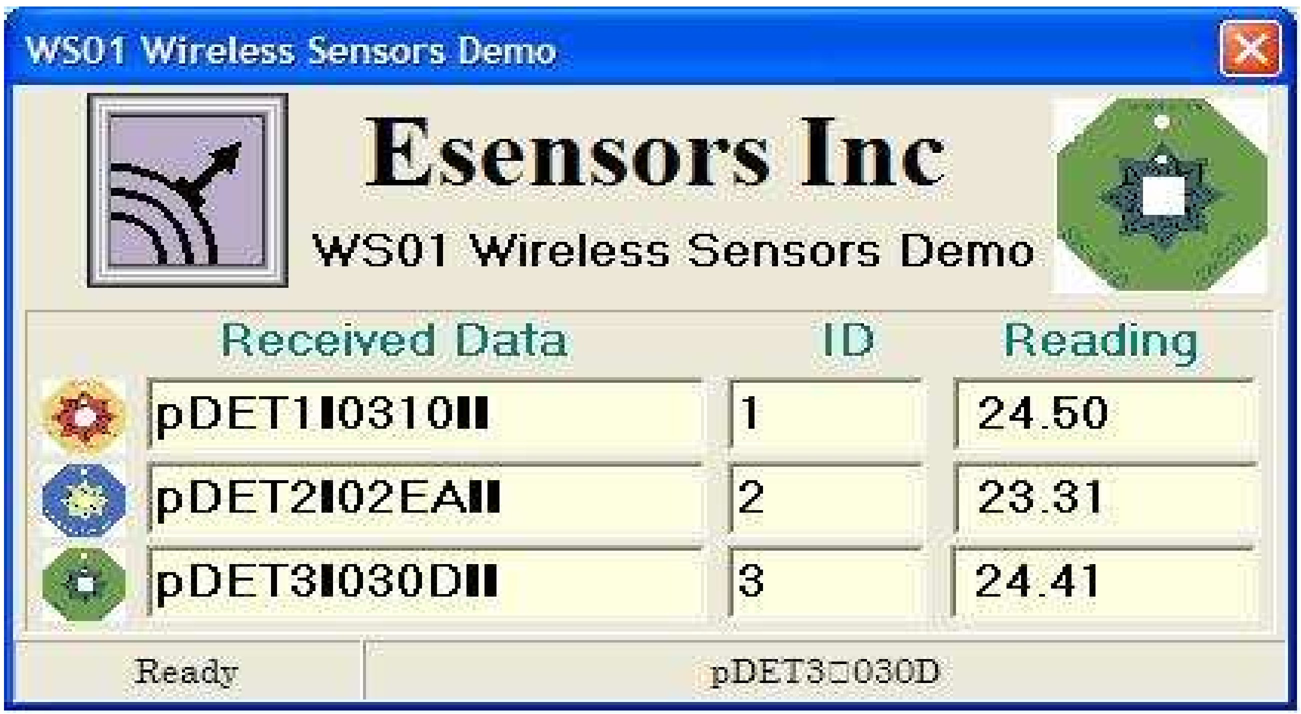
Sensor Data and TEDS (Dot4) sent using this format

Transmitted Wireless Data



Received Data
(raw data and temperature in ^{o}C)

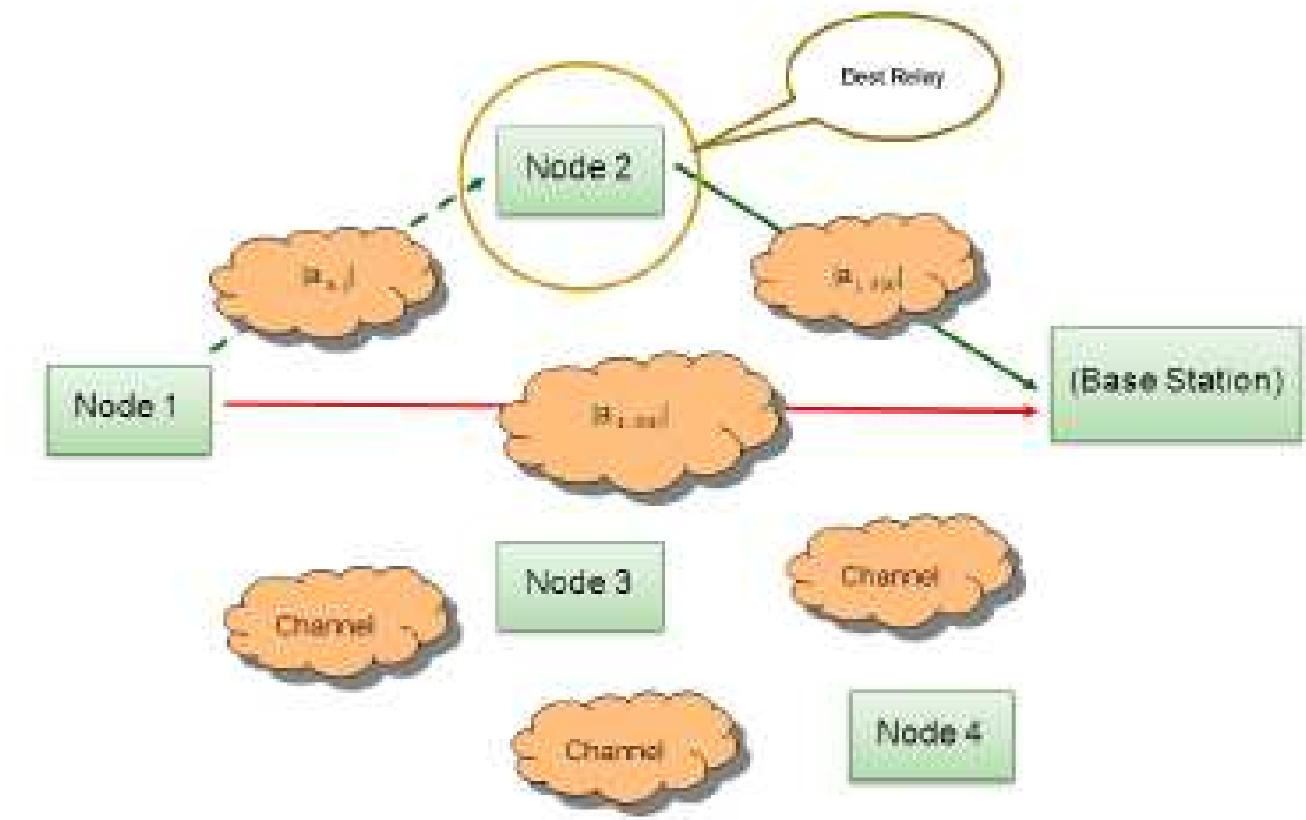
Three wireless sensors sending data



Opportunistic Mesh Network

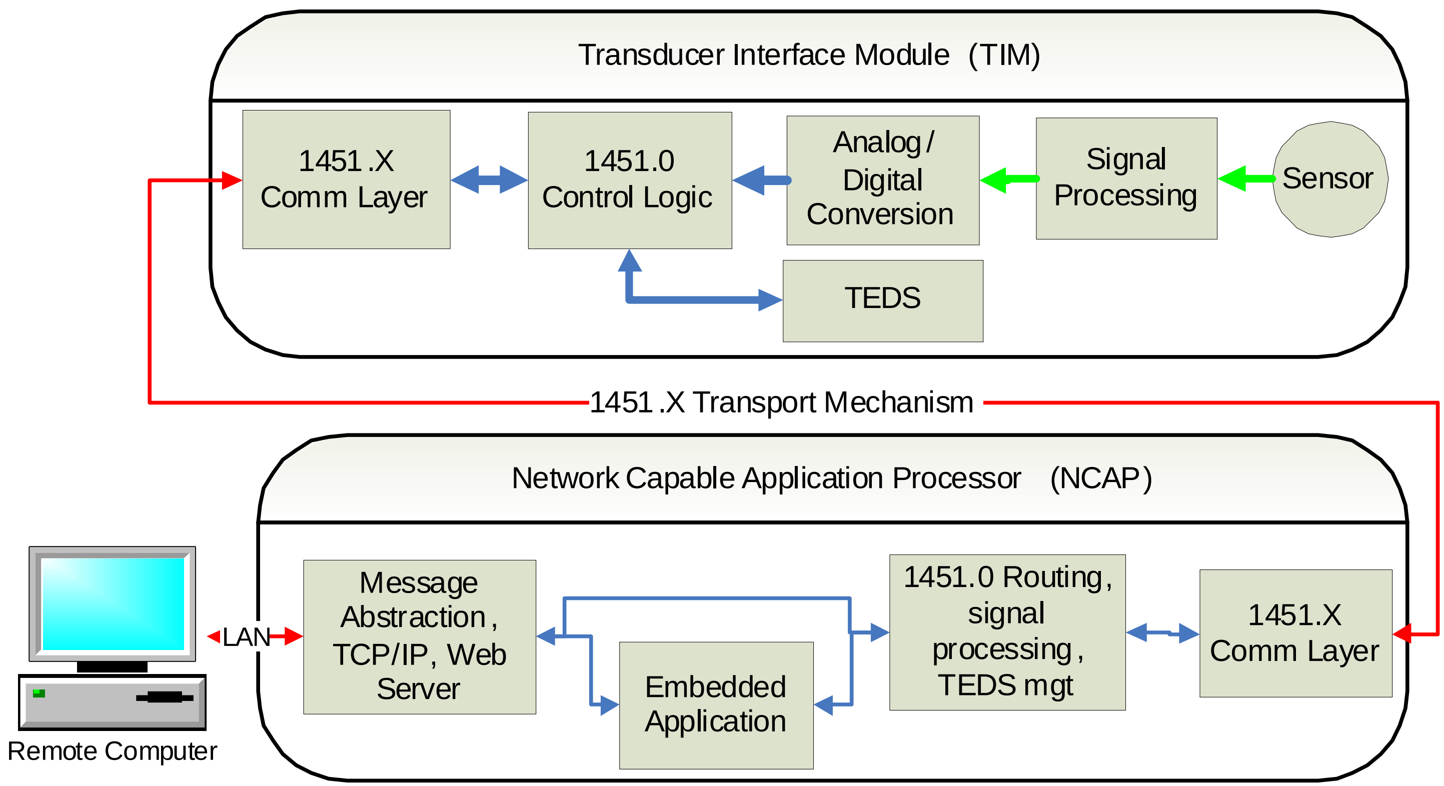
- Wireless mesh network which minimized node-to-node transmission energy
- Includes error/missing data recovery
- Purpose: minimize battery power
- Uses receiver signal strength

Opportunistic Mesh Network Protocol



A review of the

IEEE 1451 Smart Transducer Concept

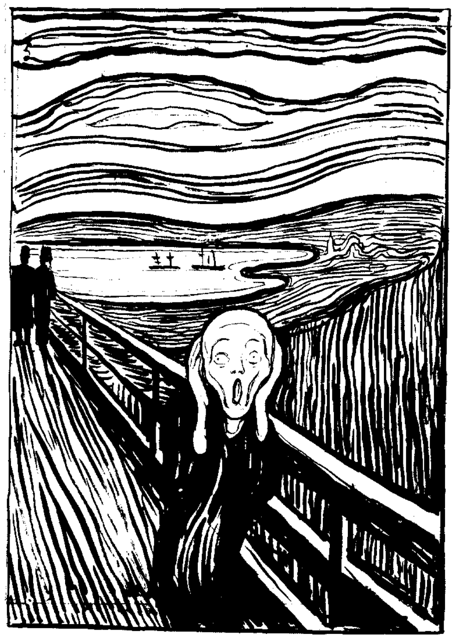


IEEE 1451 Advantages

- 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

Main parts of
IEEE 1451.0 (Dot 0) Standard

- Command /Response format
- Transducer Electronic Data Sheet (TEDS)

Dot 0 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)

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

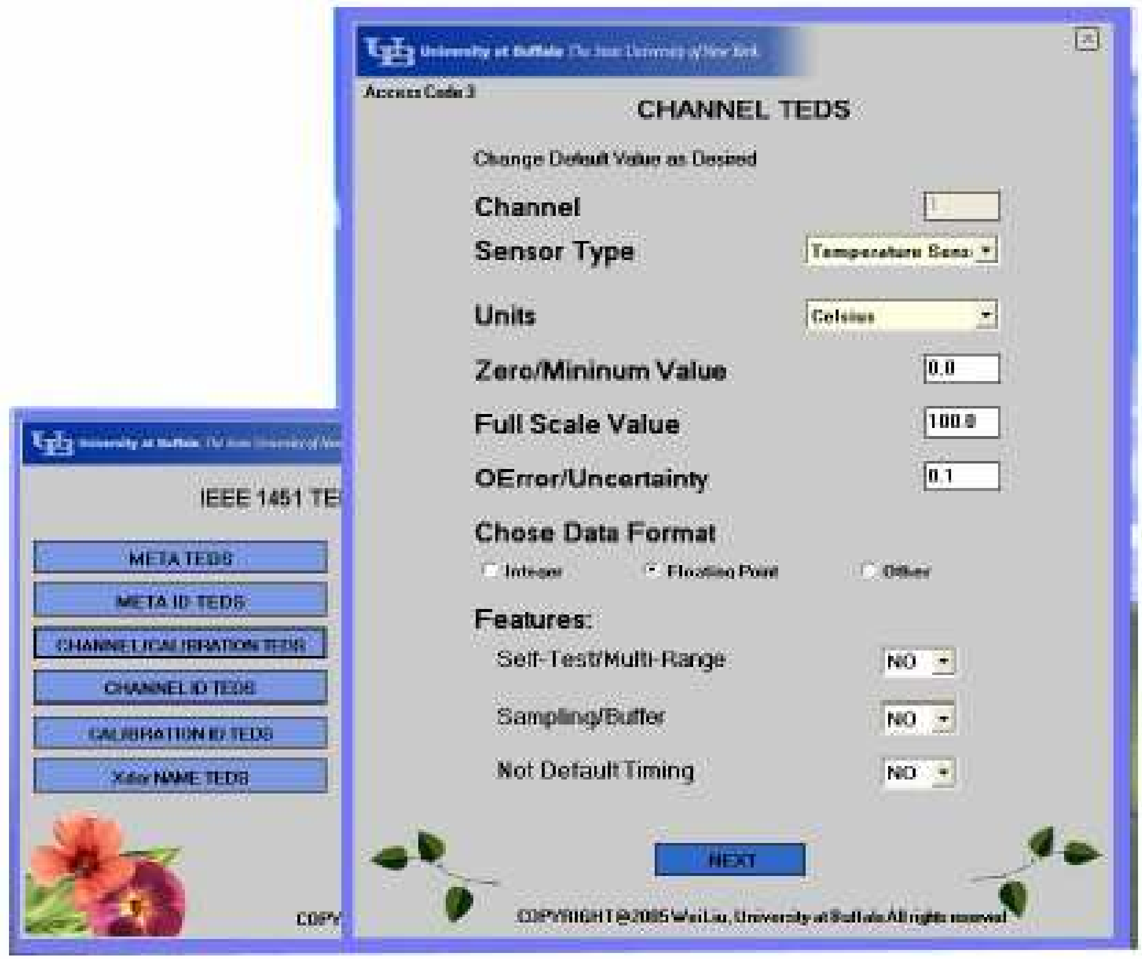
- Data Transmission [specific octet format]
  - TEDS/Status requests
  - Triggering and configuration
  - Sensor read commands and data return
  - Actuator write commands and data sending

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

Dot 0 TEDS Compiler

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



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

Wireless Dot4 TEDS

- Large TEDS (Dot 0) takes too much time and energy to transmit
- Small IEEE 1451.4 TEDS is preferable and compatible with SNAP format
- However some information is lacking and must be made up somewhere for full Dot0 compatibility
- We do the conversion in the gateway so gateway is an NCAP.

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)

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.

Summary

- Features of low-power wireless sensor were described
- Need for compact format discussed
- Advantages of IEEE 1451 explained
- Wireless temperature sensor example given

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End

- Backup Slides Follow

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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) ← Most used
1451.5 – Wireless (WiFi, Zigbee, etc)	Done (2007)
1451.6 – CAN Bus	In process
1451.7 – RFID	In process

* Needs revision

IEEE 1451 – the Universal Transducer Language

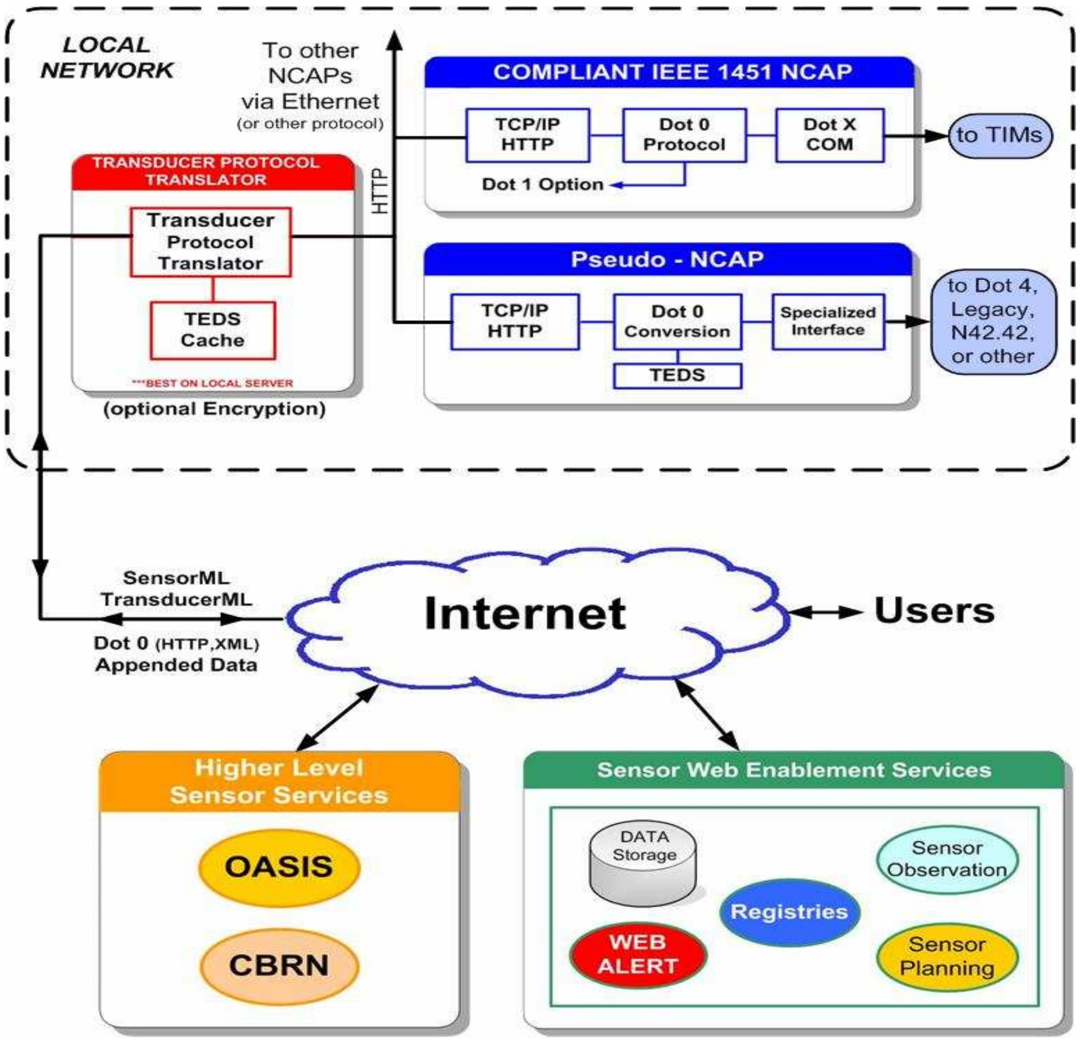
- Problem: too many network protocols in common use
- Narrow solutions and borrowed protocols have not worked
- Sensor engineers in the fragmented sensor industry need a simple method of implementation

- *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

Harmonization Meeting Summary
(Held at NIST Quarterly)

- 25-40 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).

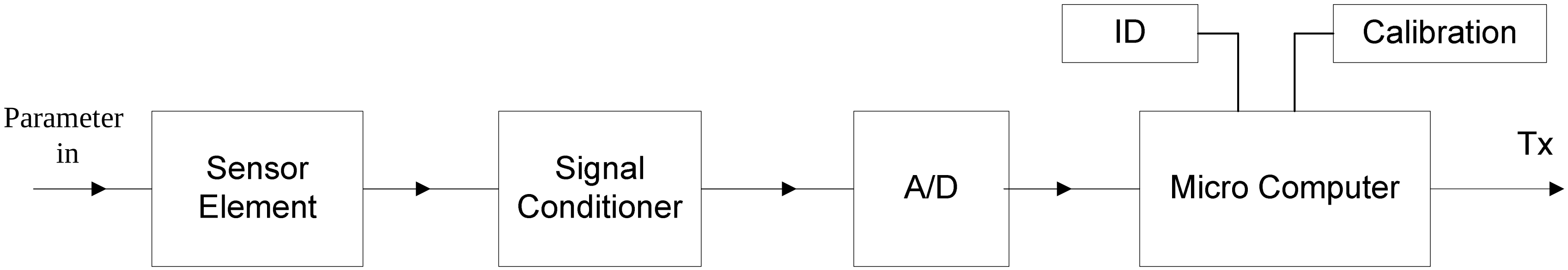
Harmonization of IEEE 1451 with Internet sensor standards



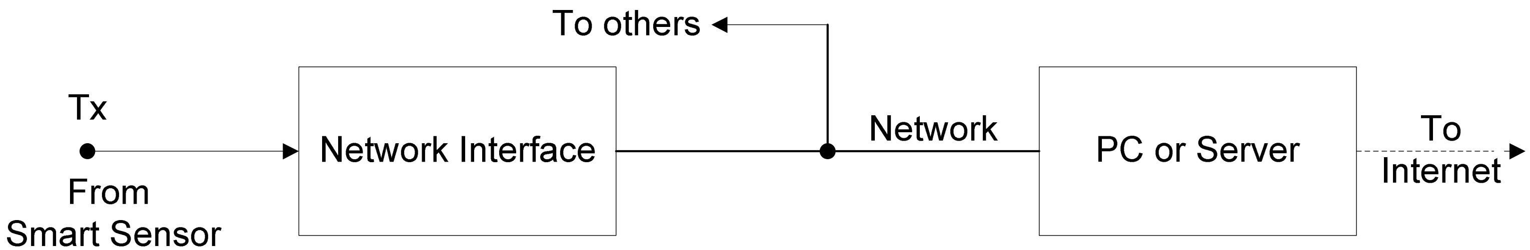
Comments on Wireless Sensor Networks

- 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.

Networked Sensor Block Diagram



SMART SENSOR



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

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

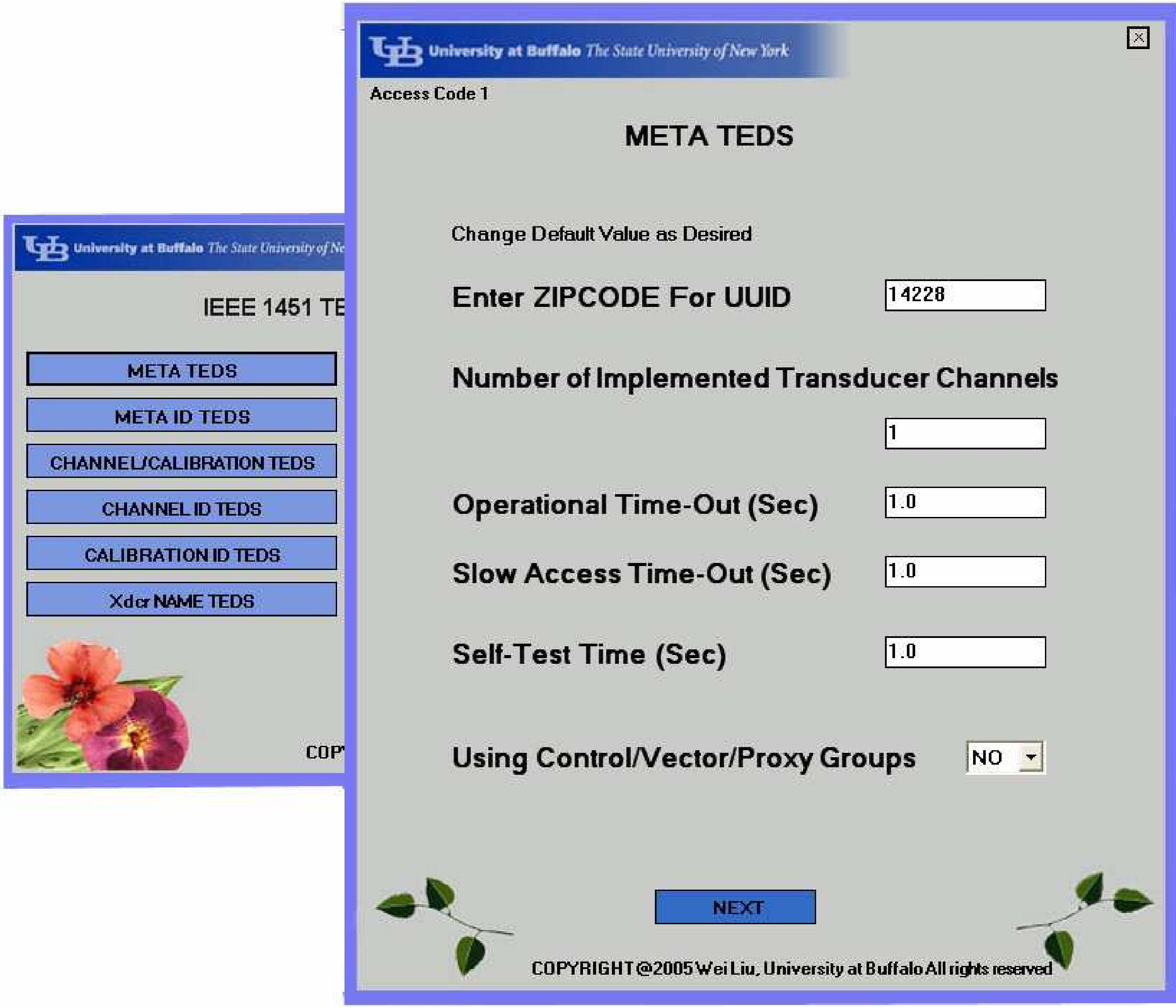
  (Must be within sensor range)

TEDS Sections Implemented

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

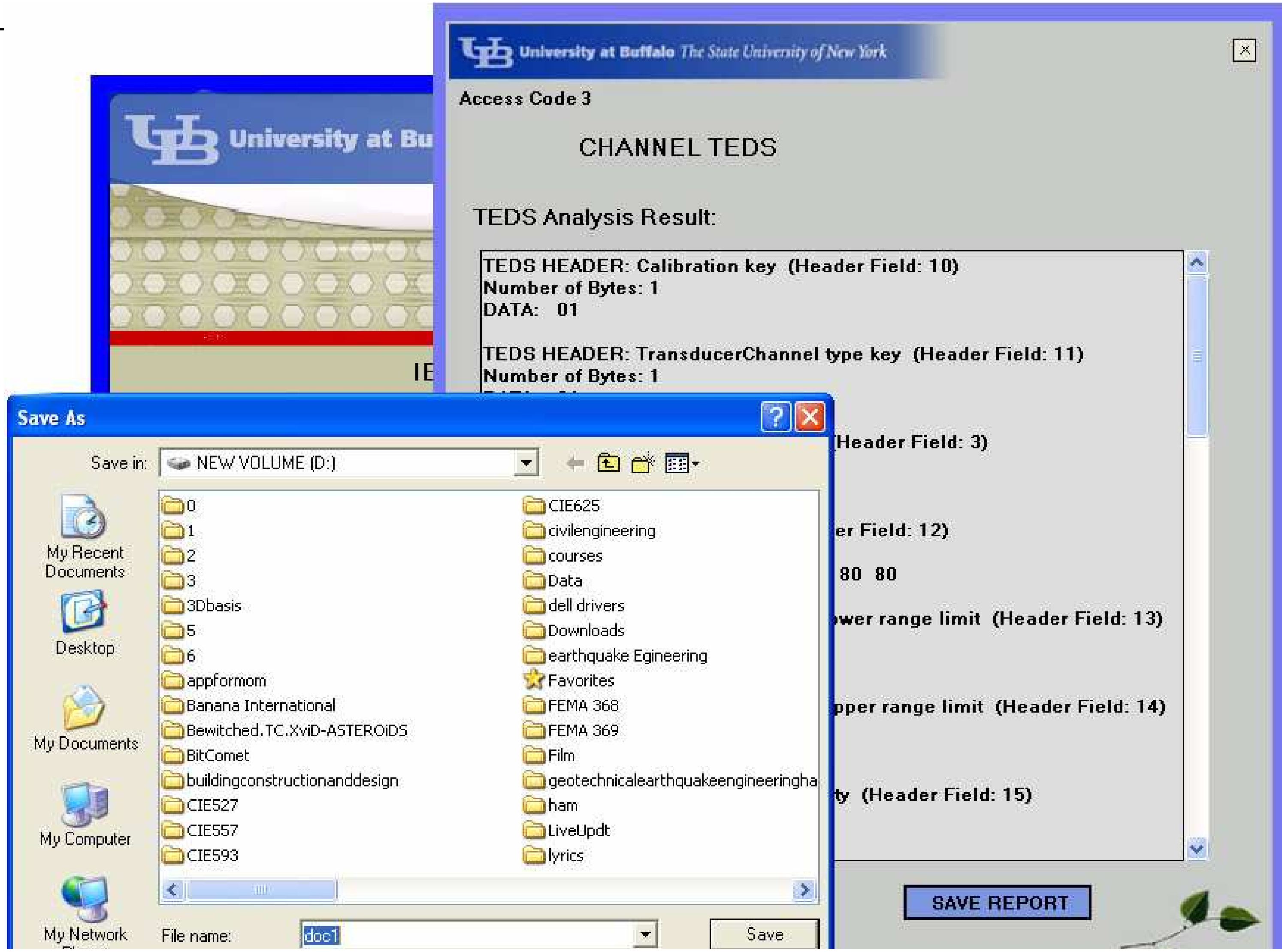
Referenced by TEDS section/access code (e.g. #1 for Meta-TEDS)

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
My Network
File name: doc1
Save

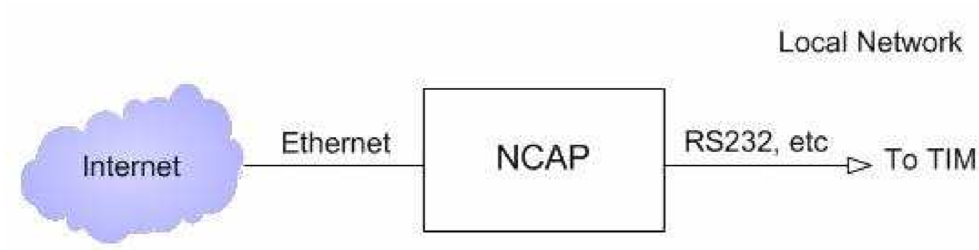
IEEE 451 TIM Compliance Tester

- TIM (Transducer Interface Module) is most complex and done by sensor design engineers

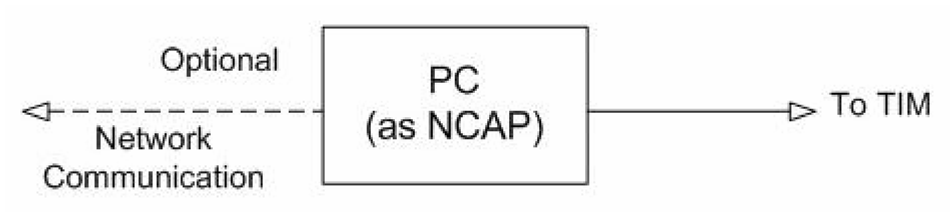
  (TIM tester can be used by the few NCAP designers)
- Tester verifies compliance of a TIM to IEEE 1451.0 (Dot 0) protocol
- Focus is on TEDS checking and data transfer format
- Physical device compliance not checked (part of other standards, e.g. RS485, Bluetooth)
- Tester uses serial bus (RS232)
- Testing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

Network side (NCAP) options (wired)

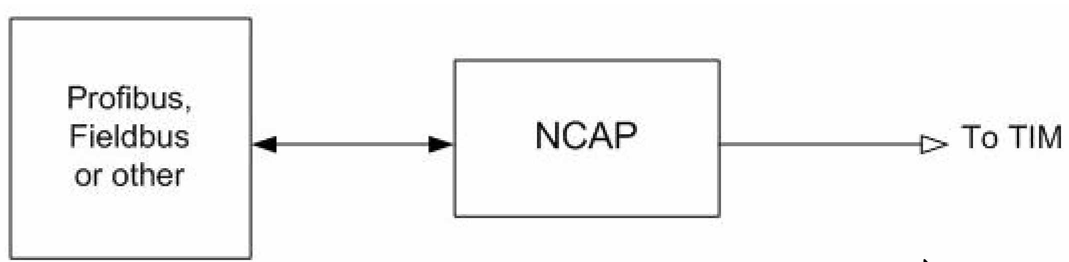
- Internet/Ethernet



- PC Readout



- Industrial network



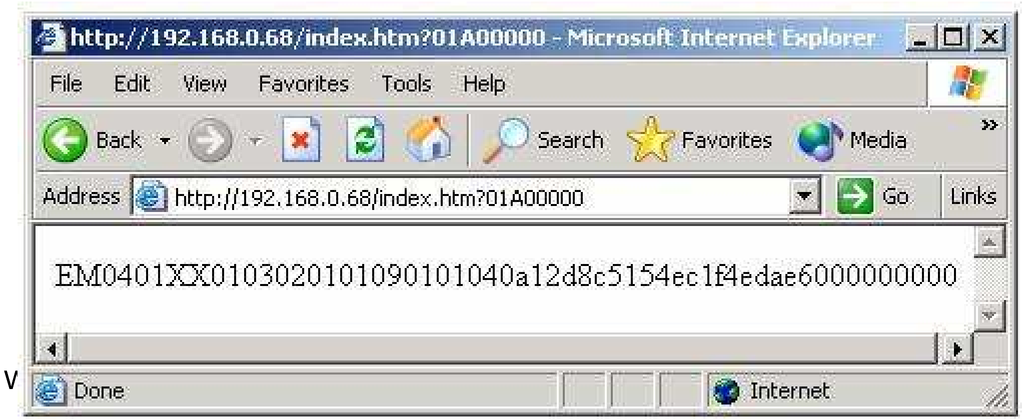
All use Dot 0 protocol

Data Readout Examples

(via Internet)

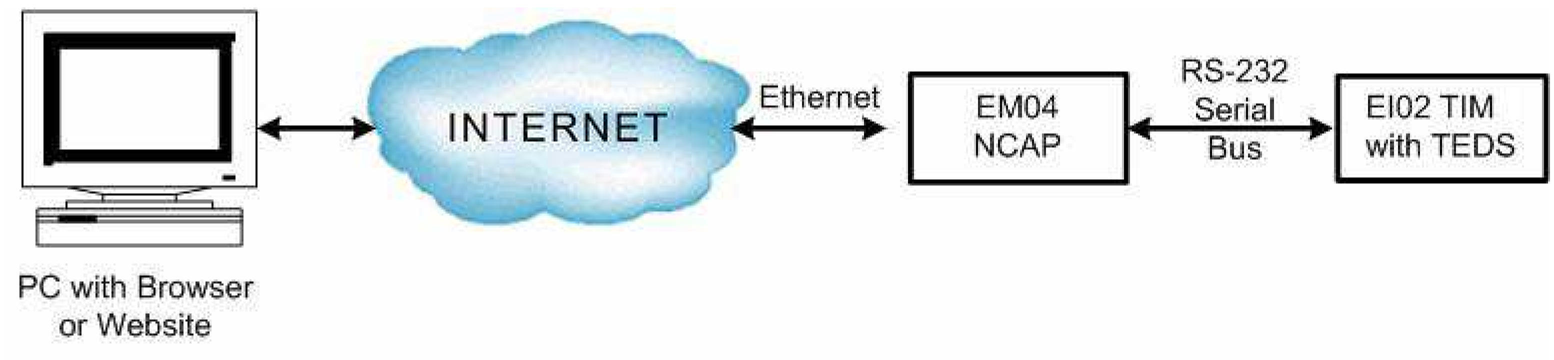
- Sensor data converted to ASCII for display

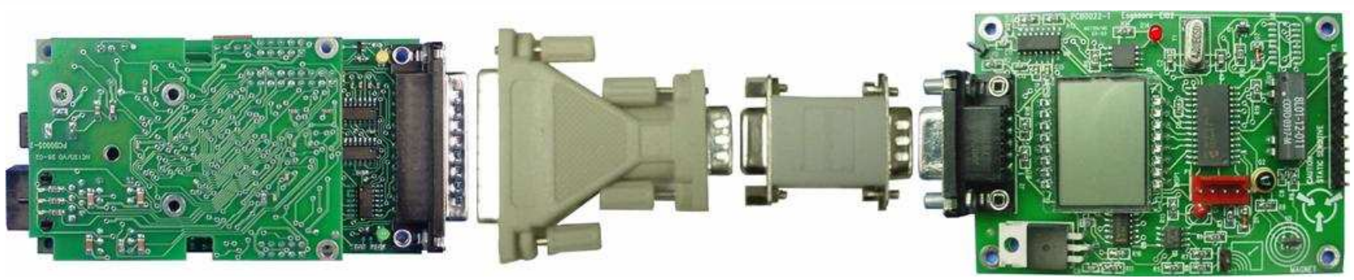
- TEDS data is displayed in hexadecimal form



Prototype TIM and NCAP

- NCAP interfaces to Internet via Ethernet





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

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.

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.

Dot 4 TEDS Writer and Reader

(PC Screens)

Writer

Reader

TIM Tester – Data retrieval

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)