NISTIR 6930

Second Workshop on Wireless Sensing: Proceedings

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Technology Administration
National Institute of Standards and Technology
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NIST

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Second Workshop on Wireless Sensing

Proceedings

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October 4, 2001

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SENSORS

SENSORS EXPO & CONFERENCE 2001

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1 Overview of the Second Wireless Sensing Workshop

The second Workshop on Wireless Sensing was held on October 4, 2001, at the Sensors Expo & Conference at the Philadelphia Convention Center in Philadelphia, PA. The National Institute of Standards and Technology (NIST), SENSORS magazine, Sensors Conference, Institute of Electrical and Electronics Engineers (IEEE) Instrumentation and Measurement Societyís Technical Committee on Sensor Technology (TC-9), and IEEE Sensors Council cosponsored the workshop. NIST is an agency of the U.S. Department of Commerceís Technology Administration. Its mission is to help increase U.S. industry competitiveness through advanced research, standards, and technology collaboration.

Recently, there has been considerable interest from industry and government in applying wireless technology to sensor-based applications. Wireless technology has seen an explosion over the last couple years with the introduction of Bluetooth and higher speed wireless Ethernet. These technologies are moving from the office environment to the industrial plant floor as engineers discover how flexible and easy to use they are.

The Sensor Development and Application Group at NIST has been working with industry and IEEE to establish IEEE 1451, titled ì A Standard for a Smart Transducer Interface for Sensors and Actuatorsî. In response to the industryís interest in wireless sensing, NIST initiated, cosponsored and conducted a workshop in June of 2001. The workshop in June provided NIST with valuable information as to the direction it should take in helping develop a wireless version of IEEE 1451. At the first workshop, it was proposed that a second workshop be held in order to discuss some of the more important issues as well as work on forming a study group for wireless 1451. The second workshop provided a more concentrated format in order to discuss the issues.

The format for the workshop consisted of a meeting of the IEEE 1451.2 committee for the first couple hours and the rest of the day taken up by the wireless sensing workshop. Eighteen people attended the IEEE 1451.2 committee meeting split approximately 4 to 3 to 3 between vendors, users, and government employees respectively. Twenty-three people attended the wireless sensing workshop split approximately 4 to 4 to 2 between vendors, users, and government employees respectively. Overall attendance at the conference was down by over 70% compared with the June 2001 conference. It is assumed that the severe drop in attendance of the second workshop compared to the first is due to the events of September 11th and not due to the lack of interest in the subject matter.

The main purpose of the 1451.2 committee meeting was to review and update any parts of the four-year old standard that the members felt needed updating. The meeting consisted of a series of papers with free discussions during and after the papers. Most of the discussion centered on the Transducer Electronic Data Sheet (TEDS) and how it has become one of the most important components of IEEE 1451. Another main topic discussed was the separation of hardware from software in the standard. Other topics discussed were the industries view of IEEE 1451 and the real-time aspects of the standard.

The major portion of the day was taken up by the second Workshop on Wireless Sensing. The workshop was more structured that the 1451.2 meeting earlier in the day, consisting of a series of presentations and then discussions afterward. Presentations were made on some implementations of IEEE 1451 or wireless technology, Bluetooth, wireless Ethernet (IEEE 802.11), and a standard under development in the IEEE 802.15.4 committee. A summary of the previous workshop and its results was then presented. After which, discussions started as to the direction the group should take in developing a wireless version of IEEE 1451.

As a direct result of this workshop, a working group was formed to begin developing a proposed IEEE 1451.5 wireless standard. As a starting point for the possible standard, one company that attended the workshop offered to provide one of its patents to the group. The working group was then tasked with coming up with a mission and purpose in order to apply for a formal study group through IEEE.

2 Issues & Discussions

2.1 Workshop on IEEE 1451.2 Specification Enhancement

A workshop focused on the enhancement of the specification of the IEEE 1451.2 standard took place before the second workshop on wireless sensing was conducted. Although this group is separate from the wireless sensing group, many of the 1451.2 attendees are concerned about a wireless extension to the 1451 standard and attended the wireless sensing workshop. Eighteen people attended the working group meeting with the distribution being split 44% vendors, 28% users, and 28% government.

With the initial IEEE 1451.2 standard being published four years earlier, the main purpose of this meeting was to review the standard as it is right now and determine if changes should be made and what should be considered. The 1451.2 workshop consisted of a series of presentations and open discussions during and after the presentations.

The Transducer Electronic Data Sheet (TEDS) has emerged as the most important part of the of the IEEE 1451.2 standard thus far. Many companies are trying to implement digital interfaces to their products, and others are trying to incorporate a TEDS-like system, but these are not standardized. Only the TEDS provides a common way for sensors to store calibration and identification information and communicate that over a sensor network. One of the major drawbacks with the TEDS currently is the disharmony between the TEDS of the different dot standards (refers to the IEEE 1451.2, P1451.3, and P1451.4 standards either in place or being developed). The different dot committees and standards have much different requirements and the version of TEDS that each of them uses is somewhat different at this point.

Some users look at IEEE 1451 as an unnecessary layer of abstraction being applied to their sensors and/or sensor networks. The attendees felt that these users need to be shown that IEEE 1451 has benefits that the users might easily overlook. The plug-and-play aspects of the standard and the TEDS need to be promoted more in order to show how they will reduce the upgrade and maintenance costs for the overall sensor system as well as reducing the time for individual sensor installation and configuration. While no formal survey has been conducted, conversations with system integrators and users have indicated that setup and configuration of complex systems can be a major undertaking. With many industrial systems containing hundreds or thousands of sensors, it can take a large amount of time with many mistakes in order to configure each individual sensor, the appropriate drivers, and the sensor parameters into the control system. With IEEE 1451 and specifically TEDS, these times can be greatly reduced and more accurate.

One of the main topics discussed was redefining the 1451.2 standard such that the hardware and software portions were split. The dot2, dot3, and dot4 committees (referring to the 1451.2, 1451.3, and 1451.4 committees or standards) have all been developed in relative seclusion from one another. Even though the groups do have some common members, each standard has a different goal. Therefore, three very different standards addressing different needs to interface sensor, network, and instrument have emerged. IEEE 1451.2 provides interface specification for connecting sensors and microprocessors or networks. P1451.3 specifies interfaces for high-speed distributed systems for reading a large array of sensors. While, P1451.4 defines a set of specifications for connecting sensors and instruments via a very simple 2 to 4 wire interface. A potential confusion could occur because companies might have difficulty in choosing what standard to develop their products. Some efforts are needed to educate the sensor community.

By redefining the standard, the software portions of the dot2, dot3, and dot4 standards would be separated from the hardware portions. The software components of these standards could be made more consistent with less difficulty, especially the model of the transducer and the communications protocol. The hardware portions of the standard would then be separated by the different dot standards. The different dot standards could also include modifications to the software portion as necessary, but would not be required to do so.

The dot3 committee has begun the process of extracting the hardware potion of its standard from the software portion. They are following a modified version of the International Standards Organization (ISO) 7-layer model with fewer layers. This allows the committee to define the standard in a way that allows for it to be split up at some future date with less difficulty than if they hardware and software were integrated. The dot2 committee also feels that this is a good idea, and is going to try and move in that direction.

An additional topic that was brought up in the discussions was the fact that some people might have difficulty understanding the overall purpose of IEEE 1451. Many developers and users feel that IEEE 1451 is just another communications standard, and though it is an interesting idea, will not work for them since there are many other industrial and sensor networks that they may already use. The committee agreed that IEEE 1451 should not be the platform to create a new standard for communications. It should standardize the data model, control model, and electronic data sheets, then provide the tools to map these models over any network or communication protocol. The IEEE 1451 committee and the vendors developing products for 1451 need to make it more clear that the standard is not another communication network, but is a way for sensors to connect to any communication network in a standard way. The standard allows any 1451 compliant device to attach to any network and report its data using a standard method. Any computer or device capable of reading the 1451 "language" can read that data and make use of it.

One last topic mentioned was the term "real-time" needs to be used carefully. To some industries and users, real-time may mean doing full motion audio/video over a network or it may mean reading 1 byte of data at 100 Hz. Most things in the sensor world can be done with a bandwidth of 19.2 kilobits per second (kbps). RS-232 can handle these speeds very well, and still remains a very popular choice for a sensor interface.

2.2 Second Workshop on Wireless Sensing

This workshop was held on October 4, 2001 at the 2001 Fall Sensors Expo & Conference at the Philadelphia Convention Center in Philadelphia, PA. It was a follow on to the first workshop held in Chicago, IL on June 4, 2001. Twenty-three people attended this workshop with a distribution of 39% vendors, 39% users, and 22% government. The second workshop was much smaller than the first workshop, probably due to the tragic events of September 11, 2001 and not to the lack of interest by people in the sensor community.

The workshop consisted of a series of presentations either summarizing material from the first workshop or presenting new material since the first workshop. These presentations were followed by a short discussion of the previous workshop's results and a long discussion on how to go about developing a wireless sensing standard.

2.2.1 Results from first workshop

As part of the previous workshop discussions, the issue of where the wireless communications should be located was brought up. The first workshop provided two places for the wireless communications to be used in the overall sensor system: 1) at the Sensor Transducer Interface Module (STIM) level, and 2) at the Network Capable Application Processor (NCAP) node level. In addition to providing those two examples, the first workshop decided that the second of these was the better of the two. The attendees of the second workshop felt that both cases were valid, and the choice of one over another was more application dependant than one being better in all situations. The two different cases would provide many different requirements for the sensors, including more or less intelligence, power, or cost.

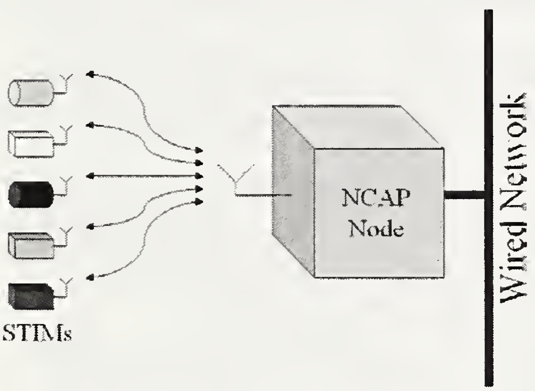

Figure 1 - Wireless STIMs

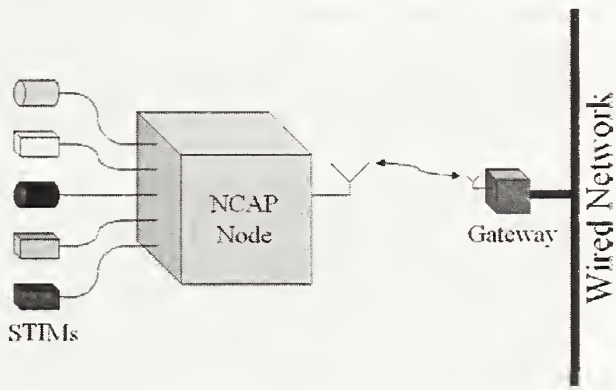

Figure 2 - Wireless NCAP Node

Battery lifetime was also discussed in the results from the first workshop. Some people commented that while 100 mW may wear down a battery during continuous use, reducing the frequency and length of transmission were ways to use 100 mW of power and extend battery lifetime. Using 100 mW of transmission power is useful in many cases where signal noise is encountered. Lower transmission power signals can be swamped by even small amounts of noise in the area. By using 100 mW, the signal can be blasted through some noise and received at greater distances.

The attendees felt that the wireless standard should be defined such that the hardware component of the standard should be removed from the software component. This view is similar to the discussion held at the IEEE 1451.2 meeting earlier in the day, in which the standards would be separated on their hardware portions, and would not include a software component unless necessary. Additional examples were given with respect to the IEEE 802 committee and specifically the 802.11 (wireless Ethernet) and 802.15 (Bluetooth-related) subcommittees.

2.2.2 Second Workshop Discussions

Based the first and second workshop, it appears that a wireless sensor standard is something that the sensor industry would like to see. It would provide wireless sensor interoperability, easier wireless sensor upgrades, plug-and-play capability, scalability, and lower overall cost for the wireless sensor network. These benefits would not only be for the end user of the product, but also to system integrators who would not have to work with a multitude of de-facto or somewhat related standards to develop their products. IEEE 1451 will serve as the basis for this new standard, but there will be enough differences between the current versions of the standard and the possible requirements of a wireless version that it will justify adding a new dot standard to the 1451 family. The new standard will incorporate existing wireless communication standards in order to speed up the development time, but this will also add additional complexity to the overall design. Different technologies will be reviewed for their appropriateness and capabilities for this particular application.

While TEDS-like enabled products have been available from sensor manufacturers for some time, IEEE 1451 TEDS is still in its infancy. Some IEEE 1451.2-based products have been developed with this capability, but they havenít been widely implemented in the market. The group felt that it would be a good idea for the IEEE 1451.2 committee to look into separating out the TEDS portion of the standard in order to gain wider acceptance. This would also allow for better development of the wireless standard since the TEDS would not have to be redefined for the wireless standard, just modified with a part dedicated to the wireless communications.

One of the participants in these discussions, a company named Axxon, is a vendor with a long history of developing wireless sensors. Axxon believed that developing this standard would not reduce their marketability, as some vendors may believe, but would actually increase their profitability. Axxon would be able to spend less time and effort developing new communications protocols and electronics for new applications, speeding up their overall time-to-market for new products. Axxon is willing to release one of their patents to the committee in order to develop a wireless sensor standard quicker than developing one from scratch. They would have to discuss the issue with their legal department, however, there did not seem to be any issues as the discussions were taking place.

After Axxon offered to release one of their patents, this sparked a discussion of patent law and the legal ramifications of such an action. Some of the participants brought up the point that Axxon would not have to freely distribute the patent without expecting any compensation. They could release the patent with the expectation of royalties or some sort of licensing fee. Axxon will have to make a decision on this before releasing the patent to the committee. Care must be taken to avoid any legal problem when developing a standard based on any patent not to exclude or require any particular companies from the standard.

After it appeared that the substantive discussions were winding down, the issue of forming the working group under the IEEE 1451 committee was undertaken. Although all the people that attended the meeting were interested in the wireless smart sensors standard, some of the participants were already involved in other committees and could not spare the time to be part of this group. A meeting of the IEEE PAR (Project Authorization Request) review board will be held on December 15th, and this group will need to put together its plan forty days prior to this meeting. Until the time when the PAR committee officially approves the formation of a working group on this subject, Kang Lee of NIST, the Chair of the Sensor Technology Technical Committee, will initiate a study group. Steven Chen of 3e Technology Inc. was proposed to be the head of this study group.

While it may be good for the committee to look at a wide range of technologies and applications in its research, the scope of the working group should be limited in order to make it feasible to develop a standard in a reasonable amount of time. By including too many members from too wide a range of applications, the group may run into to trouble of the extremely different requirements of the various applications. Industries like security tags and RFIDs would seem to be applicable to a wireless sensor standard; they have many different requirements that require them to be excluded from the planned committee distribution. It will be important for the group to maintain ties with both the IEEE 802.11 and 802.15 committees, though. These two standards have been discussed as possible physical layers for the wireless smart sensor standard, and this study group will need to keep abreast of the status of those standards committees. Data synchronization was an issue that was briefly discussed. Kang Lee pointed out that the IEEE P1588 working group is developing a proposed ì Standard for Precise Clock Synchronization in Networked Measurement and Control Systemsî to address this issue.

The study group will need to provide a timeframe for developing this standard to the PAR review board as part of its application. A year may be too short to develop the wireless standard, but the time should be limited in order to promote current technology in the standard. All committee efforts take longer than initially expected, so that should also be taken into account when writing up the application. Axxon was asked to provide a strawman for a standard to the group members in order to begin the process of developing the standard. This allows the group to work from a starting point, and can usually speed up the process considerably. Other sensor vendors and chip manufacturers will need to be included in this group as well. Without the development resources of sensor vendors and chipmakers, it will be unlikely that the standard will gain wide acceptance. It would take vendors a long period of time to ramp up development for the particular standard if they adopted it at all.

The workshop broke up well after the scheduled time with the participants feeling that the standard could and should be developed. The group planned to work quickly over the next couple weeks in order to file the application for the IEEE working group. There was no planned follow-up workshop now that the group planned on actually developing the standard through the IEEE process.

3 Presentations from "Enhancement of IEEE 1451.2, A Smart Transducer Interface Standard"

3.1 A Standard Smart Transducer Interface - IEEE 1451

Smart Transducer Interface Standard - IEEE 1451

A Standard Smart Transducer Interface
- IEEE 1451

Robert Johnson, Telemonitor, Inc.
Kang Lee, NIST
James Wiczer, Sensor Synergy, Inc.
Stan Woods, Agilent Technologies, Inc.

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Smart Transducer Interface Standard - IEEE 1451

Agenda

- Measurement and control systems
- Smart transducers
- Introduction to IEEE 1451
- Benefits of the 1451 standard
- Contacts for further information

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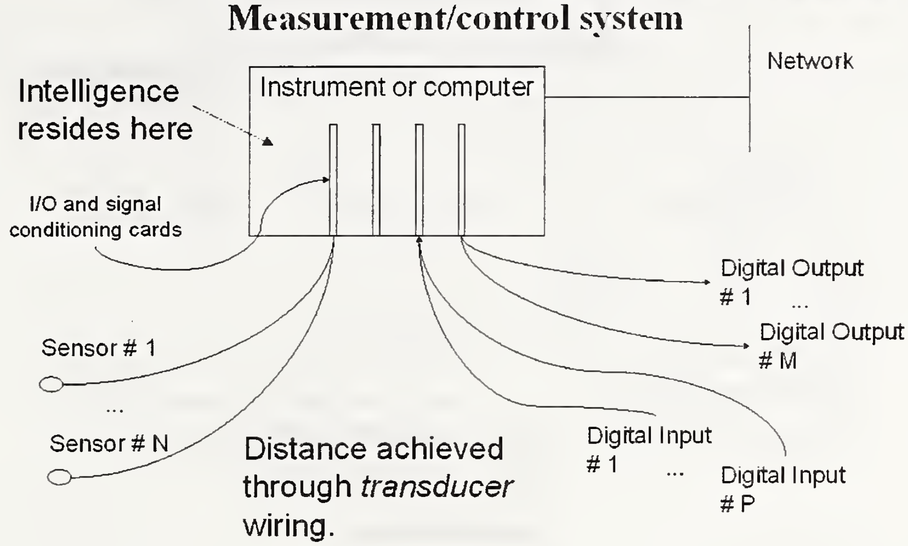
Smart Transducer Interface Standard - IEEE 1451

Measurement/control system



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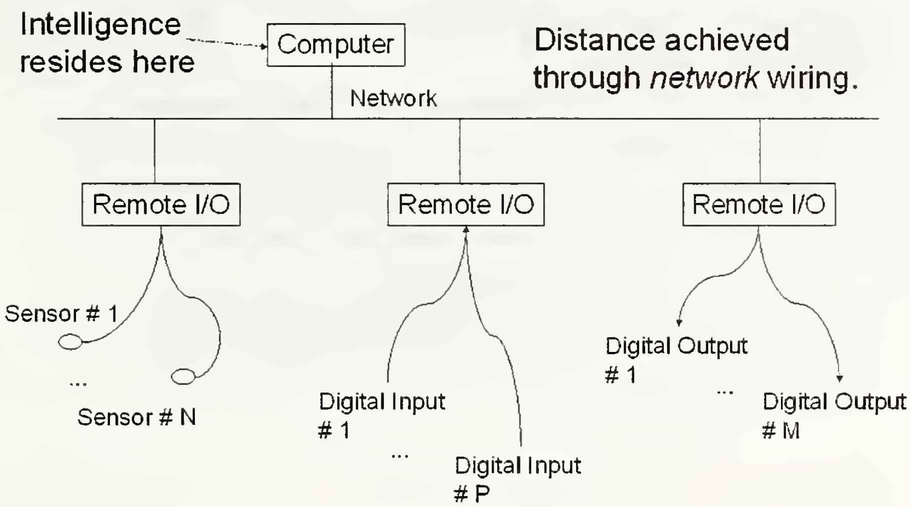
Smart Transducer Interface Standard - IEEE 1451

Distributed measurement/control system



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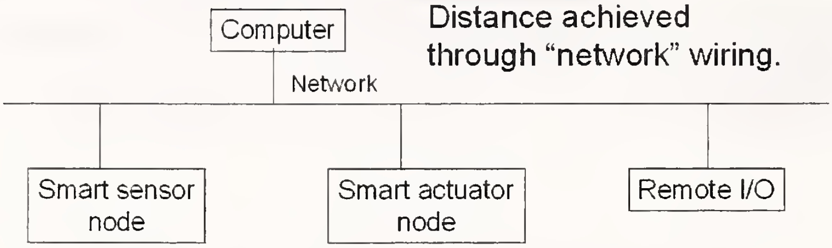
Smart Transducer Interface Standard - IEEE 1451

Distributed smart sensor/actuator system

Distance achieved through "network" wiring.



Intelligence is distributed; role of computer changes.

However:
smart nodes are still network and transducer specific with vendor specific data and control models.

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Smart Transducer Interface Standard - IEEE 1451

Main goals for 1451

- Develop network independent and vendor independent transducer interfaces.
- Allow transducers to be replaced/moved with minimum effort.
- Eliminate error prone, manual system configuration steps.
- Support a general transducer data, control, timing, configuration and calibration model.
- Develop Transducer Electronic Data Sheets that remain together with the transducer during normal operation.

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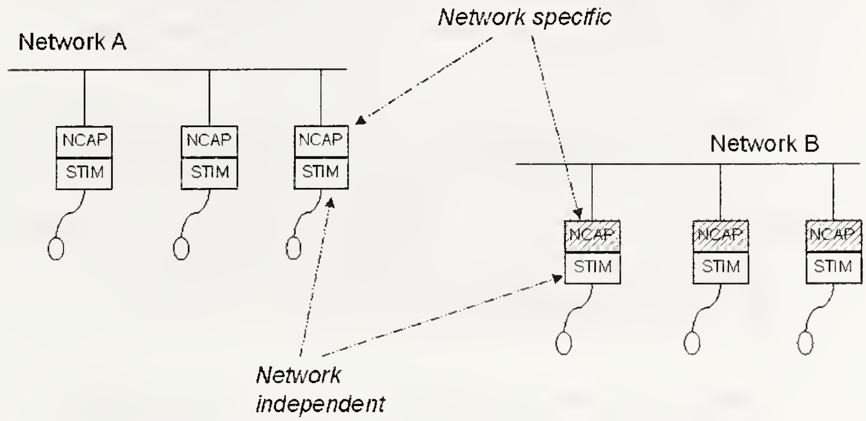
Smart Transducer Interface Standard - IEEE 1451

Network independent transducers



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Smart Transducer Interface Standard - IEEE 1451

Desirable functions in sensors that provide "smarts"

- Self-identification, self-diagnostic.
- Output digital data in standard engineering units.
- "Time aware" for timestamping and correlation
- Software functions, e.g.:
  - signal processing and data logging
  - measurements derived from multi-channels
- Conforming to a standard data and control protocol

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Smart Transducer Interface Standard - IEEE 1451

What standards are being developed ?

- **IEEE Std 1451.1-1999,** Network Capable Application Processor (NCAP) Information Model for smart transducers -- Published standard.
- **IEEE Std 1451.2-1997,** Transducer to Microprocessor Communication Protocols and Transducer Electronic Data Sheet (TEDS) Formats -- Published standard.
- **IEEE P1451.3,** Digital Communication and Transducer Electronic Data Sheet (TEDS) Formats for Distributed Multidrop Systems -- Being developed
- **IEEE P1451.4,** Mixed-mode Communication Protocols and Transducer Electronic Data Sheet (TEDS) Formats --- Being developed

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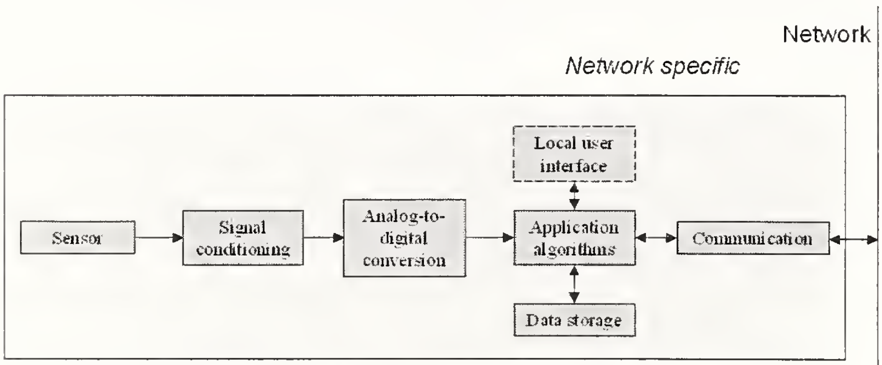
Smart Transducer Interface Standard - IEEE 1451

A general model of a smart sensor



Some points regarding "smart":
- Moving intelligence closer to the point of measurement/control.
- Confluence of transducers, computation and communication towards common goal.
- Goal: make it cost effective to integrate/maintain distributed systems.

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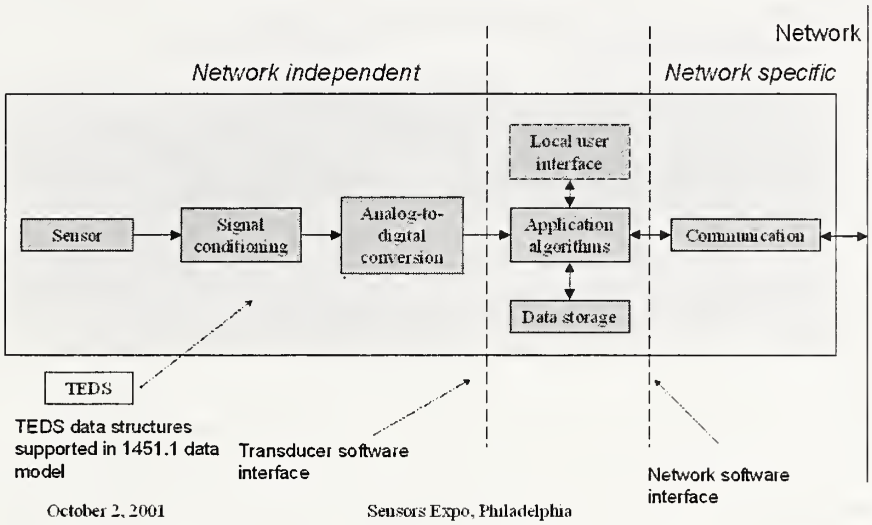
Smart Transducer Interface Standard - IEEE 1451

1451.1 partition of general model



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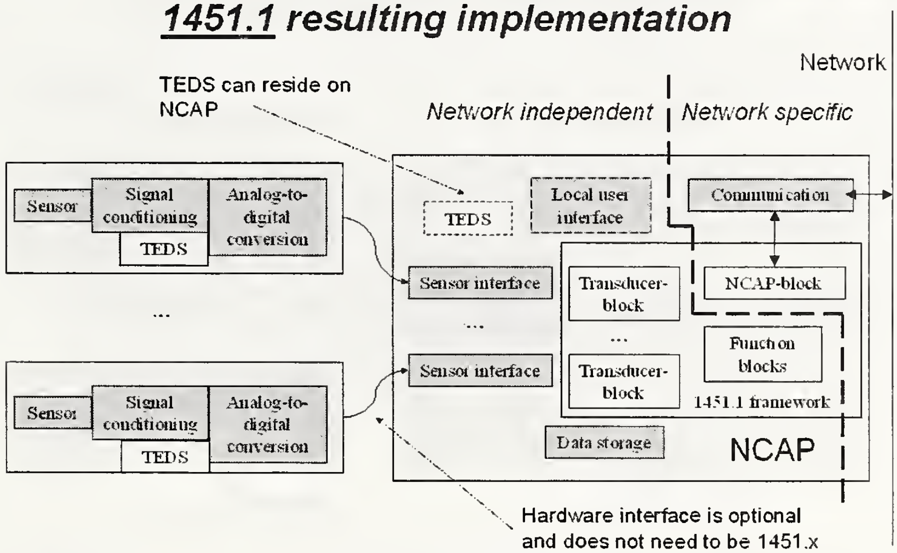
Smart Transducer Interface Standard - IEEE 1451

1451.1 resulting implementation



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Smart Transducer Interface Standard - IEEE 1451

IEEE Std 1451.1-1999 distinguishing features

- Common object model can be used with multiple networking protocols.
- Uniform models for key functions needed in smart transducers including physical parametric data, application functionality and communication.
- Framework is defined to help create smart transducers.

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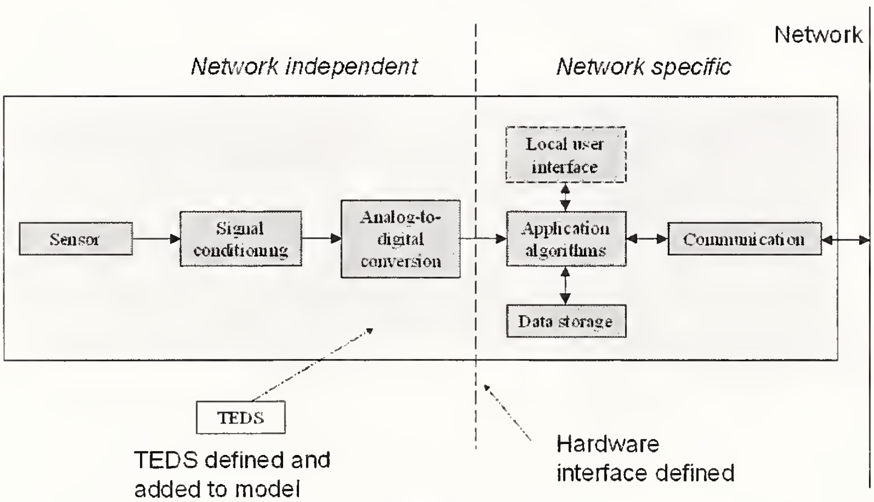
Smart Transducer Interface Standard - IEEE 1451

1451.2 partition of general model



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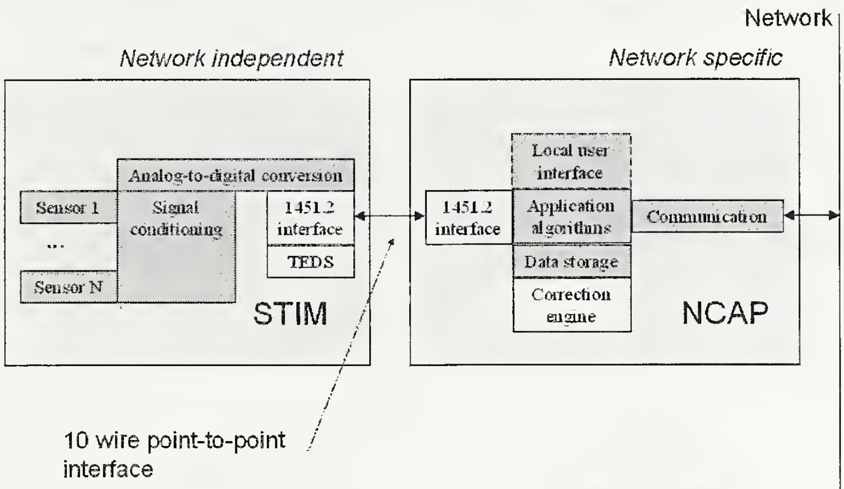
Smart Transducer Interface Standard - IEEE 1451

1451.2 resulting implementation



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Smart Transducer Interface Standard - IEEE 1451

IEEE Std 1451.2-1997 distinguishing features

- Extensible Transducer Electronic Data Sheet (TEDS)
- General calibration/correction model for transducers.
- Physical units representation based on SI units.
- Triggering and control model defines how channels are accessed.
- All channels may be triggered simultaneously, timing parameters are used to indicate channel differences.
- Models for different kinds of sensors
- Powerful concept of correction engine and flexible location of correction engine.

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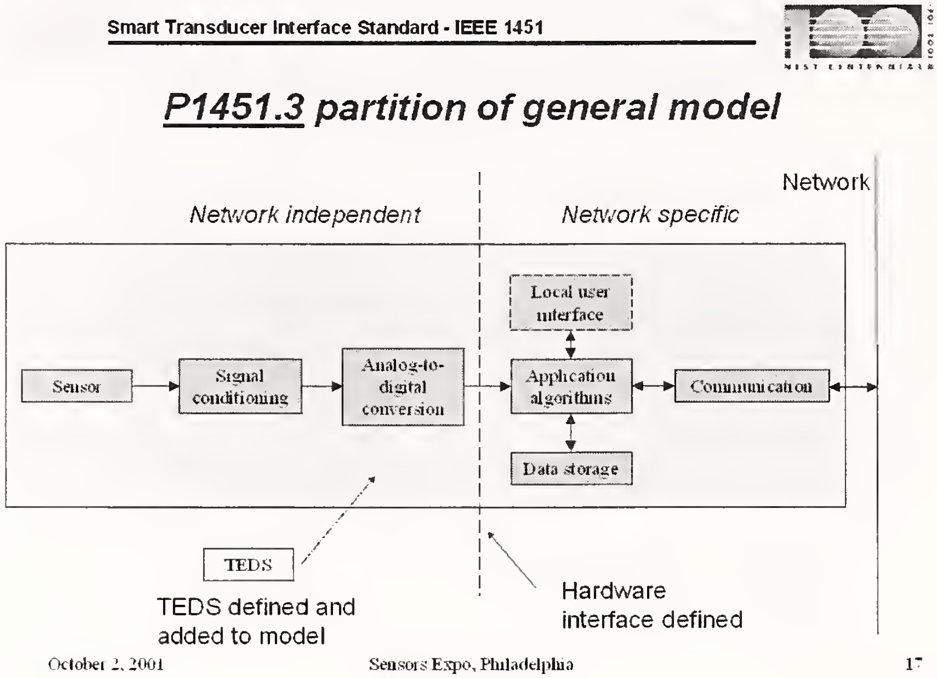
Smart Transducer Interface Standard - IEEE 1451
P1451.3 partition of general model
Network
Network independent
Network specific
Local user interface
Sensor
Signal conditioning
Analog-to-digital conversion
Application algorithms
Communication
Data storage
TEDS
TEDS defined and added to model
Hardware interface defined
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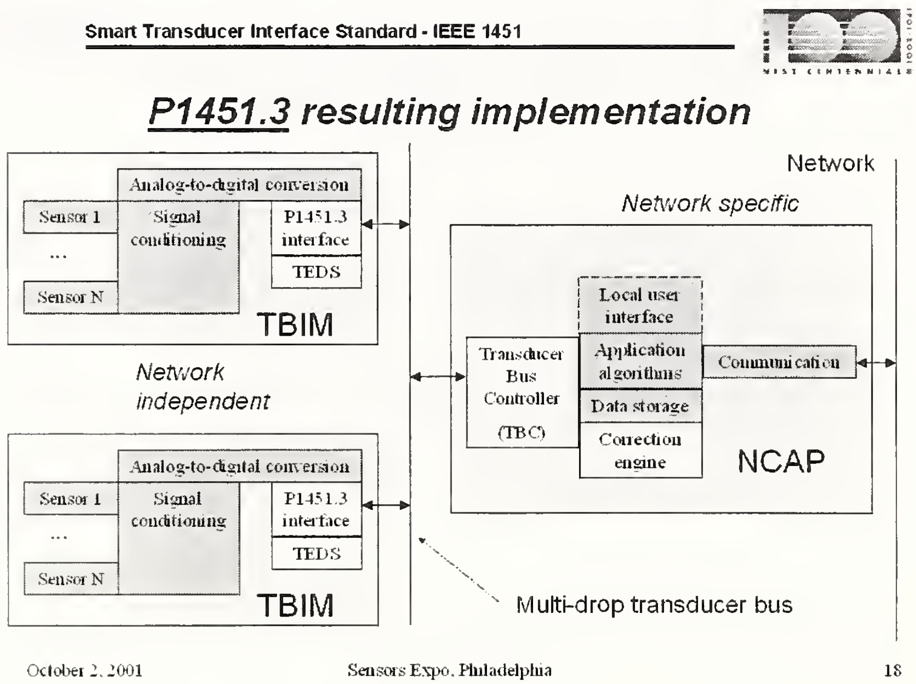
Smart Transducer Interface Standard - IEEE 1451
P1451.3 resulting implementation
Network
Network specific
Analog-to-digital conversion
Sensor 1
Signal conditioning
P1451.3 interface
TEDS
Sensor N
TBIM
Local user interface
Transducer Bus Controller (TBC)
Application algorithms
Communication
Data storage
Correction engine
NCAP
Network independent
Analog-to-digital conversion
Sensor 1
Signal conditioning
P1451.3 interface
TEDS
Sensor N
TBIM
Multi-drop transducer bus
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Smart Transducer Interface Standard - IEEE 1451

IEEE P1451.3 distinguishing features

- Multi-drop, high speed interface permits continuous streaming of data to host.
- Similar to 1451.2 in terms of TEDS, calibration/correction model, triggering/control model, data models.
- TEDS enhanced with new features such as XML format, more actuator models.
- Synchronized measurements at the Transducer Bus Interface Module (TBIM).

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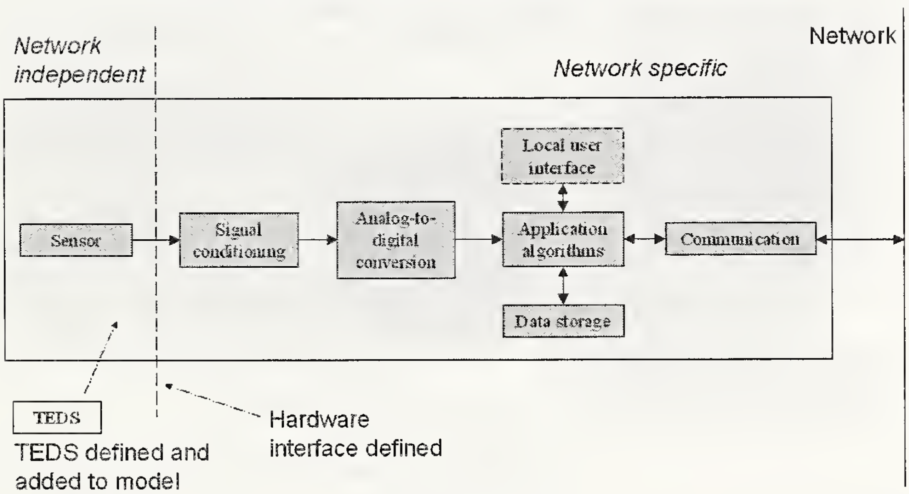
Smart Transducer Interface Standard - IEEE 1451

P1451.4 partition of general model



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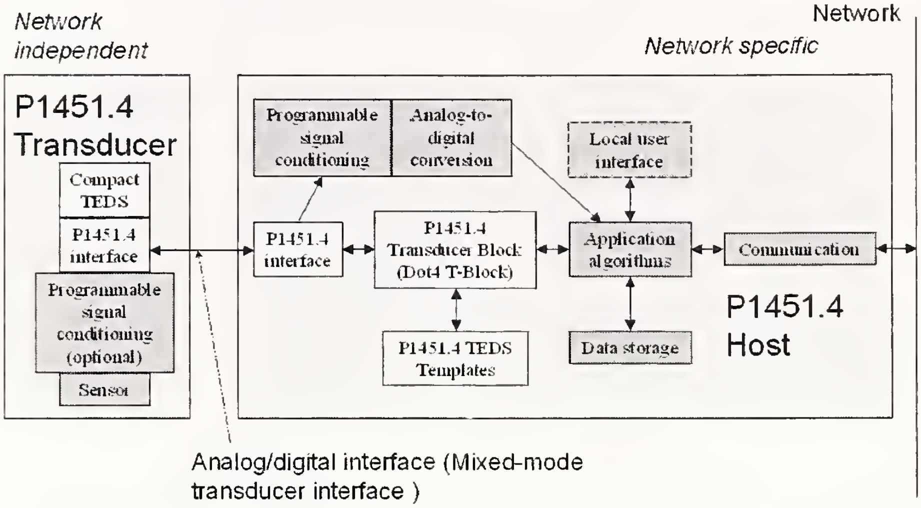
Smart Transducer Interface Standard - IEEE 1451

P1451.4 resulting implementation



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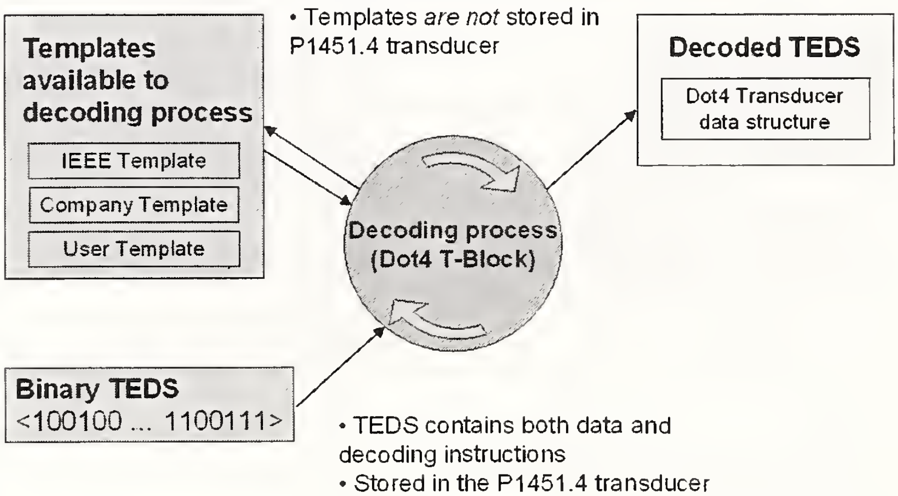
Smart Transducer Interface Standard - IEEE 1451

Decoding a P1451.4 TEDS



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Smart Transducer Interface Standard - IEEE 1451

IEEE P1451.4 distinguishing features

- Compact TEDS is very small, sized in *bits* (as small as 67 bits, typically 256 bits), *not bytes.*
- TEDS plus Templates permits extensible self-identification of key transducer parameters.
- Mixed mode interface:
  - Digital interface to read and write the TEDS or control the transducer. For example: adjust pre-amplifier gain, change filter setting, start self-test.
  - Analog interface to make measurements in normal manner.

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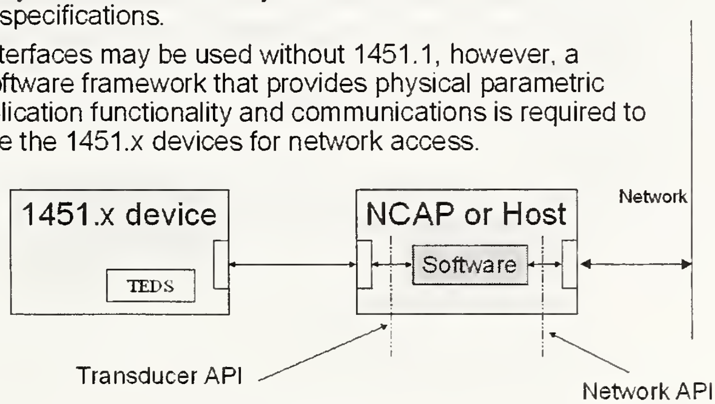
Smart Transducer Interface Standard - IEEE 1451

Relationship between 1451 standards

- The 1451 standards are being developed to work together, however they also stand on their own.
- 1451.1 may be used without any of the other 1451.x hardware interface specifications.
- 1451.x interfaces may be used without 1451.1, however, a similar software framework that provides physical parametric data, application functionality and communications is required to fully utilize the 1451.x devices for network access.



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Smart Transducer Interface Standard - IEEE 1451

Benefits from 1451

Sensor manufacturers

- Multiple products may be developed just by changing the TEDS.
- Standard physical interfaces
- Standard calibration specification

System integrators

- Self-documenting hardware and software
- Systems that are easier to maintain
- Rapid transducer replacement
- Mechanism to store installation details

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Smart Transducer Interface Standard - IEEE 1451

Benefits from 1451 (continued)

Application software programmers

- Standard transducer model for control and data
- Same model for accessing a wide variety of measurements
- "Hooks" for synchronization, exceptions, simultaneous sampling
- Support for multiple languages

End users

- Sensors that are easier to use; "you just plug them in".
- Analysis software that can automatically provide:
  - physical units
  - readings with significant digits
  - transducer specifications
  - installation details such as physical location and ID of transducer

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Smart Transducer Interface Standard - IEEE 1451

For more information

1451 standard	Contact	Telephone	Email
IEEE P1451	Kang Lee	301-975-6604	kang.lee@nist.gov
IEEE 1451.1	Jay Warrior	650-485-2086	Jay_Warrior@agilent.com
IEEE 1451.2	Stan Woods	650-485-5067	Stan_Woods@agilent.com
IEEE P1451.3	Larry Malchodi	206-655-5695	larry.a.malchodi@boeing.com
IEEE P1451.4	Torben Licht	+45 77412313 Denmark	TRLICHT@bk.dk

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3.2 Key Technical Features of IEEE Std 1451.2-1997

Smart Transducer Interface Standard - IEEE 1451

Key technical features of IEEE Std 1451.2-1997

Stan Woods

Agilent Technologies
October 4, 2001

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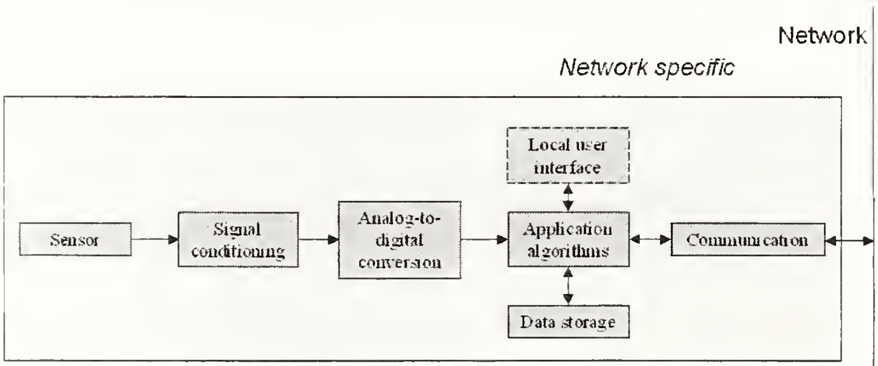
Smart Transducer Interface Standard - IEEE 1451

A general model of a smart sensor



Some points regarding "smart":
- Moving intelligence closer to the point of measurement/control.
- Confluence of transducers, computation and communication towards common goal.
- Goal: make it cost effective to integrate/maintain distributed systems.

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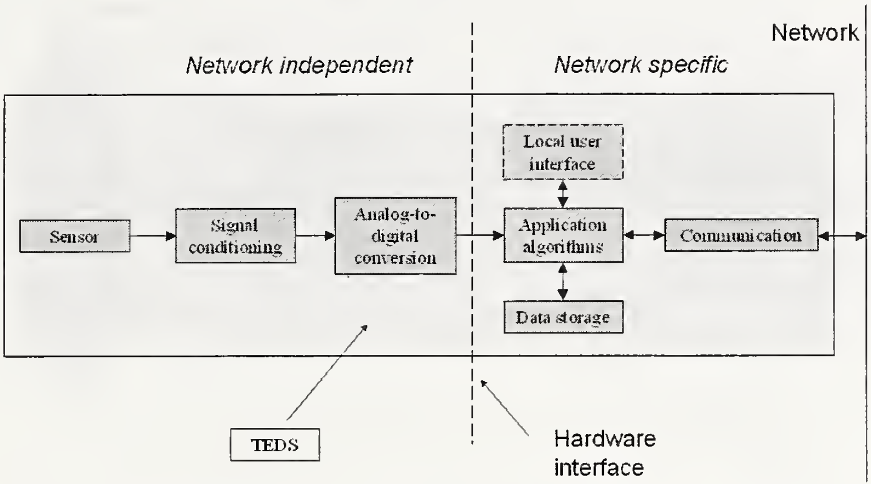
Smart Transducer Interface Standard - IEEE 1451

1451.2 partition



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Smart Transducer Interface Standard - IEEE 1451

IEEE Std 1451.2-1997 distinguishing features

- Extensible Transducer Electronic Data Sheet (TEDS)
- General calibration/correction model for transducers.
- Physical units representation based on SI units.
- Triggering and control model defines how channels are accessed.
- All channels may be triggered simultaneously, timing parameters are used to indicate channel differences.
- Models for different kinds of sensors
- Powerful concept/location of correction engine allows flexibility in system design.

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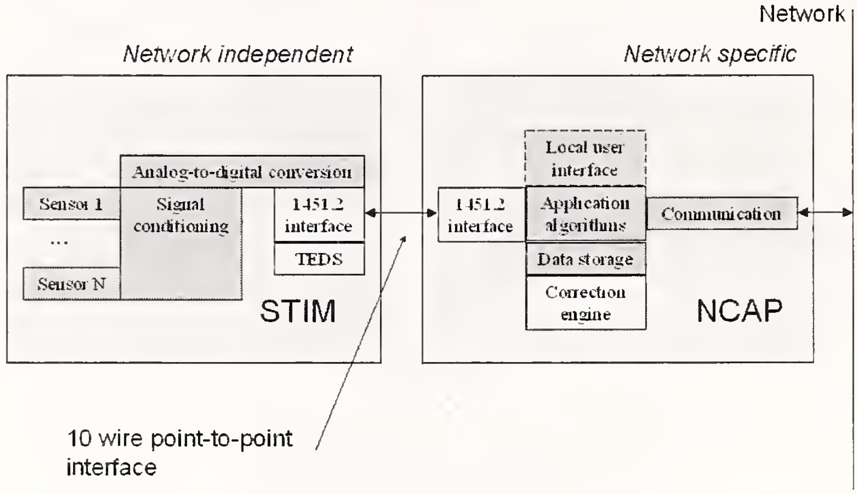
Smart Transducer Interface Standard - IEEE 1451

1451.2 smart sensor model



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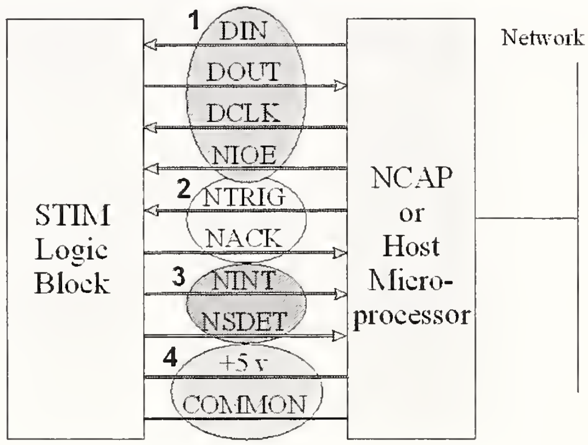
Smart Transducer Interface Standard - IEEE 1451

1451.2 hardware interface

1) Communication
2) Triggering/handshaking
3) Interrupts and hot swap
4) Power



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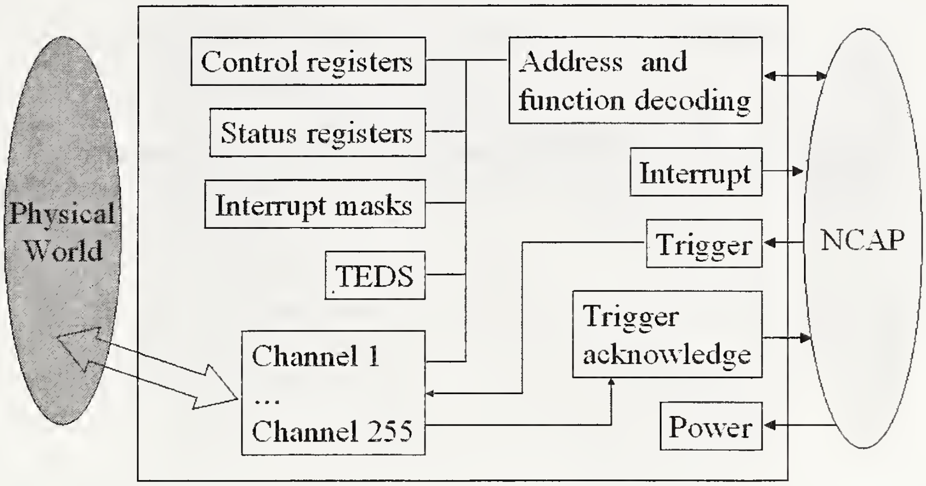
Smart Transducer Interface Standard - IEEE 1451

STIM control/data model



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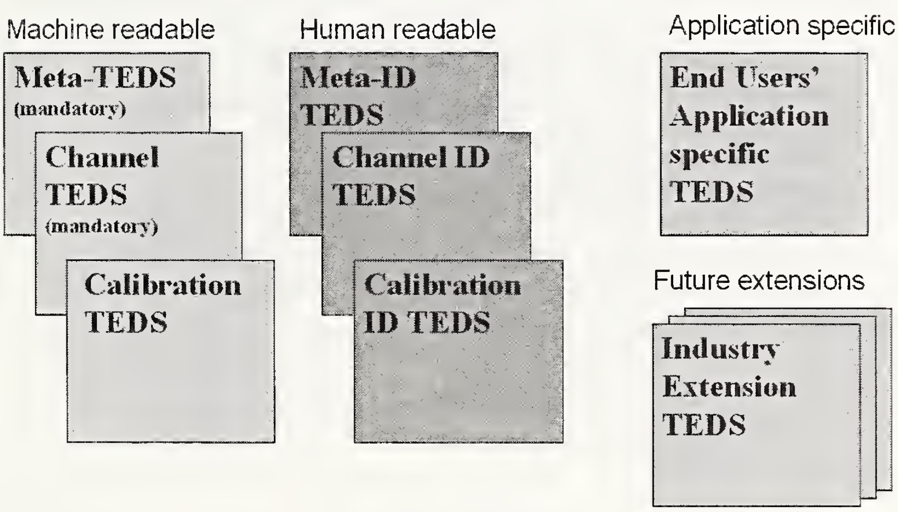
Smart Transducer Interface Standard - IEEE 1451

1451.2 TEDS blocks



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Smart Transducer Interface Standard - IEEE 1451

System issues addressed by 1451.2 architecture

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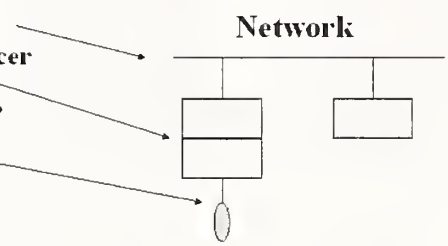
Smart Transducer Interface Standard - IEEE 1451

1451.2 Architecture

- **Distance is achieved with the network**
- **Plug and play at the transducer level with short distance interface (or hidden if NCAP and STIM are integrated).**
- **Last few feet achieved with analog wiring.**



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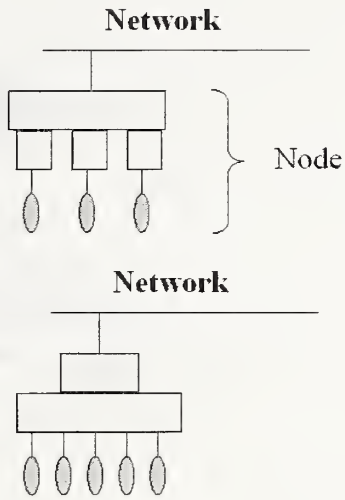
Smart Transducer Interface Standard - IEEE 1451

Node Design Tradeoffs

- **Big NCAP and little STIMs:**
  e.g. NCAPs with multiple 1451.2 ports.
- **Little NCAP and big STIMs:**
  e.g. STIMs with many channels.
- **Scalability**
  - type of network
  - processing power
  - type of processor
  - number of channels
  - types of sensors and actuators
  - hardware interface speed
  - connectors or PCB traces



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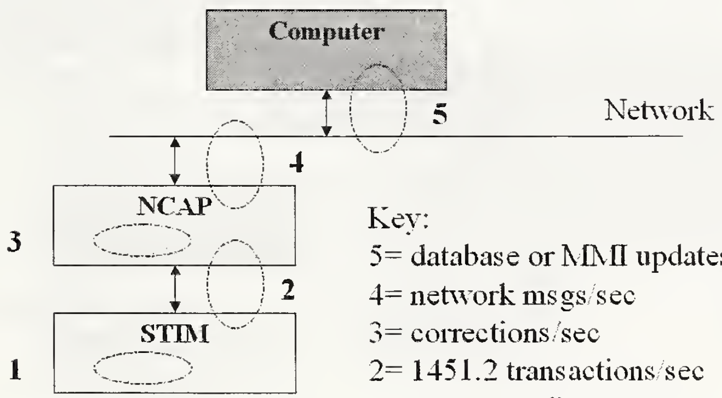
Smart Transducer Interface Standard - IEEE 1451

System performance issues



Key:
5= database or MMI updates/sec
4= network msgs/sec
3= corrections/sec
2= 1451.2 transactions/sec
1= sensor readings/sec

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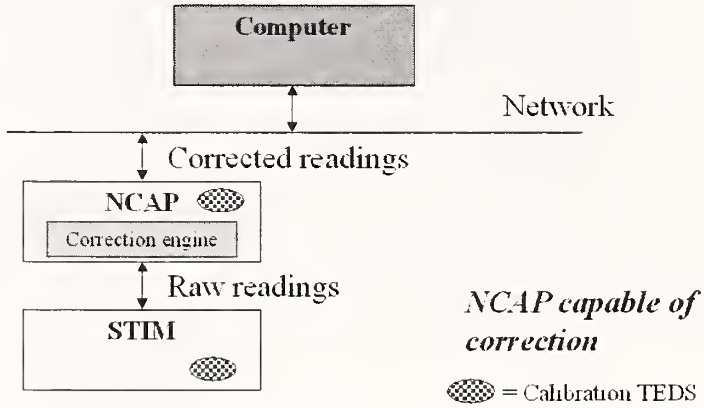
Smart Transducer Interface Standard - IEEE 1451

1451.2 correction engine in the NCAP



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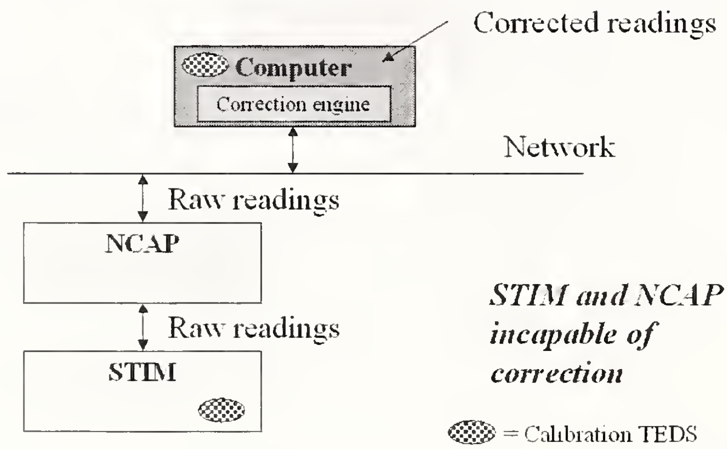
Smart Transducer Interface Standard - IEEE 1451

1451.2 correction engine "elsewhere" in the system



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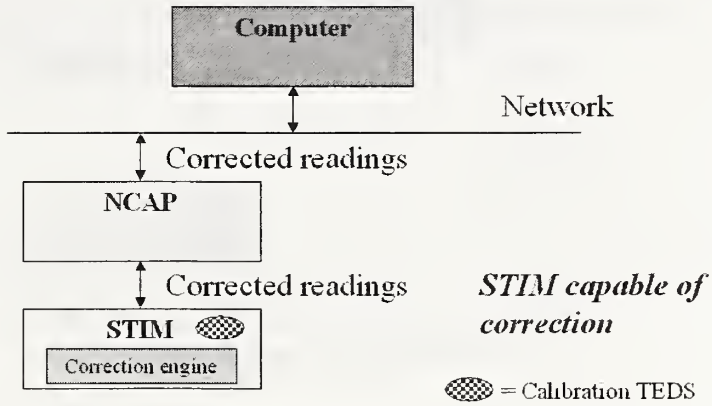
Smart Transducer Interface Standard - IEEE 1451

1451.2 correction engine in the STIM



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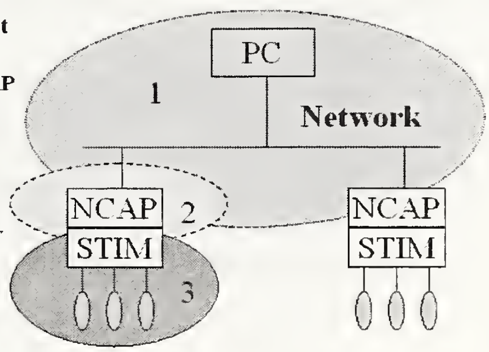
Smart Transducer Interface Standard - IEEE 1451

Measurement/control loops

- With the network / 1451.2 architecture there are three loops which may be used for measurement and control.
  - 1) Control by layers above the NCAP
  - 2) NCAP-based control of STIM channels
  - 3) Control done within a STIM
- Control may be:
  - Client/server (poll/set, 'pull', tightly coupled)
  - Publish/subscribe ('push', loosely coupled)



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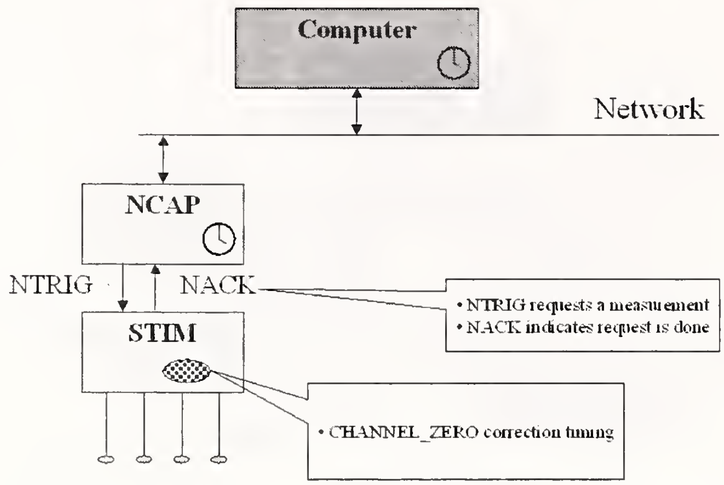
Smart Transducer Interface Standard - IEEE 1451

Synchronization



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Smart Transducer Interface Standard - IEEE 1451

Next steps

- **Consider changes to:**
  - **TEDS**
  - **Data/control model**
  - **Hardware interface**
- **The following presentations will provide perspectives on the implementation of 1451.2 and more information on proposed changes.**

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3.3 Proposed Enhancements to the IEEE 1451.2 Standard for Smart Transducers

Proposed Enhancements to the IEEE 1451.2 Standard for Smart Transducers

Robert N. Johnson, Telemonitor, Inc.
Stan Woods, Agilent Technologies, Inc.

October 2, 2001

Introduction

- General benefits of smart sensors and of IEEE 1451.2 have been discussed in the previous presentations
- IEEE 1451.2-1997 was approved in September, 1997
- Defined terms and established basic principles of smart transducers and communications with transducers
- Received wide praise for technical accomplishments but has not enjoyed wide use
- Due for five-year review and vote on renewal next year
- This paper will discuss requested changes and proposed enhancements
- Workshop October 4, 2001 to discuss this in more detail
- Please attend the workshop! We want your feedback and support

Smart Transducer Interface Standard - IEEE 1451

What is a smart sensor?

- Several definitions of smart sensor; we will use the one from IEEE 1451.2-1997
- A Smart Transducer is "A transducer that provides functions beyond those necessary for generating a correct representation of a sensed or controlled quantity. This functionality typically simplifies the integration of the transducer into applications in a networked environment."
- A Smart Sensor is "A sensor version of a smart transducer."
- Key concept: A smart sensor adds value to the data to enable or support distributed processing and decision making

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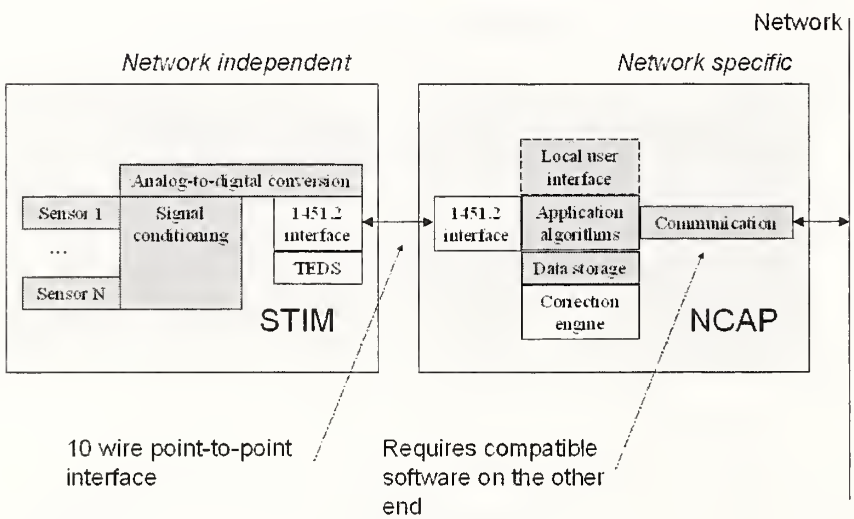
Smart Transducer Interface Standard - IEEE 1451

IEEE 1451.2 smart sensor model



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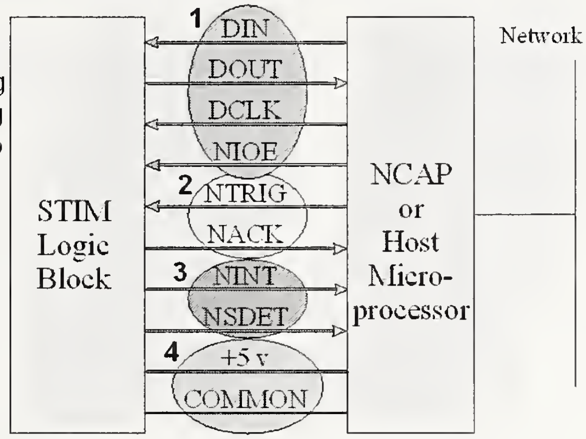
Smart Transducer Interface Standard - IEEE 1451

IEEE 1451.2 hardware interface

1) Communication/framing
2) Triggering/handshaking
3) Interrupts and hot swap
4) Power



Intended for closely
-coupled systems

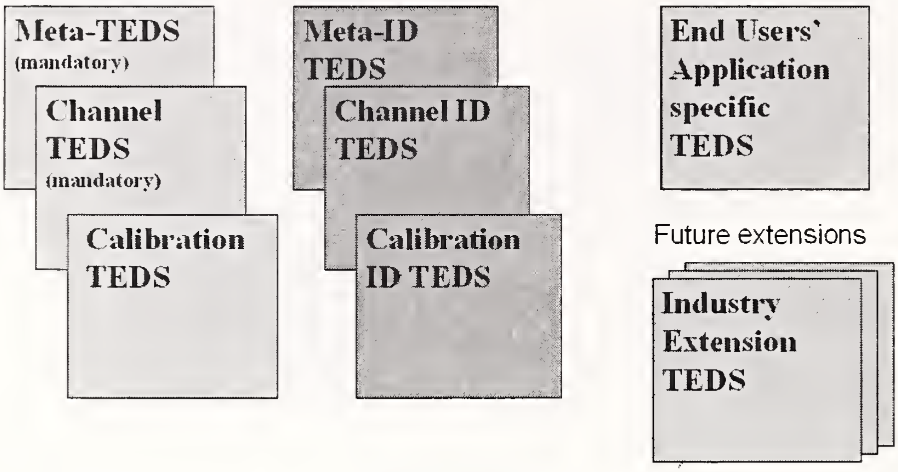
Smart Transducer Interface Standard - IEEE 1451

IEEE 1451.2-1997 valuable features

- Extensible Transducer Electronic Data Sheet (TEDS)
- General calibration/correction model for transducers
- Physical units representation based on SI units
- Triggering and control model defines how channels are accessed
- All channels may be triggered simultaneously, timing parameters are used to indicate channel differences
- Models for different kinds of sensors
- Powerful concept/location of correction engine allows flexibility in system design

Smart Transducer Interface Standard - IEEE 1451

IEEE 1451.2 TEDS blocks



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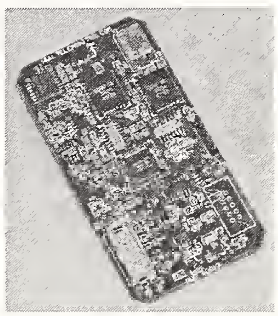
Smart Transducer Interface Standard - IEEE 1451

Power of TEDS plus correction engine

Multi-channel acceleration/tilt sensor:

- Hardware channels for temperature and acceleration
- Correction engine performs temperature compensation
- Virtual actuators for zero correction
- Virtual sensors for tilt (roll and pitch)
- Correction engine converts to angle
- Number order of channels is important



Data Channels

No.	Property	Type	Units	Minimum	Maximum
1	Temperature	Sensor	K	233 15 (-40° C)	358.15 (85° C)
2	Roll Zero	Actuator	radians	-1.57 (-90°)	1.57 (90°)
3	Pitch Zero	Actuator	radians	-1.57 (-90°)	1.57 (90°)
4	Roll Zero	Sensor	radians	-1 57 (-90°)	1 57 (90°)
5	Pitch Zero	Sensor	radians	-1.57 (-90°)	1.57 (90°)
6	X Acceleration	Sensor	m/s^2	-19.6 (-2 g)	19.6 (2 g)
7	Y Acceleration	Sensor	m/s^2	-19 6 (-2 g)	19.6 (2 g)
8	Roll (about X)	Sensor	radians	-1.31 (-75°)	1.31 (75°)
9	Pitch (about Y)	Sensor	radians	-1.31 (-75°)	1.31 (75°)

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Smart Transducer Interface Standard - IEEE 1451

Most requested changes to IEEE 1451.2

- Make it easier to understand and implement
- Make the hardware interface faster
- Use less wires
- Pick a standard connector
- Provide for electrical isolation
- Allow real-time reconfiguration
- Add frequency response to TEDS and correction engine
- Make NCAPs readily available and compatible with existing systems
- Don't add unnecessary expense to simple transducers
- Add security, timestamps, data logging, etc.

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Smart Transducer Interface Standard - IEEE 1451

Most requested changes, con't.

- Make it easier to understand and implement
  - New, broad-reaching standard
  - Wide adoption will produce user guides, books, etc.
  - Not everyone must understand the details
  - OEMs can convert raw transducers to STIMs without having to design signal conditioning and conversion
- Make the hardware interface faster
  - Minimum of 6,000 bit/s supports inexpensive hardware
  - Maximum not specified; several million bit/s has been demonstrated
  - Digital interface may not be appropriate for all applications (*e.g.* IEEE P1451.4)

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Smart Transducer Interface Standard - IEEE 1451

Most requested changes, con't.

- Use less wires
  - Originally for single close-coupled transducer to microprocessor
  - Based on SPI with hardware handshaking
  - Supports synchronized trigger and data acquisition
  - Simpler interfaces are appropriate for some uses
- Pick a standard connector
  - Connectors are very application-dependent
  - Started defining connectors for some applications
  - Alternate physical layers may include connectors
  - True "plug-and-play" requires connector definition

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Smart Transducer Interface Standard - IEEE 1451

Most requested changes, con't.

- Provide for electrical isolation
  - Isolation less of an issue for close-coupled system
  - Using existing standard physical layers will help
- Allow real-time reconfiguration
  - STIM cannot tell NCAP that the TEDS has changed
  - No standard mechanism for selectable gain, sample rate, number of samples, etc.
- Add frequency response to TEDS and correction engine
  - Standard provides for extensions to TEDS but not to correction engine

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Smart Transducer Interface Standard - IEEE 1451

Most requested changes, con't.

- Make NCAPs readily available and compatible with existing systems
  - Standard visualizes complete system including STIMs, NCAPs, network-level software
  - Need growth path to bring benefits of IEEE 1451 to existing systems
- Don't add unnecessary expense to simple transducers
  - Target is applications where interchangeable communicating smart transducers add value
  - Some applications are too cost-sensitive
  - Line between the two will shift over time

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Smart Transducer Interface Standard - IEEE 1451

Most requested changes, con't.

- Add security, timestamps, data logging, etc.
  - Originally viewed as higher-level functions
  - Appropriate to consider for proposed enhancements
  - Will depend on the interests of the people who participate in the working group
  - Must avoid "rampant featuritis!"

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Smart Transducer Interface Standard - IEEE 1451

Proposed enhancements to IEEE 1451.2

- Primary enhancements:
  - Partition the TEDS
  - Alternative physical layers
  - Partition the standard
- Secondary enhancements:
  - Enhance the TEDS
  - Add functions
  - Standalone function
  - Corrections and additions

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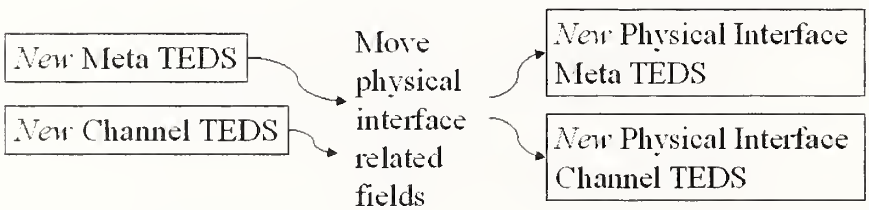
Smart Transducer Interface Standard - IEEE 1451

Partition the TEDS



Meta-ID TEDS

Channel-ID TEDS

⋮

Other TEDS blocks can remain the same.

Supports use of different physical layers.

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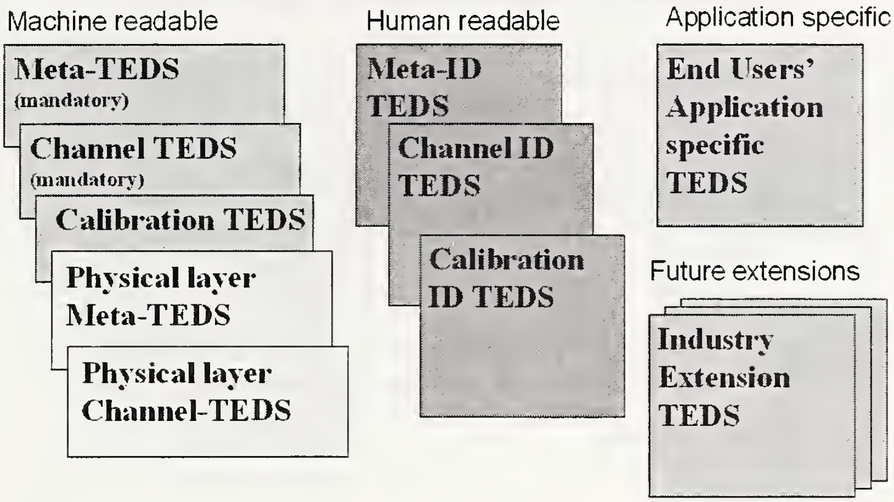
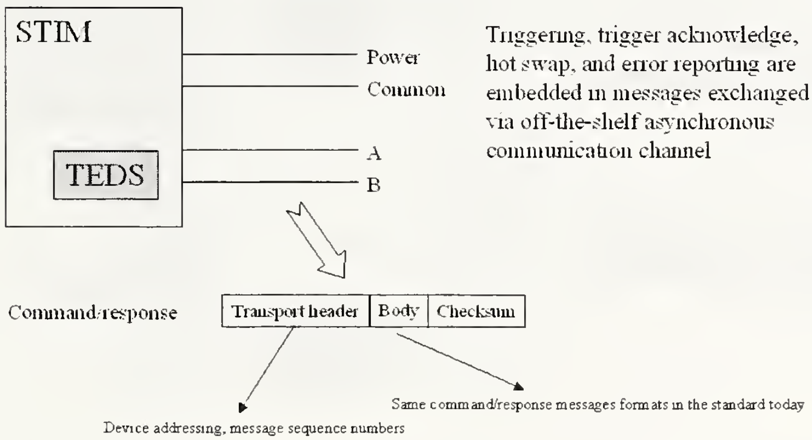
Proposed new IEEE 1451.2 TEDS blocks



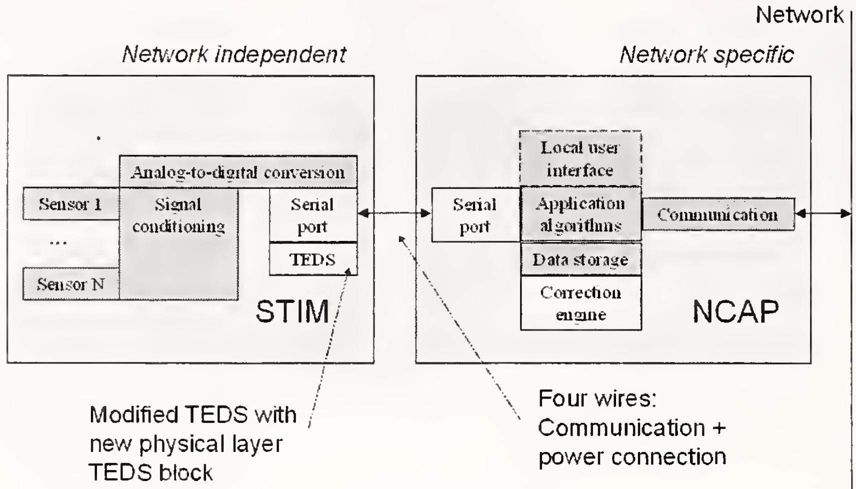
Alternate physical layers



Triggering, trigger acknowledge, hot swap, and error reporting are embedded in messages exchanged via off-the-shelf asynchronous communication channel

Smart Transducer Interface Standard - IEEE 1451

Proposed serial version of IEEE 1451.2



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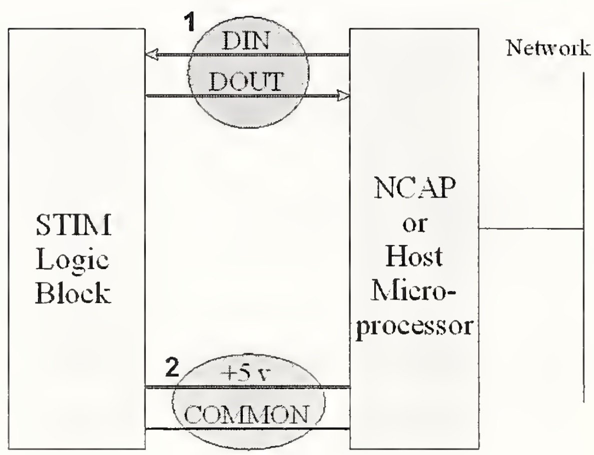
Smart Transducer Interface Standard - IEEE 1451

Proposed IEEE 1451.2 serial interface

1) Communication, triggering, error reporting
2) Power

Signal names for 1) will depend on particular physical layer



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Smart Transducer Interface Standard - IEEE 1451

Support for serial IEEE 1451.2

Trends in UART support:
- present on most microprocessors
- chips have become smaller, less expensive, more robust
- multi-port UARTs
- supported in ADI Microconverter family

Where can we plug into serial ports?
- Instruments
- I/O cards
- Computers
- "Slot 0" controllers in VME, VXI, CPCI, PXI card cages
- Handhelds, PDAs

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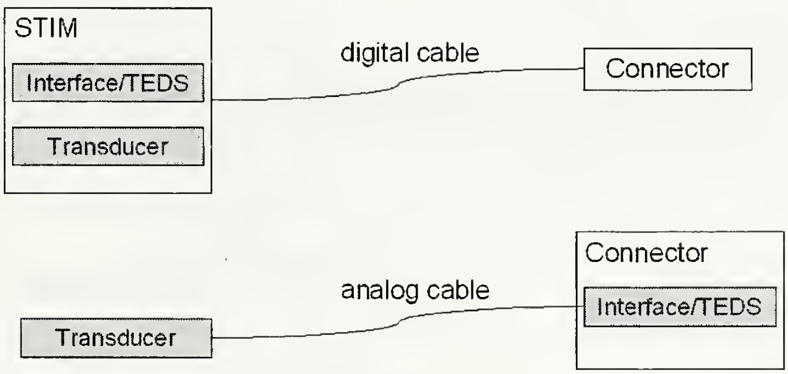
Smart Transducer Interface Standard - IEEE 1451

Where to put the STIM interface electronics?



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Smart Transducer Interface Standard - IEEE 1451

Partition the Standard

- Organize the standard around the OSI information model
- Separate sections for major functions:
  - TEDS
  - Correction engine
  - Physical layer

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Smart Transducer Interface Standard - IEEE 1451

Partition the standard (allow TEDS only)

New Meta TEDS

New Channel TEDS

No physical interface related fields

Meta-ID TEDS

Channel-ID TEDS

⋮

Other TEDS blocks can remain the same.

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Smart Transducer Interface Standard - IEEE.1451

Secondary enhancements

- Enhance the TEDS
  - Add features from IEEE P1451.3 and IEEE P1451.4
    - Bandwidth
    - Frequency response
    - XML format
    - Etc.
- Add functions
  - Control function to tell NCAP to reload TEDS
  - Support STIM reconfiguration:
    - Gain, bandwidth, etc.
    - Changes in channels due to hot-swap in local sub-net, including IEEE P1451.3 or IEEE P1451.4

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Smart Transducer Interface Standard - IEEE 1451

Secondary enhancements, con't.

- Standalone function
  - Support use with existing data and control systems
  - Map IEEE 1451.2 functions to existing protocols:
    - Modbus RTU
    - Modbus/TCP
    - ProfiBus
    - HTTP URL-based
    - XML
    - Etc.
- Corrections and additions
  - Miscellaneous comments received since publication
  - Others identified during review and updating process

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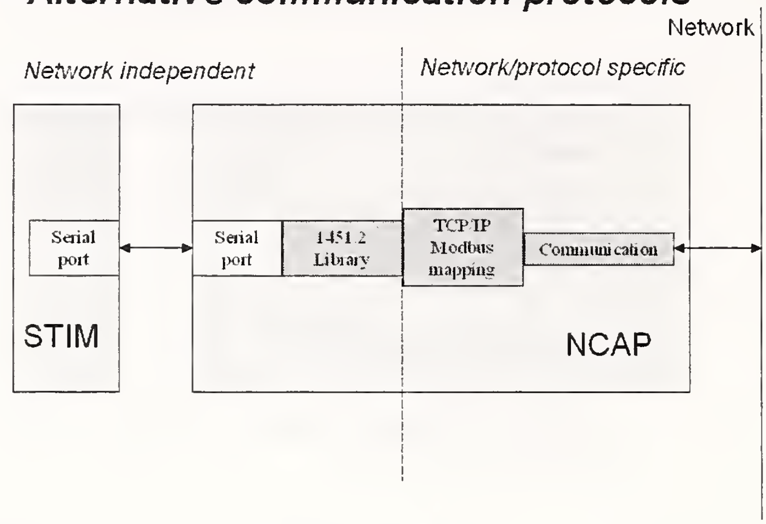
Smart Transducer Interface Standard - IEEE 1451

Alternative communication protocols



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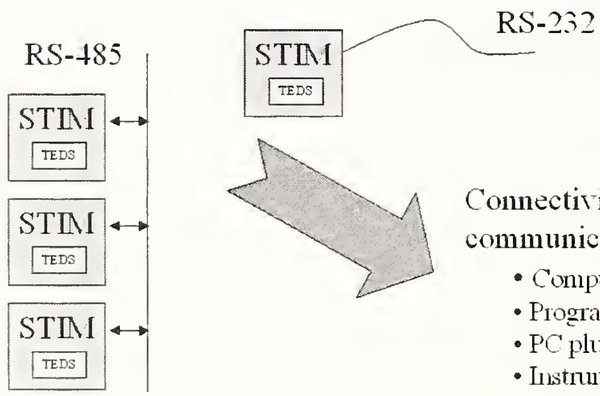
Smart Transducer Interface Standard - IEEE 1451

New connectivity enabled by enhancements



Connectivity to existing communication ports:
- Computers
- Programmable logic controllers
- PC plug-in cards
- Instruments
- NCAPs

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Smart Transducer Interface Standard - IEEE 1451

Applications for serial IEEE 1451.2

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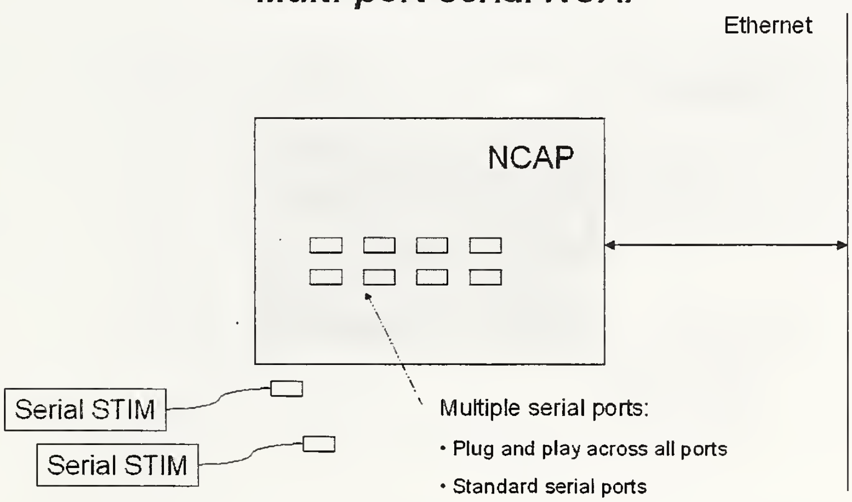
Smart Transducer Interface Standard - IEEE 1451

Multi-port serial NCAP



Multiple serial ports:

- Plug and play across all ports
- Standard serial ports

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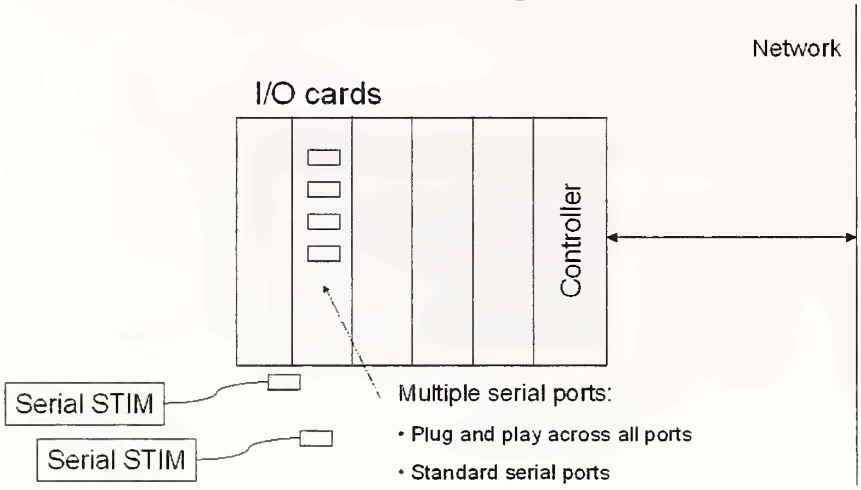
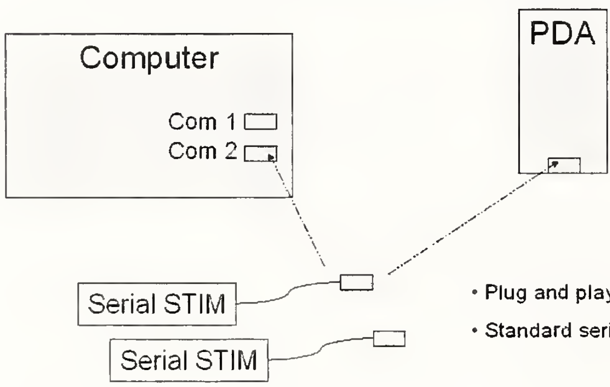
Smart Transducer Interface Standard - IEEE 1451

Industrial card cage I/O card



Smart Transducer Interface Standard - IEEE 1451

Computers and PDAs



- Plug and play across serial ports
- Standard serial ports

Smart Transducer Interface Standard - IEEE 1451

Most requested changes to IEEE 1451.2

Addressed by going to serial interface

Addressed by other proposed enhancements

- Make it easier to understand and implement
- Make the hardware interface faster
- Use less wires
- Pick a standard connector
- Provide for electrical isolation
- Allow real-time reconfiguration
- Add frequency response to TEDS and correction engine
- Make NCAPs readily available and compatible with existing systems
- Don't add unnecessary expense to simple transducers
- Add security, timestamps, data logging, etc.

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Smart Transducer Interface Standard - IEEE 1451

Conclusions

- IEEE 1451.2 established several valuable basic principles of smart transducers
- The most important of these is the TEDS
- We need to keep the best parts of the original standard while addressing the current needs of the marketplace
- The proposed enhancements will address the major requested changes and will result in:
  - More flexibility
  - Lower cost
  - Improved connectivity
- We need user comments and feedback on the proposed enhancements

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Smart Transducer Interface Standard - IEEE 1451

Please attend the IEEE 1451.2 workshop on October 4, 2001!

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3.4 Requested Changes to the IEEE 1451.2 Standard for Smart Transducers

Smart Transducer Interface Standard - IEEE 1451

Requested Changes to the IEEE 1451.2 Standard for Smart Transducers

Robert N. Johnson, Telemonitor, Inc.
Stan Woods, Agilent Technologies, Inc.

October 4, 2001

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Smart Transducer Interface Standard - IEEE 1451

Most requested changes to IEEE 1451.2

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- Allow real-time reconfiguration
- Add frequency response to TEDS and correction engine
- Make NCAPs readily available and compatible with existing systems
- Don't add unnecessary expense to simple transducers
- Add security, timestamps, data logging, etc.

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Smart Transducer Interface Standard - IEEE 1451

Most requested changes, con't.

- Make it easier to understand and implement
  - New, broad-reaching standard
  - Wide adoption will produce user guides, books, etc.
  - Not everyone must understand the details
  - OEMs can convert raw transducers to STIMs without having to design signal conditioning and conversion
- Make the hardware interface faster
  - Minimum of 6,000 bit/s supports inexpensive hardware
  - Maximum not specified; several million bit/s has been demonstrated
  - Digital interface may not be appropriate for all applications (*e.g.* IEEE P1451.4)

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Smart Transducer Interface Standard - IEEE 1451

Most requested changes, con't.

- Use less wires
  - Originally for single close-coupled transducer to microprocessor
  - Based on SPI with hardware handshaking
  - Supports synchronized trigger and data acquisition
  - Simpler interfaces are appropriate for some uses
- Pick a standard connector
  - Connectors are very application-dependent
  - Started defining connectors for some applications
  - Alternate physical layers may include connectors
  - True "plug-and-play" requires connector definition

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Smart Transducer Interface Standard - IEEE 1451

Most requested changes, con't.

- Provide for electrical isolation
  - Isolation less of an issue for close-coupled system
  - Using existing standard physical layers will help
- Allow real-time reconfiguration
  - STIM cannot tell NCAP that the TEDS has changed
  - No standard mechanism for selectable gain, sample rate, number of samples, etc.
- Add frequency response to TEDS and correction engine
  - Standard provides for extensions to TEDS but not to correction engine

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Smart Transducer Interface Standard - IEEE 1451

Most requested changes, con't.

- Make NCAPs readily available and compatible with existing systems
  - Standard visualizes complete system including STIMs, NCAPs, network-level software
  - Need growth path to bring benefits of IEEE 1451 to existing systems
- Don't add unnecessary expense to simple transducers
  - Target is applications where interchangeable communicating smart transducers add value
  - Some applications are too cost-sensitive
  - Line between the two will shift over time

October 4, 2001 Sensors Expo, Philadelphia 6

Smart Transducer Interface Standard - IEEE 1451

Most requested changes, con't.

- Add security, timestamps, data logging, etc.
  - Originally viewed as higher-level functions
  - Appropriate to consider for proposed enhancements
  - Will depend on the interests of the people who participate in the working group
  - Must avoid "rampant featuritis!"

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3.5 A Sensor Manufacturer's Perspective

Smart Transducer Interface Standard - IEEE 1451

A Sensor Manufacturer's Perspective

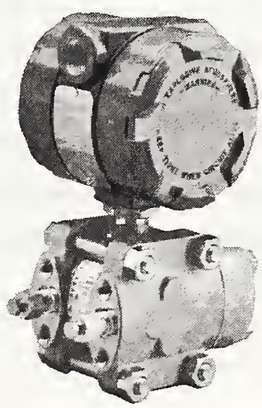
True confessions of a 1451.2 Pioneer

Jim Moore
Telemonitor, Inc

Oct 4, 2001 Sensors Expo 1

Smart Transducer Interface Standard - IEEE 1451

A Generic Differential Pressure Transmitter



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The Pressure Transmitter market

- 1.4 Million units/year with 4.3% CAGR
  - ARC Advisory Group, Inc data
- Manufacturers are vertically integrated
- Need > 50K/year to be profitable
- Moore Products developed the MycroSensor to compete in this market
  - 1985 started MycroSensor development
  - 1993 introduced the XTC Pressure transmitter
- However.....

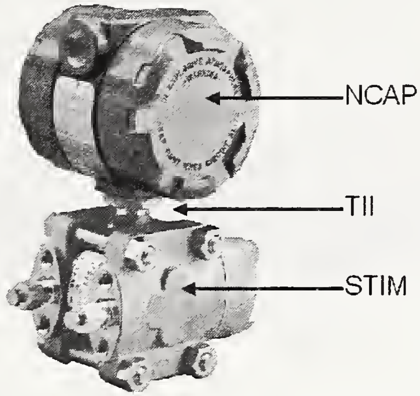
But If.........

We could rewrite the transmitter business model:

- Multiple vendors of pressure sensing STIMS
  - Capacitive such as MycroSensor
  - Piezoresistive
- NCAPS (transmitters) manufactured for targeted markets
  - 4-20mA/HART(~90% of market)
  - Profibus, FF, etc
  - Ethernet – future?

Smart Transducer Interface Standard - IEEE 1451

A 1451 Differential Pressure Transmitter



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Smart Transducer Interface Standard - IEEE 1451

New Applications

- **Remote monitoring**
  - **Maintenance**
  - **Environmental**
  - **Security, both defensive and offensive**
- **Gas flow measurement in the "Oil Patch" (an example)**
  - **Approximately 50K units per year**
  - **Requires accurate measurement of 2 pressures and temperature.**
  - **Low power requirements**
  - **Replace old circular chart recorders**

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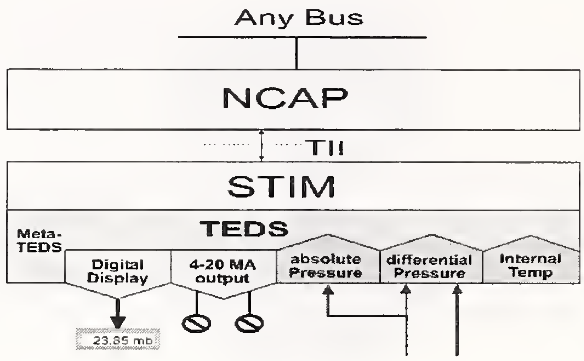
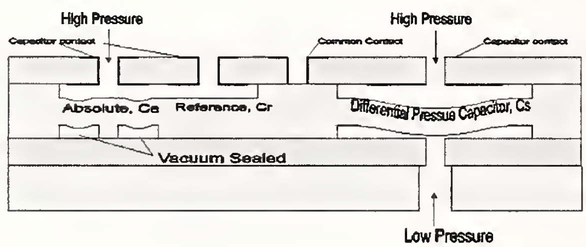
Smart Transducer Interface Standard - IEEE 1451

Ethernet MV Pressure transmitter



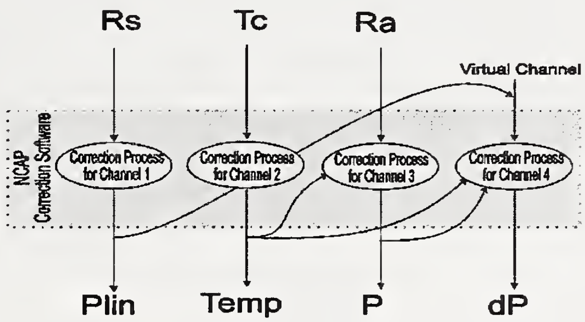
Smart Transducer Interface Standard - IEEE 1451

The MycroSensor



Smart Transducer Interface Standard - IEEE 1451

Correction Model for a MV transmitter



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Smart Transducer Interface Standard - IEEE 1451

Lessons Learned and Path forward

- **Not going to remake an established, commodity market**
- **IEEE 1451.2 is *not* a product!**
- **TII importance?**
  - **Sensor mfg → OEM –No**
  - **Sensor mfg → End user - Yes**
- **1451 standards can provide the means to unleash existing sensor technology into *new* markets and applications.**
- **Rapid growth of TCP/IP will create many new application that are hungry for sensor data. Many sensor technologies available to feed this need**
- **The goal of the 1451 standards is to bring these together**

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Smart Transducer Interface Standard - IEEE 1451

"We have the trains, we have the places to go; the 1451 standards can provide the rails to make it happen!"

Thank You

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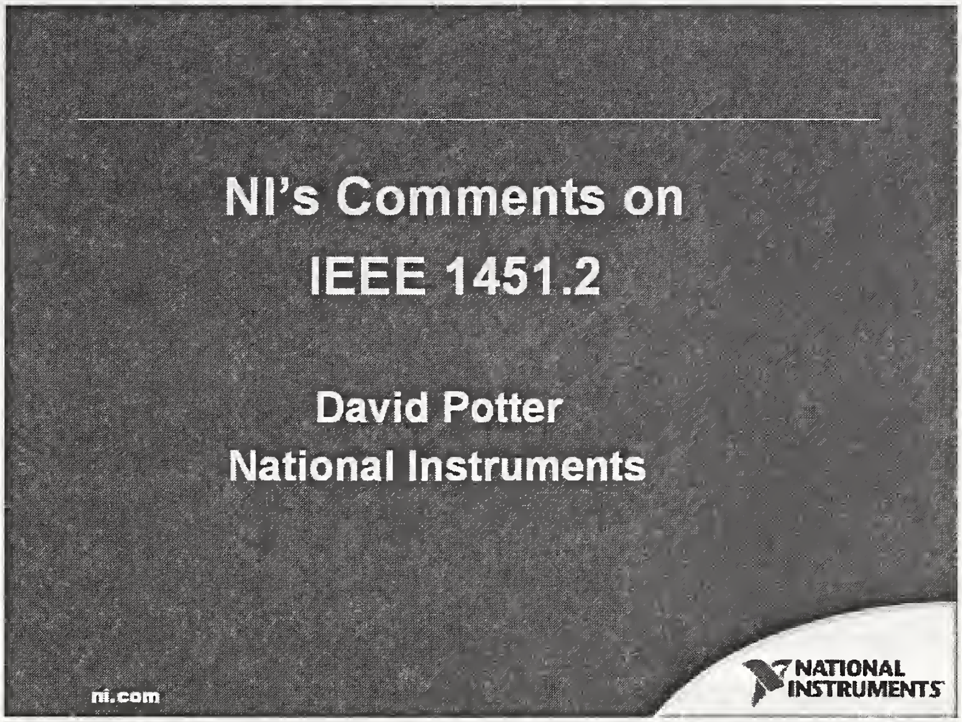
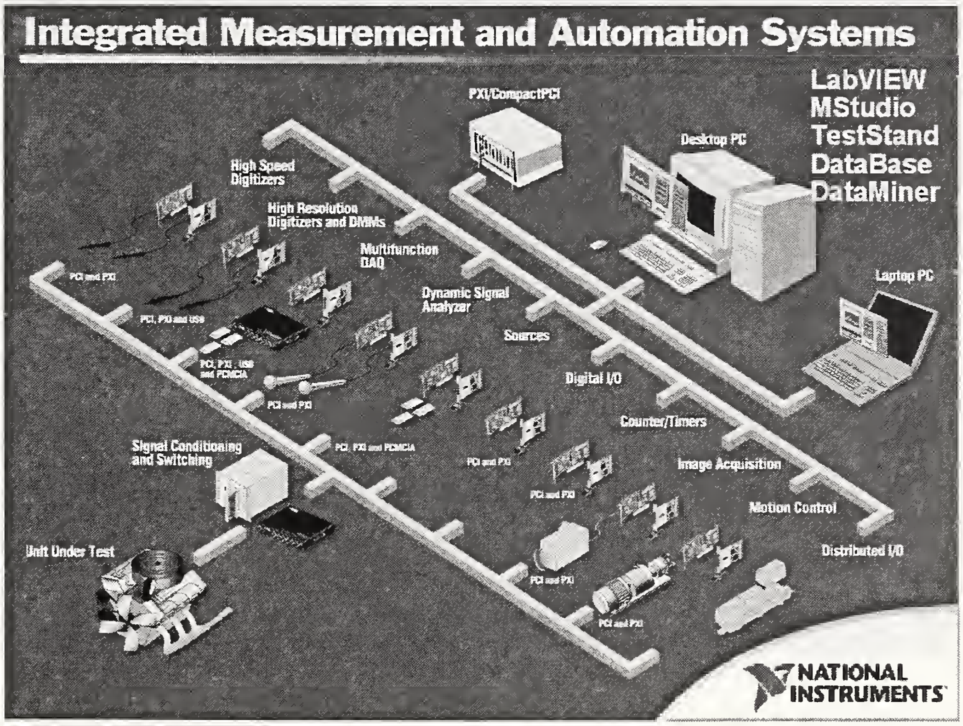
3.6 NI's Comments on IEEE 1451.2





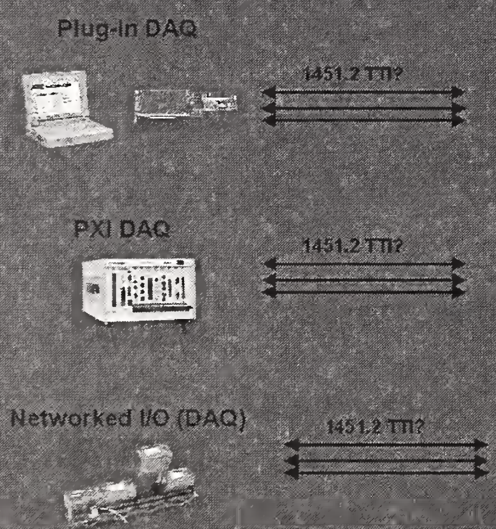
NI and Smart Sensors: The Big Picture…

- Smart sensors will be increasingly important in Measurement and Automation
  - Main driver: easier connectivity and use of sensors
- 'Smart' sensors, smart modules, smart systems,…
  - "What is smart" is less important than building integrated systems that deliver the end user benefits
- NI as *both* software and hardware supplier
  - As software supplier: support many networks, devices, instruments, as requested and required by customers
  - As hardware supplier: highly selective of technology for interfaces

ni.com

NATIONAL INSTRUMENTS

As hardware supplier… Possible Implementations?



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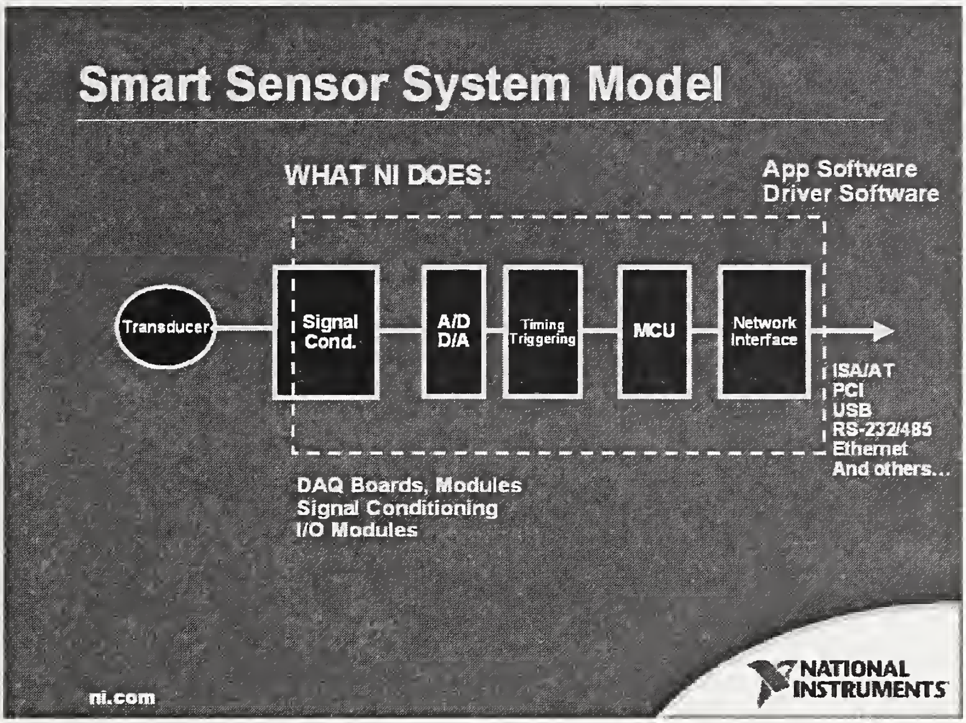
NATIONAL INSTRUMENTS


Smart Sensor System Model
WHAT NI DOES:
App Software
Driver Software
Transducer
Signal Cond.
A/D D/A
Timing Triggering
MCU
Network Interface
ISA/AT
PCI
USB
RS-232/485
Ethernet
And others...
DAQ Boards, Modules
Signal Conditioning
I/O Modules
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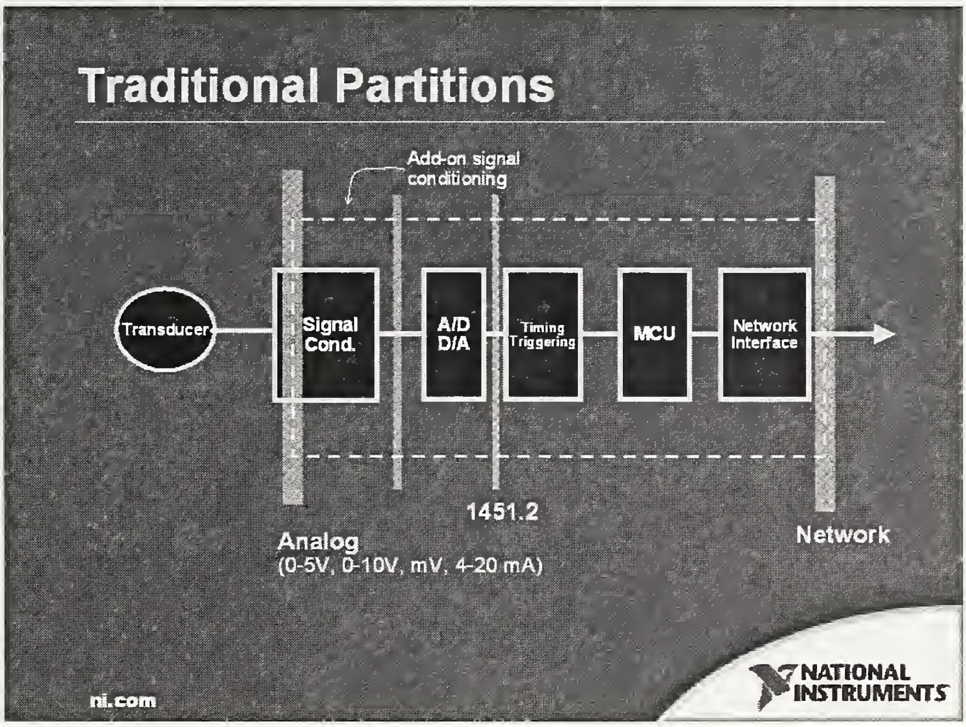
NATIONAL INSTRUMENTS


Traditional Partitions
Add-on signal conditioning
Transducer
Signal Cond.
A/D D/A
Timing Triggering
MCU
Network Interface
1451.2
Analog
(0-5V, 0-10V, mV, 4-20 mA)
Network
ni.com
NATIONAL INSTRUMENTS

NI's Thoughts/Reactions on dot2

- Partition Location
  - 1451.4 partition at analog is good fit
- Seemed more appropriate as OEM (chip-level, module) level interface, rather than an end user interface
- Standardized TEDS can ease setup, configuration
  - Particularly useful: calibration information
  - Very useful if can somehow used across multiple electrical/physical implementations

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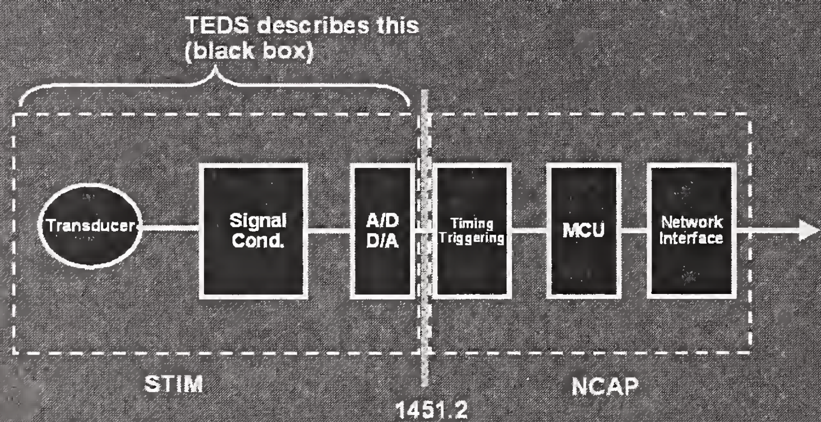
NATIONAL INSTRUMENTS

"Generalized" TEDS?



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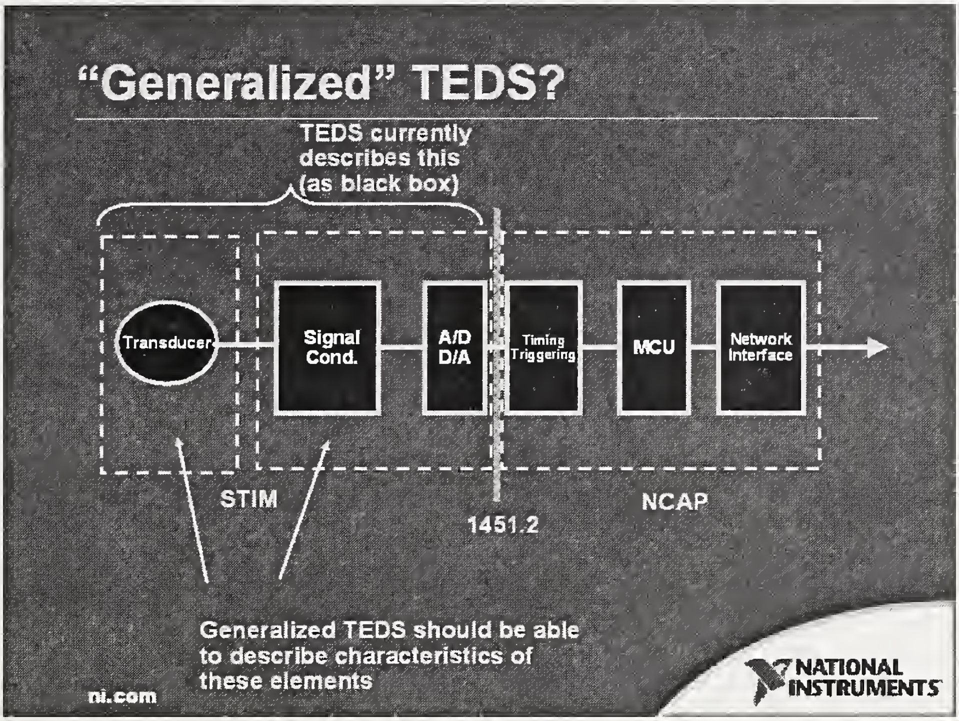
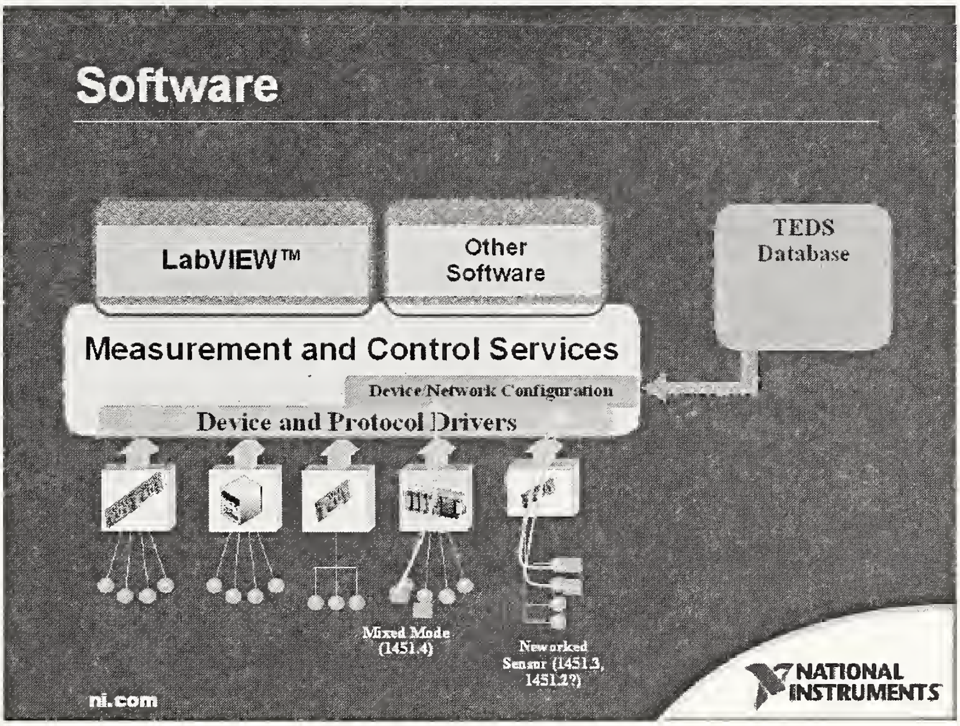
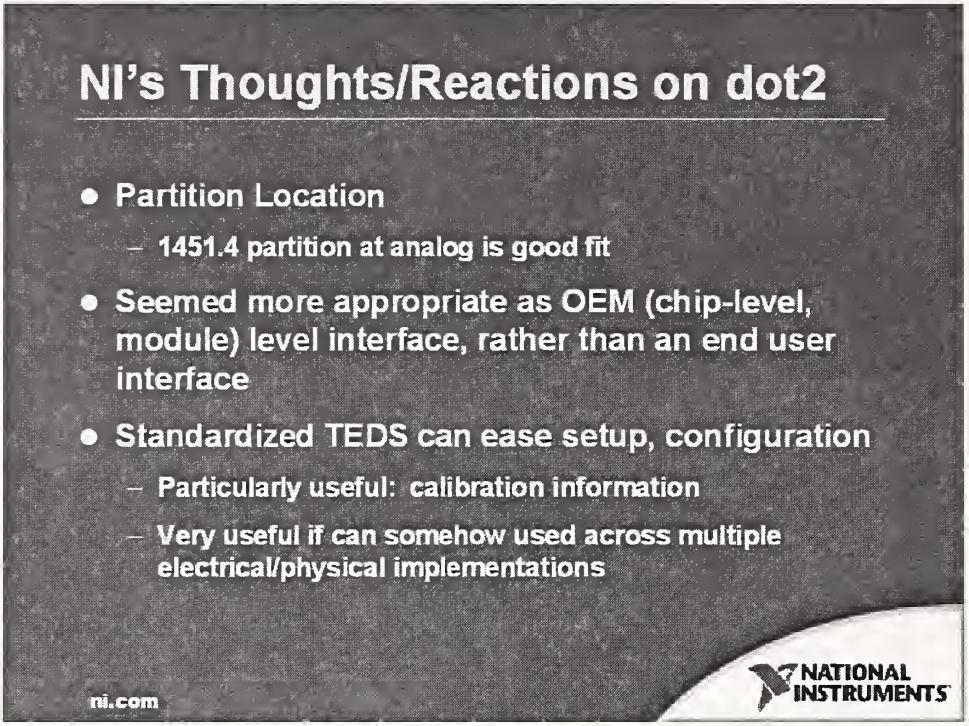

"Generalized" TEDS?
TEDS currently
describes this
(as black box)
Transducer
Signal
Cond.
A/D
D/A
Timing
Triggering
MCU
Network
Interface
STIM
1451.2
NCAP
Generalized TEDS should be able
to describe characteristics of
these elements
ni.com
NATIONAL
INSTRUMENTS


Software
LabVIEW™
Other
Software
TEDS
Database
Measurement and Control Services
Device/Network Configuration
Device and Protocol Drivers
Mixed Mode
(1451.4)
Neworked
Sensor (1451.3,
1451.2?)
ni.com
NATIONAL
INSTRUMENTS


NI's Thoughts/Reactions on dot2
Partition Location
1451.4 partition at analog is good fit
Seemed more appropriate as OEM (chip-level, module) level interface, rather than an end user interface
Standardized TEDS can ease setup, configuration
Particularly useful: calibration information
Very useful if can somehow used across multiple electrical/physical implementations
ni.com
NATIONAL INSTRUMENTS

3.7 Proposed Enhancements to the IEEE 1451.2 Standard for Smart Transducers

Smart Transducer Interface Standard - IEEE 1451

Proposed Enhancements to the IEEE 1451.2 Standard for Smart Transducers

Robert N. Johnson, Telemonitor, Inc.
Stan Woods, Agilent Technologies, Inc.

October 4, 2001

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Smart Transducer Interface Standard - IEEE 1451

Most requested changes to IEEE 1451.2

- Make it easier to understand and implement
- Make the hardware interface faster
- Use less wires
- Pick a standard connector
- Provide for electrical isolation
- Allow real-time reconfiguration
- Add frequency response to TEDS and correction engine
- Make NCAPs readily available and compatible with existing systems
- Don't add unnecessary expense to simple transducers
- Add security, timestamps, data logging, etc.

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Smart Transducer Interface Standard - IEEE 1451

Proposed enhancements to IEEE 1451.2

- Primary enhancements:
  - Partition the TEDS
  - Alternative physical layers
  - Partition the standard
- Secondary enhancements:
  - Enhance the TEDS
  - Add functions
  - Standalone function
  - Corrections and additions

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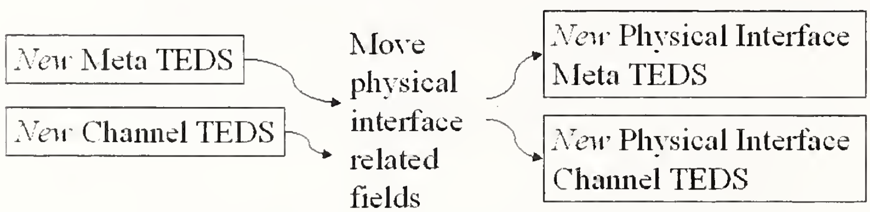
Smart Transducer Interface Standard - IEEE 1451

Partition the TEDS



Meta-ID TEDS

Channel-ID TEDS

⋮

Other TEDS blocks can remain the same.

Supports use of different physical layers.

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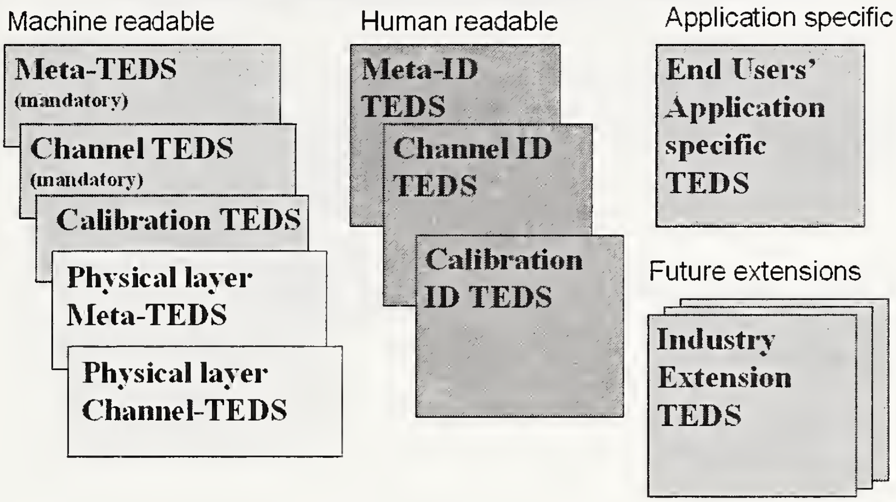
Smart Transducer Interface Standard - IEEE 1451

Proposed new IEEE 1451.2 TEDS blocks



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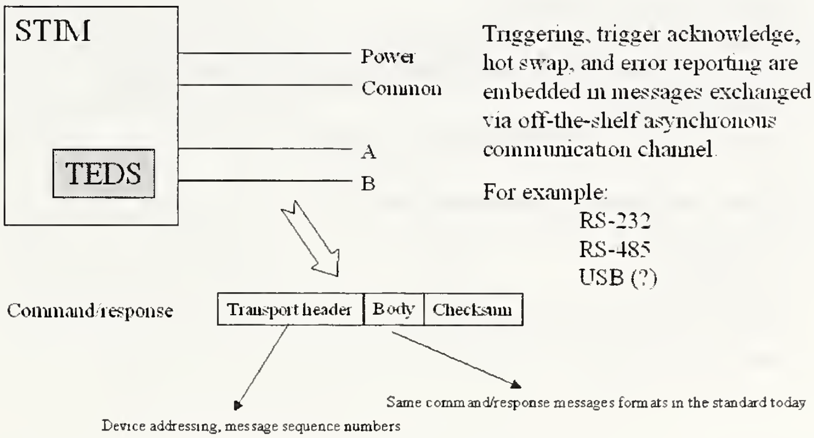
Smart Transducer Interface Standard - IEEE 1451

Alternate physical layers



Triggering, trigger acknowledge, hot swap, and error reporting are embedded in messages exchanged via off-the-shelf asynchronous communication channel.

For example:
- RS-232
- RS-485
- USB (?)

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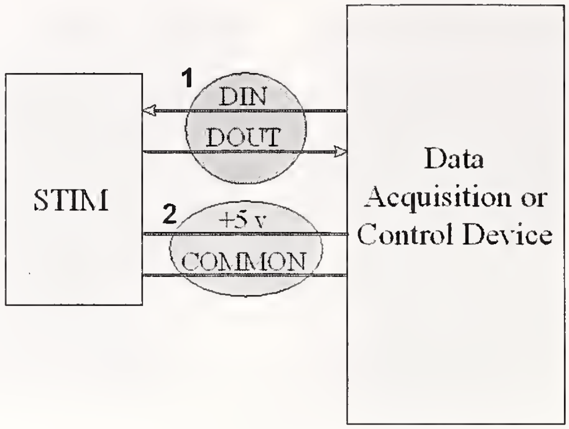
Smart Transducer Interface Standard - IEEE 1451

Proposed IEEE 1451.2 serial interface

1) Communication, triggering, error reporting
2) Power



Signal names for 1) will depend on particular physical layer

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Smart Transducer Interface Standard - IEEE 1451

Support for serial IEEE 1451.2

Trends in UART support:
- present on most microprocessors
- chips have become smaller, less expensive, more robust
- multi-port UARTs
- supported in ADI Microconverter family

Where can we plug into serial ports?
- Instruments
- I/O cards
- Computers
- VME, VXI, CPCI, PXI card cages
- Handhelds, PDAs

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Partition the Standard

- Organize the standard around the OSI information model
- Separate sections for major functions:
  - TEDS
  - Correction engine
  - Physical layer

Smart Transducer Interface Standard - IEEE 1451

Partition the standard (allow TEDS only)

New Meta TEDS

New Channel TEDS

No physical interface related fields

Meta-ID TEDS

Channel-ID TEDS

⋮

Other TEDS blocks can remain the same.

Smart Transducer Interface Standard - IEEE 1451

Secondary enhancements

- Enhance the TEDS
  - Add features from IEEE P1451.3 and IEEE P1451.4
    - Bandwidth
    - Frequency response
    - XML format
    - Etc.
- Add functions
  - Control function to tell NCAP to reload TEDS
  - Support STIM reconfiguration:
    - Gain, bandwidth, etc.
    - Changes in channels due to hot-swap in local sub-net, including IEEE P1451.3 or IEEE P1451.4

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Smart Transducer Interface Standard - IEEE 1451

Secondary enhancements, con't.

- Standalone function
  - Support use with existing data and control systems
  - Map IEEE 1451.2 functions to existing protocols:
    - Modbus RTU
    - Modbus/TCP
    - ProfiBus
    - HTTP URL-based
    - XML
    - Etc.
- Corrections and additions
  - Miscellaneous comments received since publication
  - Others identified during review and updating process

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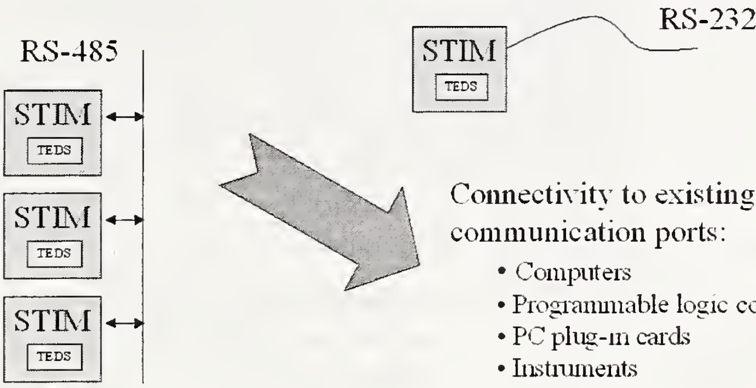
Smart Transducer Interface Standard - IEEE 1451

New connectivity enabled by enhancements



Connectivity to existing communication ports:

- Computers
- Programmable logic controllers
- PC plug-in cards
- Instruments
- NCAPs

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Smart Transducer Interface Standard - IEEE 1451

Applications for serial IEEE 1451.2

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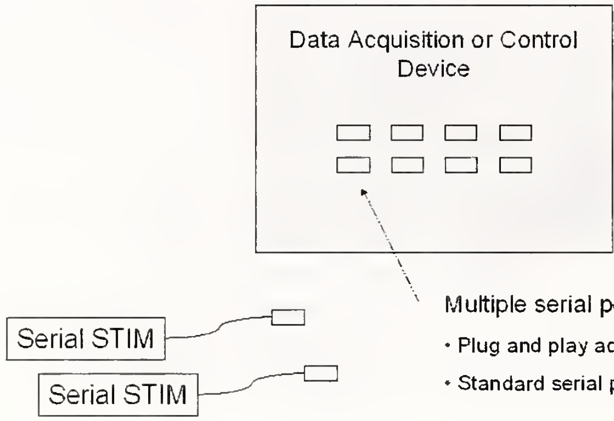
Smart Transducer Interface Standard - IEEE 1451

Multi-port serial device



Multiple serial ports:

- Plug and play across all ports
- Standard serial ports

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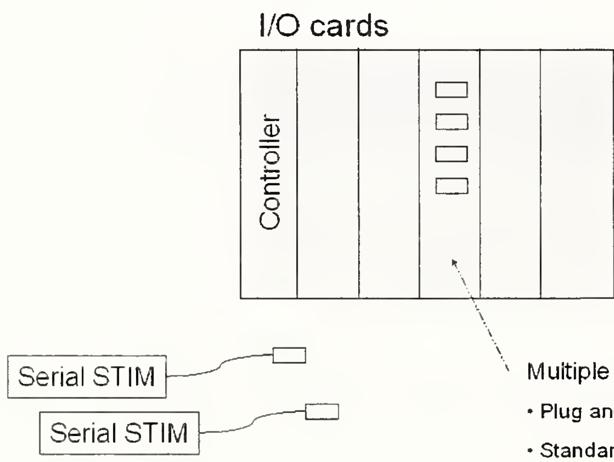
Smart Transducer Interface Standard - IEEE 1451

Industrial card cage I/O card



Multiple serial ports:

- Plug and play across all ports
- Standard serial ports

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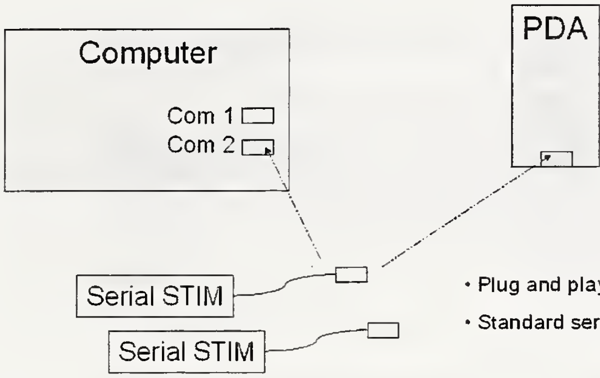
Smart Transducer Interface Standard - IEEE 1451

Computers and PDAs



- Plug and play across serial ports
- Standard serial ports

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Smart Transducer Interface Standard - IEEE 1451

Most requested changes to IEEE 1451.2

- Make it easier to understand and implement
- Make the hardware interface faster
- Use less wires
- Pick a standard connector
- Provide for electrical isolation
- Allow real-time reconfiguration
- Add frequency response to TEDS and correction engine
- Make NCAPs readily available and compatible with existing systems
- Don't add unnecessary expense to simple transducers
- Add security, timestamps, data logging, etc.

Addressed by going to serial interface

Addressed by other proposed enhancements

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Smart Transducer Interface Standard - IEEE 1451

Conclusions

- IEEE 1451.2 established several valuable basic principles of smart transducers
- The most important of these is the TEDS
- We need to keep the best parts of the original standard while addressing the current needs of the marketplace
- The proposed enhancements will address the major requested changes and will result in:
  - More flexibility
  - Lower cost
  - Improved connectivity
- We need user comments and feedback on the proposed enhancements

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Smart Transducer Interface Standard - IEEE 1451

Questions/Comments?

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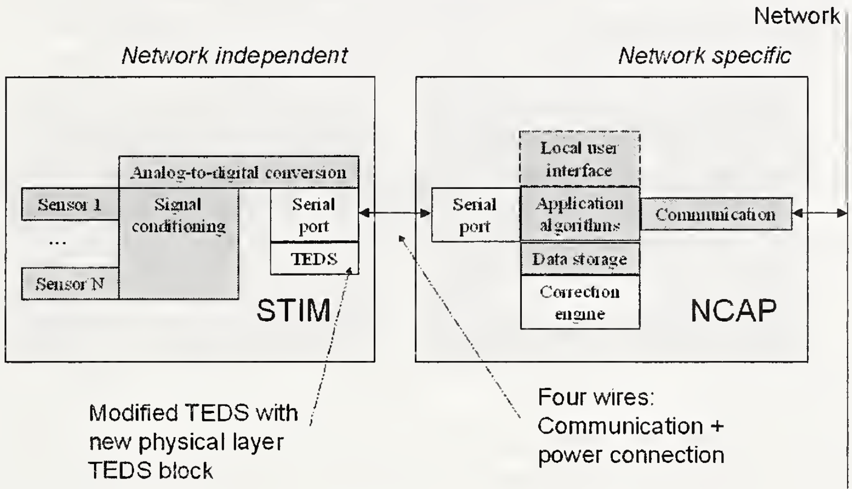
Smart Transducer Interface Standard - IEEE 1451

Proposed serial version of IEEE 1451.2



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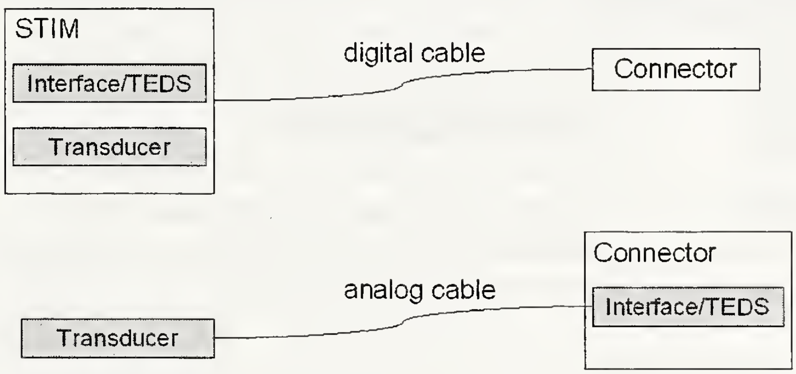
Smart Transducer Interface Standard - IEEE 1451

Where to put the STIM interface electronics?



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4 Presentations From "Second Workshop on Wireless Sensing"

4.1 An IEEE 1451.1 Summary

An IEEE 1451.1 Summary

Rick Schneeman, Computer Scientist
rschneeman@nist.gov

US Department of Commerce
National Institute of Standards and Technology (NIST)
Gaithersburg, Maryland 20899 USA

Introduction

- Who we are: NIST mission is to help increase US industry competitiveness through advanced research, standards, and technology collaboration
- Member of the Sensor Development and Application Group (SDAG) within the Manufacturing Engineering Laboratory (MEL) at NIST
- Member of the Working Group on the IEEE Standard for a Smart Transducer Interface for Sensors and Actuators — Network Capable Application Processor (NCAP) Information Model, or IEEE 1451.1 ("dot1")

An IEEE 1451.1 Summary 2

IEEE 1451 Overview/Goals

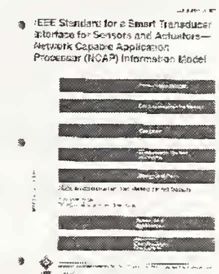
- Provide standardized communication interfaces for smart transducers, both sensors and actuators. In the form of a standard hardware and software definition/specification.
- Simplify the connectivity and maintenance of transducers to device networks through such mechanisms as common Transducer Electronic Data Sheet (TEDS) and standardized Application Programming Interfaces (API)
- Allow plug-and-play with 1451 compatible transducers among different devices using multiple control networks
- Give sensor manufacturers, system integrators, and end-users the ability to support multiple networks and transducer families in a cost effective way

An IEEE 1451.1 Summary

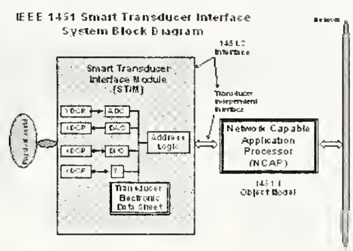
3

Part 1: IEEE 1451.1 Overview/Goals

- "*The specifications provide a comprehensive data model for the factory floor. and a simple application framework to build interoperable distributed applications...*" Dr. Jay Warrior, Agilent Technologies, Chair IEEE 1451.1 WG
- In general, IEEE 1451.1 accomplishes this by providing:
  - Transducer application portability (software reuse)
  - Plug-and-play software capabilities (components)
  - Network independence (network abstraction layer)



- The standard specifies these capabilities by defining software interfaces for:
  - Application functions in the NCAP that interact with the network that are independent of any network
  - Application functions in the NCAP that interact with the transducers that are independent of any specific transducer driver interface



An IEEE 1451.1 Summary

4

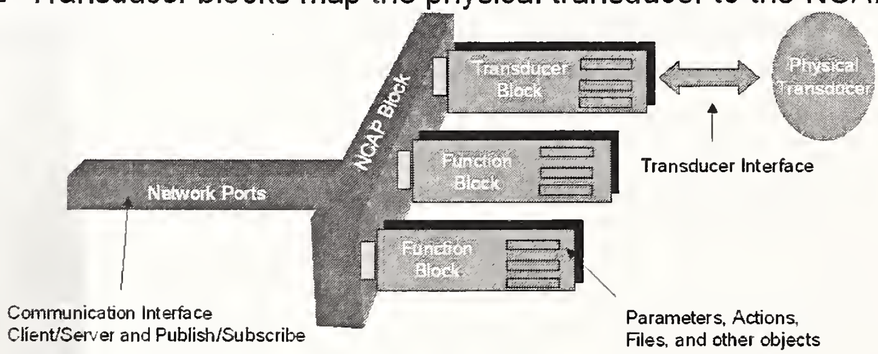
IEEE 1451.1 Overview/Goals (Cont.)

- IEEE 1451.1 software architecture is defined using three different models or views of the transducer device environment:
  - An Object Model, defines transducer device specific abstract objects – or, classes with attributes, methods, and state behavior
  - A Data Model, defines information encoding rules for transmitting information across both local and remote object interfaces
  - A Network Communication Model, supports a client/server and publish/subscribe paradigm for communicating information between NCAPs

An IEEE 1451.1 Summary 5

Conceptual View of an IEEE 1451.1 NCAP

- Uses a "backplane" or "card cage" concept
- NCAP centralizes and "glues" all the system and communications facilities together
- Network communication viewed through the NCAP as ports
- Function block application code is "plugged" in as needed
- Transducer blocks map the physical transducer to the NCAP



An IEEE 1451.1 Summary 6

IEEE 1451.1 Communication Model

- Provides two styles of inter-NCAP communication
- Client/Server: A tightly coupled, point-to-point model for one-to-one communication scenarios – typically used for configuration, attribute accessors, and operation invocations
- Publish/Subscribe: A loosely coupled, model for many-to-many and one-to-many communication scenarios – typically used for broadcasting or multicasting measurement data and configuration management (i.e., node or NCAP discovery) information

An IEEE 1451.1 Summary 7

Implementing IEEE 1451.1

- An IEEE 1451.1 C++ Reference Implementation provides a concrete representation of the abstract Smart Transducer Information Model (IEEE Std 1451.1-1999, Dated 18 April 2000). The NIST implementation is called "1451.1 Lite", as it is a subset of the complete specification.
- A subset of the IEEE 1451.1 implementation has also been developed in Java to provide an architecture neutral NCAP configuration tool.
- The C++ implementation uses the open-source Adaptive Communication Environment (ACE) from the Washington University at St. Louis.

An IEEE 1451.1 Summary 8

IEEE 1451.1 Benefits

- Using P1451.1 provides:
  - an extensible object-oriented model for smart transducer application development and deployment
  - application portability achieved through agreed upon application programming interfaces (API)
  - network neutral interface allows the same application to be plug-and-play across multiple network technologies
  - leverages existing networking technology, does not re-implement any control network software or protocols
  - a common software interface to transducer hardware i/o

An IEEE 1451.1 Summary 9

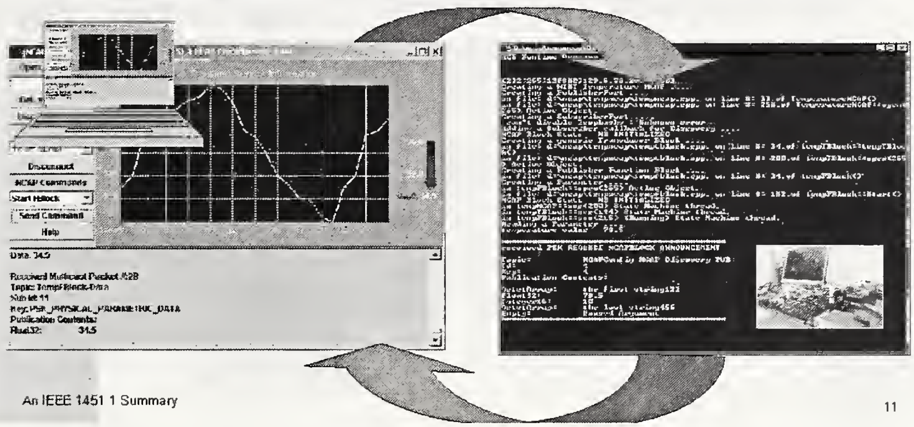
Looking at an IEEE 1451.1 Application

- A minimal IEEE 1451.1 application consist of a few classes:
  - An NCAP Block (consolidates system and communication housekeeping)
  - A Transducer Block (provides the software connection to the transducer device)
  - A Function Block (provides the transducer application algorithm (i.e., obtain and multicast temperature data every second)
  - Parameters (contains the network accessible variables that hold and update the data)
  - Ports (network communication objects for publishing and subscribing to information or interacting with other NCAPs using client/server

An IEEE 1451.1 Summary 10

Executing an IEEE 1451.1 Application

- An embedded Temperature NCAP Application is running from a remote location on the NIST Intranet
  - As part of the system configuration, a NIST developed Java tool on a Notebook issues a discovery multicast, finds the NCAP, and starts the remote NCAP's Function Block
  - The remote NCAP Function Block responds by publishing temperature data every second as the Java tool records the information

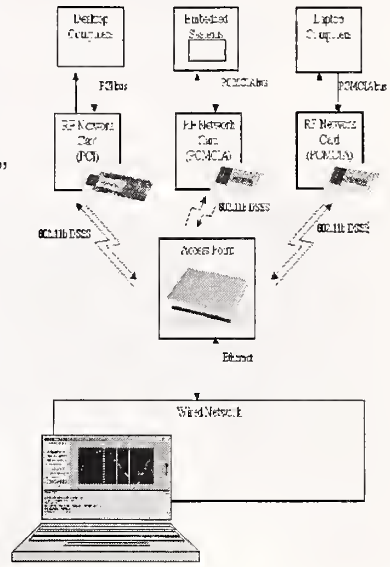


How NIST uses IEEE 1451.1 in a Wireless Environment

- The NIST C++ IEEE 1451.1 reference implementation uses TCP/IP as its underlying control network.
- From TCP/IP, IP multicast and TCP unicast features are used to implement publish/subscribe and client/server, respectively
- ACE is used to abstract the networking code from the application; therefore it is highly adaptive to various protocols
- Wired 802.3 Ethernet has been used primarily for testing. No changes were needed in ACE to support this protocol.
- Wireless 802.11b (11Mbps) Ethernet has also been used for testing. Again, no changes were made to ACE as the TCP/IP protocol is compatible with both 802.3 and 802.11b physical mediums.

How NIST uses IEEE 1451.1 in a Wireless Environment

- Testing scenarios included using a wired subnet connected to a wireless extension of the subnet
- Wireless extension uses an Agere (formerly Lucent) Orinoco AP-1000 dual card "access point"
- Range extender antennas are also connected to the access point and each PC-CARD
- Each node on the wireless side executes an IEEE 1451.1 NCAP application
- Java Configuration tool executes beyond the wireless net on the wired subnet



An IEEE 1451.1 Summary

13

Summary

- IEEE 1451.1 is a large and comprehensive standard that addresses the needs of the smart transducer industry for providing portability and network independent access.
- NIST has begun implementing a good deal of the standard with emphasis on getting the software communication and infrastructure in place in order to start using the code.
- Choosing and implementing the standard with a solid object-oriented framework such as ACE provides a robust environment for real-time network communication.
- Migrating the implementation to other middleware such as CORBA for heavier weight uses will be reasonable to do
- Several projects at NIST will use the implementation for supporting manufacturing related activities

An IEEE 1451 1 Summary

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Summary (cont)

- Continued testing in the wireless space is required to gauge the effectiveness of the implementation.
- Bluetooth trials are forthcoming; however, the lack of multicast support will severely impact the applications – continued research here is a must
- Other lightweight middleware packages are going to be isolated – xml and soap, etc; however, these protocols do not support asynchronous messaging or publish subscribe in efficient ways
- Slimmer implementations of the IEEE 1451.1 will need to be experimented with for use with the smaller micro platforms.

An IEEE 1451.1 Summary 15

For more information....

- **ACE can be found at:** *www.cs.wustl.edu/~schmidt/ACE.html*
- **1451.1-1999 IEEE Standard for a Smart Transducer Interface for Sensors and Actuators - Network Capable Application Processor Information Model 2000: ISBN 0-7381-1768-4**
- **The NIST IEEE 1451 Web Site provides information about 1451, publications, and demonstrations at:** *ieee1451.nist.gov*

An IEEE 1451.1 Summary 16

4.2 Bluetooth for 1451

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Bluetooth for 1451

Sensor Area Networks (SANs)

Thurston Brooks
IEEE P1451.4 & P1453.3 Member
Bluetooth IA SG Vice Chair

with contributions by
Ericsson Mobile Communications AB

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Wireless Monitoring

- Will reduce monitoring installation cost
  - $20/ft typical, as much as $2000/ft some apps (e.g., Nuclear)
  - Cabling is 30-45% of TOC
- Spread spectrum technology is now available for low cost
- Mobile connections
- Real-time dynamic range is expensive
  - Power
  - Cost $
- Immediate alert of alarm conditions and follow-up data dumps are also feasible

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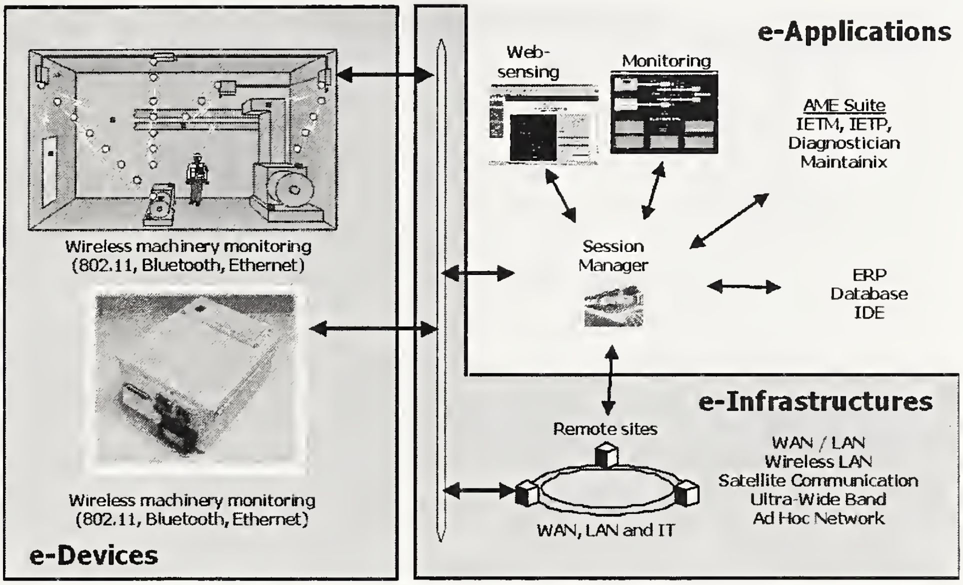
Machinery Monitoring Implementation with NCAP



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Wireless Manufacturing Solutions

- Majority of wireless products in marketplace are proprietary spread spectrum and narrow band solutions in the ISM bands (400MHz, 900MHz, 2.4GHz)
  - Today 80% of customers → SS (*Garner Group)
- Typically constrain user to buy from a particular vendor
- Interoperability, low-cost, and broad user base (i.e., market demand) have been stimulated by Standards
  - IEEE 802.11 (2.4GHz @1-2Mbps) LAN
  - Bluetooth (2.4GHz @ .75Mbps) PAN
  - Potential Interference between 802.11 and Bluetooth

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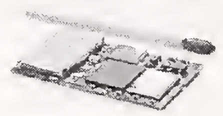
Bluetooth Features

- Low-Cost
  - Highly Integrated ASICs
- Low-Power
- Small Size
- Frequencies
  - covers all of the 2.4GHz ISM band
- Time Division Duplex
- Stand-by Modes
  - Park
  - Hold
  - Sniff
  - Standby



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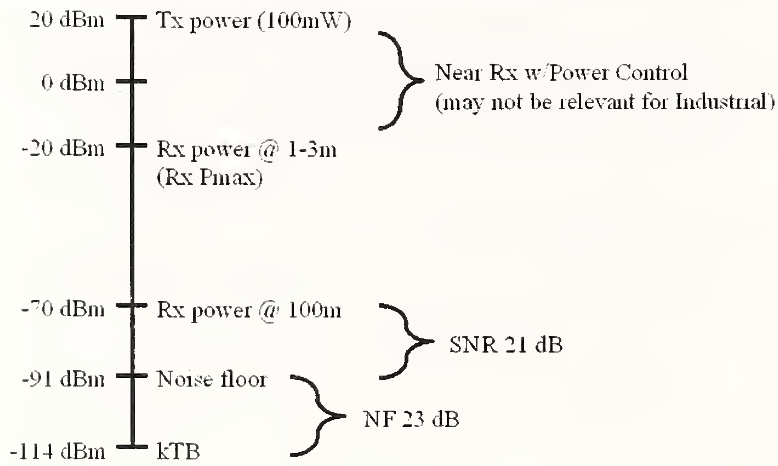
Bluetooth Link Budget for Max Power TX



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Operational States

- Standby
- Inquiry-Paging
- Connections
  - Active
  - Power Conserving
    - Hold (delta t)
    - Sniff (Poling)
    - Park (Listen but do not disturb master)
- Synchronous Connection-Oriented (SCO) Link (primarily used for voice – could be used for deterministic link)
- Asynchronous Connection-Less (ACL) Link (packet data)

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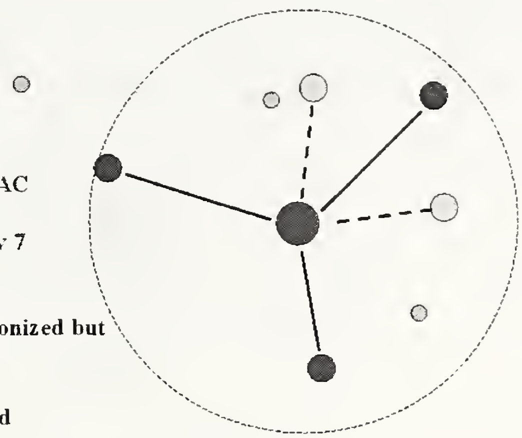
Operational States

Master – sets the hopping sequence

Active Slave – 3-bit MAC address for immediate communication → only 7 slaves in a piconet

Parked Slave – synchronized but has no MAC address

Standby – Unconnected



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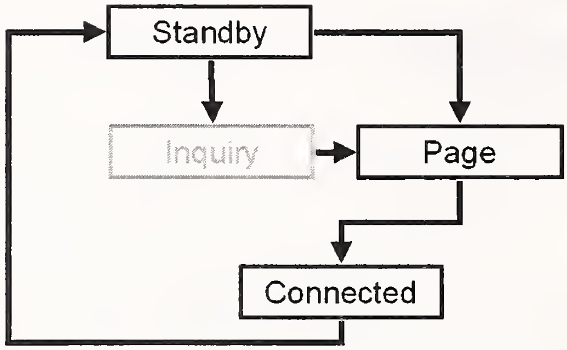
Making a Connection



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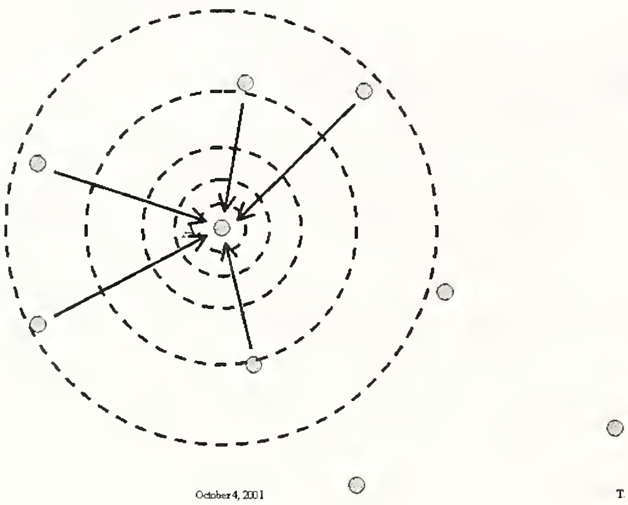
Inquiry



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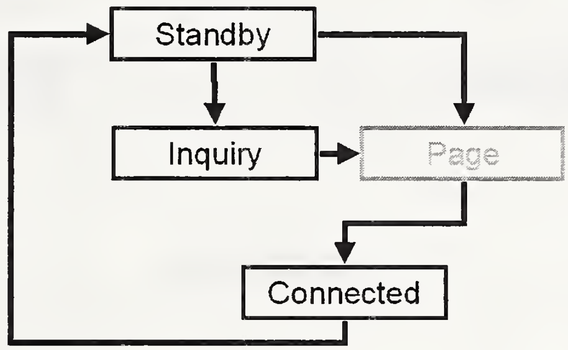
Making a Connection



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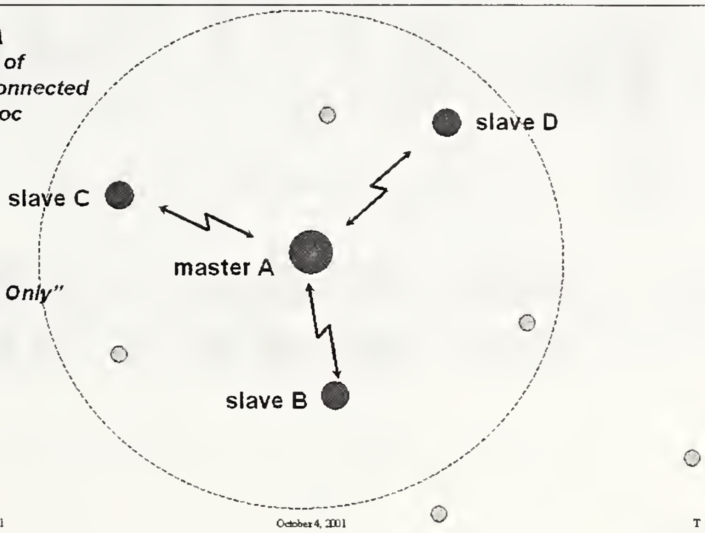
Creating a Piconet

***Piconet:** A collection of devices connected in an ad hoc fashion*

"By Invite Only"



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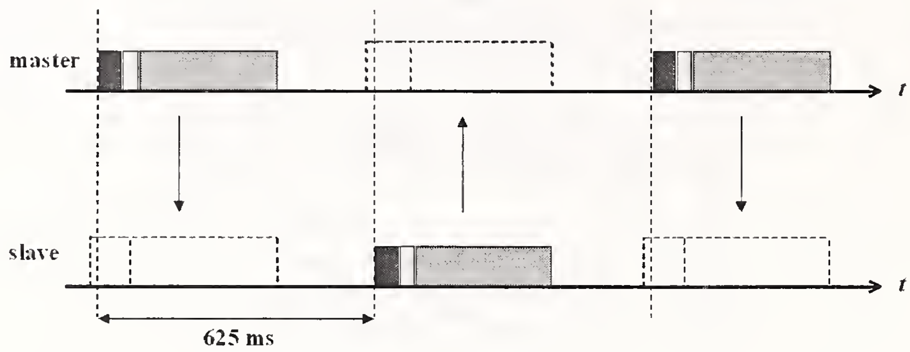
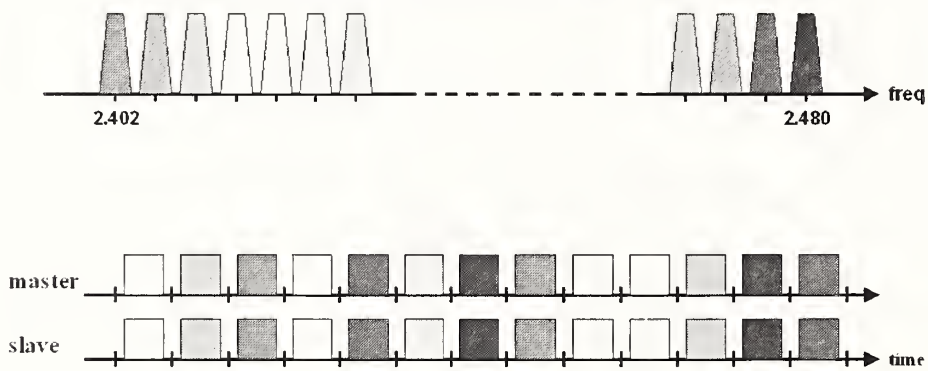
FH with TDD Channel



Frequency Hopping



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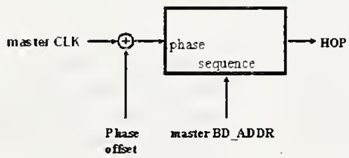
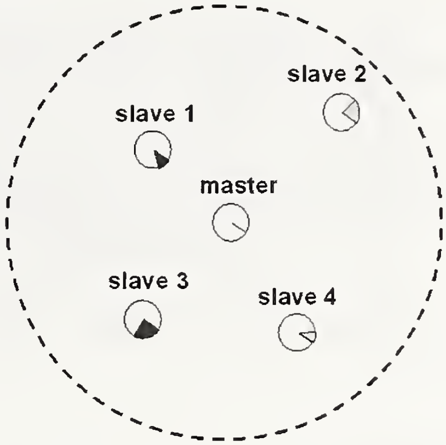
Synchronisation of Physical Channel

master BD_ADDR → hop sequence

master CLOCK → phase





Master Unit is the device in a piconet whose clock and hopping sequence are used to synchronize all other devices in the piconet

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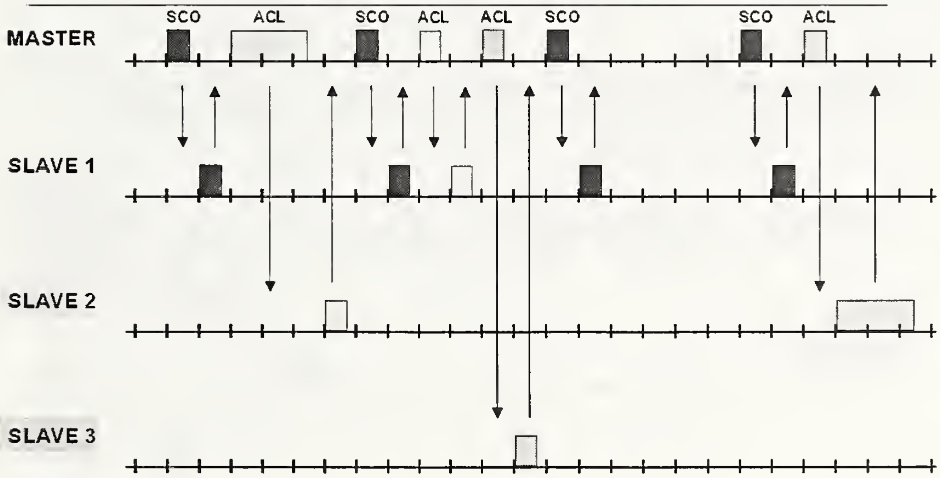
Mixed Link Example



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Data Rates (kb/s)

type	symmetric	asymmetric	
DM1	108.8	108.8	108.8
DH1	172.8	172.8	172.8
DM3	258.1	387.2	54.4
DH3	390.4	585.6	86.4
DM5	286.7	477.8	36.3
DH5	433.9	723.2	57.6

Master unit controls the link bandwidth, decides how much is given to each slave, and sets the symmetry of the link

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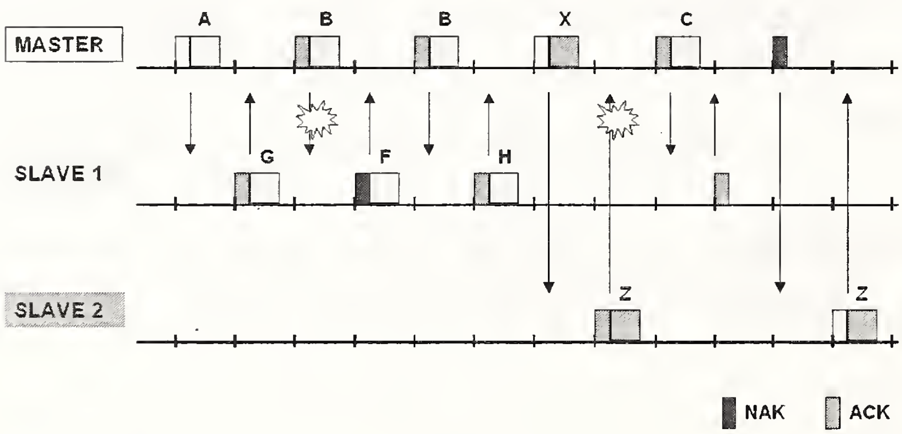
Automatic Repeat Request (ARQ) Scheme



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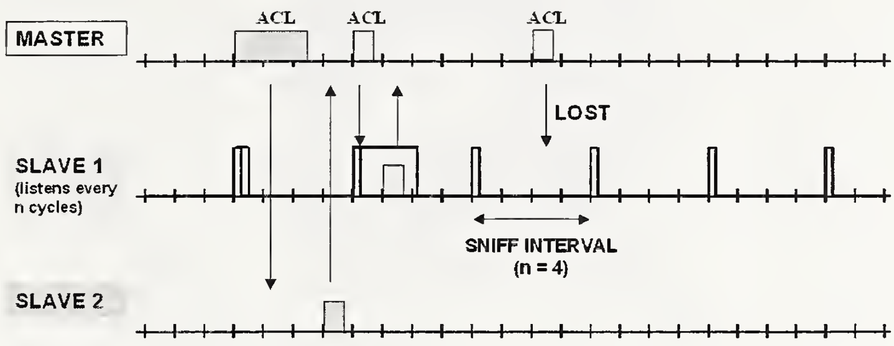
Sniff Mode



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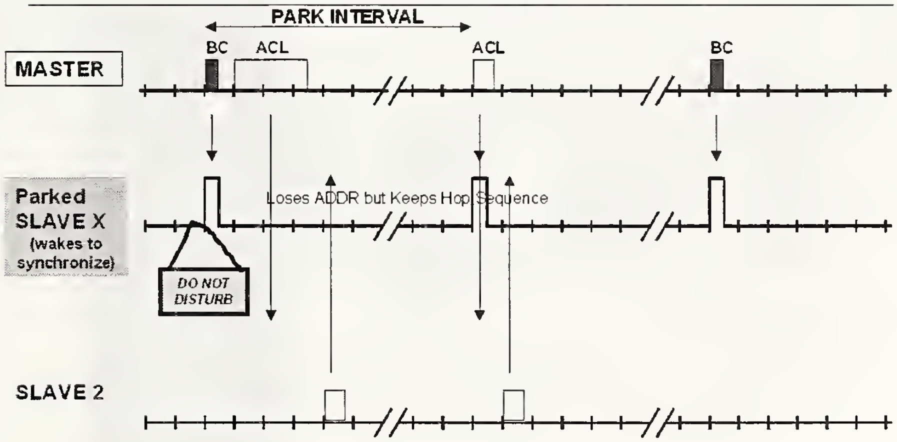
Park Mode



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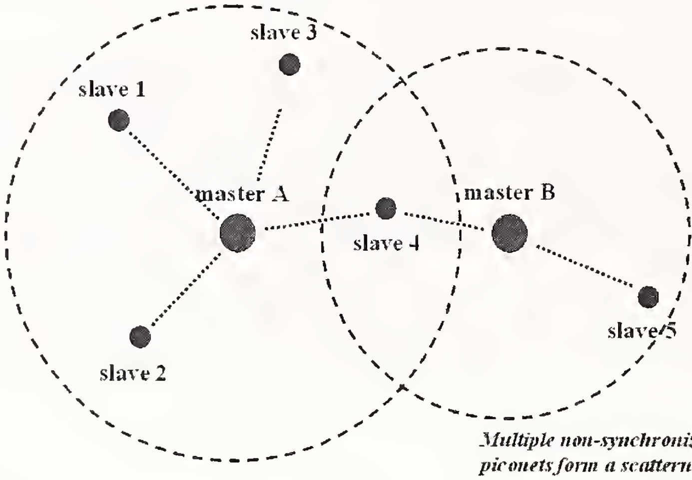
Scatternet



Multiple non-synchronized piconets form a scatternet

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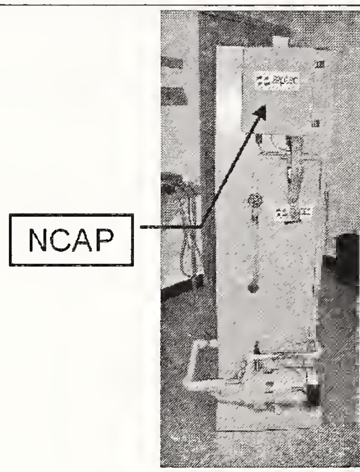
Wireless NCAP Unit

- Watertight
- Small size (8W x 10H x 5D)
- IEEE 802.11b or Bluetooth with Antenna diversity
- Connectorized
- LabView HMI
- Eight 1451 smart sensor inputs using modular plug-in design
  - Vibration
  - Temperature
  - Pressure
  - Flow
  - Etc
- Future Revisions
  - V.90 Modem



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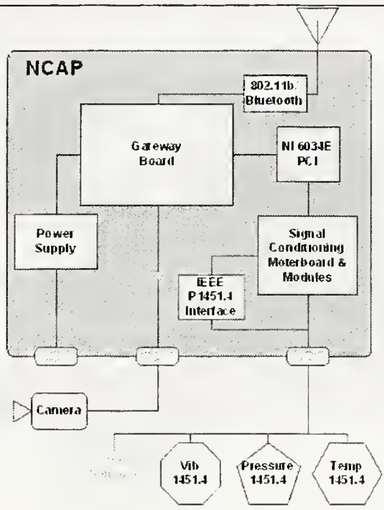
NCAP Architecture



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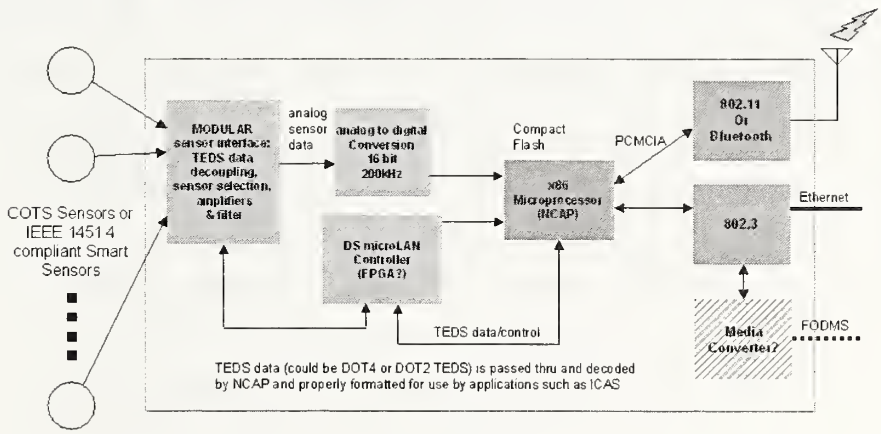
NCAP Block Diagram



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Bluetooth Today (242 products)

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4.3 Synopsis on Wireless Ethernet (IEEE 802.11)

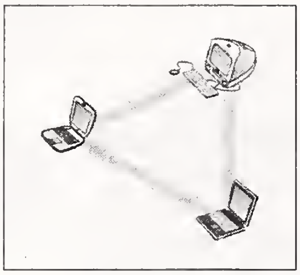
Synopsis on Wireless Ethernet (IEEE 802.11)

James D. Gilsinn
National Institute of Standards & Technology
Intelligent Systems Division
james.gilsinn@nist.gov

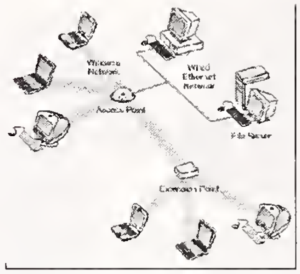
What is IEEE 802.11?

- IEEE 802.11 is an extension of the Ethernet standard (802.3) into wireless communications
- Allows roaming computers to talk to other devices (peer-to-peer) or connect to a wired network (transmitter/receiver)
- IEEE standard allows interoperability between multiple vendor's products

802.11 Network Examples



Peer-to-Peer Network



Transmitter/Receiver
(Wired/Wireless Network)

Pictures from Vicomsoft Web Site, http://www.vicomsoft.com/

IEEE 802.11 Specification

- Original specification 1997, revised 1999
- Speed: 1/2 Mbps
- Operating Range: 10-100m inside, 300m outside
- Power Output: 100mW typical
- Frequency Hopping (FHSS), Direct Sequence (DSSS), Infrared (IrDA)
  - Networks are NOT compatible with one another
- Uses 2.4 GHz ISM band (2.402-2.480 GHz)

802.11 Variations

- IEEE 802.11a
  - Speed: 6-54 Mbps
  - Uses 5 GHz ISM band (5.15-5.35 GHz)
  - Standard approved in 1999, but chip-sets and products only just starting to emerge
  - Recently selected by the Dedicated Short Range Communications (DSRC) Vendors' Consortium as the preferred technology to provide the national interoperability for Public Safety based applications

802.11 Variations (cont'd)

- IEEE 802.11b
  - Speed: 5.5/11 Mbps
  - Direct Sequence Spread Spectrum (DSSS) only
  - Backward compatible with 802.11 devices using DSSS
  - Most common implementation of wireless Ethernet
- IEEE P802.11e
  - Make Quality of Service (QoS) enhancements
- IEEE P802.11f
  - Improve the interoperability of Access Points

802.11 Variations (cont'd)

- IEEE P802.11g
  - Develop higher speed extension for 802.11b standard
  - Speed: > 20 Mbps
- IEEE P802.11h
  - Enhance the 802.11 and 802.11a standards to enable regulatory acceptance of 5 GHz products
- IEEE P802.11i
  - Originally part of P802.11e
  - Improve the security and authentication mechanisms

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802.11 Variations (cont'd)

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802.11 Security

- IEEE 802.11 uses Wired Equivalent Privacy (WEP) algorithm to prevent eavesdropping
- WEP algorithm is self-synchronizing
- 64-bit key (40-bit secret code, 24-bit "init" vector)
  - 128-bit keys seem common in production devices
- Data integrity checked with 32-bit cyclical redundancy check (CRC-32)
- Can be implemented in hardware or software

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802.11 Security (cont'd)

- Uses the same key to encrypt/decrypt message
  - This is a known security problem
- 64-bit WEP has been cracked!
  - Multiple groups have reported being able to crack the secret code from a 64-bit WEP network in 15 minutes
- It is unclear whether the 128-bit encryption would provide much better security!
- Like wired networks, other precautions may be required to ensure data security

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802.11 and Bluetooth

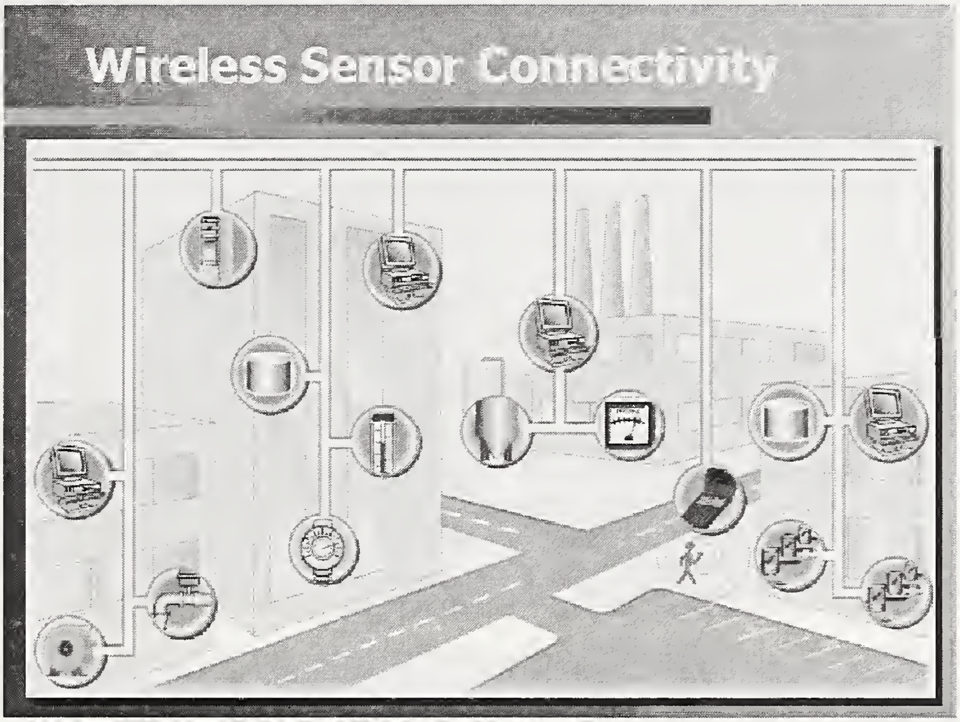
- Tests have shown significant affects of having both IEEE 802.11b and Bluetooth devices in close proximity
  - Good results as long as Bluetooth devices are kept 10m away from the 802.11 Access Point (AP)
  - Worse results when Bluetooth devices are near Station

Summary & References

- 802.11 provides
  - Flexibility
  - Interoperability
  - Upgradability
  - Ease of Use
- Although it has its drawbacks, 802.11 may provide a good extension to industrial Ethernet

- http://www.ieee.org
- http://www.wlana.com
- http://www.wirelessethernet.org
- http://www.itsa.org
- http://www.zdnet.com
- http://www.internetnews.com
- http://www.oreillynet.com
- http://www.vicomsoft.com
- http://www.atheros.com
- http://www.proxim.com
- http://www.cisco.com

4.4 Reliable Wireless Connectivity for Sensing & Control Applications



Industry Quotes

"It's not going to be people... , it's going to be sensors, microcontrollers. Trillions of these will be connected to the Internet."

Scott McNealy, SUN MICROSYSTEMS

"... there will be a day when a person makes use of tens of hundreds of telemetry devices per day without even knowing it."

THE YANKEE GROUP REPORT

AXONN

Industry Quotes

"Everyday devices ... will be connected [to the Internet], reporting on their usage and status. Each of these applications of digital information is approaching an inflection point ..."

Bill Gates, MICROSOFT

AXONN

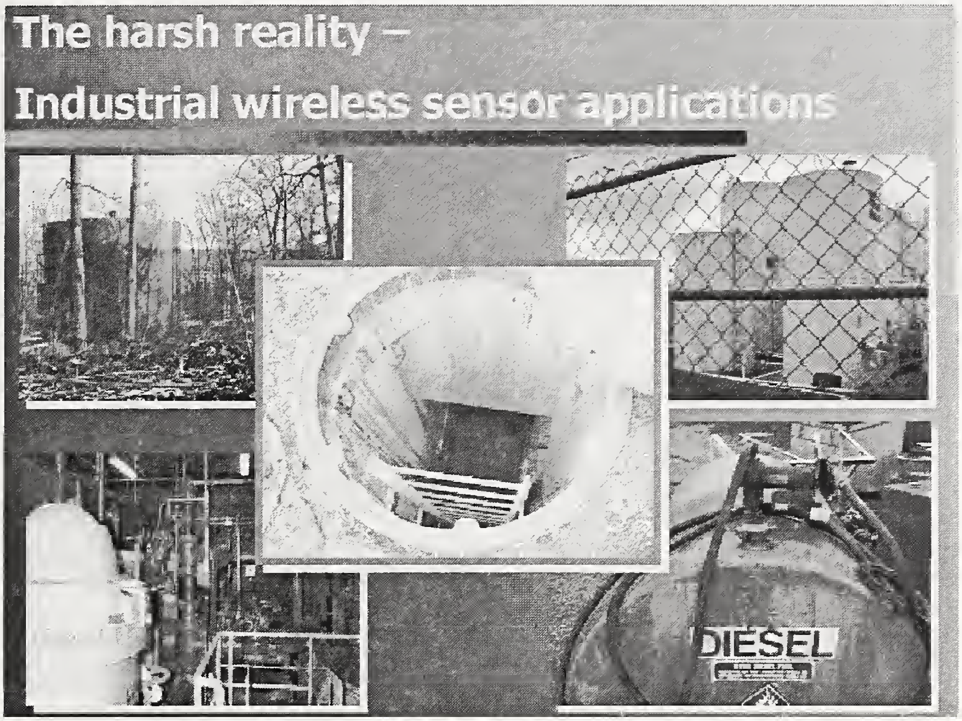
Wireless sensing: cost benefits

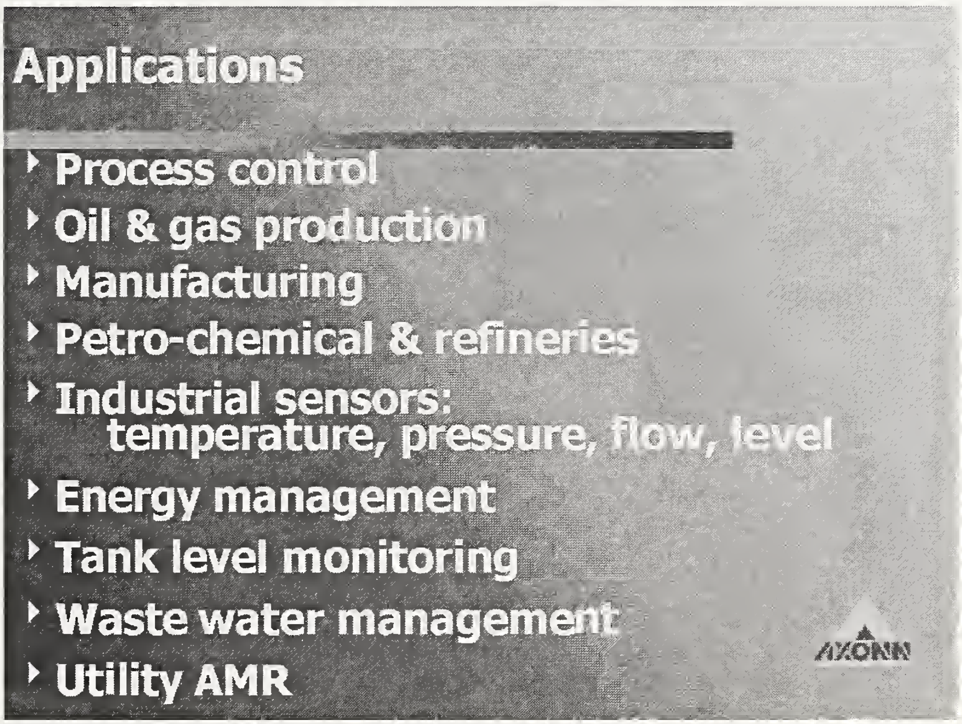
- Wire Installation Cost:

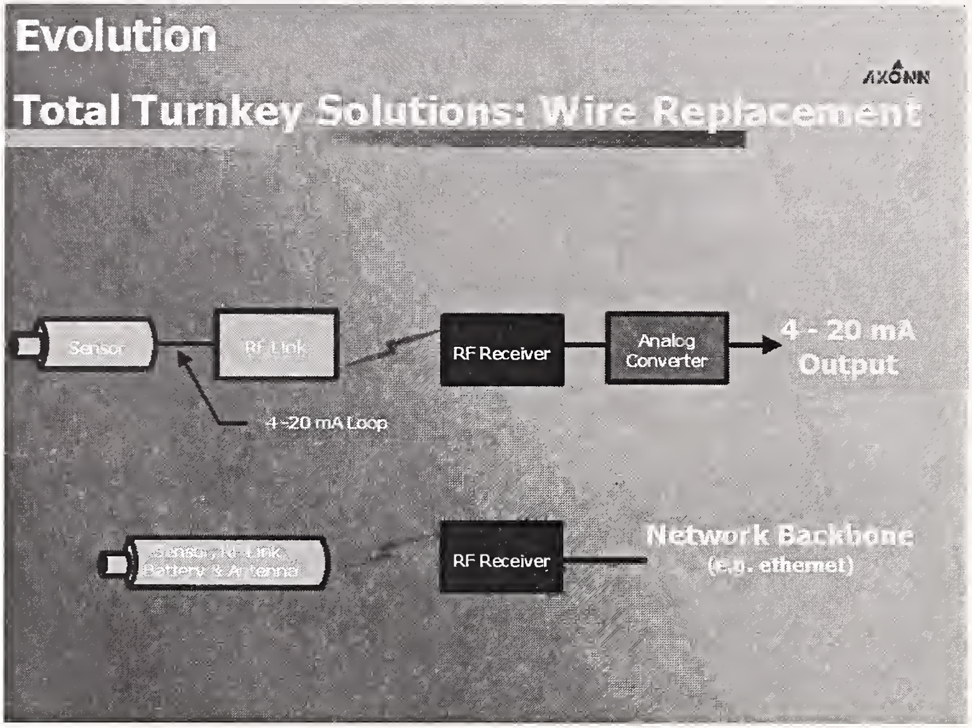
  $20-$50 per foot, more in some environments

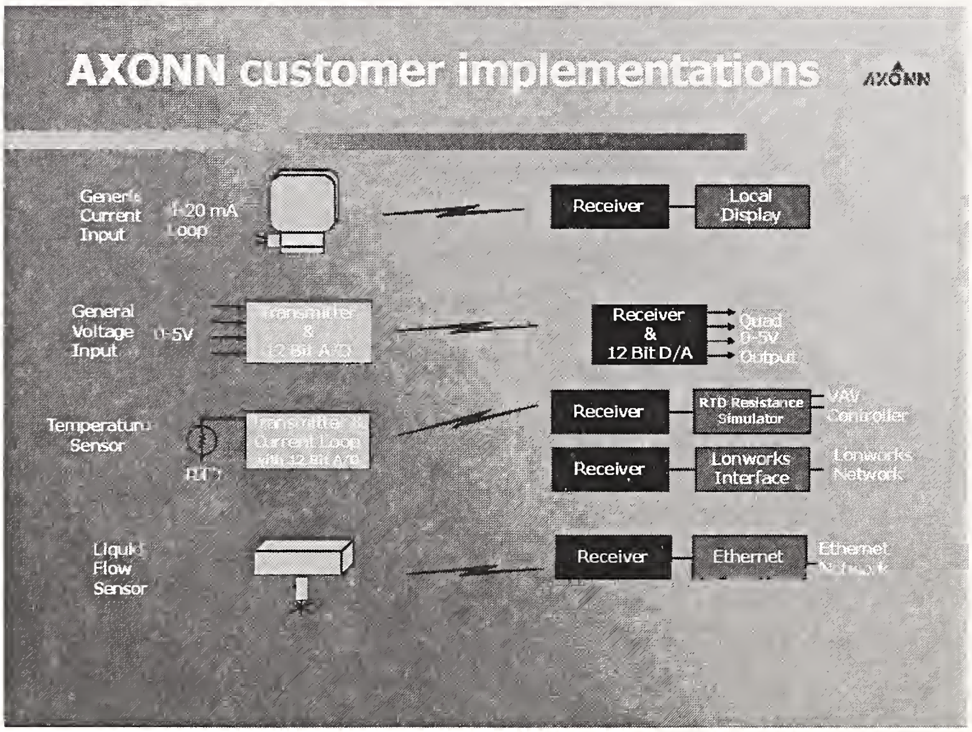
- Often too expensive to wire – data is lost, efficiencies are impeded
- Wireless is easy to install

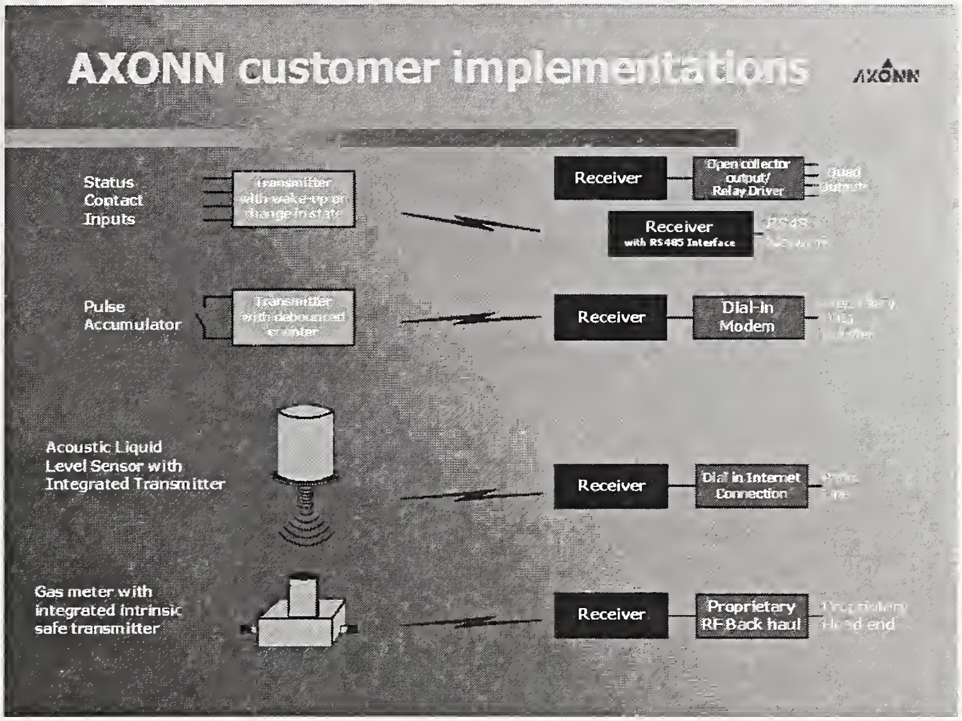
AXONN

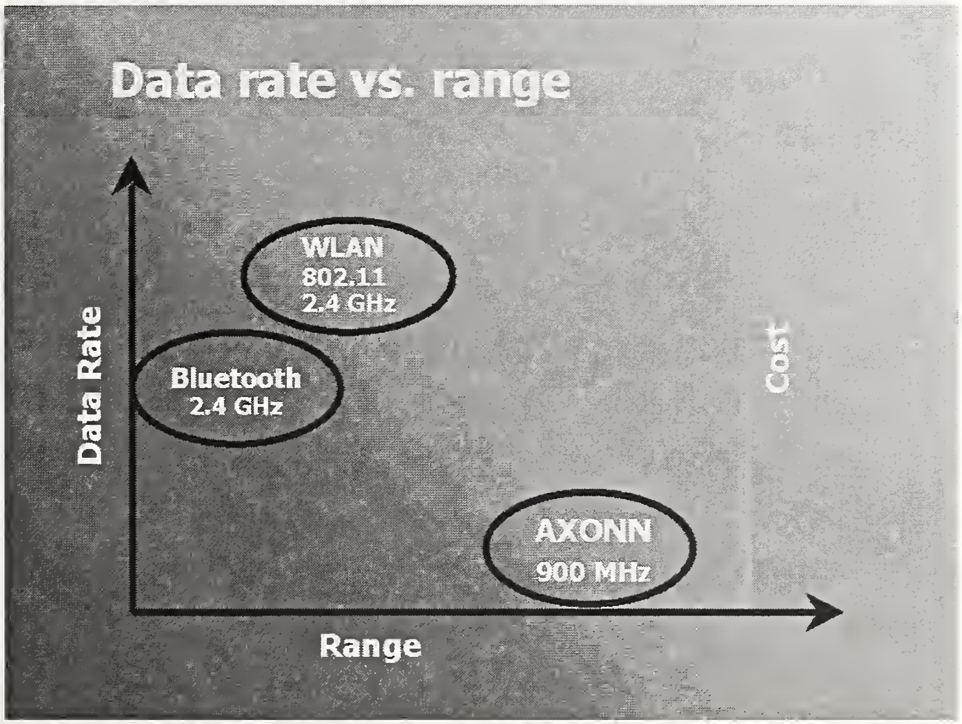

The harsh reality –
Industrial wireless sensor applications
DIESEL


Applications
Process control
Oil & gas production
Manufacturing
Petro-chemical & refineries
Industrial sensors:
temperature, pressure, flow, level
Energy management
Tank level monitoring
Waste water management
Utility AMR
AXONN


Evolution
AXONN
Total Turnkey Solutions: Wire Replacement
Sensor
RF Link
RF Receiver
Analog Converter
4 - 20 mA Output
4-20 mA Loop
RF Receiver
Network Backbone
(e.g. ethernet)


AXONN customer implementations
AXONN
Current
Input
Loop
Receiver
Local Display
General
Voltage
Input
0-5V
Receiver
&
12 Bit D/A
Quad
0-5V
Output
Sensor
Receiver
RTD Resistance Simulator
Receiver
Lonworks Interface
Flow
Sensor
Receiver
Ethernet
Ethernet

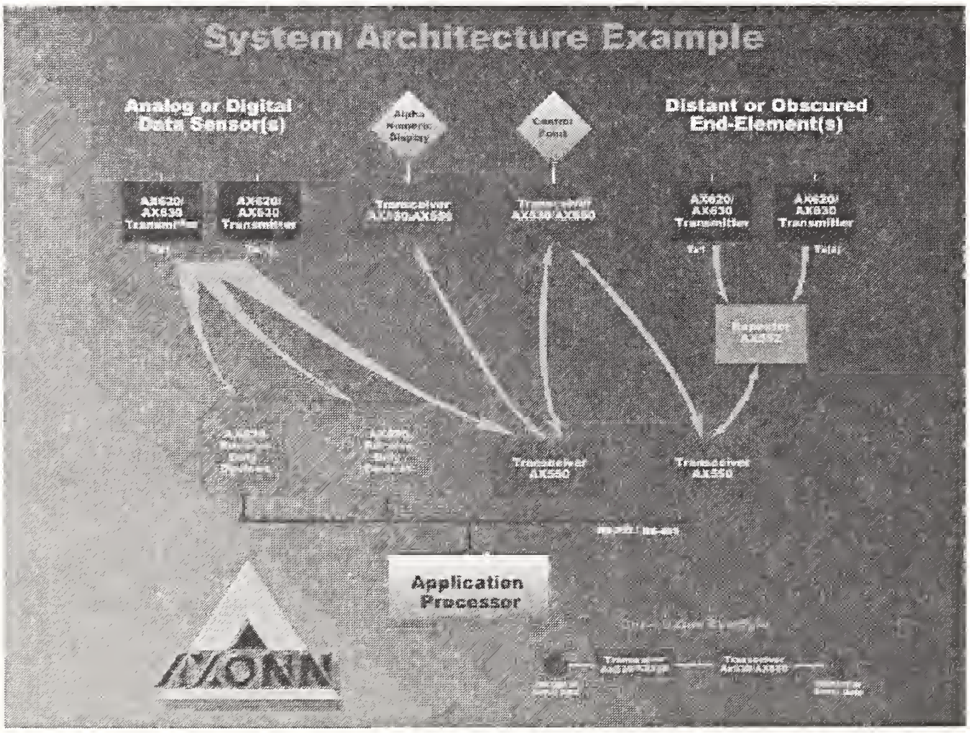

AXONN customer implementations
Status
Contact
Inputs
Receiver
Open collector output/ Relay Driver
Receiver
with RS485 Interface
Pulse
Accumulator
Receiver
Dial-In
Modem
Acoustic Liquid
Level Sensor with
Integrated Transmitter
Receiver
Dial in Internet Connection
Gas meter with
integrated intrinsic
safe transmitter
Receiver
Proprietary
RF Back haul


Data rate vs. range
WLAN
802.11
2.4 GHz
Bluetooth
2.4 GHz
AXONN
900 MHz
Data Rate
Cost
Range

Wireless Sensing: Spread Spectrum Radio Technology Comparison

Technology	WLAN-802.11b	Bluetooth	Axonn 900MHz
Frequency	2.4GHz	2.4GHz	900MHz
SS Modulation	DSSS	FHSS	DSSS
Data Rate	High 5-11 Mbps	High 1Mbps	Low 19.2Kbps
Receiver Sensitivity	Various	-70dBm	-110dBm
Radio Range (maximum: RX at 8ft)	100M-300M	10M-100M	1.2mile
Temp Range	N/A	N/A	-40C to +85C
Band Crowding	High*	High*	Medium
Building Penetration & Propagation	Low	Low	Medium
Standardized	Yes	Yes	De-Facto
ISM Band	Yes	Yes	Yes
Multipoint Coexistence Capability	Low	Medium	High
Vendor Diversity	Yes	Yes	Proprietary Multi Sourced
Target Application	Wireless Ethernet	PANs/Mobility	Remote Monitoring

* Hundreds of millions of devices are forecasted to be in use by end 2002 (Source: www.bluetooth.com)



900MHz Wireless Technology Highlights

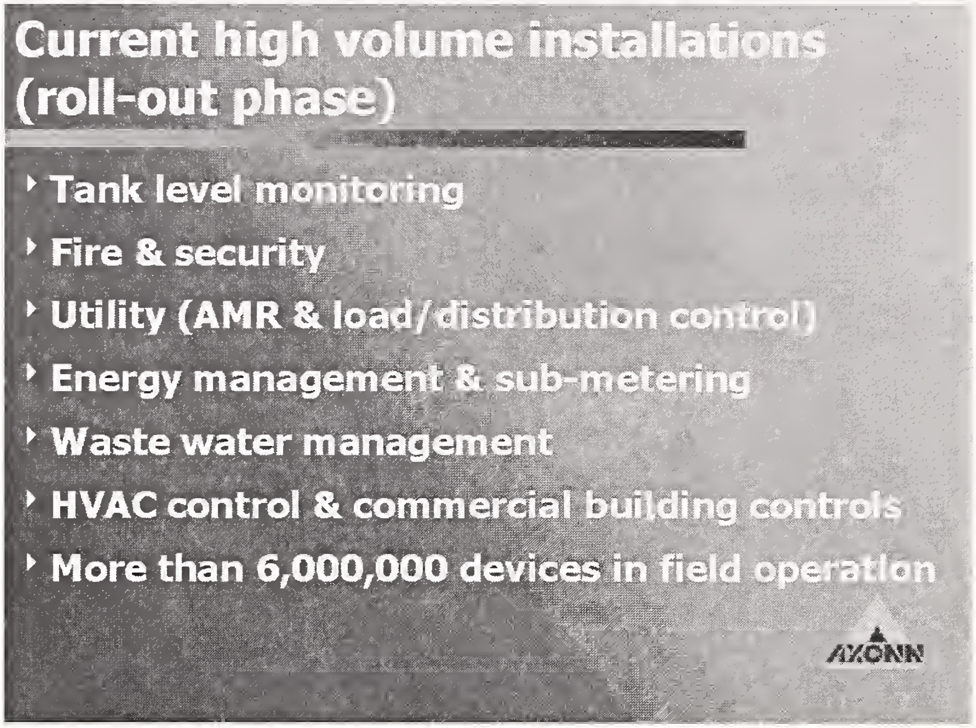
- 902--928MHz in 8 Channels (programmable 3MHz steps).
- CDMA & TDMA Operation.
- Unlicensed ISM Band Operation: Unrestricted Transmission (update) Rate.
- FCC Approved Now.
- 868MHz European version: Modular compatibility.
- 50-250mW Output Power.
- 1 mile range (LOS).
- Receive Sensitivity – 110dBm @ 19.2Kbps data rate.
- DSP Based Anti-Jam & Interference Rejection.
- Intrinsically Safe RF Transmitter Endpoints: Class I, Div I.
- Integrated Antenna (external antennae optional)
- Battery operated transmitters (Life: 7years for 1min supervisory for 3Volt LiMnO2 battery)

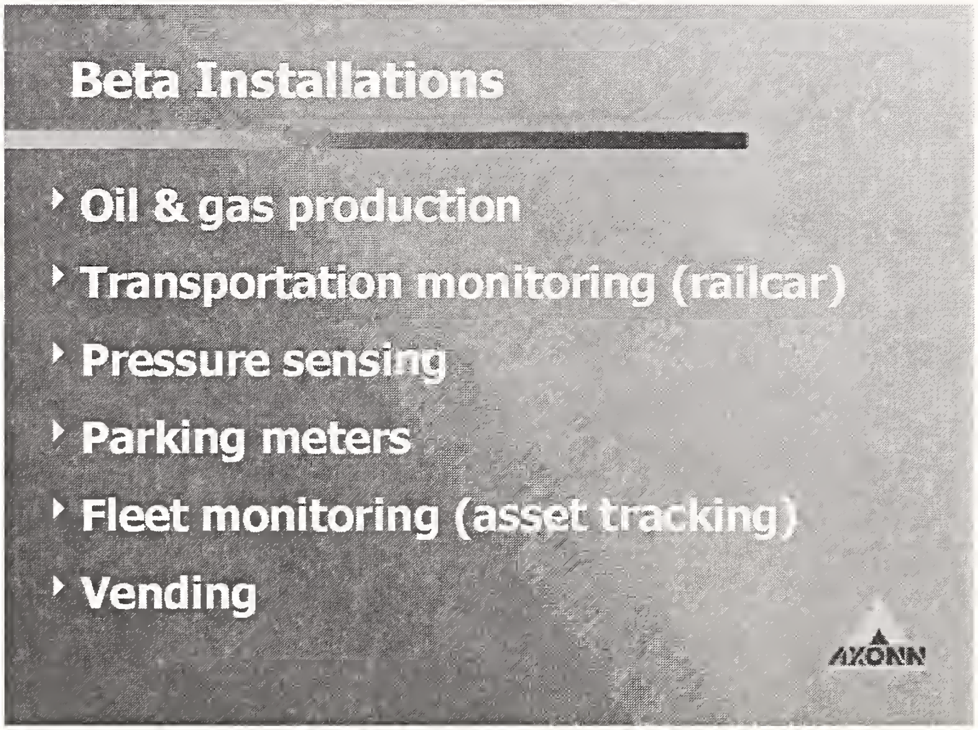
AXONN

900MHz Wireless Technology Highlights

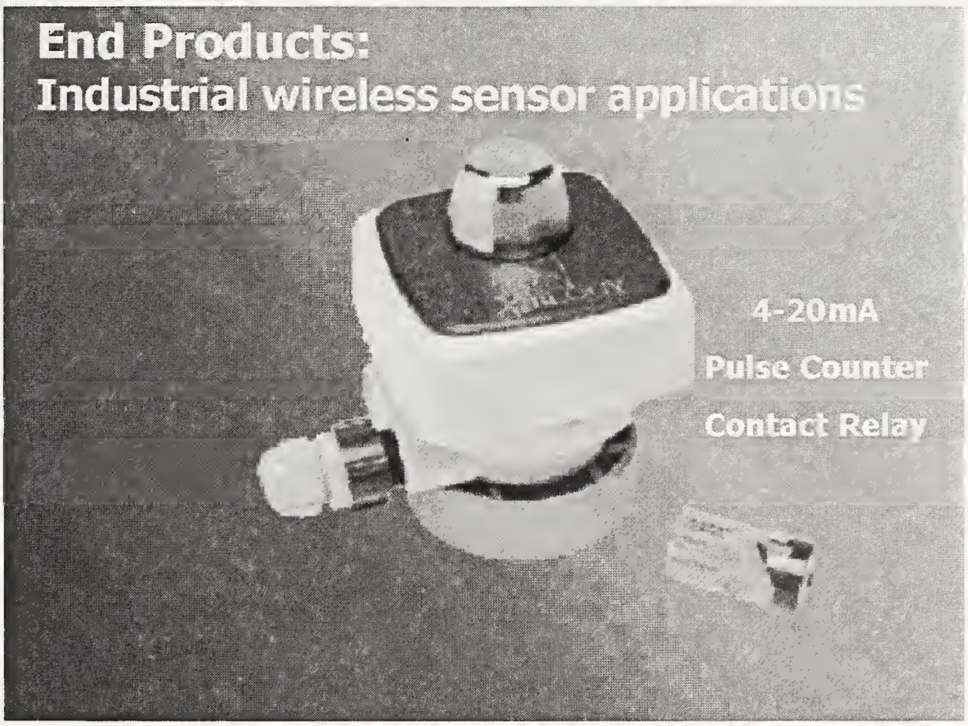
- Industrial Temperature Range: -40C to +85C.
- RF communications redundancy options incorporated
- Modular Radio, or Plug & Play options
- Conform to NFPA & FAA "Wire Equivalency" Requirements
- Technology Foundation:
  - 60 patents & Patents Pending.
  - Full Custom Mixed signal ASICS (multi-sourced)
- Comprehensive System Architecture
- Proven in the field now

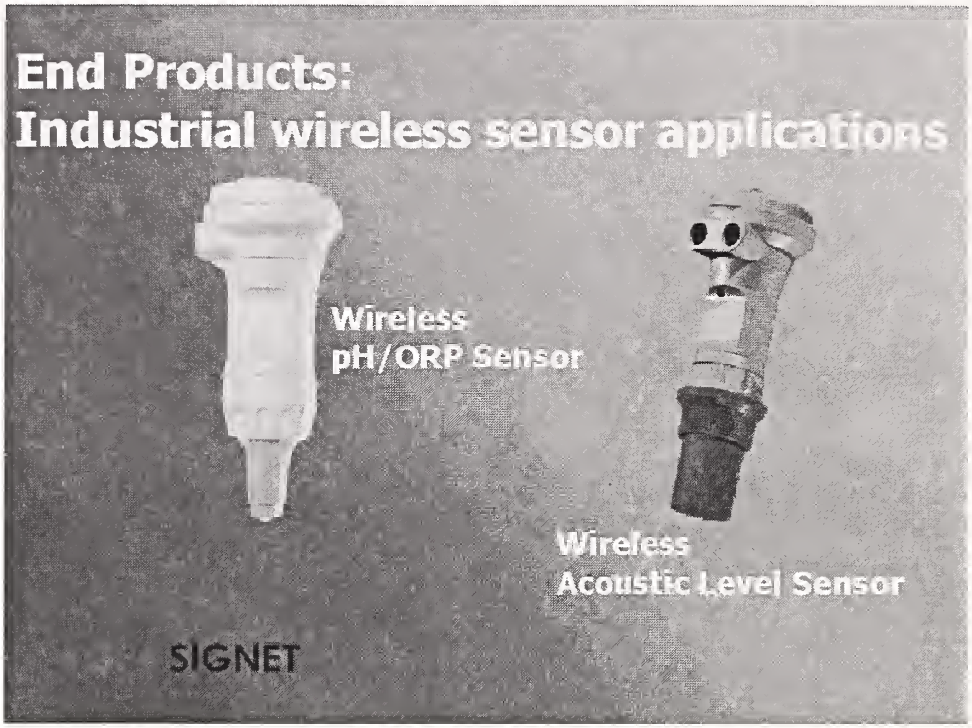
AXONN

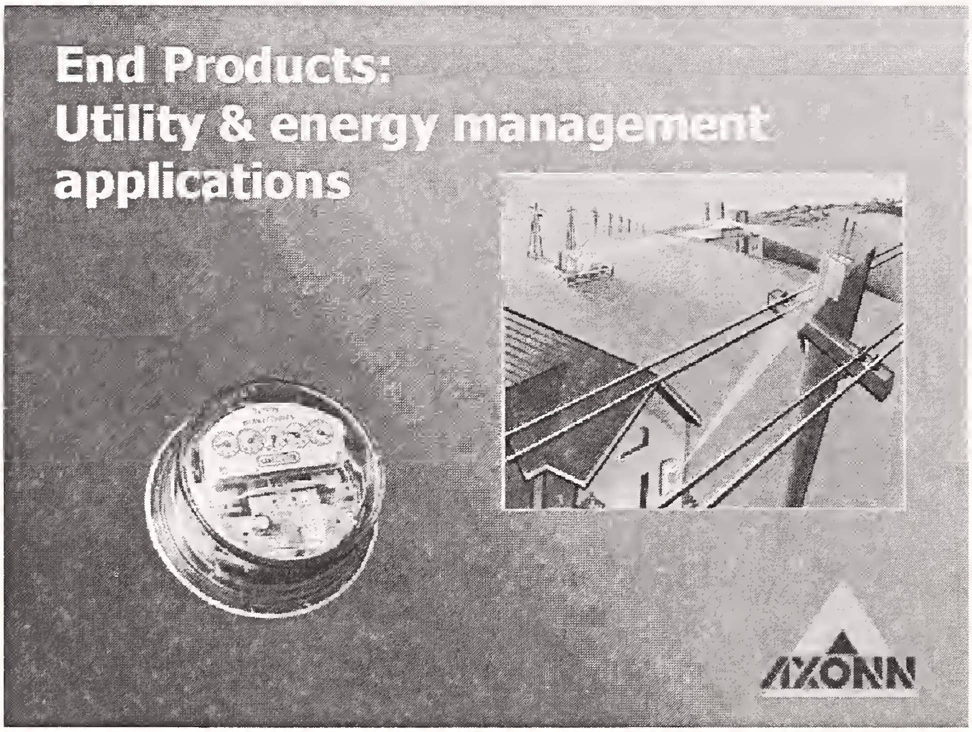

Current high volume installations (roll-out phase)
Tank level monitoring
Fire & security
Utility (AMR & load/distribution control)
Energy management & sub-metering
Waste water management
HVAC control & commercial building controls
More than 6,000,000 devices in field operation
AXONN

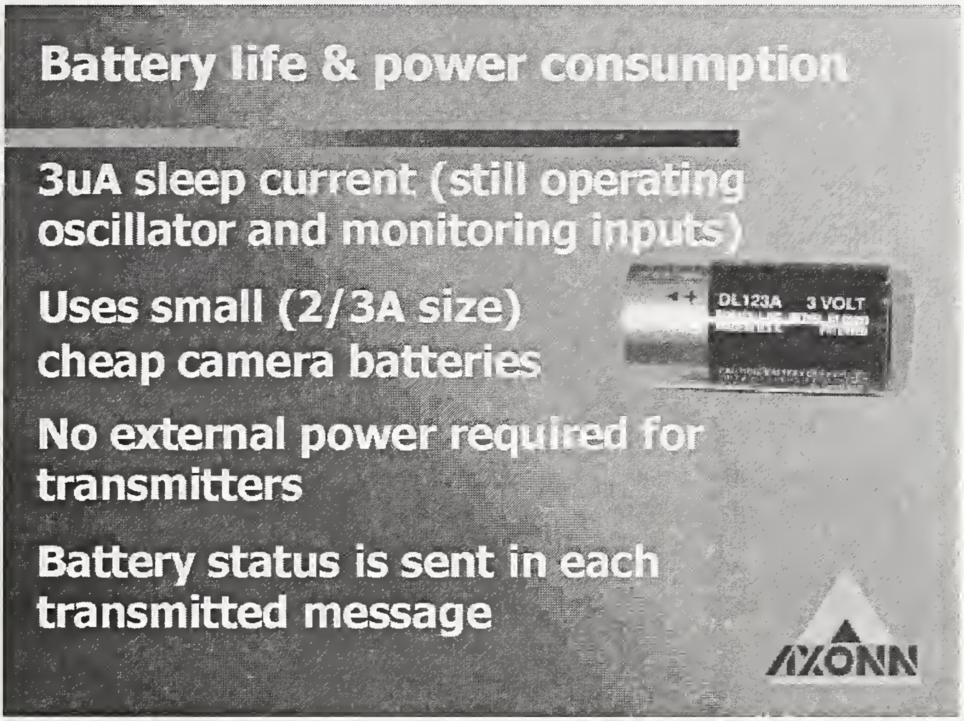

Beta Installations
Oil & gas production
Transportation monitoring (railcar)
Pressure sensing
Parking meters
Fleet monitoring (asset tracking)
Vending
AXONN

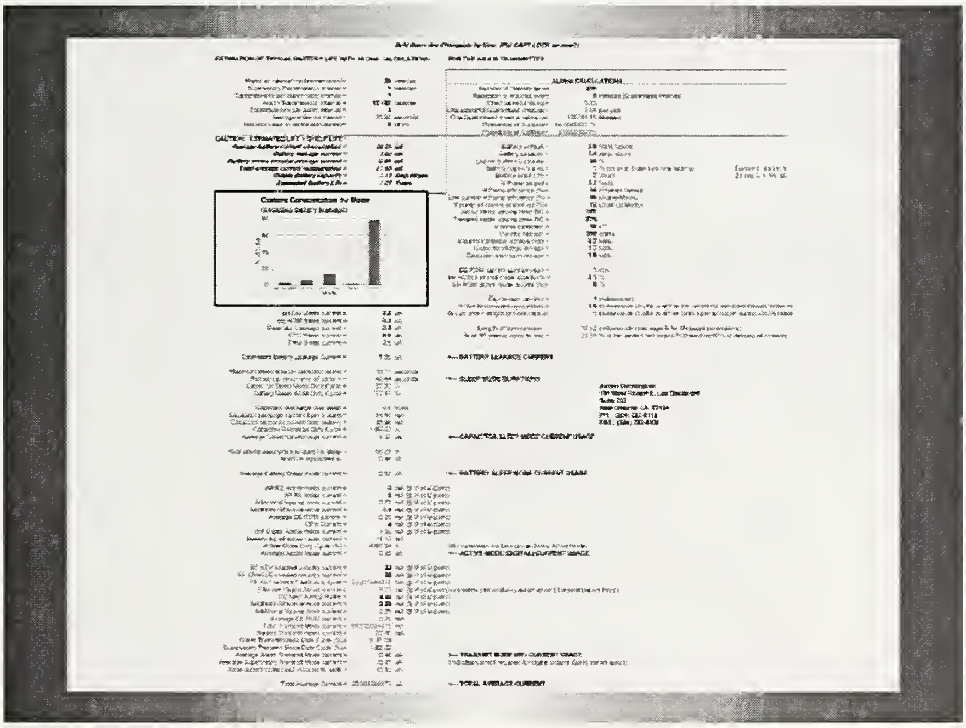

End products in use
Robertshaw

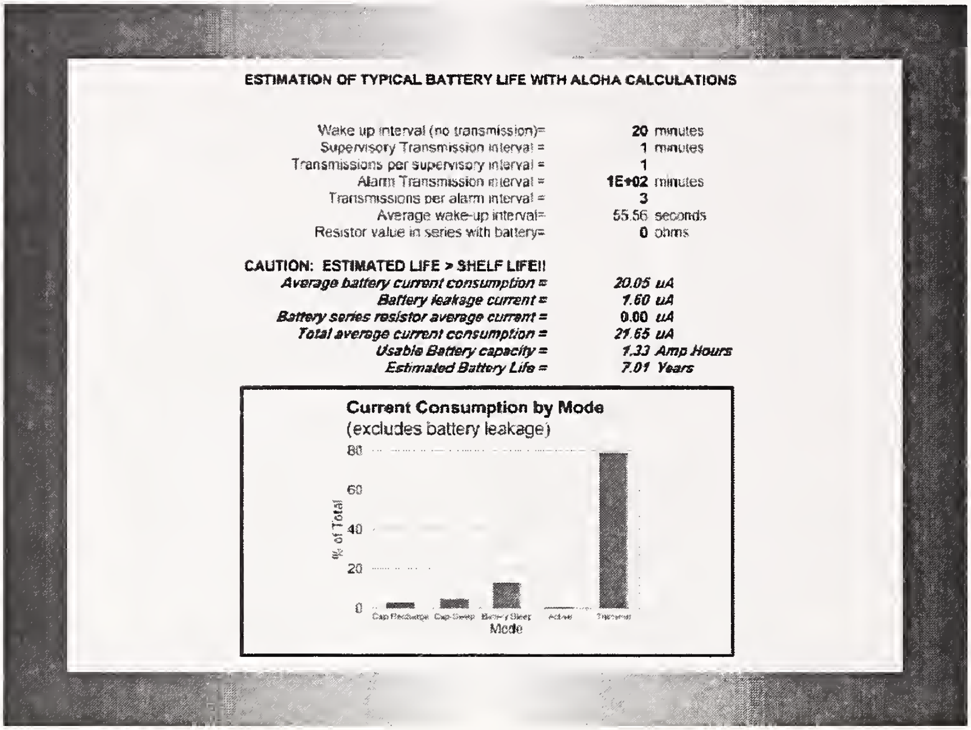

End Products:
Industrial wireless sensor applications
4-20mA
Pulse Counter
Contact Relay

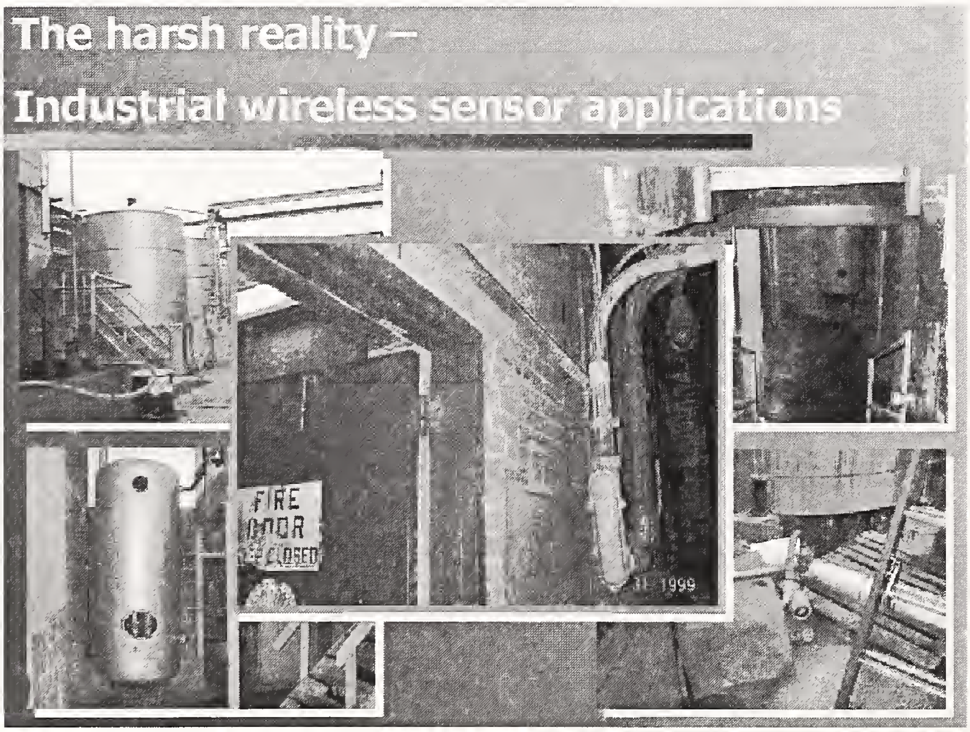

End Products:
Industrial wireless sensor applications
Wireless
pH/ORP Sensor
Wireless
Acoustic Level Sensor
SIGNET

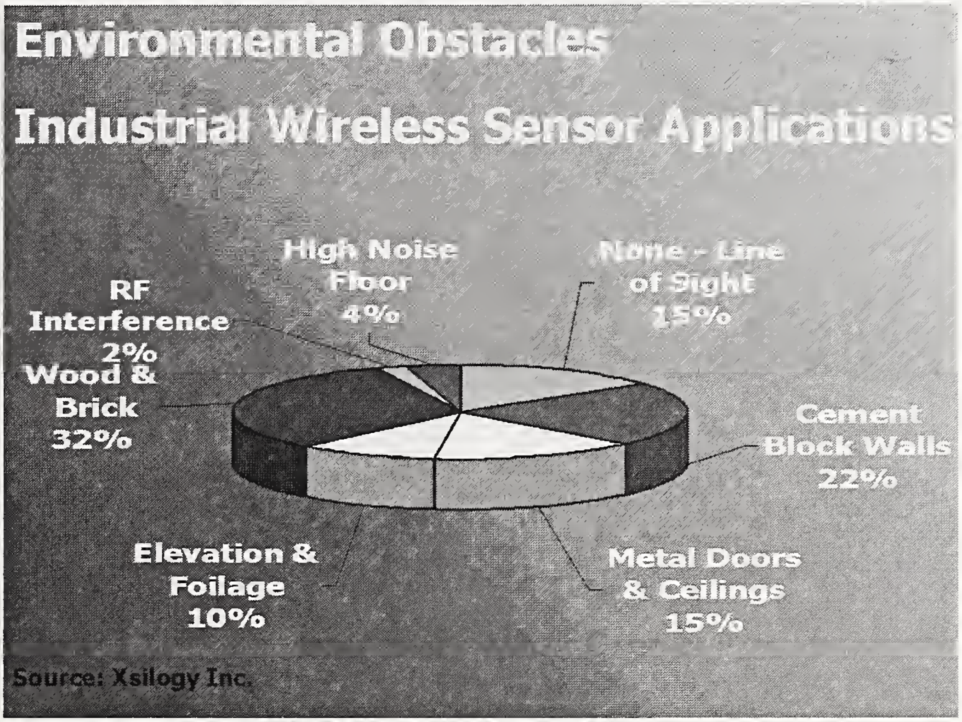

End Products:
Utility & energy management applications
AXONN

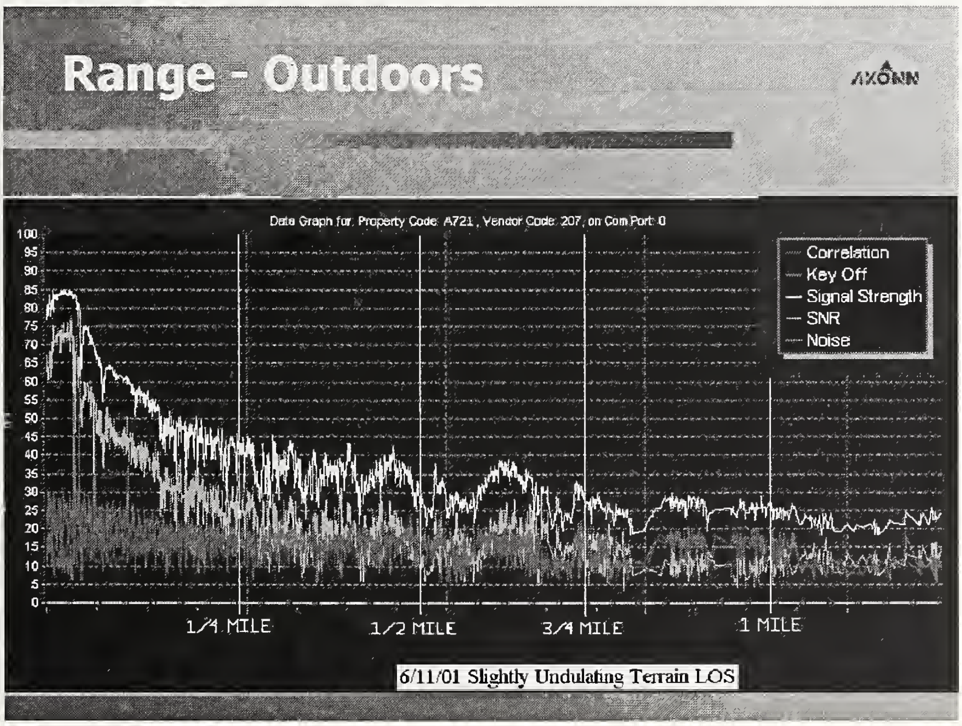

Battery life & power consumption
3uA sleep current (still operating oscillator and monitoring inputs)
Uses small (2/3A size) cheap camera batteries
DL123A 3 VOLT
No external power required for transmitters
Battery status is sent in each transmitted message
AXONN



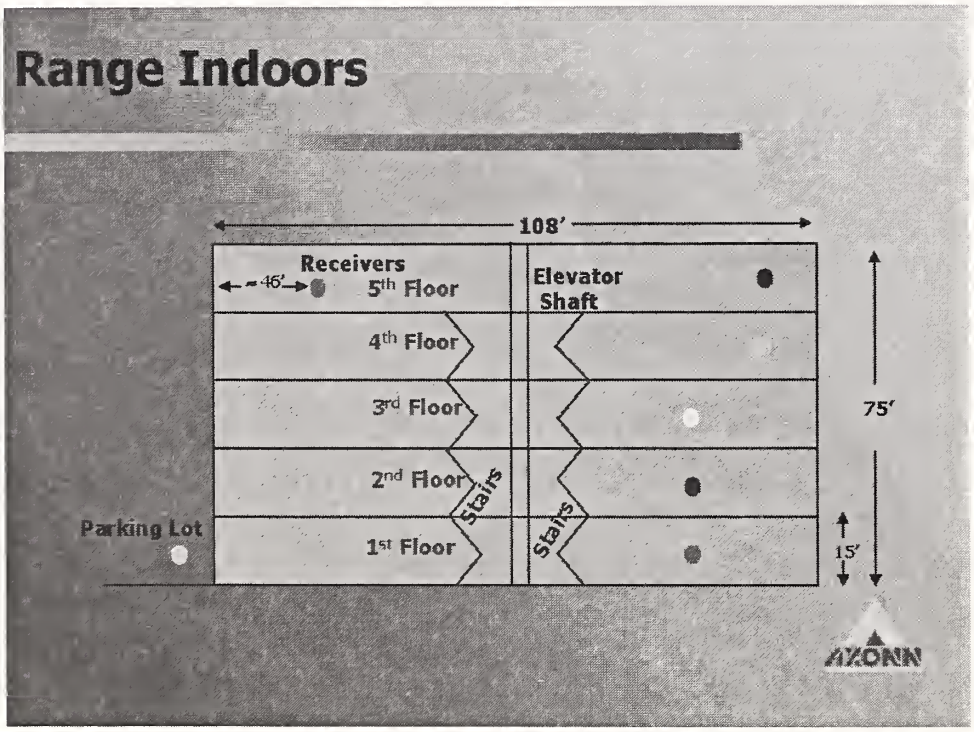

ESTIMATION OF TYPICAL BATTERY LIFE WITH ALOHA CALCULATIONS
Wake up interval (no transmission)= 20 minutes
Supervisory Transmission interval = 1 minutes
Transmissions per supervisory interval = 1
Alarm Transmission interval = 1E+02 minutes
Transmissions per alarm interval = 3
Average wake-up interval= 55.56 seconds
Resistor value in series with battery= 0 ohms
CAUTION: ESTIMATED LIFE > SHELF LIFE!!
Average battery current consumption = 20.05 uA
Battery leakage current = 1.60 uA
Battery series resistor average current = 0.00 uA
Total average current consumption = 21.65 uA
Usable Battery capacity = 1.33 Amp Hours
Estimated Battery Life = 7.01 Years
Current Consumption by Mode
(excludes battery leakage)
80
60
40
20
0
% of Total
Mode


The harsh reality –
Industrial wireless sensor applications
FIRE
DOOR


Environmental Obstacles
Industrial Wireless Sensor Applications
High Noise Floor 4%
None - Line of Sight 15%
RF Interference 2%
Wood & Brick 32%
Cement Block Walls 22%
Elevation & Foilage 10%
Metal Doors & Ceilings 15%
Source: Xsilogy Inc.


Range - Outdoors
AXONN
Data Graph for: Property Code: A721, Vendor Code: 207, on Com Port: 0
Correlation
Key Off
Signal Strength
SNR
Noise
1/4 MILE
1/2 MILE
3/4 MILE
1 MILE
6/11/01 Slightly Undulating Terrain LOS


Construction 2000


Range Indoors
108'
Receivers
46'
5th Floor
Elevator
Shaft
4th Floor
3rd Floor
75'
2nd Floor
Stairs
Stairs
Parking Lot
1st Floor
15'
AXONN

Reliability: Operation

- Operating Temperature Range

  -40C to +85C

- Intrinsic Safety: Class I, DIV I

  Needed for many sensing end-point applications

AXONN

Reliability: RF Communication

Multiple redundancy approaches used for RF communication reliability.

- ✓ Redundant transmissions:

  Burst of transmissions randomly spaced in time

- ✓ Redundant receivers:

  Overlapping coverage

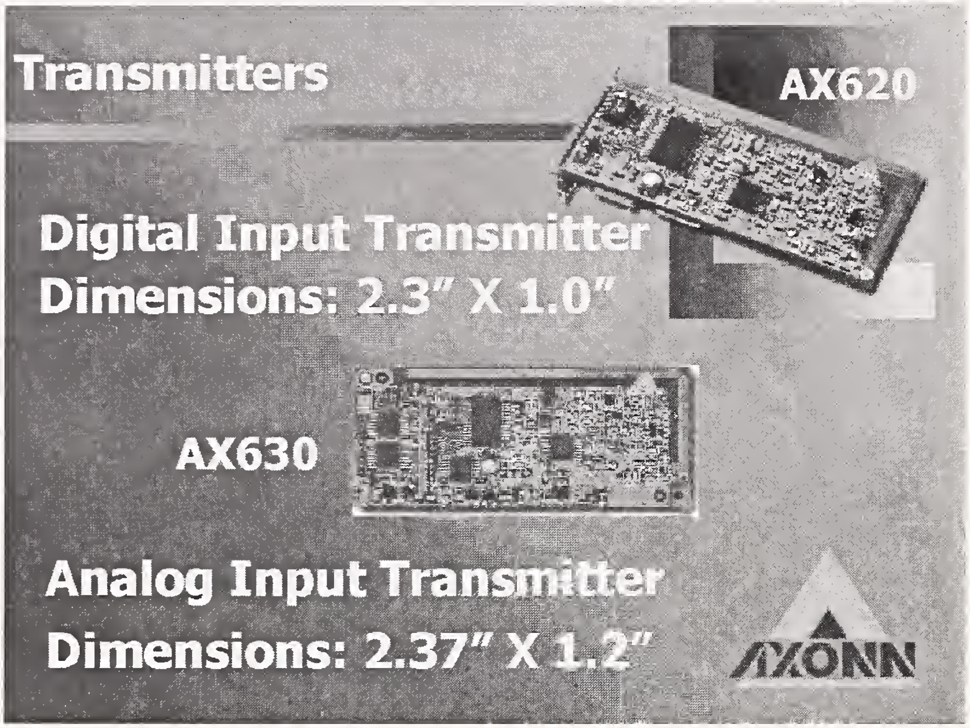
- ✓ Antenna Diversity:

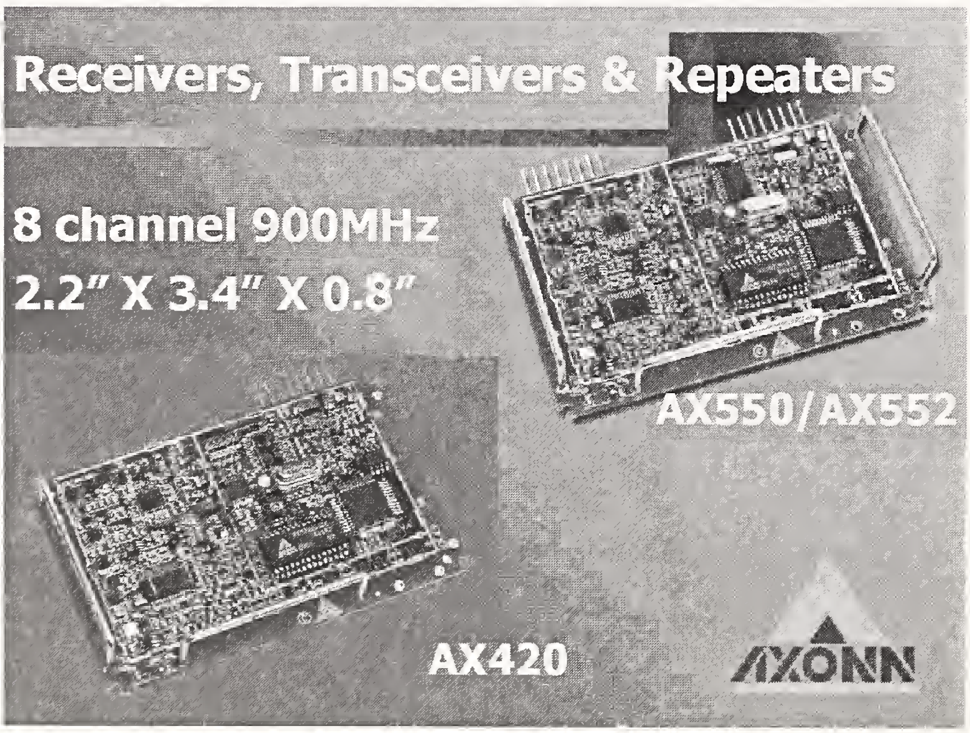
  Reduce fading effects

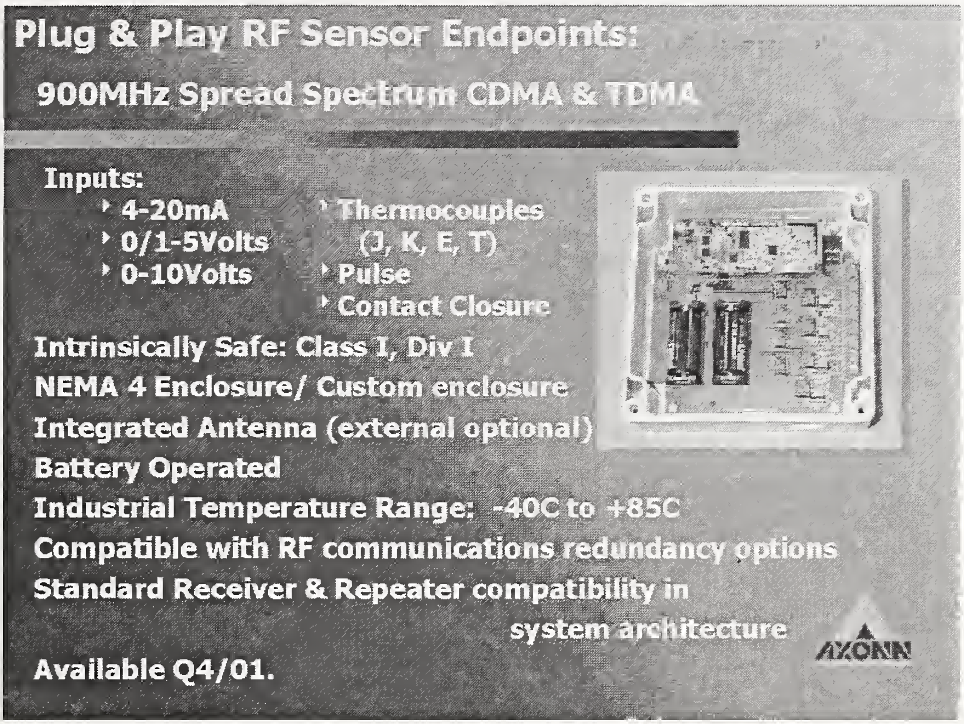
- ✓ Frequency Diversity:

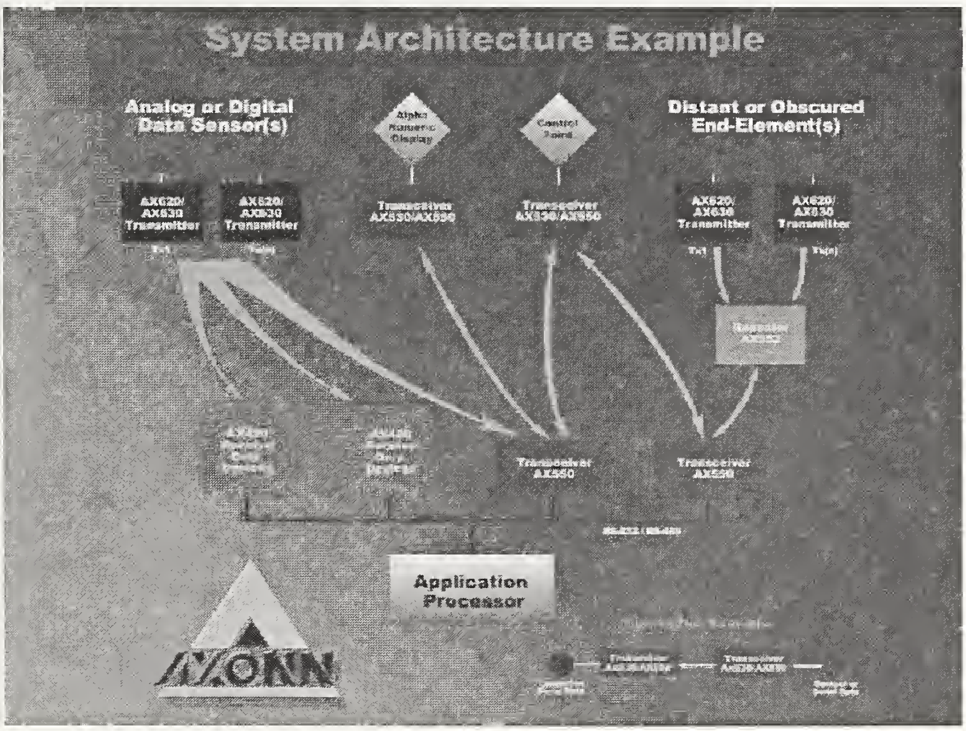
  Multiple frequencies to circumvent jamming sources

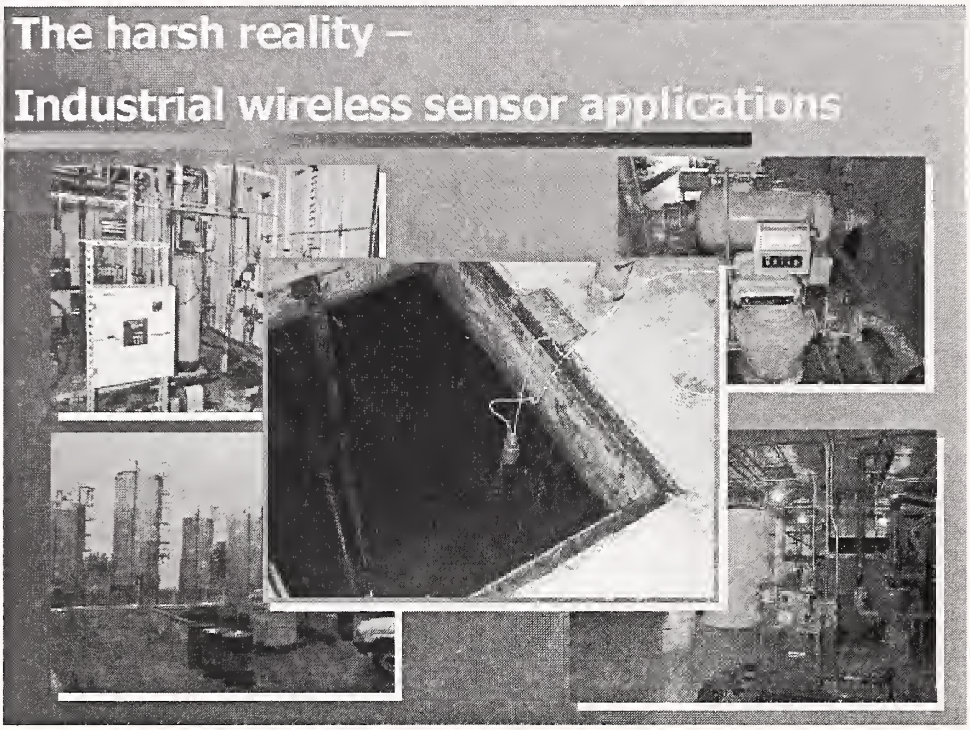
AXONN

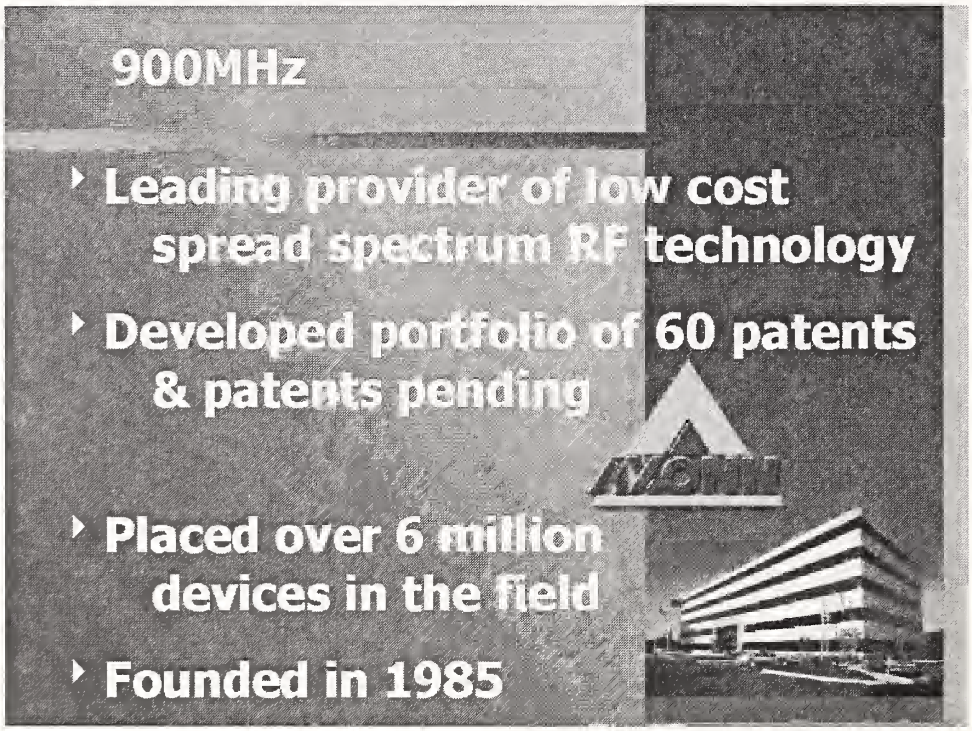

Transmitters
AX620
Digital Input Transmitter
Dimensions: 2.3" X 1.0"
AX630
Analog Input Transmitter
Dimensions: 2.37" X 1.2"
AXONN

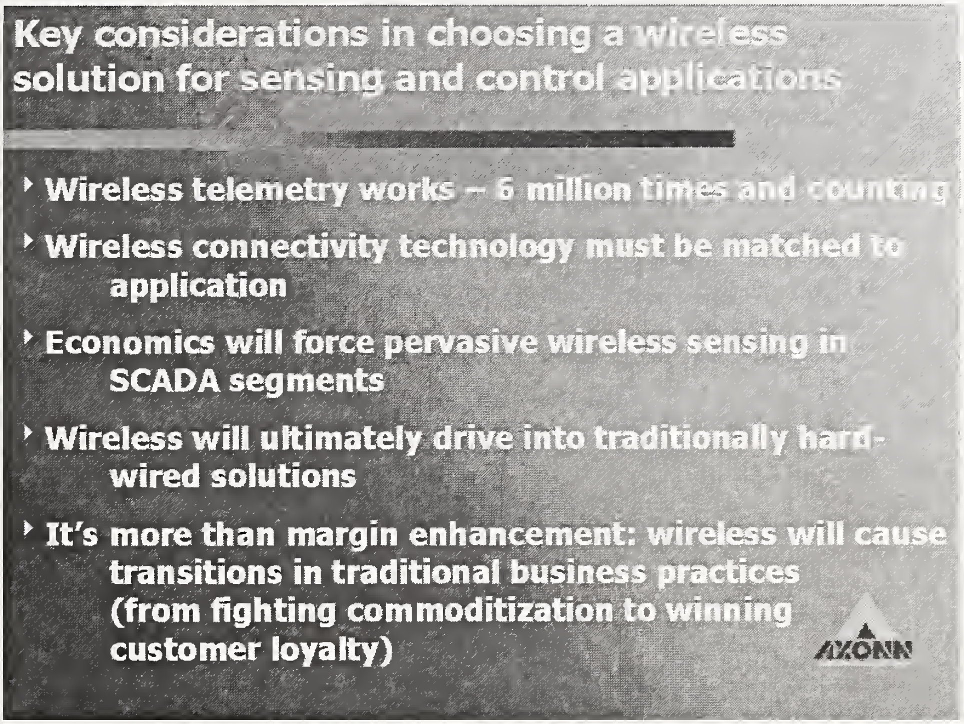

Receivers, Transceivers & Repeaters
8 channel 900MHz
2.2" X 3.4" X 0.8"
AX550/AX552
AX420
AXONN

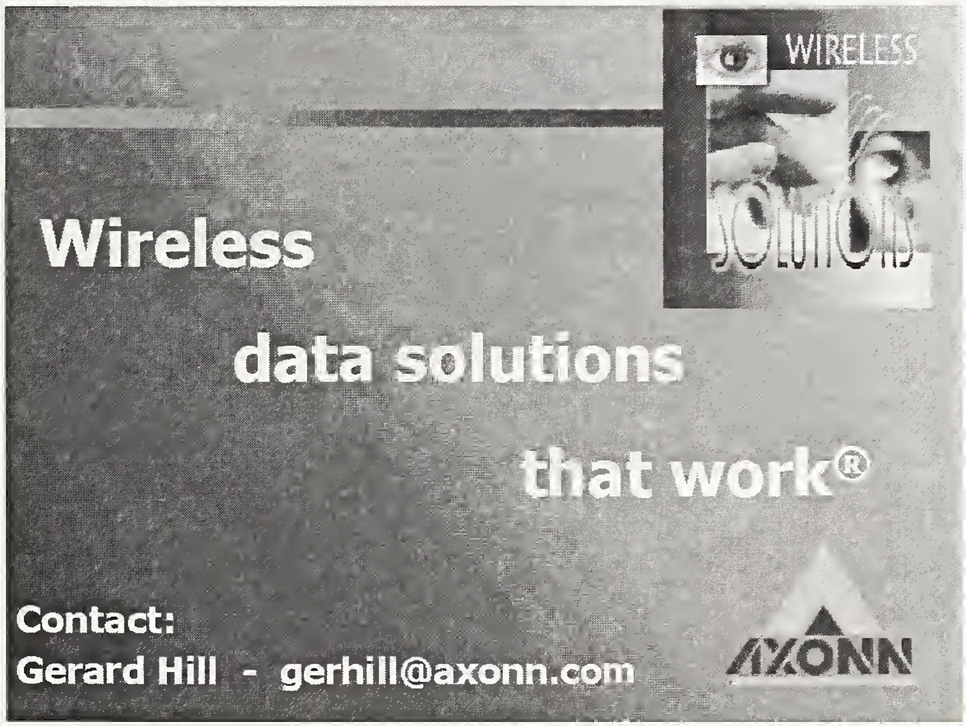

Plug & Play RF Sensor Endpoints:
900MHz Spread Spectrum CDMA & TDMA
Inputs:
4-20mA
0/1-5Volts
0-10Volts
Thermocouples (J, K, E, T)
Pulse
Contact Closure
Intrinsically Safe: Class I, Div I
NEMA 4 Enclosure/ Custom enclosure
Integrated Antenna (external optional)
Battery Operated
Industrial Temperature Range: -40C to +85C
Compatible with RF communications redundancy options
Standard Receiver & Repeater compatibility in system architecture
Available Q4/01.
AXONN


System Architecture Example
Analog or Digital Data Sensor(s)
Distant or Obscured End-Element(s)
AX620/ AX630 Transmitter
AX620/ AX630 Transmitter
Transceiver AX530/AX550
Transceiver AX530/AX550
AX620/ AX630 Transmitter
AX620/ AX630 Transmitter
Transceiver AX550
Transceiver AX550
Application Processor
AXONN


The harsh reality –
Industrial wireless sensor applications


900MHz
Leading provider of low cost spread spectrum RF technology
Developed portfolio of 60 patents & patents pending
Placed over 6 million devices in the field
Founded in 1985


Key considerations in choosing a wireless solution for sensing and control applications
Wireless telemetry works – 6 million times and counting
Wireless connectivity technology must be matched to application
Economics will force pervasive wireless sensing in SCADA segments
Wireless will ultimately drive into traditionally hard-wired solutions
It's more than margin enhancement: wireless will cause transitions in traditional business practices (from fighting commoditization to winning customer loyalty)
AXONN


WIRELESS
SOLUTIONS
Wireless
data solutions
that work®
Contact:
Gerard Hill - gerhill@axonn.com
AXONN

4.5 IEEE 802.15.4 Low Rate Personal Area Networks

NSF Sponsored Workshop on Tether-free Technologies for e-Manufacturing and e-Maintenance/Service

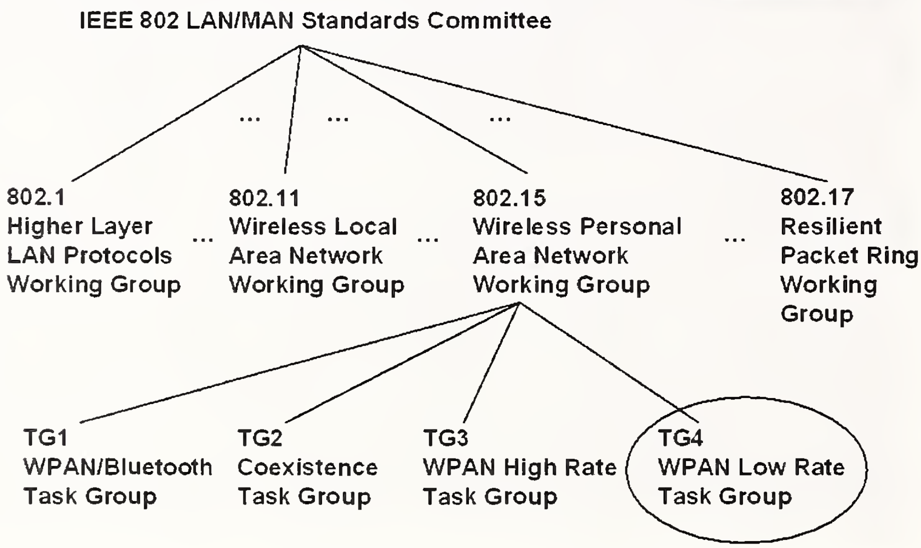
IEEE 802.15.4 Low Rate Wireless Personal Area Networks

Ed Callaway
Florida Communication Research Lab
Motorola Labs
ed.callaway@motorola.com

UWM-IMS | *01 October 2001* | Ed Callaway

IEEE What?

Center for Intelligent Maintenance Systems
ims



UWM-IMS 2 | *01 October 2001* | Ed Callaway

Now in Development ...

Center for Intelligent Maintenance Systems
ims

A low-rate wireless personal area network communications protocol that:

-Supports multiple network types,

-Has long battery life (months or years from a AAA cell)

-Is low cost

For systems with moderate data throughput (< 250 kb/s) and QoS requirements.

UWM-IMS 3 | *01 October 2001* | Ed Callaway

MAC Features

Center for Intelligent Maintenance Systems
ims

- Supports star & peer-peer topologies
  - Master/slave, point to any point, cluster tree, etc.
- Access is slotted CSMA-CA
- Data rates of 31.25 kb/s & 250 kb/s
- Optional use of network beacons
- Optional time slots for low latency transfer
- Super-frame is contention based

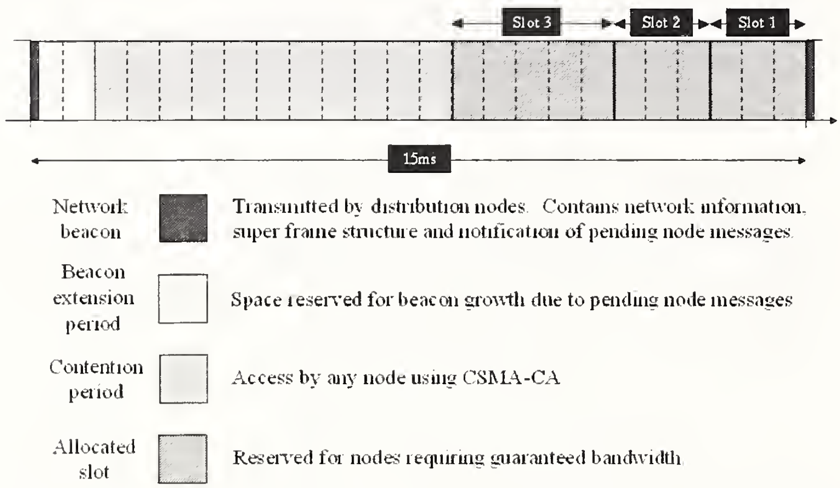
UWM-IMS 4 | *01 October 2001* | Ed Callaway

Node Types

- Distribution node
  - Controls the network topology at that node
  - Master/coordinator or mediation device
    - Stores routing information
  - Talks to other distribution and slave nodes
- Slave node
  - Cannot control the network
  - Very simple implementation
    - Does not store routing information
  - Talks only to a distribution node

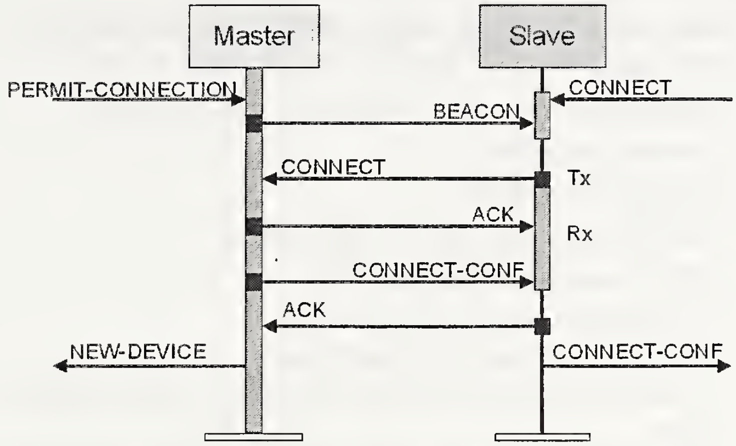
UWM-IMS 5 *01 October 2001* Ed Callaway

Optional Super Frame Structure



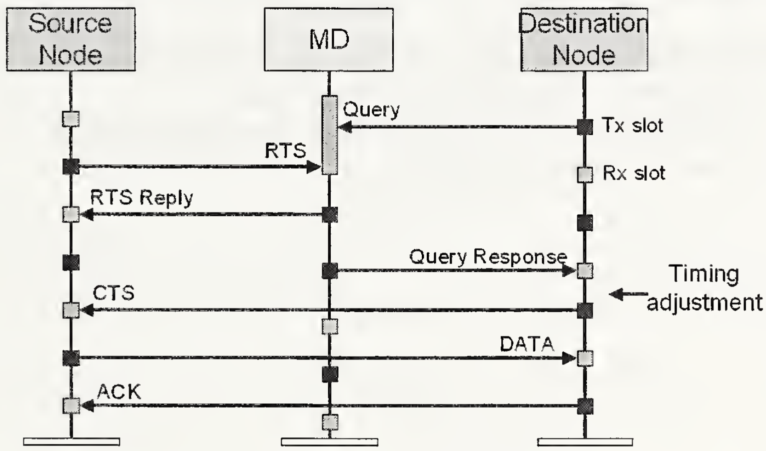
UWM-IMS 6 *01 October 2001* Ed Callaway

Master/Slave: Network Connection



UWM-IMS 7 | *01 October 2001* | Ed Callaway

Mediation Device Operation



... Solves synchronization problem for low cost, low duty cycle peer-peer systems

UWM-IMS 8 | *01 October 2001* | Ed Callaway

PHY Features

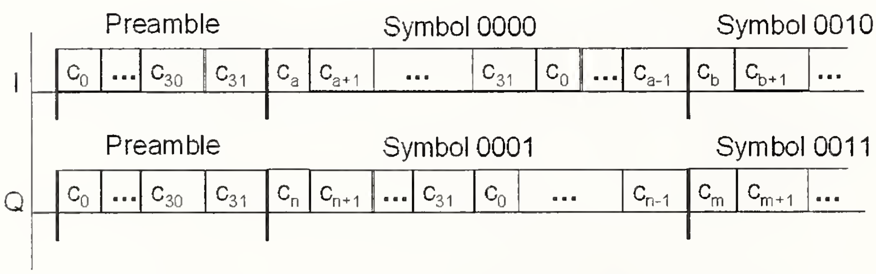
- 31.25 and 250 kb/s operation
- DSSS with low chip rate (1 MHz) for low power operation
- O-QPSK, for constant envelope modulation
  - Simple, low-cost PA
- Orthogonal coding
  - Greater range for a given output power
- 5 MHz channel separation
  - 16 channels in the 2.4 GHz band
  - 5 channels in the U.S. 915 MHz band
  - 1 channel (at lower data rates) in the European 866 MHz band
  - Eases channel filter requirements to lower die size & cost

UWM-IMS 9 *01 October 2001* Ed Callaway

Principle of Code Phase Shift Keying

The starting position of a single pn sequence is modulated with the transmitted data

- Multiple bits may be sent in a single symbol time → better battery life



UWM-IMS 10 *01 October 2001* Ed Callaway

For Further Information

Center for Intelligent Maintenance Systems
ims

- The IEEE 802.15.4 web site:
  http://www.ieee802.org/15/pub/TG4.html

UWM-IMS 11 *01 October 2001* Ed Callaway

4.6 Wireless Implementations for an Open Standard Sensor Bus

Wireless Implementations of an Open Standard Sensor Bus

Wireless 1451 Workshop
Sensors Expo
October 4, 2001

Michael R. Moore
Oak Ridge National Laboratory

Intelligent Integrated Sensors & Systems

Wireless Sensor Networks Are a Key Element of Industries of the Future

- What They Will Provide
  - Reduced Install Cost
  - Greater Flexibility
- What It Will Take
  - Short Term
    - » Higher Reliability
    - » Small, Fast and Cheap (Pick any two)
  - Long Term
    - » Improved Inter-System Compatibility (EMC/IT)
    - » Standardization

Intelligent Integrated Sensors & Systems

Who Needs Sensor Networks?

- Industry
- Science
- Military

Intelligent Integrated Sensors & Systems

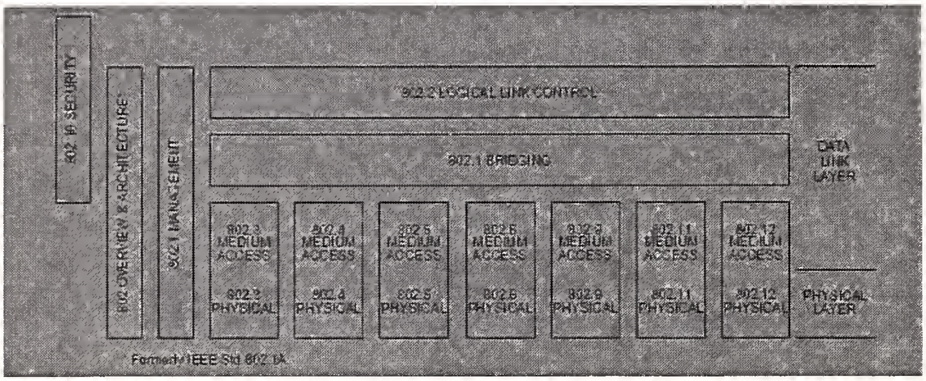
Standards Are Necessary to Reach Long-Term Goals

- Provide Commonly Accepted Infrastructure
- Can Evolve With Technology

So we will examine a couple of standards families --
IEEE 802 and IEEE 1451

Intelligent Integrated Sensors & Systems

The IEEE 802 Family Has Successfully Evolved With Technology



Intelligent Integrated Sensors & Systems

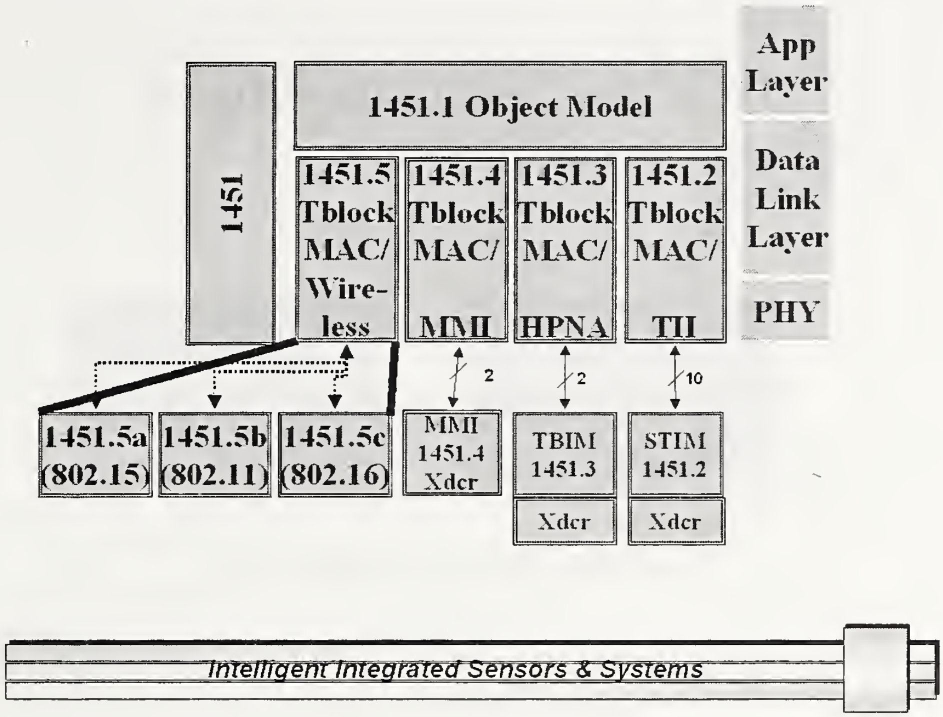
Candidate 1451 MAC/PHY From Other Wireless Standards

(Technology Issues)

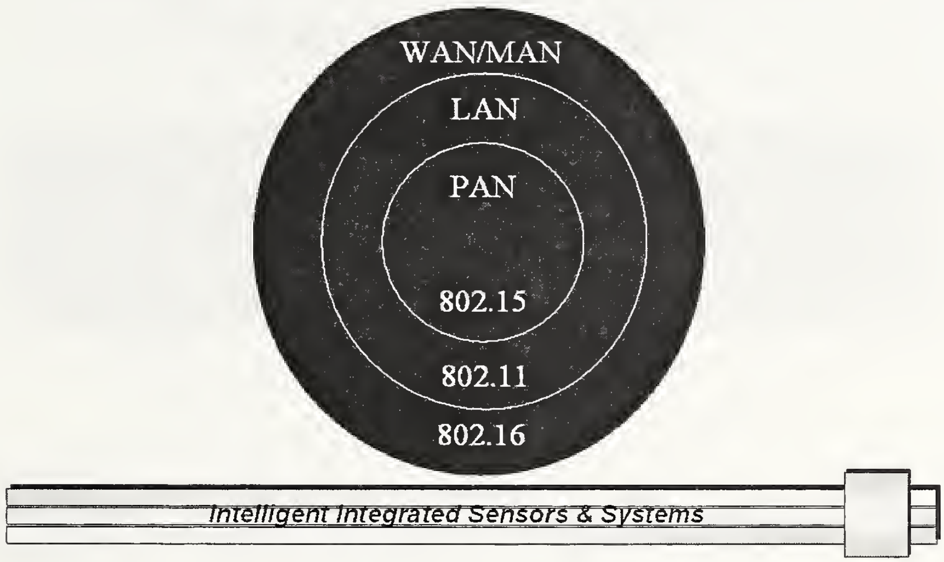
Std	OFDM	FHSS	DSSS	GHz	Size	Mbps
IS-95			x	1 +/-	Cell	0.x
Bluetooth		x		2.45	PAN	1
P802.15		x		2.45	PAN	1
P802.16b	x			5	WAN	54
802.11a	x			5	LAN	54
802.11		x	x	2.45	LAN	1, 2
802.11b			x	2.45	LAN	5.5, 11

OFDM - Orthogonal Frequency Division Multiplexing
FHSS - Frequency Hopping Spread Spectrum
DSSS - Direct Sequence Spread Spectrum

Intelligent Integrated Sensors & Systems



Size of Network vs PHY



IEEE 802 Wireless Projects

- IEEE 802.15 (Bluetooth)
- IEEE 802.11
    - » Clause 14 - 1,2 Mbps FHSS LAN MAC for 2.4 GHz
    - » Clause 15 - 1,2 Mbps DSSS LAN for 2.4 GHz
  - – IEEE 802.11a
    - » Adds Clause 17 - ≤54 Mbps OFDM LAN for 5 GHz
  - – IEEE 802.11b
    - » Adds Clause 18 - 5.5 and 11 Mbps DSSS for 2.4 GHz
- IEEE 802.16b (task group 4) Wireless High-Speed Unlicensed Metropolitan Area Network (Wireless HUMAN)
    - » MAC: IEEE 802.16
    - » PHY: IEEE 802.11a; ETSI BRAN HIPERLAN/2

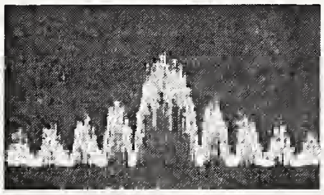
Intelligent Integrated Sensors & Systems

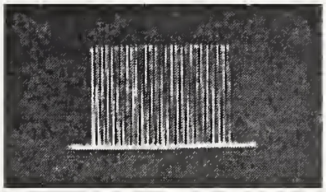
Finding the Right RF Technology for the Application

- Conventional Narrowband
- Frequency-Hopping Spread Spectrum
- Direct-Sequence Spread Spectrum
- Orthogonal Frequency Division Multiplexing

Intelligent Integrated Sensors & Systems

DSSS vs FHSS





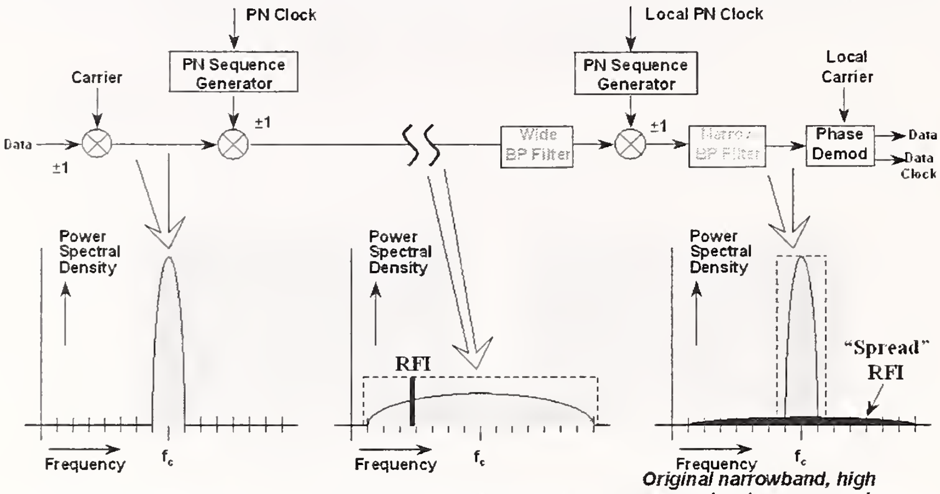
Intelligent Integrated Sensors & Systems

Picking the Right Technology is Very Application Dependent

Typical Rank	Spectral Eff. (Bits/sec/Hz)	Non-interfering	Power Req'd	Data Reliability	Effective Range
Best	OFDM	DSSS	FHSS	OFDM	OFDM
Median	DSSS	FHSS	DSSS	DSSS	DSSS
Worst	FHSS	OFDM	OFDM	FHSS	FHSS

Intelligent Integrated Sensors & Systems

DIRECT-SEQUENCE SPREAD-SPECTRUM SIGNALS



Narrow spectrum at output of modulator before spreading

Spectrum has wider bandwidth and lower power density after spreading with PN sequence (PN Rate >> Data Rate)

Original narrowband, high power density spectrum is restored if local PN sequence is same as and lined up with received PN sequence

Intelligent Integrated Sensors & Systems

Conclusions

- Wireless Sensor Networks Are a Key Part of Future Industries (and for the Military)
- Short-Term Goals Focus on Reliable Links and Reasonable Costs of Individual Systems so that Industries Will Accept Them.
- Long-Term Goals (Inter-System Compatibility) Require Standards Efforts and Improved RF Technologies.

Intelligent Integrated Sensors & Systems

4.7 Review Issues & Discussions from First Workshop

Review Issues & Discussions from First Workshop

James D. Gilsinn
National Institute of Standards & Technology
Intelligent Systems Division
james.gilsinn@nist.gov

Overview

- The first Wireless Sensing Workshop was held on June 4, 2001, at the Sensors Expo/Conference at the Rosemont Convention Center in Chicago, IL
- The workshop was organized in order to explore industry's interest in wireless sensing.
- 90 people attended the workshop representing:
  - Manufacturing, Process Control, Aerospace, Home Automation, Automotive, and Government

Overview (cont'd)

- Overview of IEEE 1451
- Application of IEEE 1451.1
- Review of Current Technologies
  - Wireless Ethernet (IEEE 802.11*x*)
  - Bluetooth
  - Hardware & Software tools
- Proposed P1451.5 wireless standard
- Open forum & discussion

Proceedings

- Paper Copy of Proceedings
  - Contact Kang Lee, kang.lee@nist.gov
- CD Copy of Proceedings
  - Available here, or
  - Contact James Gilsinn, james.gilsinn@nist.gov
- Web Accessible Copy of Proceedings
  - Available online at http://ieee1451.nist.gov

Why Use Wireless?

- Some attendees questioned whether wireless communications should be used for sensors
- Wireless may not be the best solution for all cases
- Many cases may allow for less deterministic communications. These may present possibilities where wireless is a best-fit solution
  - Large facilities
  - Low-speed, long-range communications
  - Hazardous environments

October 4, 2001 National Institute of Standards & Technology Intelligent Systems Division 5

Data Reliability

- Data reliability was the largest issue raised
- Data reliability depends on:
  - Availability of the wireless signal (hardware)
  - Integrity of the data message (software)
  - Confidentiality of the data message (software)
- Availability
  - Many sensors use ISM band
  - ISM band is free, but full of other users
  - Some standards allow for signal degradation

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Data Reliability (cont'd)

- Data Integrity and Confidentiality
  - Error checking of data to prevent bad data packets
  - Algorithms available to correct errors in the data
  - IEEE 1451.2 specification for Transducer Electronic Data Sheet (TEDS) has simple error checking
  - Wireless communication lends itself to confidentiality problems
  - Vendors should incorporate additional security features to prevent industrial espionage

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Intelligent Systems Division 7

Bandwidth Requirements

- An informal survey of the bandwidth requirements for workshop attendees was conducted
  - <u>Bandwidth</u> <u>Interested Parties</u>
  - <= 300 bps 63%
  - 300 bps - 50 kbps 25%
  - 50 kbps - 250 kbps 3%
  - 250 kbps - 1.5 Mbps 6%
  - > 1.5 Mbps 3%

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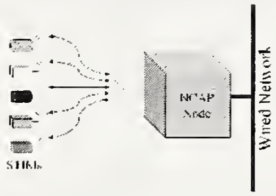
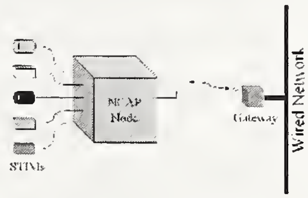
Intelligent Systems Division 8

Where Should Wireless Be Located?

- The workshop attendees had varying opinions on where wireless communications should be incorporated into a wireless sensor system



Wireless STIMs



Wireless NCAP Node

Devices Per Node

- NCAP nodes allow multiple sensors to be attached to the network using a common point of access
- An informal survey was taken to determine how many sensors per NCAP node users wanted
  - Sensors/Node — Interested Parties
  - 8 — 26%
  - 32 — 53%
  - 256 — 21%

Transmission Power vs. Battery Lifetime & Safety

- Some wireless communication standards use 100mW of transmission power
- Some sensors expected to run years before replacing batteries
- Batteries lifetime may be reduced because of transmission power
- 100mW transmission power may be too high in hazardous environments

"Hot" Wireless Technology

- Although Bluetooth and 802.11 may not be exactly what sensor vendors want, they may help bring wireless communications to sensors
- Sensor manufacturers and vendors need to consider development cost vs. performance benefits of using standardized technology vs. ASIC chips
- Development systems for some standardized technology may be prohibitively expensive

ISM Band Users

- The Industrial, Scientific, and Medical (ISM) bands setup by the FCC are unlicensed
- Many consumer & commercial devices are designed to use these frequencies
  - 900 MHz — Cell phones, portable phones, home electronics, spread spectrum
  - 2.4 GHz — Portable phones, spread spectrum
  - 5 GHz — Satellite communications

Are Multiple IEEE 1451 Wireless Standards Needed?

- With the seemingly disjoint worlds of low-speed and high-speed wireless communications, is it possible to create one standard that fits the needs of everyone?
- Will multiple versions of an IEEE 1451 wireless standard be needed to account for the varying needs of its users?

Other Issues

- Sensor reconfiguring & reprogramming
  - 2-way links necessary
  - Uplink and downlink can run at different speeds
- Broadcast vs. targeted communications
- High-speed data synchronization by multiple sensors
- Can the NCAP and STIM be combined?

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Proceedings

- Paper Copy of Proceedings
  - Contact Kang Lee, kang.lee@nist.gov
- CD Copy of Proceedings
  - Available here, or
  - Contact James Gilsinn, james.gilsinn@nist.gov
- Web Accessible Copy of Proceedings
  - Available online at http://ieee1451.nist.gov

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5 Workshop Agenda

Sensors Expo & Conference
Philadelphia, PA
October 4, 2001

Enhancement of IEEE 1451.2, A Smart Transducer Interface Standard

8:00am	**Introduction and Purpose** Kang Lee, NIST *(Moderator)*
8:05am	**Definition of Smart, Review Valuable Features of 1451.2** Stan Woods, Agilent Technologies
8:20am	**Requested Chances to 1451.2** Robert Johnson, Telemonitor, Inc.
8:35am	**Sensor Manufacturer's Perspective** Jim Moore, Telemonitor, Inc.
8:50am	**Software Supplier's Perspective** David Potter, National Instruments
9:05am	**Procedure for Review/Renewal of IEEE Standards** Stan Woods, Agilent Technologies
9:10am	**Proposed Enhancements of 1451.2** Robert Johnson, Telemonitor, Inc.
9:30am	**Open Discussion with Participants** Stan Woods, Agilent Technologies
10:20am	**Wrap-up, Summary, and Action Items** Kang Lee, NIST
10:30am	**Meeting Adjourn**

Second Workshop on Wireless Sensing

10:40am	**Welcome / Introduction** Kang Lee, NIST *(Moderator)*
10:45am	**Synopsis on IEEE 1451** Rick Schneeman, NIST
11:05am	**Synopsis on Bluetooth** Thurston Brooks, 3e Technologies International
11:25am	**Synopsis on Wireless Ethernet (802.11)** James Gilsinn, NIST
11:45am	**Reliable Wireless Connectivity for Sensing & Control Applications** H Britton Sanderford / Gerard Hill, Axonn
12:00pm	*Lunch Break*
1:10pm	**IEEE P802.15.4 Low Rate Wireless Personal Area Networks** Kang Lee, NIST
1:30pm	**Wireless Interface Option for 1451** Mike Moore & Steve Smith, Oak Ridge National Lab
1:40pm	**Review Issues and Discussions from First Workshop** James Gilsinn, NIST
2:00pm	**Open Group Discussion on New Issues, New Technologies, and Standardization Approach**
3:00pm	**IEEE Procedure and Process for Setting up Standards Working Group** Kang Lee, NIST
3:30pm	**Meeting Adjourn**

6 List of Attendees

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