IEEE P1451.3
Smart Transducer Interface Standard for SENSORS and ACTUATORS

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1. Introduction

The goal of this standard is to develop a transducer bus architecture that accomplishes the following on a single coaxial cable:

(1) Synchronizing data acquisition of a large array of transducers.
(2) Communicating simultaneously with a large array of transducer-interface nodes.
(3) Providing power for operation of all transducers and associated electronics.

This transducer network will allow scalability of architecture and a range of cost and capability options. It will allow TDMA, FDMA and CDMA multiple-access schemes. It also provides the option of combining two or more physical layer (PHY) on a single coaxial cable.

2. Architecture

The bus can be characterized as a distributed multidrop system (see Figure 1), consisting of one or more Transducer Bus Interface Modules (TBIMs), a Transducer Bus Controller (TBC), and the actual physical transducer bus. A TBIM consists of one or more transducers and contains the means for storing or associating a Transducer Electronic Data Sheet (TEDS), a real-time clock (RTC) for time-stamping data, a microprocessor for formatting the data and a transceiver chip set for CDMA and/or FDMA purposes. The TBC will control the transducer bus and could concurrently incorporate, or be a component of, a Network-Capable Applications Processor (NCAP) or any other acquisition system.

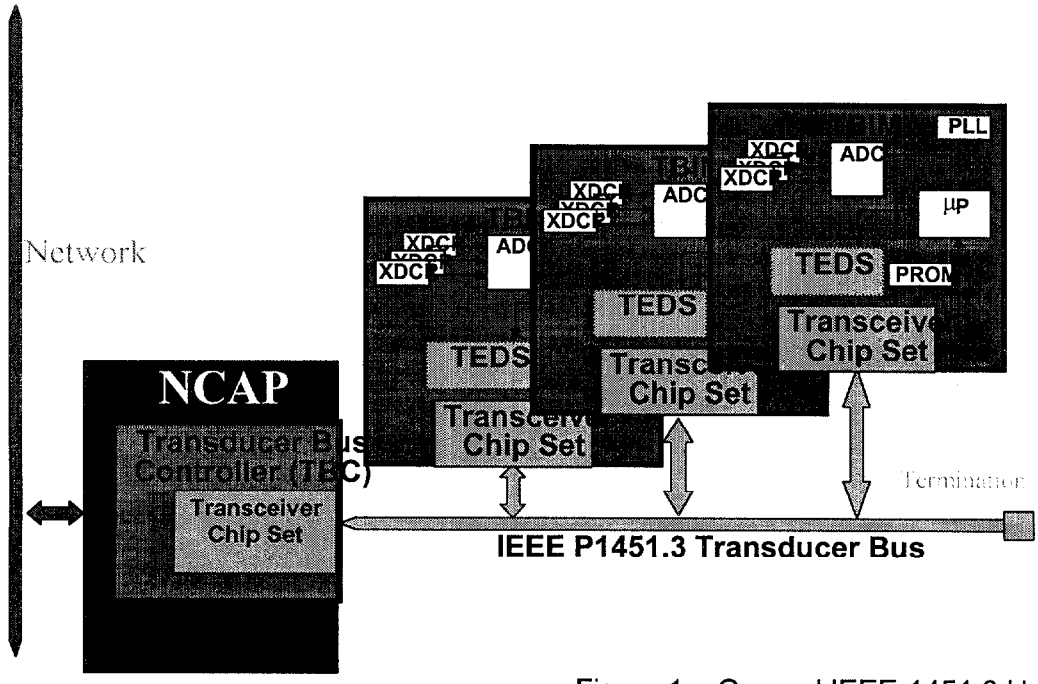

Figure 1 – General IEEE-1451.3 Hardware Architecture.

3. Physical Layer (PHY) Implementations

Currently there are at least three proposed physical layer implementations. At least two PHY will be incorporated into the standard at the time of balloting. The three implementations discussed in this paper are: 1) a cable-modem (DOCSIS) based PHY, 2) a Home Phoneline Networking Alliance[1,2] (HomePNA) based PHY, and 3) Endevco's proposed PHY. The cable-modem like implementation will be used for the higher capability (FDMA/CDMA) systems, that need many Mbps of bandwidth and will require a coaxial cable transmission medium. The other two PHY will target lower cost applications that only require a few Mbps. The Endevco PHY operates on twisted-pair cable while the HPNA based PHY uses phone lines.

As shown the power will be DC (or low freq AC in user adapted systems), the lower frequency synchronization signal will be 1 MHz and the HPNA protocol or Endevco system will operate in the 4-10 MHz band. Thus, physical media that only guarantee about 10 MHz of bandwidth are capable of utilizing synch, power and data on one transmission line. For media that have at least 80 MHz of bandwidth, the lower portion of the cable modem band can be utilized as detailed in the lower blocks of the figure. For systems having up to about 900 MHz, the complete cable modem designated frequencies can be used.

The sub-bands designated as FDMA or CDMA indicate the default allocation. In FDMA-only applications any of these bands can be used for FDMA. In CDMA capable systems they can be re-allocated as FDMA or CDMA within any of these bands. The "Bus" designation shows the spectrum allocated for the bus management channel. The "Comm" designation shows the spectrum allocated TBIM communication channels.

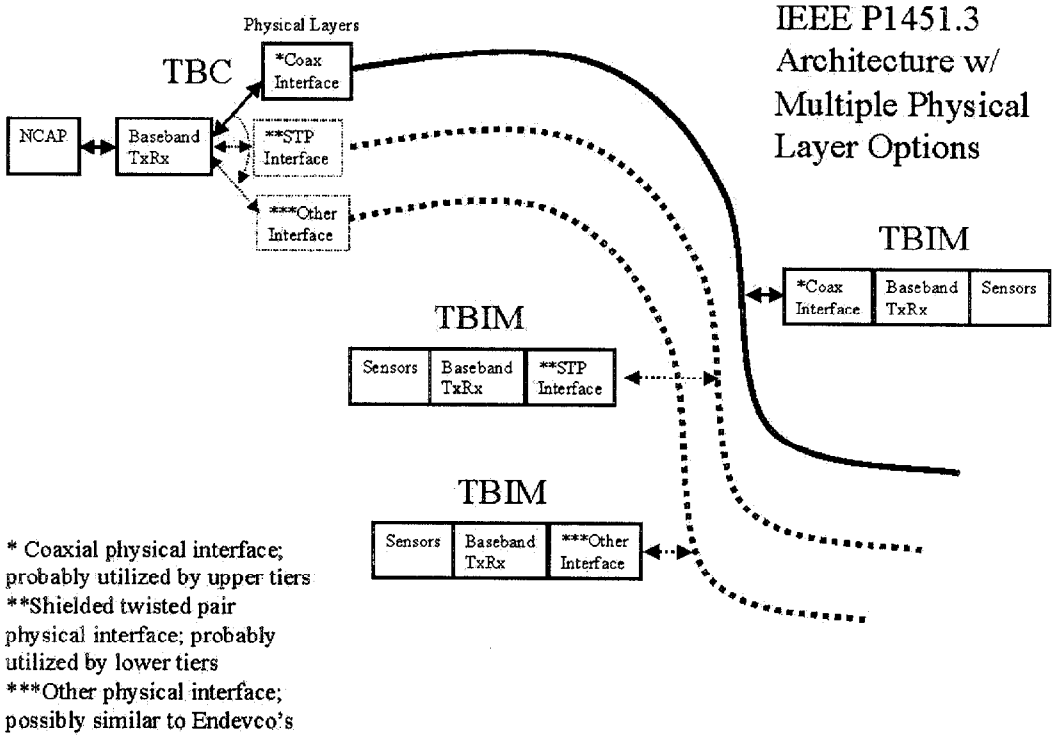

Figure 2 – Multiple Physical Layer Block Diagram

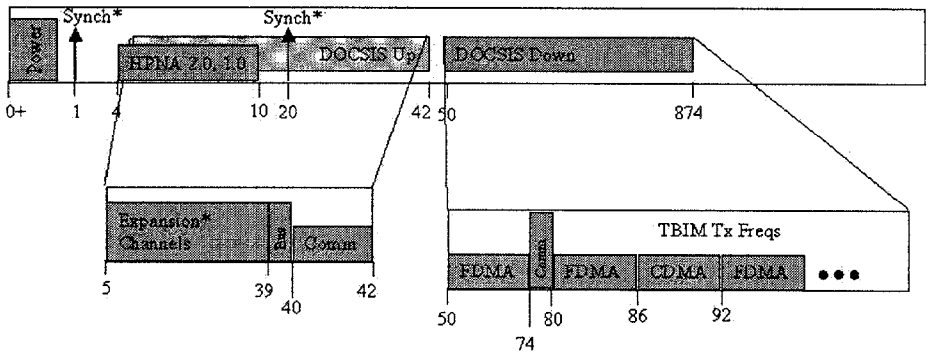

Figure 3 – Spectrum overview for cable-modem and HPNA PHY.

Expansion* Channels refer to frequencies that may be used for synch, additional communication or data or may be left unutilized especially when both physical layers A and B are present simultaneously.
Synch* - The lower frequency applications will probably utilize a synch frequency at or just above 1 MHz while the higher frequency applications will probably use a synch frequency of 10, 20 or 50 MHz or so. The upper synch frequency may be raised to accommodate the increased bandwidth of proposed enhanced HPNA protocols.

3.1 Cable-Modem Based PHY (DOCSIS)

The cable modem consortium has developed a well thought out series of standards for communicating digital data over an infrastructure that originally existed for the distribution of television video. Also, there are IC and OEM manufacturers that are committed to supporting these standards. Therefore, a sensor network based on the DOCSIS protocols has been proposed. It would benefit both from existing IC lines and from the maturity of the TDMA/FDMA portions of the protocol.

This PHY will provide power, synchronization, data and communications over a single coaxial cable. The capability options range from units that communicate less than 10 Mbps in a TDMA only fashion to 100's of Mbps utilizing TDMA, FDMA and/or CDMA. The lower capability options will only require oscillators that cover 5 MHz to about 80 MHz and a cable that maintains reasonable loss at these frequencies. The highest capability applications will require tuning ranges from 5 MHz to about 900 MHz and a cable that has reasonable losses over this range.

3.2 HPNA based PHY

An adaptation of the HomePNA 2.0 specification holds great promise as an alternate PHY layer. HomePNA 2.0 was designed to provide 16-Mbps transmission over the existing copper wires used in homes and consequently uses a shared physical medium[3], e.g., a "multi-drop bus". HomePNA uses a fixed 7-MHz carrier. It normally operates at 2 or 4 Mbaud and is capable of dynamically adjusting the modulation encoding from 2 to 8 b per symbol to accommodate poor line-quality. HomePNA 2.0 uses a modified version of QAM known as frequency-diverse QAM (FD-QAM) at 2 Mbaud to address the case of extreme nulls. It transparently controls equalizer settings/training, demodulation and rate negotiation using a self-describing frame format. HomePNA 2.0 adopted an IEEE 802.3 packet-framing format and an Ethernet carrier-sense multiple access with collision detection (CSMA/CD) MAC.

We envision adapting HomePNA 2.0 by layering the P1451.3 specific command and control logic at the link layer. We can also replace the normal CSMA/CD MAC with a deterministic MAC controlled by the TBC; options include a pole-response, TDMA or a hybrid method incorporating pole-response, TDMA and CSMA/CD. We will also specify the additional components necessary to provide power and sync on the same PHY.

4. TEDS

There are two different elements of an IEEE P1451.3 TBIM that allow the users system to use it. The first is the Universal Unique Identifier or UUID. This is an eighty-bit number that is unique for each TBIM. The standard supplies an algorithm that the manufacturer uses to determine this eighty-bit number to guarantee uniqueness. All TBIMs are required to have the UUID stored within the TBIM. The other element is the Transducer Electronic Data Sheets or TEDS.

The Transducer Electronic Data Sheets (TEDS) allow the user system access to all of the key operating parameters of the transducers that are networked via the IEEE p1451.3 Transducer Bus. Table 1 lists a number of possible TEDS and the standard provides for all of them. However, only three of these TEDS are required. The rest are things that the working group believes will be useful so provisions are made for them in the standard. However, since memory resources in a small TBIM may be limited they are not required. The working group also believes that having the TEDS in the TBIM, so that there is no way to separate the TBIM from it's supporting information, is the most desirable way to operate, but that this will not always be possible. For these reasons the standard allows the TEDS to be embedded within the TBIM or stored externally in the users system or even accessed from the manufacturers web site. These remotely accessible TEDS are known as "virtual" TEDS. If some TEDS are virtual and others embedded it will be possible to provide a Virtual TEDS Location TEDS which will supply pointers to the virtual TEDS. For TBIMs with all TEDS virtual the users system will be required to be able to locate the virtual TEDS using some mechanism that cross references the location of the TEDS with the UUID. Having virtual TEDS allows manufacturers to produce modules having less memory but still supplying all needed information electronically.

The Module Meta-TEDS and the Transducer Specific TEDS provide parameters that allow software to be written that permits a large range of devices to be supported by providing the constants necessary for the operation of the specific TBIM with the TBIM rather than in a separate manual or data sheet. The Commissioning TEDS is required to give the users system a place to store a small amount of information about the application of the device that will not be lost when the device is powered down or moved to a different transducer bus.

TEDS are divided into two major categories. They are either text-based or binary depending upon the intended application. Text-based TEDS are usually intended to supply information that will be displayed for the system operator. The text-based TEDS will be described using XML (eXtensible Markup Language) to allow the system to display the contents of the TEDS using an XML enabled web browser. The binary TEDS are used to provide operating parameters to the system software. Since the structure of these binary TEDS is specified in the standard, a simple translator can be written to translate the binary information into an XML format to allow them to be displayed and possibly edited using a browser as well. This allows users to quickly generate the TEDS entries without learning a new software language or having to purchase a TEDS editor.

Table 1—TEDS Access Commands

TEDS	Required or Optional	Binary or Text-based	Comment
Module Meta-TEDS	Required	Binary	This TEDS is used to define the worst case operating characteristics of the TBIM. It is intended to be read and used by the NCAP. Basic communications capabilities of the TBIM may also be included within this TBIM.
Meta-Identification	Optional	Text-	This TEDS is used to provide data sheet type

TEDS		Based	information about the TBIM to the system for display to an operator.
Transducer Specific TEDS	Required	Binary	This TEDS is used to provide the operating characteristics of a particular transducer within a TBIM. It is intended to be read and used by the NCAP.
Transducer Identification TEDS	Optional	Text-Based	This TEDS is used to provide data sheet type information about the transducer to the system for display to an operator.
Calibration TEDS	Optional	Binary	This TEDS is used to provide the calibration constants of a particular transducer within a TBIM. It may be used by the TBIM, NCAP or System.
Calibration-Identification TEDS	Optional	Text-Based	This TEDS is used to provide information about the transducer calibration to the system for display to an operator.
End Users' Application Specific TEDS	Optional	User defined	This TEDS is intended to allow the user a place to store information about the use of a particular transducer or TBIM. It's format and content are user defined.
Transfer Function TEDS	Optional	Binary	This TEDS is used to provide the frequency response of a particular transducer within a TBIM. It may be used by the TBIM, NCAP or System.
Commands TEDS	Optional	Text-Based	This TEDS is used to by the TBIM manufacturer to define extensions to the standard command set described in the standard.
Commissioning TEDS	Required	User defined	This TEDS is intended to allow the user a place to store a small amount of information about the use of a particular transducer or TBIM. The intent is to provide a parameter name that other system components will use to identify the application intended for this transducer. It's format and content are user defined.
Virtual TEDS Location TEDS		Text-Based	This TEDS is required if the TBIM supports virtual TEDS. If all TEDS are embedded it is not required. It provides a location for the virtual TEDS. It will normally be initially supplied by the manufacturer and overwritten by the user when the virtual TEDS are loaded into the users system.
Title TEDS	Optional	Text-Based	This TEDS is used to provide a name for a manufacturer unique TEDS.

5. Multiple Access Methods

5.1 TDMA

There are various schemes of TDMA, typically divided by the degree of synchronism required to coordinate the messages. In a poll-response scheme, the controller (TBC in this case), sends messages that require responses from the TBIMs. The TBIMs do not communicate until the TBC requests information. This method is used for bus management (configuration.) A more tightly coordinated method assigns a time period to each TBIM. It may only transmit during its time allocation. The TBC also allocates guard times between the assignments and independently synchronizes to each message inbound from the various TBIMs. This method is

used for some TBIM data channels. The most tightly coordinated TDMA schemes require sufficiently tight synchronization that once one message is synchronized, all successive messages are treated as part of an unbroken chain of data. At this time, P1451.3 does not incorporate this type of TDMA.

5.2 FDMA

As shown in Figure 3, different functions (or channels) will occupy different portions of the RF spectrum. The bus management commands will be communicated over dedicated frequencies. This channel acts as the default communication channel among all entities. There are also dedicated frequency bands for command and control. These frequency assignments are made via the bus management channel and are used for dedicated communications between a single TBIM and the TBC.

Most of the spectrum is dedicated to data channels. These frequency bands are allocated by the TBC. Some of the bands are dedicated to CDMA channels in systems that have this capability.

There are also dedicated potions of the spectrum for synchronization signals and power. As shown in Figure 3, the data and communication channels are separated from the power and synchronization allocations by sufficient guard bands to accommodate separation of the signals by conventional filtering.

5.3 CDMA

This standard provides for a CDMA option. Parameters such as preamble length, power control and spreading codes specifically address these systems. Only the highest capability systems will utilize CDMA. The protocols allow CDMA channels to exist in dedicated bands while narrow band modulation schemes are being used in other regions of the spectrum.

6. Synchronization

Synchronization is a key element of the P1451.3 protocol. It will enable time-synchronized sampling from a multitude of sensors that are spread over a large area. The synchronization mechanisms in the standard will accommodate systems needing better than 1 s resolution within a given P1451.3 network. Commands and timing correction protocols will be available for users that desire to build systems with even greater synchronicity. The standard will accommodate synchronization time-base distribution either via an analog pulse stream for local relative sync or via a digital packet for delivering Time of Day.

The accuracy of the timestamps applied to data from any given P1451.3 bus will be dependent on the time distribution method used to distribute time from the master clock source to the various P1451.3 busses. The methods and accuracy's of this mechanism are outside the realm of the P1451.3 standard. However, the standard will include protocols for interfacing between the relative timing (synchronicity) of its local system and the distributed time-base delivered to the associated NCAP.

7. Power

Power will be DC typically. However, the standard allows for optional low frequency AC. However, the user will be responsible for adapting the AC power of the bus to DC power at the input of the TBIMs. Thus, TBIM manufacturers can all build DC powered units.

8. Summary

IEEE P1451.3 will provide an open standard for sensor networking that will accommodate power, synchronization and high bandwidth capabilities over a single coaxial cable. Options within the standard allow minimal entry-level cost as well as room for long term growth.

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[1]http://www.homepna.org/
[2]http://www.hpna.com/
[3]see Attaining Fast, Scaleable Home Networks, Communication Systems Design, March 2001, p. 44 for a good overview of HomePNA 2.0. http://www.csdmag.com/story/OEG20010221S0081/

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