Sensors Converge

June 20-22, 2023
Santa Clara, CA

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#SensorsConverge

Interoperability & Standards

Smart Sensor and Actuator Standards and Interoperability for IoT, IIoT & CPS

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National Institute of Standards and Technology

Smart Sensor & Actuator Standards and Interoperability for IoT/IIoT/CPS

1. Sensors & Actuators Are Used Everywhere in IoT/IIoT/CPS Applications
2. What Are IoT/IIoT/CPS Requirements for Sensors and Actuators?
3. What Are Smart Sensors and Actuators?
4. IEEE 1451 Interface Standards for Smart Sensors & Actuators, and Networks
5. Key Takeaways

1. Sensors & Actuators Are Used Everywhere

Aerospace

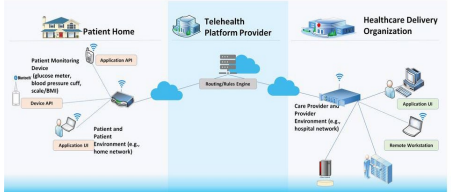
Automobile

Global Warming & Environmental Monitoring

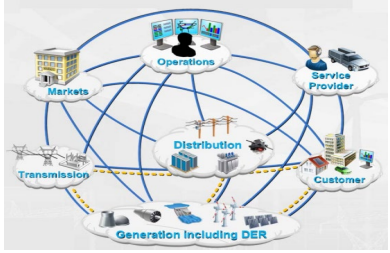
Smart Cities

Sensors and Actuators Are Used Everywhere In IoT/IIoT/CPS Applications

Health Care



Smart Grid



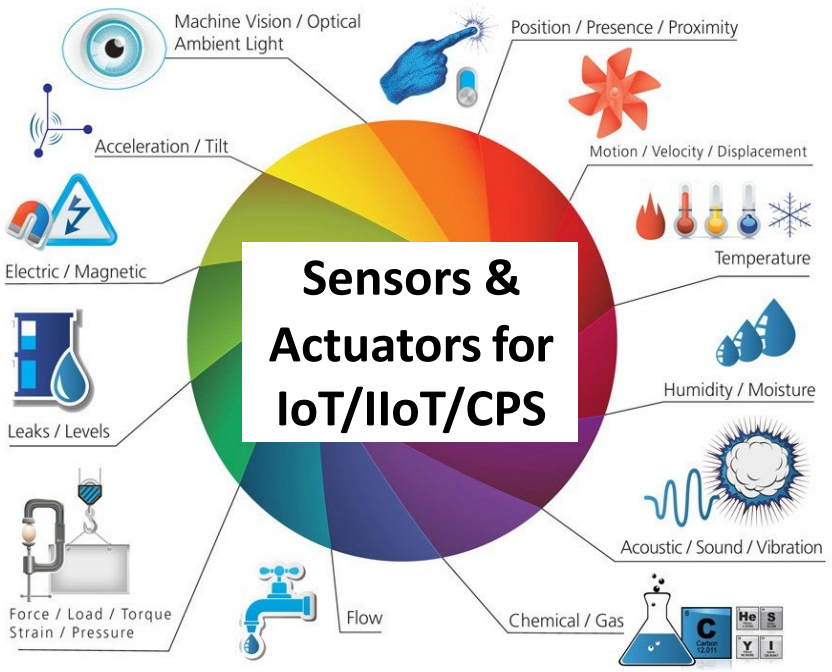
Smart Home and Building

Industrial Automation/Manufacturing

2. What Are IoT/IIoT/CPS Requirements for Sensors & Actuators?

IoT/IIoT/CPS Requirements for Sensors and Actuators:

- **Sensing/actuation capability**
- **Uniquely and globally identified**
- **Internet or network access**
- **Security and Privacy**
- **Time-aware & synchronization**
- **Location-awareness**
- **Self-description/identification**
- **Edge computing with AI**
- **Network communication protocols and interfaces to achieve interoperability**

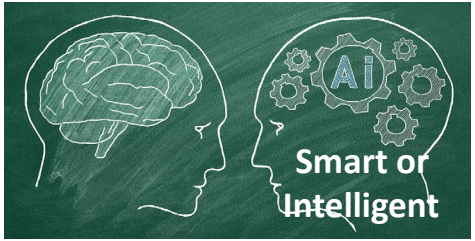


Source: https://www.postscapes.com/wp-content/uploads/2018/05/sensors.jpg

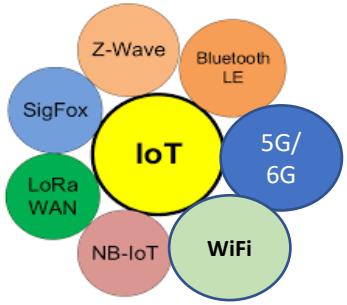
2. What Are IoT/IIoT/CPS Requirements for Sensors & Actuators? (Cont'd)

Sensors and Actuators:

- **Should be smart and intelligent enough using edge computing and AI**
- **Should adopt various standards:**
  - **Global identity**
  - **Security**
  - **Time synchronization**
  - **Network communication protocols and interfaces to achieve interoperability and plug & play.**



Source: https://www.industryweek.com/operations/continuous-improvement/article/21170962/dumb-smart-or-intelligent-whats-really-relevant-in-the-factory

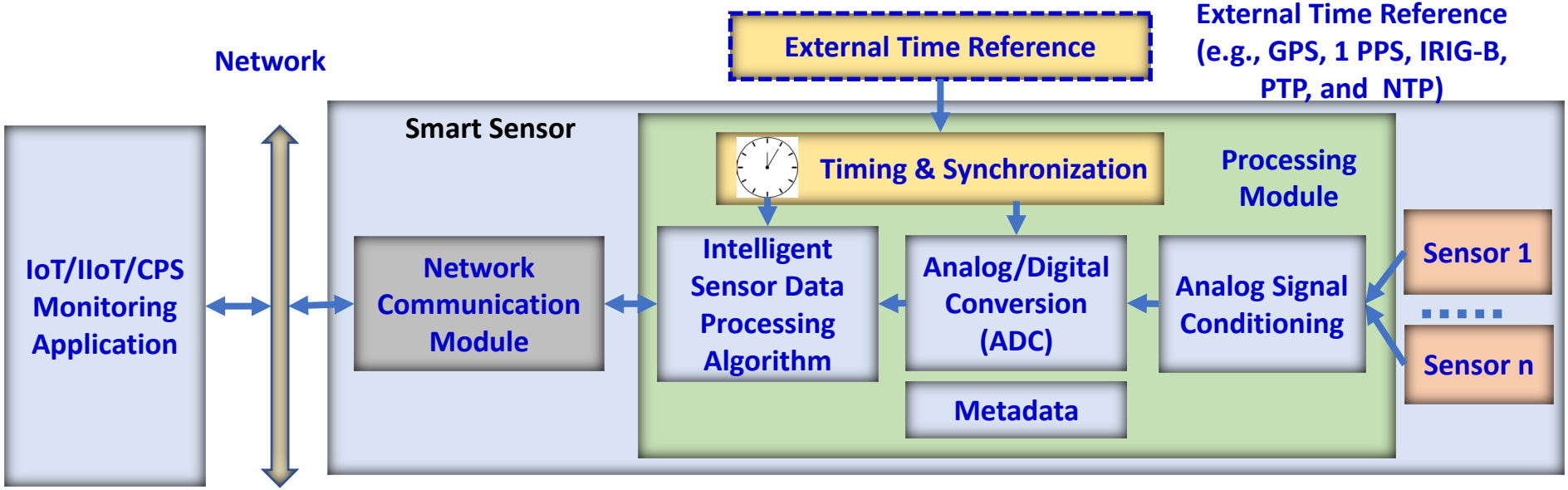


Standards

Plug & Play

3. What Are Smart Sensors and Actuators?

What Is A Smart Sensor?

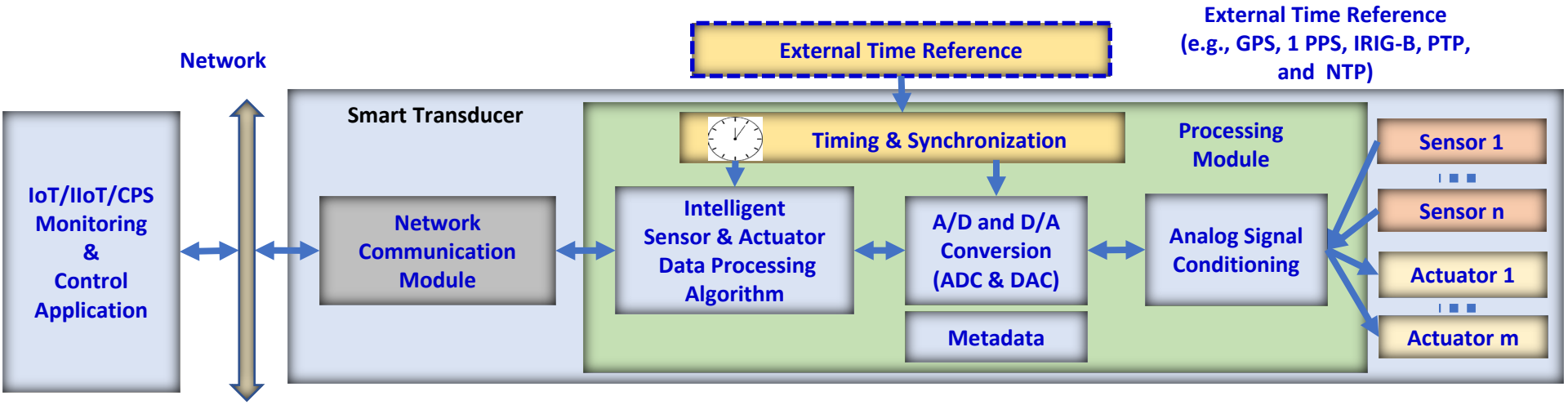


Smart Sensor Capabilities:

- Sensing
- Signal/Data Processing & Conversion
- Time & Synchronization
- Metadata
- Network Communication

3. What Are Smart Sensors and Actuators? (Cont'd)

What Is A Smart Transducer (Sensors and/or Actuators)?

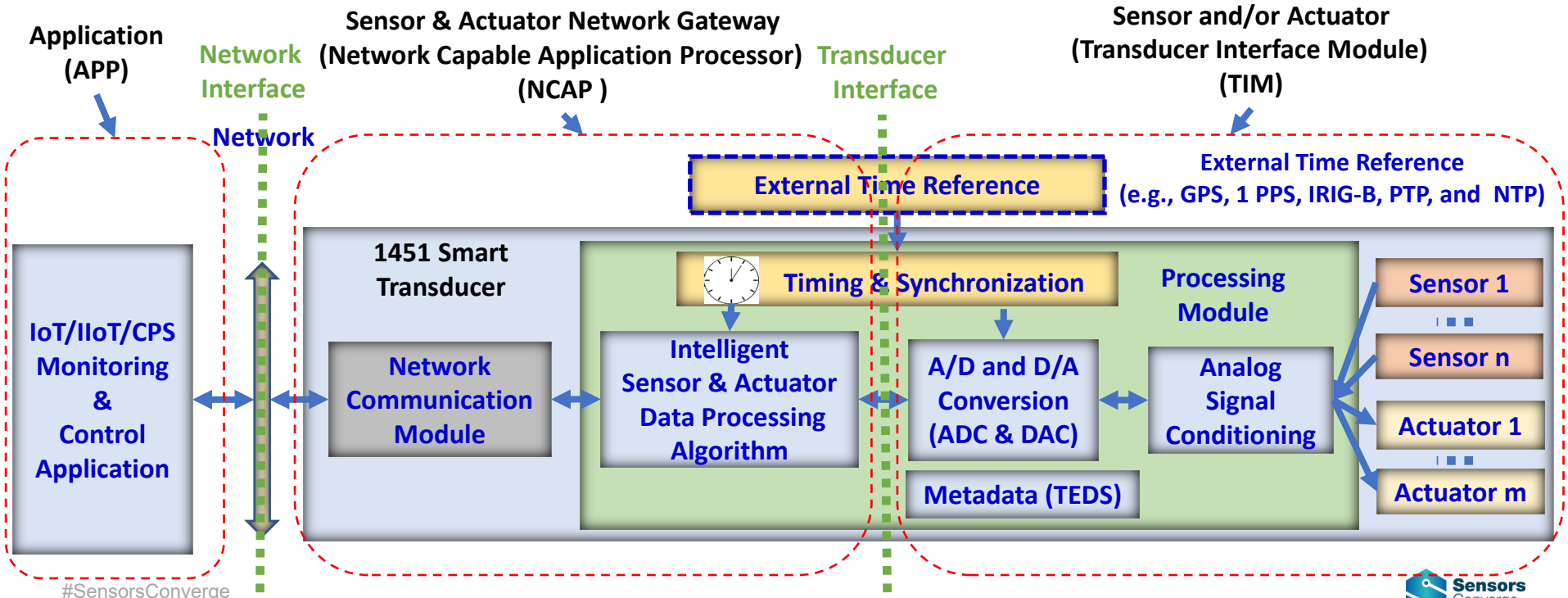


Smart Transducer (Sensor and/or Actuator) Capabilities:

- **Sensing and/or Actuation**
- **Signal/Data Processing & Conversion**
- **Time & Synchronization**
- **Metadata**
- **Network Communication via Network Interface**

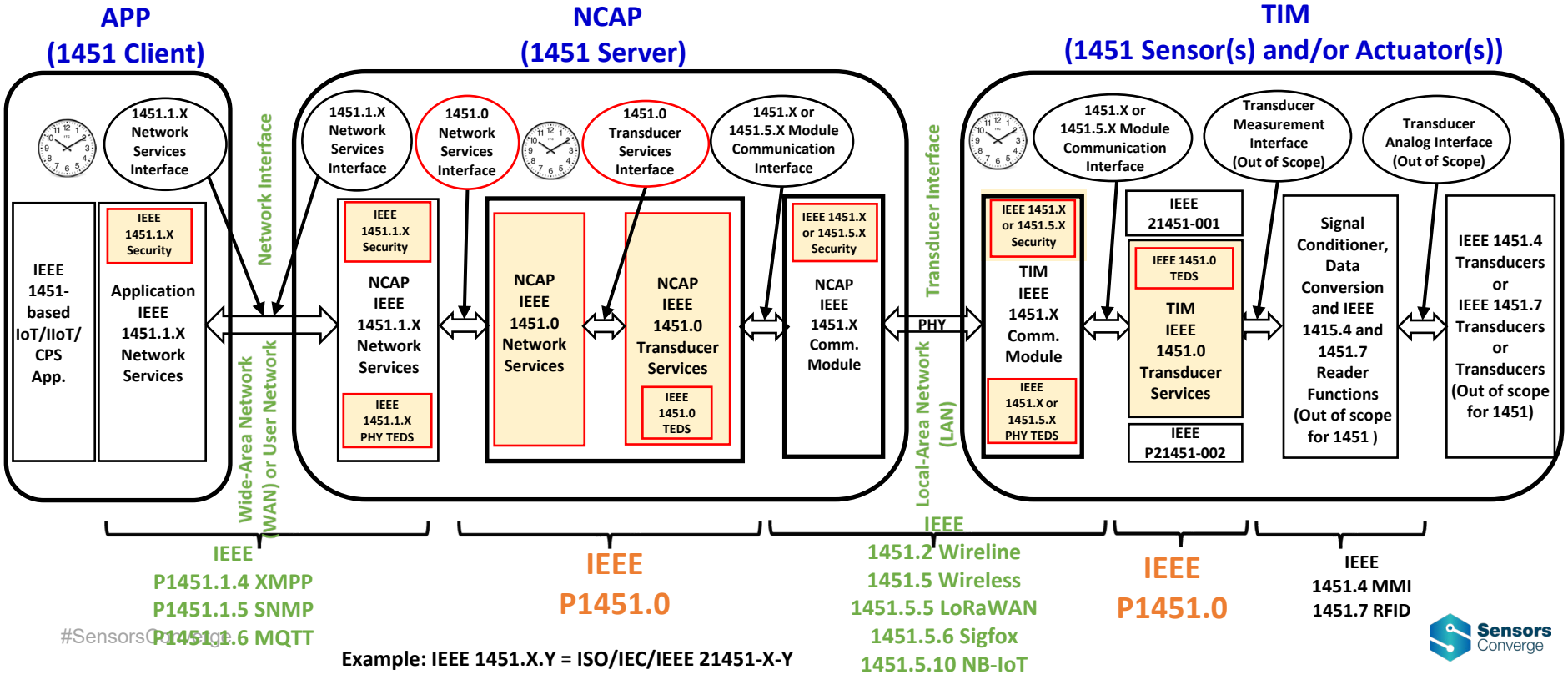
4. IEEE 1451 Interfaces Standards for Smart Transducer (Sensor & Actuator) Networks

IEEE 1451-based Smart Sensor Networks



4. IEEE 1451 Interfaces Standards for Smart Transducer (Sensor & Actuator) Networks (Cont'd)

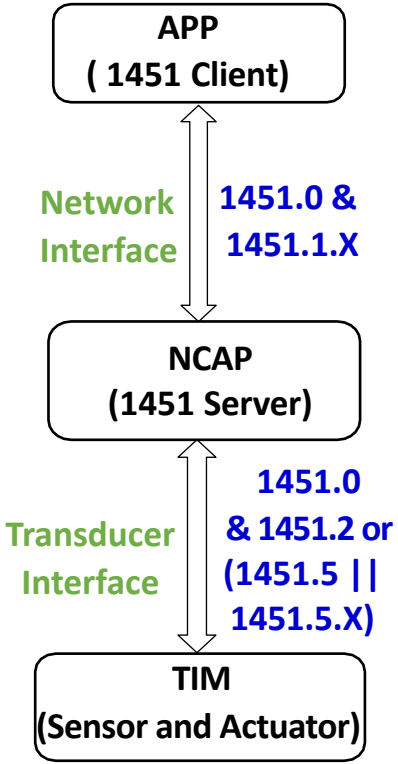
Reference Architecture for the Family of IEEE 1451 Standards

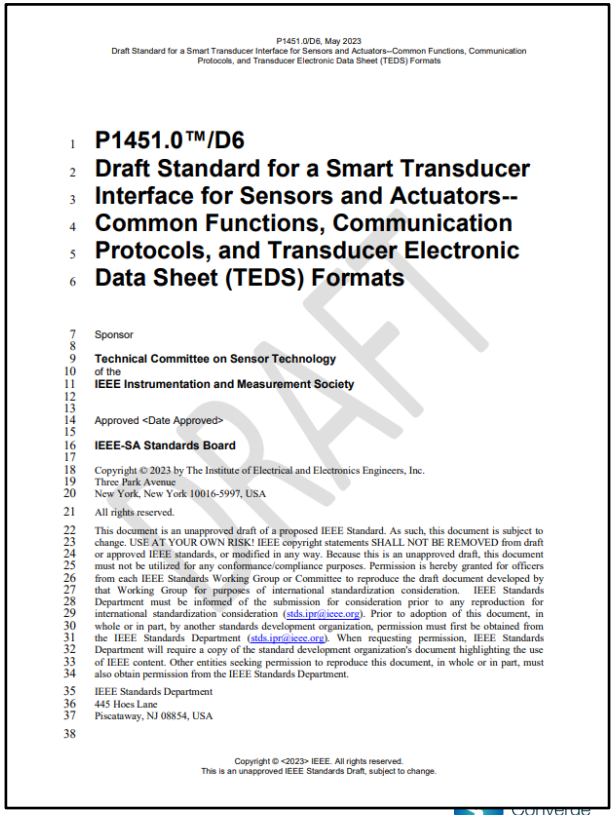


4. IEEE 1451 Interfaces Standards for Smart Transducer (Sensor & Actuator) Networks (Cont'd)

IEEE P1451.0 Standard Defines:

- **Three devices**: APP, NCAP, and TIM
- **Network services command and reply messages** between APPs and NCAPs
- **Transducer services command and reply messages** between NCAPs and TIMs
- **Universal Unique Identification** (UUID) for `appId`, `ncapId`, and `timId`
- **Transducer Electronic Data Sheet** (TEDS)
- **Security foe WAN, LAN & WLAN**
- **Time Synchronization for WAN, LAN & WLAN**





P1451.0/D6, May 2023
Draft Standard for a Smart Transducer Interface for Sensors and Actuators--Common Functions, Communication Protocols, and Transducer Electronic Data Sheet (TEDS) Formats

P1451.0™/D6
Draft Standard for a Smart Transducer Interface for Sensors and Actuators--Common Functions, Communication Protocols, and Transducer Electronic Data Sheet (TEDS) Formats

Sponsor

Technical Committee on Sensor Technology
of the
IEEE Instrumentation and Measurement Society

Approved <Date Approved>

IEEE-SA Standards Board

IEEE Standards Department
445 Hoes Lane
Piscataway, NJ 08854, USA

4. IEEE 1451 Interfaces Standards for Smart Transducer (Sensor & Actuator) Networks (Cont'd)

Universal Unique Identification (UUID)

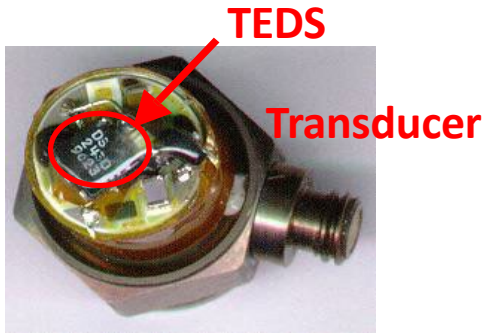
- **The UUID establishes uniqueness by assembling an identification number comprising of manufacturer location and specific information, year and time of manufacture.**
- **UUID for APP (`appId`), NCAP (`ncapId`) and TIM (`timId`)**

```
struct UUID  {// 16 bytes     (128 bits)
OctetArray   geolocation;     //  6 bytes  (48 bits)
OctetArray   manufacturer;    //  3 bytes  (24 bits)
UInt16       year;            //  2 bytes  (16 bits)
OctetArray   time;            //  5 bytes  (40 Bits)
};
```

Smart Sensor with UUID

4. IEEE 1451 Interfaces Standards for Smart Transducer (Sensor & Actuator) Networks (Cont'd)

- **Transducer Electronic Datasheet (TEDS):** a memory device attached to the transducer in a TIM, stores **transducer identification, measurement range, calibration, location, user and manufacture-related information**.
- **Self-description and Self-identification**



IEEE P1451.0 TEDS Classification:

Meta TEDS
TransducerChannel TEDS
User's transducer name TEDS
PHY TEDS
Calibration TEDS
Frequency Response TEDS
Transfer Function TEDS
Text based TEDS
End user application specific TEDS
Manufacturer-defined TEDS

Mandatory

Optional

Meta-Identification TEDS
TransducerChannel Identification TEDS
Calibration-Identification TEDS
Commands TEDS
Location and Title TEDS
Geographic Location TEDS
Security TEDS
Time Synchronization TEDS

```
<?xml version="1.0" encoding="UTF-8"?>
<xs:schema
xmlns:stml="http://grouper.ieee.org/groups/1451/0/1451HTTPAPI"
xmlns:xs="http://www.w3.org/2001/XMLSchema"
targetNamespace="http://grouper.ieee.org/groups/1451/0/1451HTTPAPI"
elementFormDefault="qualified" attributeFormDefault="unqualified">
   <xs:include schemaLocation="SmartTransducerDataModel.xsd"/>
   <xs:element name="MetaIdTEDSDataBlock">
      <xs:annotation>
         <xs:documentation>This is the schema for the contents of the
data block for the Meta Identification TEDS</xs:documentation>
      </xs:annotation>
      <xs:complexType>
         <xs:sequence>
            <xs:element name="manufacturerId" type="stml:_String"
minOccurs="0"/>
            <xs:element name="ModelNo" type="stml:_String"
minOccurs="0"/>
            <xs:element name="ProductDescription" type="stml:_String"
minOccurs="0"/>
            <xs:element name="serialNo" type="stml:_String"
minOccurs="0"/>
            <xs:element name="dateCode" type="stml:_String"
minOccurs="0"/>
            <xs:element name="versionCode" type="stml:_String"
minOccurs="0"/>
         </xs:sequence>
      </xs:complexType>
   </xs:element>
</xs:schema>
```

4. IEEE 1451 Interfaces Standards for Smart Transducer (Sensor & Actuator) Networks (Cont'd)

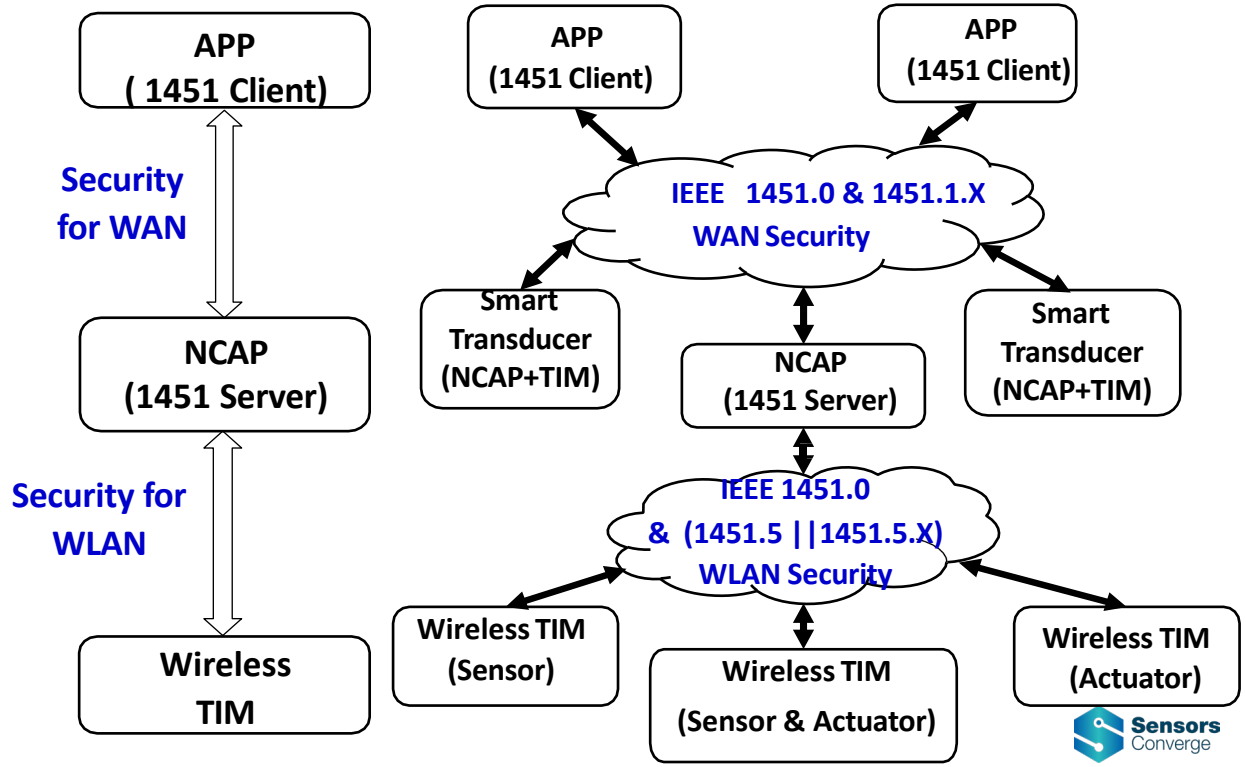
Security & Security TEDS for IEEE 1451.0-based Sensor Networks

Security Policy:

- Encryption
- Authentication
- Authorization

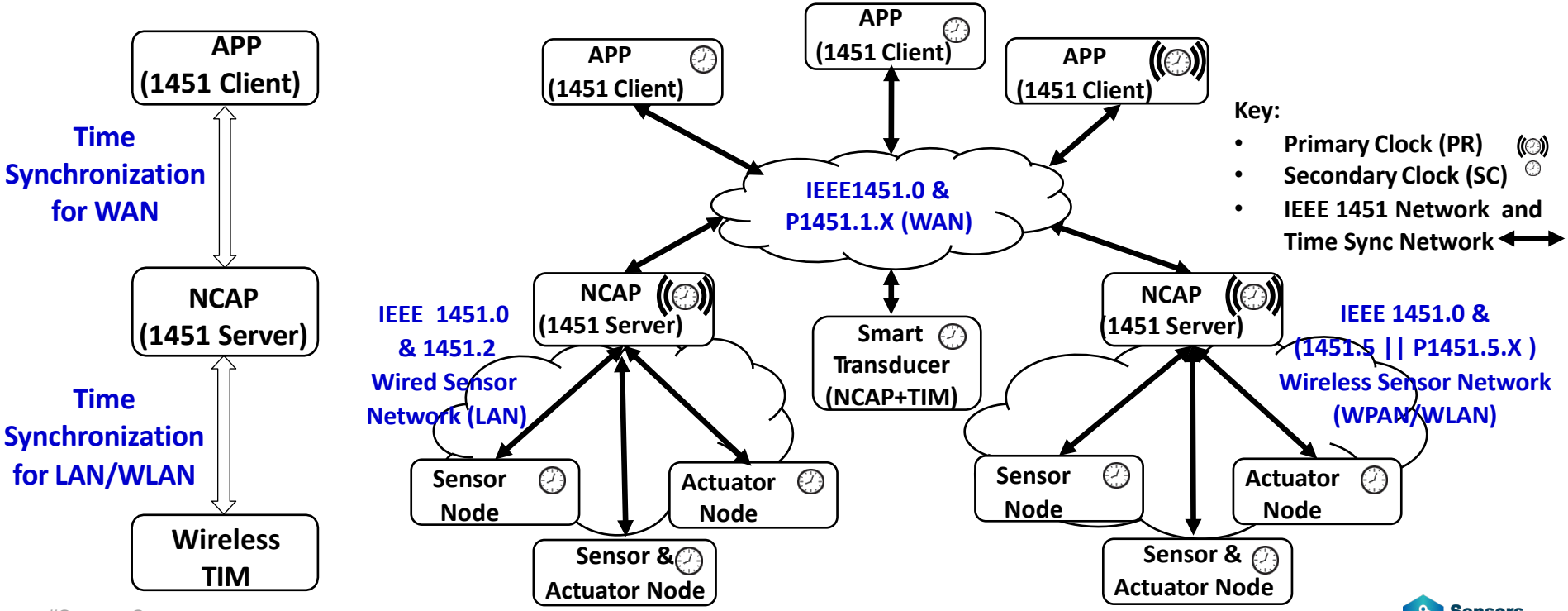
Define Six Levels of Security:

N: none
A: Encry
B: Authen
C: Encry + Authen
D: Authen + Author
E: Encry + Authen + Author



4. IEEE 1451 Interfaces Standards for Smart Transducer (Sensor & Actuator) Networks (Cont'd)

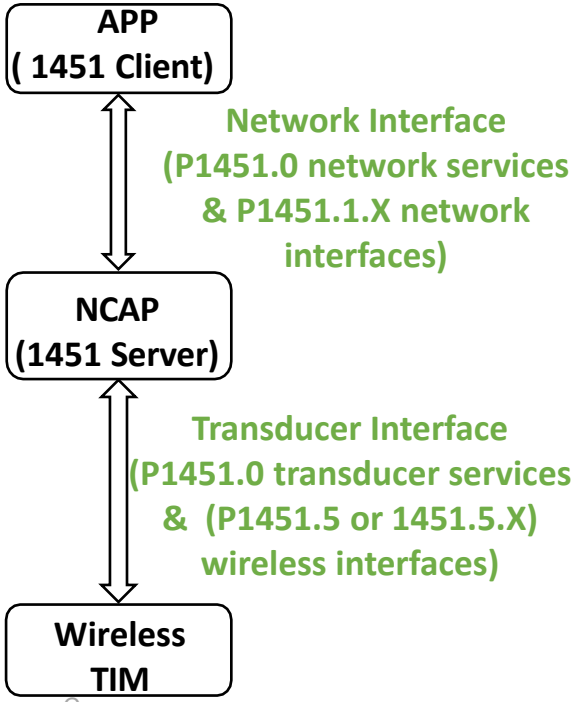
Time Synchronization and TimeSync TEDS for IEEE 1451.0-based Sensor Networks



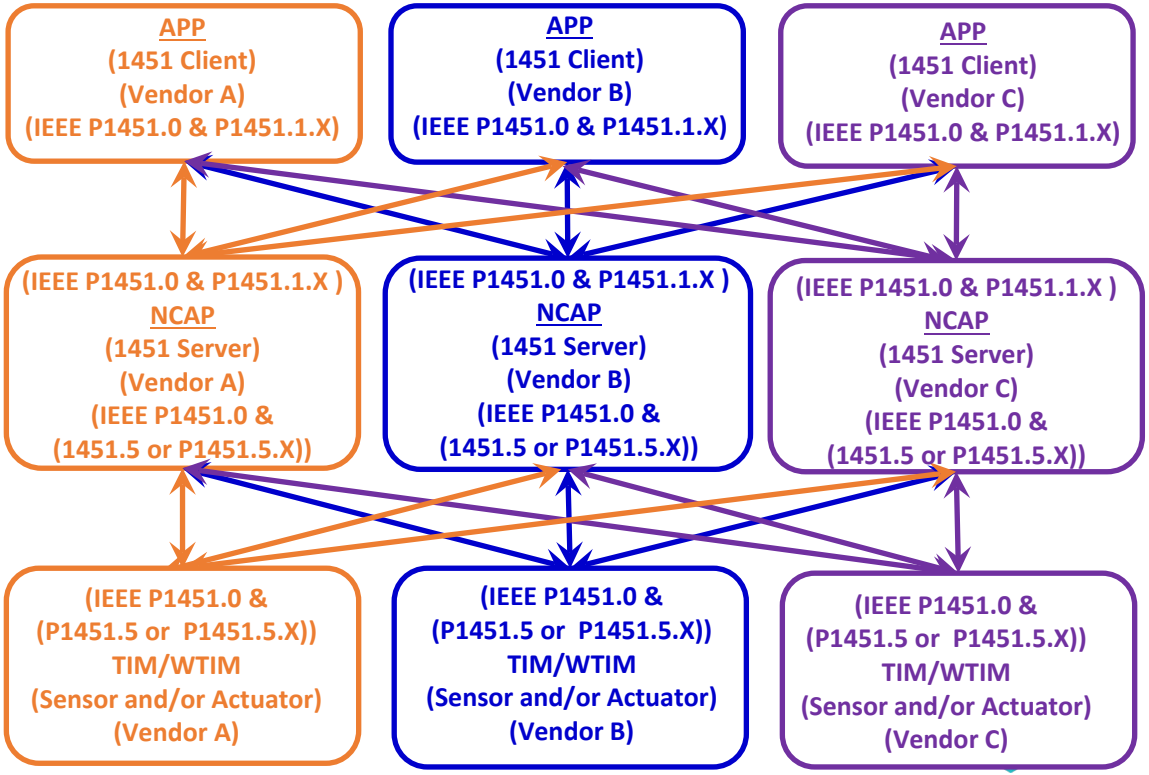
4. IEEE 1451 Interfaces Standards for Smart Transducer (Sensor & Actuator) Networks (Cont'd)

IEEE 1451 Family Standards.

Two level standard interfaces:



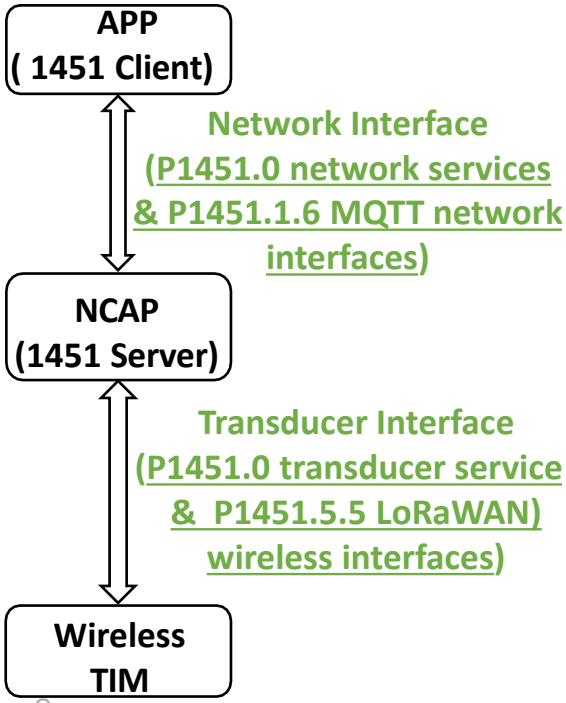
Two Levels of Interoperability



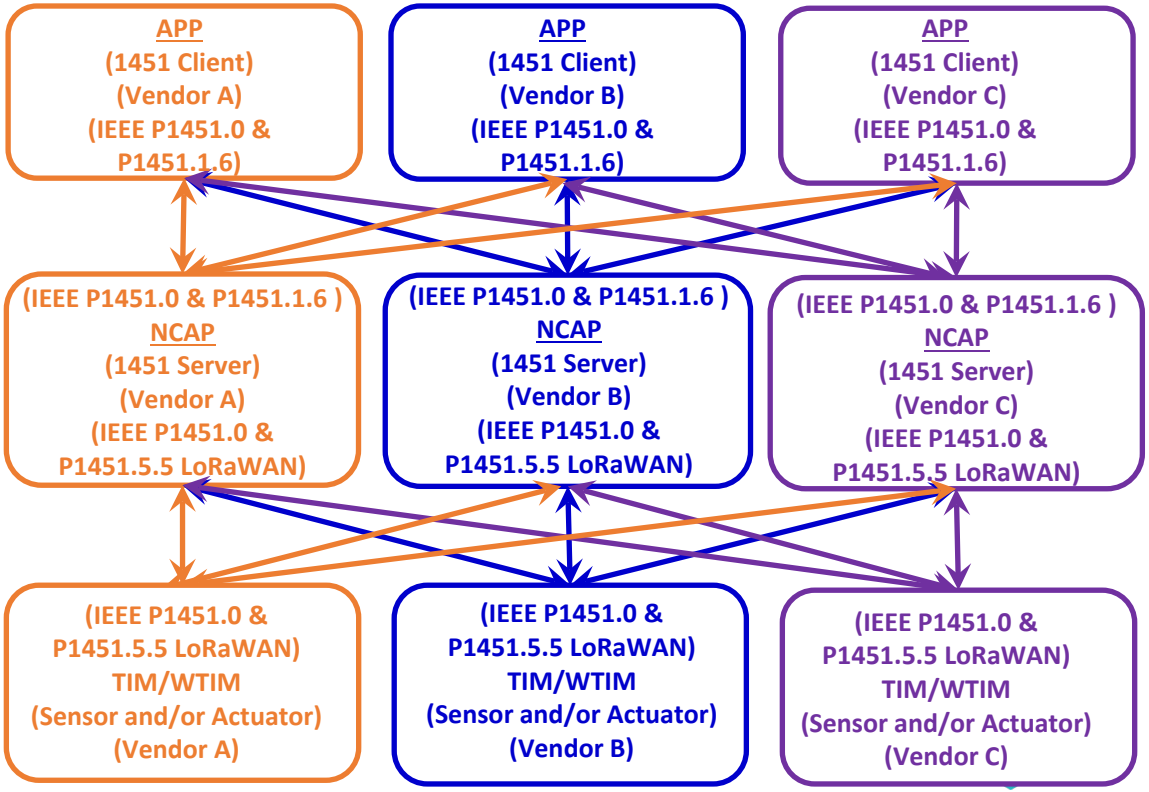
4. IEEE 1451 Interfaces Standards for Smart Transducer (Sensor & Actuator) Networks (Cont'd)

IEEE 1451 Family Standards.

Two level standard interfaces:

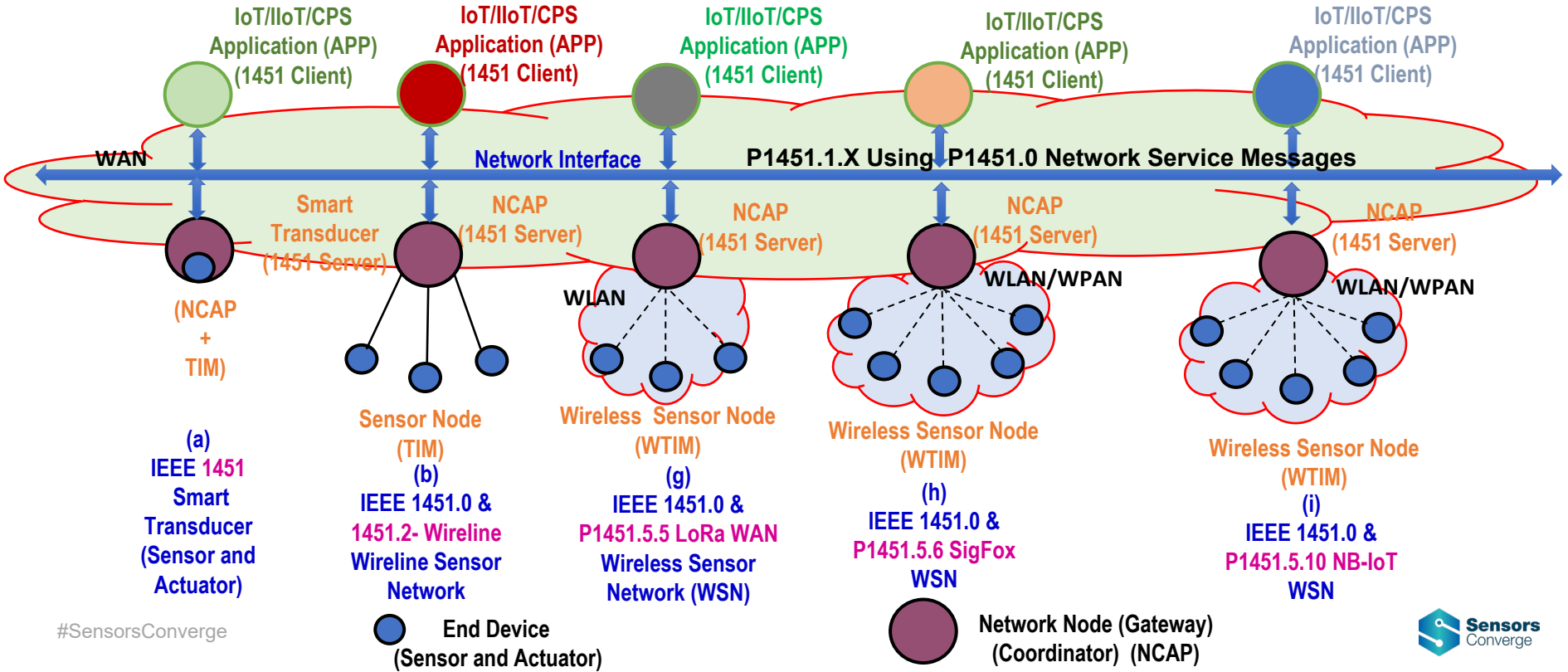


Example of Two Levels of Interoperability



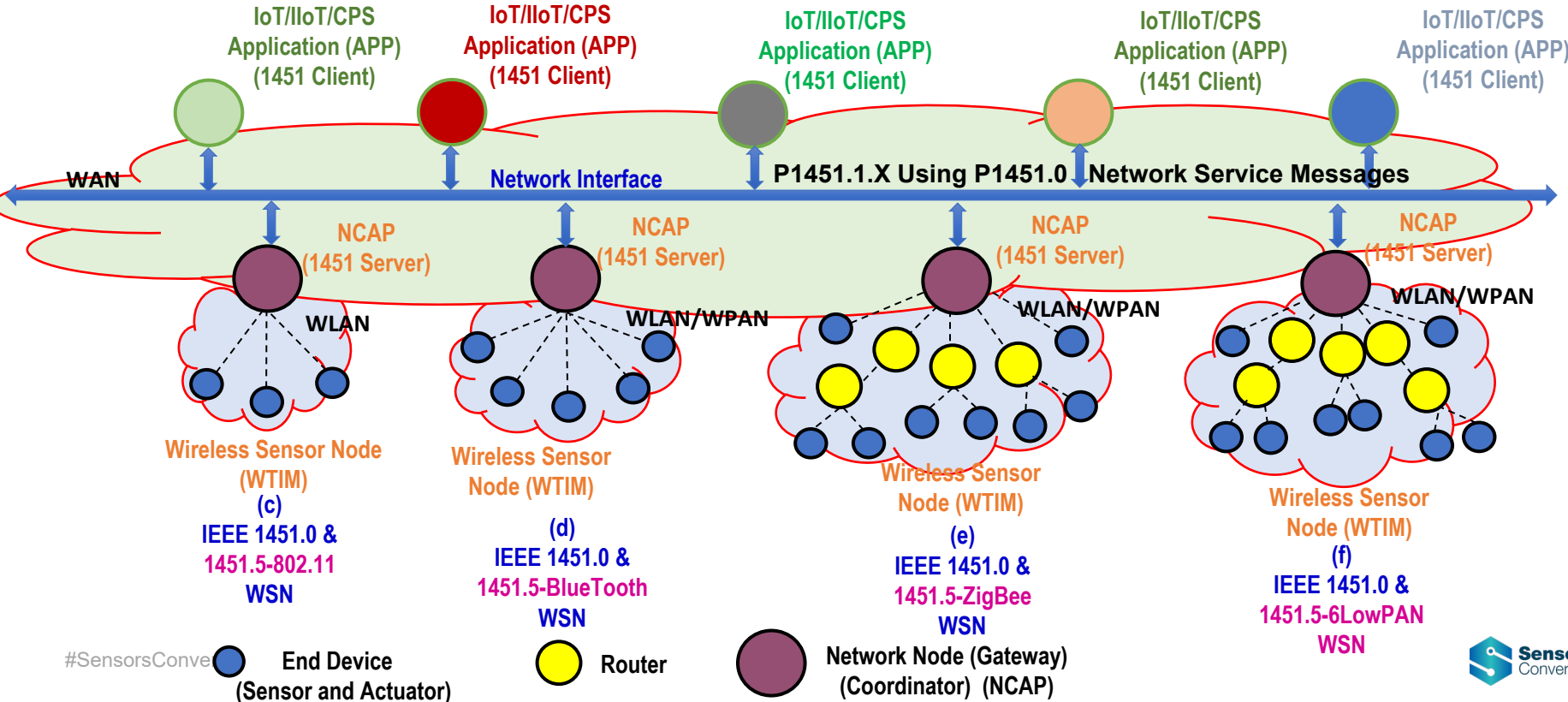
4. IEEE 1451 Interfaces Standards for Smart Transducer (Sensor & Actuator) Networks (Cont'd)

Deployment of IEEE 1451-based Smart Sensor Networks for IoT/IIoT/CPS Applications

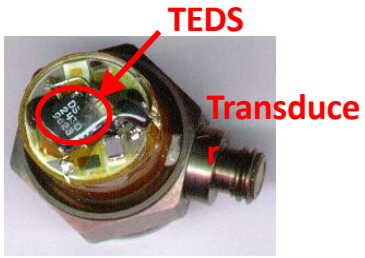


4. IEEE 1451 Interfaces Standards for Smart Transducer (Sensor & Actuator) Networks (Cont'd)

Deployment of IEEE 1451-based Smart Sensor Networks for IoT/IIoT/CPS Applications



4. IEEE 1451 Interfaces Standards for Smart Transducer (Sensor & Actuator) Networks (Cont'd)



Benefits of IEEE P1451.0 to Manufacturers and End Users

Benefits of IEEE 1451 :

- **Sensor data interoperability** (network and sensor levels) and **plug-and-play**
- **Global Identification** using UUID
- **Self-description** & **self-identification** of sensors or actuators based on TEDS & UUID
- **Security for WAN (network interface), Wireless LAN (WLAN) (transducer interface)**
- **Time synchronization for WAN, LAN & WLAN**
- **Long-term self-documentation** based on TEDS
- **Reduce human errors** (no need to enter data manually)
- **Ease field installation, upgrade, and maintenance** based on TEDS, Plug & Play
- **Reduce the total–life cycle costs** of sensor networks
- …

5. Key Takeaways

IEEE 1451 Standards Support:

- ✓UUID for APP, NCAP, and TIM
- ✓TEDS (Metadata)
- ✓Network services (messages) and transducer services (messages)
- ✓Security for WAN, and WLAN
- ✓Time synchronization for WAN, and LAN & WLAN
- ✓Sensing and actuation functions for IoT, IIoT and CPS
- ✓Wireline and wireless sensor networks for IoT/IIoT/CPS
- ✓Standards-based sensor data interoperability and plug & play

A strong business case for using IEEE 1451 standards:

- ✓Reduce human errors by using TEDS
- ✓Improve (enhance) and maintain sensor measurement accuracy by using calibration TEDS data
- ✓Ease field installation, upgrade, and maintenance (by plug & play)
- ✓Reduce the total life-cycle costs of sensor networks

Questions?

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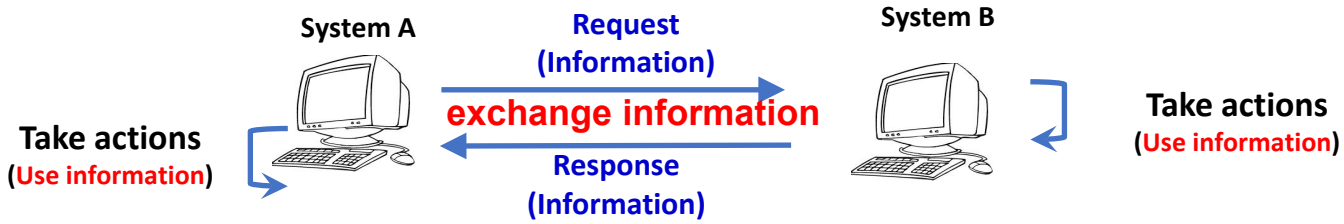
Kang Lee
Chair of IEEE I&M TC9, IEEE 1451 Family Standards
email: kang.lee@nist.gov

Backup Slides

What Is Interoperability?

Interoperability (according to IEEE):
The ability of two or more systems or components to exchange information and to use the information that has been exchanged.

Interoperability :
The ability of two or more systems to exchange information and to use the information that has been exchanged through a standard communication protocol in order to achieve the specific functions or goals.



What Are Challenges of Sensors & Actuators in IoT/IIoT/CPS Applications?

- Various wireline and wireless connectivity
- Wireless network performances (e.g., bandwidth, latency, packet loss)
- Spectrum coverage, sharing, and interference
- Cybersecurity and privacy
- Scalability
- Power consumption/energy efficiency
- Time synchronization
- Standardization & interoperability

What Are Challenges of Sensors & Actuators in IoT/IIoT/CPS Applications?

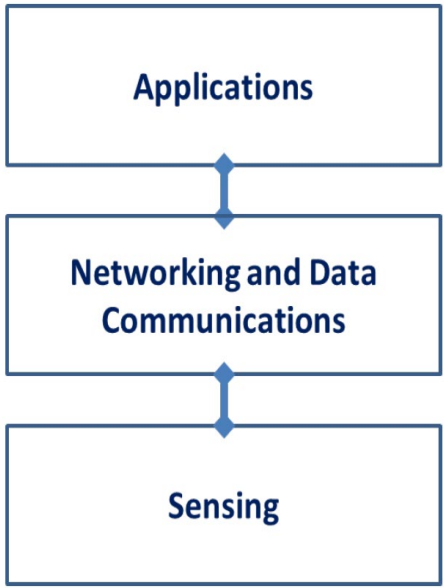
Standardization & Interoperability

1. Heterogeneity of standards and protocols
2. The lack of standard implementation
   - Limited resources to implement standards
   - Lack of implementing standards for some emerging technologies and new applications
3. Lack of standards harmonization
4. Interoperability test and plugfest
5. Lack of fundamental methodologies and software tools
   - Interoperability modeling
   - Interoperability measurement and assessment

Sensors & Actuators Are Used Everywhere

Internet of Things (IoT) is a network that connects uniquely identifiable "Things" to the Internet. (IEEE)

IEEE IoT Architecture



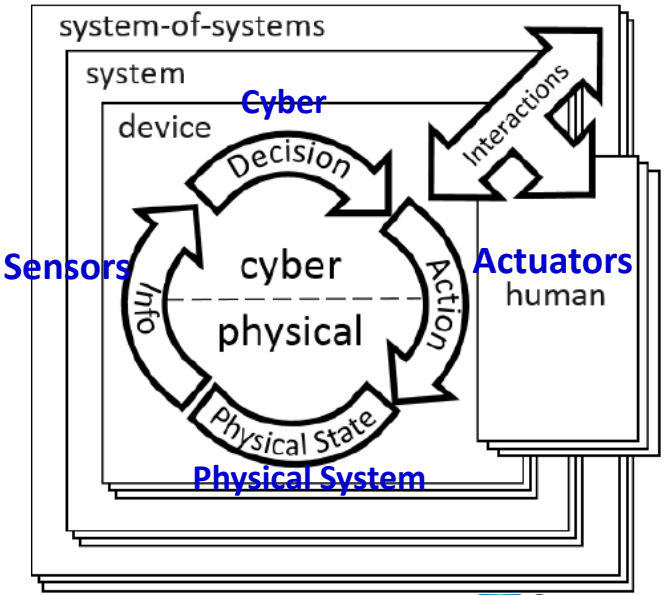
Source: https://iot.ieee.org/images/files/pdf/IEEE_IoT_Towards_Definition_Internet_of_Things_Revision1_27MAY15.pdf

IoT vs CPS:

- **IoT** is mainly **concerned about unique identification, connecting with the Internet and accessibility of "things."**
- **CPS** is mainly concerned about the **collaborative activities between cyber and physical system through sensing and actuation**
- **CPS uses IoT systems** to achieve the collaborative work of the distributed systems.

Cyber-physical systems (CPS) are smart systems that include engineered interacting networks of physical and computational components. (NIST)

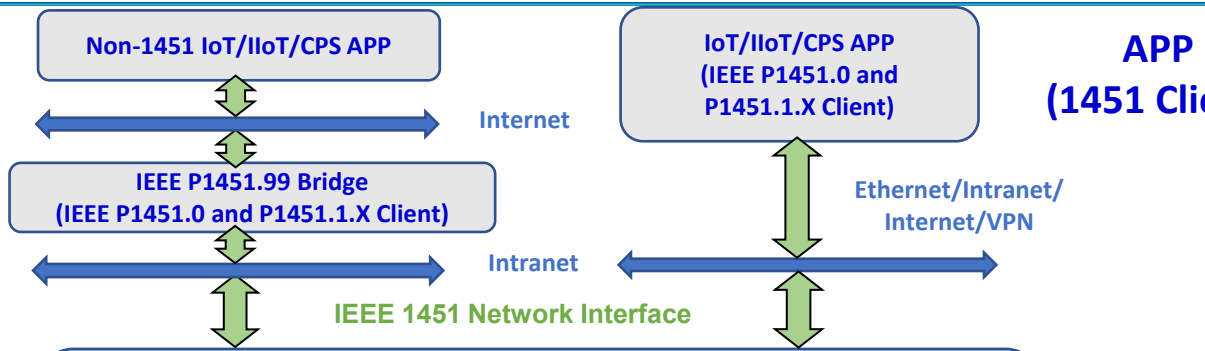
NIST CPS Conceptual Model



Source: https://pages.nist.gov/cpspwg/

Sensors Converge

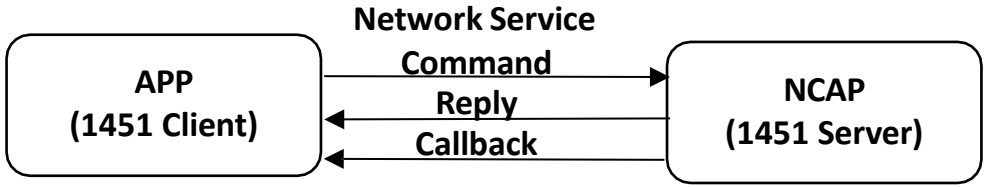
IEEE 1451 Interfaces Standards for Smart Transducer (Sensor & Actuator) Networks



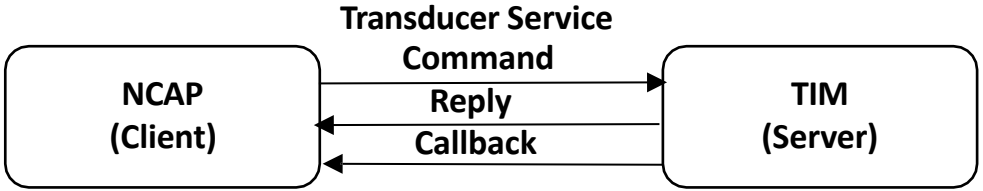
Communications Architecture for the **Family of IEEE 1451 Standards**

IEEE 1451 Interfaces Standards for Smart Transducer (Sensor & Actuator) Networks

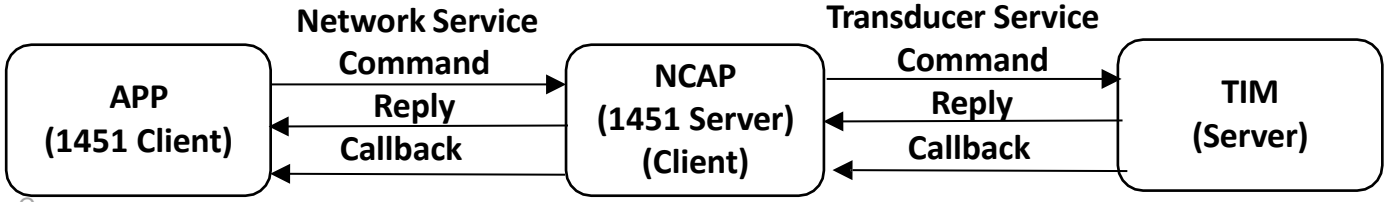
IEEE 1451.0 Client-Server Communication Model



(a)



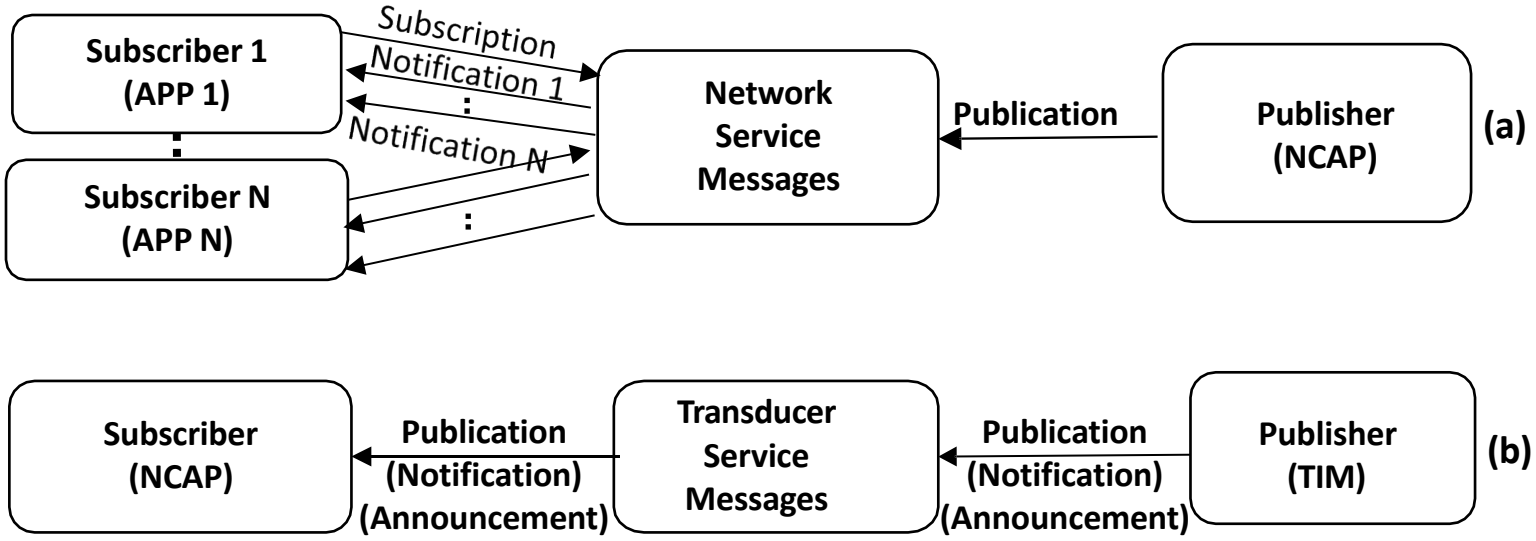
(b)



(c)

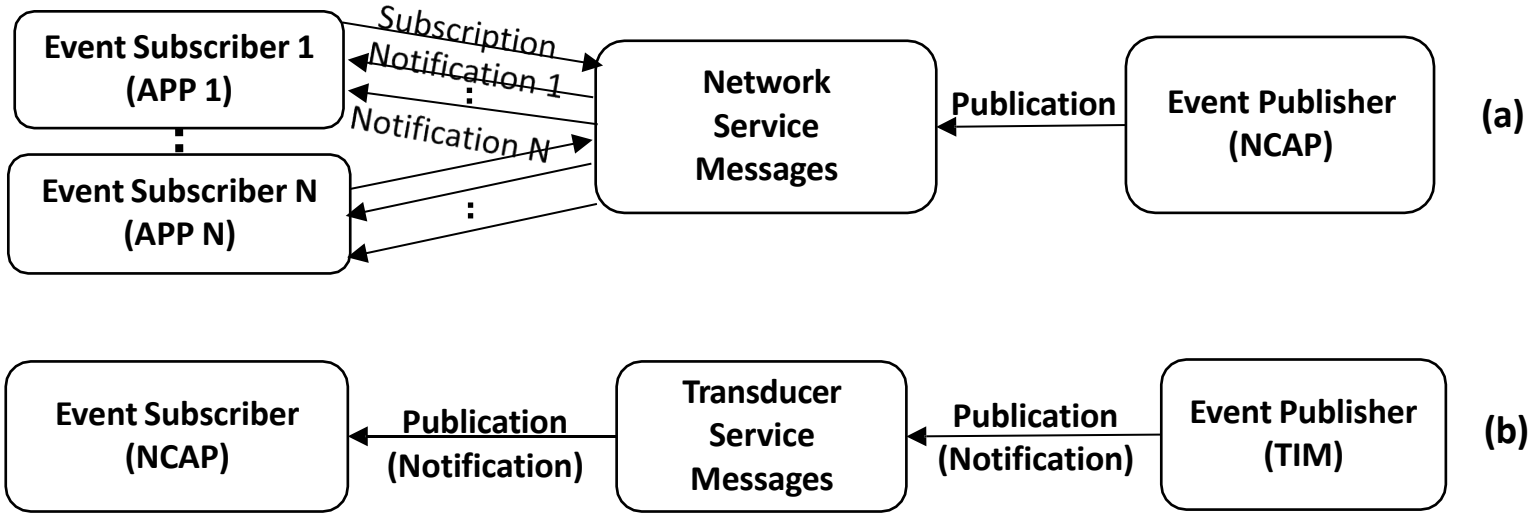
IEEE 1451 Interfaces Standards for Smart Transducer (Sensor & Actuator) Networks

IEEE 1451.0 Publish-Subscribe Communication Model



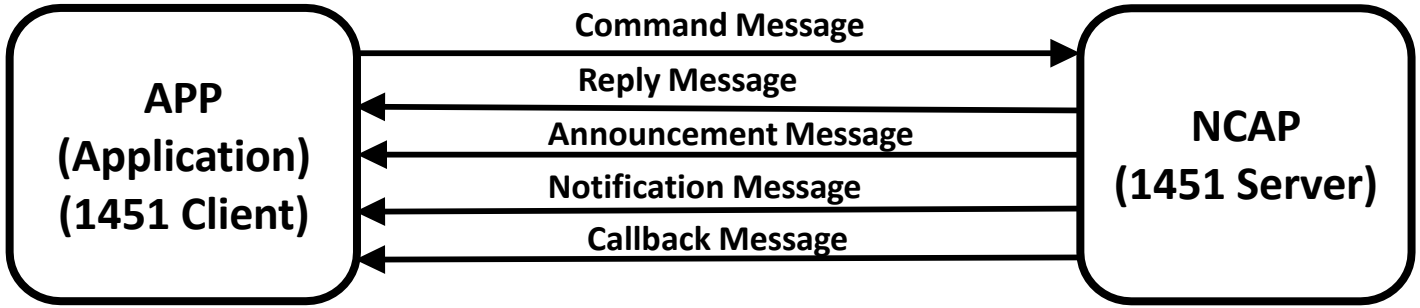
IEEE 1451 Interfaces Standards for Smart Transducer (Sensor & Actuator) Networks

IEEE 1451.0 Publish-Subscribe Communication Model



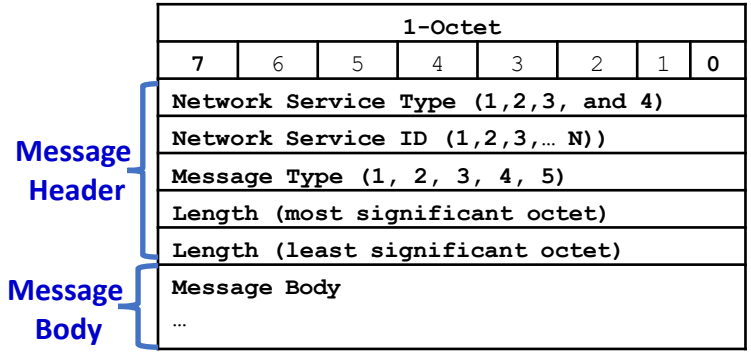
IEEE 1451 Interfaces Standards for Smart Transducer (Sensor & Actuator) Networks

IEEE P1451.0 Network Services & APIs



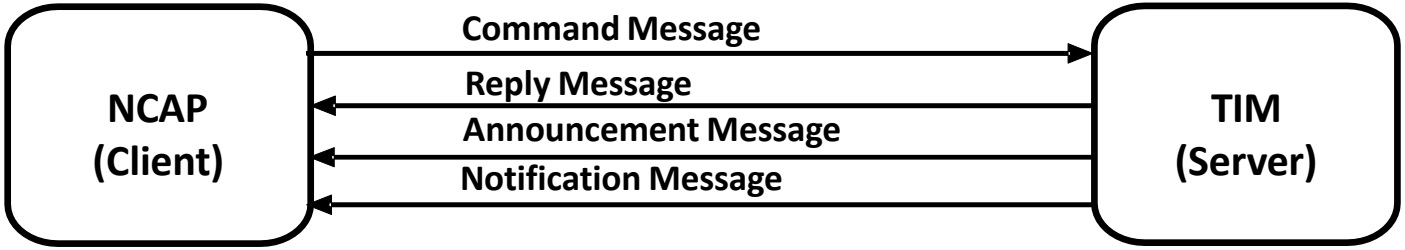
Network Service Type Name (Meaning)	Network Service Type (Enumeration)
Reserved	0
Discovery services	1
Transducer access services	2
TEDS access services	3
Event notification services	4

Message Type Name (Meaning)	Message Type (Enumeration)
Reserved	0
Command	1
Reply	2
Announcement	3
Notification	4
Callback	5



IEEE 1451 Interfaces Standards for Smart Transducer (Sensor & Actuator) Networks

IEEE P1451.0 Transducer Services & APIs



Transduce Message Type (Meaning)	XdcrMsgType (Enumeration)
Command	1
Reply	2
TIM Announcement	3
TIM Notification	4
Reserved	5-127
Open to Manufacturer	128-255

Message Section	1-Octet							
	7	6	5	4	3	2	1	0
Message Header	**Command class Id (1)**							
	Command function Id							
	Transducer Message type							
	Length (most significant octet)							
	Length (least significant octet)							
Message Body	• UUID: timId • Destination or Source TransducerChannel Number (UInt16) • Message type-dependent information. (Message class, function, msg type-dependent octets) …							