C101: Introduction to Communications Protocols and Their Uses in ITS Applications
Instructor

Raman K. Patel, Ph.D., P.E.
President
RK Patel Associates, Inc.
New York, NY, USA
Target Audience

- Telecommunications, system administration, and network management staff
- Engineering staff
- System engineers, developers, and implementers
- Traffic management and operations staff
Recommended Prerequisite(s)

- I101: Using ITS Standards: An Overview
- A101: Introduction to Acquiring Standards-based ITS Systems
Curriculum Path (Non-SEP)

1. I101 Using ITS Standards: An Overview
2. A101 Introduction to Acquiring Standards-based ITS Systems
3. A102 Introduction to User Needs Identification
4. A201 Details on Acquiring Standards-based ITS Systems
5. A202 Identifying and Writing User Needs When ITS Standards Do Not Have SEP Content
6. A103 Introduction to ITS Standards Requirements Development
7. A203 Writing Requirements When ITS Standards Do Not Have SEP Content
8. C101 Introduction to Communications Protocols and their Uses in ITS Applications

U.S. Department of Transportation
Research and Innovative Technology Administration
Curriculum Path Continuation

C101
Introduction to Communications Protocols and Their Use in ITS Applications

Center- to- Field Standards

A3xxa User Needs

A3xxb Requirements

T3xx Test Plan

Center- to- Center Standards

A3xxa User Needs

A3xxb Requirements

T3xx Test Plan
Learning Objectives

1. Be familiar with the basic terminology of the communications process used in the NTCIP.

2. Explain how the NTCIP Framework (Stack) fulfills functional requirements to meet operational needs.

3. Describe center-to-field (C2F) applications and their related NTCIP Standards.

4. Describe center-to-center (C2C) applications and their related NTCIP Standards.
Learning Objective #1 — Be familiar with the basic terminology of the communications process used in NTCIP

- What is a protocol? What is a standard?
- Communications Process
  - Open Systems Interconnect-Reference Model (OSI-RM) from the International Standards Organization (ISO)
  - National Transportation Communications for ITS Protocol (NTCIP) Framework
Let’s Ask Ourselves a Question

“What is the first thing we do when we meet someone?”
We Observe Some “Protocol”

We greet each other with a hand shake….begin conversation…
How are you?
Computers Observe Protocol

While two computers don’t shake hands physically, they do observe some rules—conventions—to begin conversation or communication.

That is what a protocol is about.
What is a Communications Protocol?

- A protocol is “a set of conventions that govern the interaction of processes, devices, and other components within a system.”

Ref. IEEE 610 Std.
Example

- A protocol is “a specific set of handshaking rules, procedures, and conventions defining the **format**, **sequence**, and **timing** of data transmission between devices that must be accepted and used to understand each other.”

  Source: NTCIP 1203 DMS standard
Parts of a Communications Protocol

- **Syntax** is the data and data format rules; these form the *Protocol Data Unit (PDU)*.
- **Semantics** are the transfer rules for PDUs. They contain control information-error handling rules.
- **Timing** deals with performance requirements for the transfer.
What is a Standard?

A standard defines the rules for the exchanges of the data and establishes a format and mandatory definition for the data elements and sequences of exchanges. The standard will include both mandatory (normative) requirements and optional (informative) information to assist in using the standard.
Example of a Standard:

Manual on Uniform Traffic Control Devices (MUTCD)

“When a sign is used to indicate that traffic is always required to stop, a STOP (R1-1) shall be used.”

“The STOP sign shall be an octagon with a white legend and border on a red background.”

Source: FHWA
ITS Standards

Deal with Data (Information) Structures and Communications, and some ITS Hardware

Benefits

- Developed to assist in obtaining interoperable systems
- Lead to an open procurement process that reduces costs and allows a multi-vendor environment
- Define the interface design details
- Reduce work for the systems manager
- Contribute to the connected transportation environment, our national agenda
Communications Protocol and Compatibility

“Compatibility is the ability of two or more systems or components to perform their required functions while sharing the same hardware or software environment.”

Ref. IEEE 610 Std.

When both ends use the same communications protocols they achieve compatibility.

Diagram:

A  ————  B
Illustration

Compatibility

Different Types of Devices Can Share a Communication Channel

Integrated or stand-alone management station

Source: Katz FDOT Dist.6

ORIGINAL EQUIPMENT

SECOND SOURCE EQUIPMENT
How to Achieve Interoperability?

- **Interoperability** is the ability of two or more systems or components to exchange information and to use the information that has been exchanged.
  
  Ref. IEEE 610 Std.

- When both ends have compatibility (use the *same protocols*) and use the *same message* definitions for the information level, they achieve interoperability.
Interchangeability

- Same functional and physical characteristics so as to be equivalent in performance and durability
- Ability to exchange devices of the same type without alteration to the device or adjoining items
What is a dialog?

- Humans and computers both exchange information in orderly conversations called **dialogs**.
- Dialogs are a sequence of exchanges (messages) that are carried out for a specific purpose.

Connection between the devices is the basis of a dialog.
Benefits of a Common Protocol

Procurement through Multiple Vendors-Cost Savings

Remote Management Capability
Easier System Expansion
Benefit of Industry Standard
Multiple Devices Common Low-Layers

Multiple Vendors for Same Devices Competitive Market

Management Station

SB EXIT 20 CLOSED
What is a Communications Process?

- A communications process handles transmission of data or information between Point A and Point B, involves systems and/or devices, and requires protocols.

- A communications process requires two entities: a common communication medium and a common protocol and common language.
Open Systems Interconnection (OSI) Reference Model (RM)

Structured Approach: Each Layer Performs a Specific Function with an Assigned Protocol

Communication Process
(Monolithic, complex, unstructured closed-program)

Application Layer
Presentation Layer
Session Layer
Transport Layer
Network Layer
Data Link Layer
Physical Layer
Understanding the Logical Structure of the OSI-RM

Upper three layers provide application services-user requirements.

Intermediate transport layer separates or masks upper and lower layers.

Lower three layers provide end-to-end-network services.

- Application Layer
- Presentation Layer
- Session Layer
- Transport Layer
- Network Layer
- Data Link Layer
- Physical Layer
NTCIP Framework

**Note:** At each level, there are profile standards to choose from. A profile standard is a collection of standards. (23xx, 22xx, and 21xx are profile standards.)
Information Level

Provides Data Dictionary Standards

- NTCIP 12xx series standards contain object definitions (vocabulary) used to configure, control, and monitor field devices.
- Functional Area Data Dictionaries such as the Traffic Management Data Dictionary (TMDD)
Application Level

Provides Standards to Exchange Data/Information

- For communications interface with Field devices (C2F)
- For information exchange with systems (C2C)
Transport Level

Provides Transport Protocols

- For connection-based transport service with TCP/IP
- For connection-less transport service with UDP/IP
- For non-routable (direct) transport service for low speed legacy situation with T2/NULL
Subnetwork Level

Provides Subnetwork Protocols Standards for Network Services

- Ethernet
- Point-to-Point Protocol (PPP) is a connection to each device; used for dial-up circuits using V series modems.
- Point-to-Multipoint Protocol (PMPP) is a shared connection where each device is assigned an address and shares a twisted pair, for example.
Plant Level

Plant Level includes Physical Layer

- At Plant Level, data in the form of “bits” are transmitted across a physical infrastructure (connectors-wires).

- Examples: Fiber Optic cable or Wireless Network

- Communication engineers perform bandwidth analysis and plant network design to enable this task.
Illustration-1

Communications Process for C2F Dialogs

Information Level NTCIP 1203 DMS
Application Level SNMP
Transport Level Protocol

User Selects Standards
Communications Processes for C2C Dialogs

**Notes:**

- Information Level TMDD Standard
- Application Level NTCIP 2306 XML Profile
- Transport Level TCP/IP Standard

**Note:** A Profile Standard is a Combination of Standards. NTCIP 2304 DATEX is also a C2C Profile.
ACTIVITY
C2F Device Data Standards are Located at:

Answer Choices

a) Information Level
b) Application Level
c) Transport Level
d) Subnetwork Level
Review of Answers

a) Information Level
Correct, because Information Level does provide C2F device data standards.

b) Application Level
Incorrect, because C2F data standards define data only, while the Application Level houses only the protocols.

c) Transport Level
Incorrect, because Transport Level protocols are used for data transfer and they are not device data standards.

d) Subnetwork Level
Incorrect, because Subnetwork Level protocols are used for sharing a communication channel and they are not device data standards.
Summary of Learning Objective #1

Be familiar with the basic terminology of the communications process used in the NTCIP.

- Discussed the communication process
  - What is protocol? What is standard?
  - *Compatibility* is achieved with the use of the same communications protocols.
  - *Interoperability* is achieved when systems are compatible and use the same dictionaries, dialogs, and protocols.
Summary of Learning Objective #1 (cont.)

Be familiar with the basic terminology of the communications process used in the NTCIP.

- Reviewed the seven layer OSI-RM
- Reviewed five levels of the NTCIP Framework and the tasks they perform
Learning Objective #2 — Explain how the NTCIP Framework (Stack) fulfills functional requirements to meet operational needs.

- What problem is NTCIP addressing?

- Organization of information level dictionaries

- Configuring, controlling, and monitoring of field devices (C2F-master/slave model)

- Information exchange among centers (C2C, peer-to-peer communication)
What Problem is NTCIP Addressing?

Inability to communicate between different vendors’ devices or share a communication channel

- Proprietary vendor-specific devices’ functionality
- Closed protocols for communications, which leads to sole source procurement and proprietary systems—more expensive future expansion and integration
Solution Offered by the NTCIP Framework

- Interoperability and vendor independence with:
  - Common data format for definitions
  - Open communications standards
NTCIP-Based Device Data Standards

Devices from multiple-vendors can share a communication channel.

- Environmental Sensor Stations
  - NTCIP 1204 ESS
- Dynamic Message Signs
  - NTCIP 1203 DMS
- Electrical Lighting Management Systems
  - NTCIP 1213 ELMS
- Signal Control Priority
  - NTCIP 1211 SCP
- Traffic Sensor Systems
  - NTCIP 1209 TSS

Center-to-Field (C2F)

- NTCIP 1202 ASC
- NTCIP 1205 CCTV
- NTCIP 1207 RMC
- NTCIP 1206 DCM
- NTCIP 1210 FM-I

Actuated Signal Controllers
CCTV Cameras
Ramp Meter Control Units
Data Collection & Monitoring
Field Master-SSM
Data Dictionaries

Information Level: NTCIP 12xx

- Device dictionary contains **objects** that represent functions—features of a device.

- A3xx series training modules cover details on objects and their structure and communication interface.
What is an Object?

“A data structure used to monitor or control one feature, attribute, or controllable aspect of a manageable device” – NTCIP Standards

- Objects are structured with Abstract Syntax Notation One (ASN.1) Language.
Management Information Base (MIB)

- MIB is a human readable file format that contains objects designed for configuring, controlling, and monitoring a specific device.

Illustration: CCTV MIB contains over 70 objects.
Protocol/MIB Relationship

MIB provides objects with values

SNMP operations manipulate values of objects

Behavior of the device function altered
Information Level C2C Data Dictionaries

- **SEP based:**
  - TMDD contains messages, data elements, and dialogs to support exchanges between traffic management systems.

- **Non-SEP based:**
  - IEEE 1512 Emergency Management standards contain only data elements and may not deliver interoperable systems consistently (without dialogs).
  - Other examples are ATIS and TCIP message standards. (See student supplement for references.)
Supports C2C System Interface Design

- Provides user needs and requirements related to traffic management applications
- Provides data elements, data frames, messages, and dialogs for system interface design
- Local project selects capabilities that are needed from the standard.
Other Functional Area C2C Dictionaries

- Emergency Management Messages (IEEE 1512)
- Advanced Traveler Information System (ATIS); Data Dictionary (J2353), Messages Sets (SAE J2354)
- Transit Communications Interface Profiles (TCIP) Applications (APTA Standards)

See Participant Student Supplement for where to find these standards.
How to Combine a Set of Standards for C2F?

Create a Stack by Selecting a Protocol at Each Level

- Data Dictionary for the Device
  - NTCIP 12xx
- Protocol to Exchange Data
  - NTCIP 23xx
- Transport Protocol
  - NTCIP 22xx
- Subnet Protocol
  - NTCIP 21xx
- Communication Plant
  - Fiber or….
Example of DMS Deployment Stack

DMS Dialogs can be carried out with this Stack.

NTCIP 1203 DMS
NTCIP 2301 SNMP
NTCIP 2202 UDP/IP
NTCIP 2103 PPP

Plant level communications could be any medium.

Source: NYCDOT
How to Combine a Set of Standards for C2C?

Create a Stack by Selecting a Protocol at Each Level

Example: Traffic Management

- Functional Area Data Dictionary—**TMDD**
- Application Profile—**NTCIP 2306 XML**
- Transport—**NTCIP 2201 TCP/IP**
- Subnetwork—**NTCIP 2104 Ethernet**
- Web—Connectivity
NTCIP 12xx Device Standards Provide:

**Answer Choices**

a) Management Information Base (MIB) for each field device
b) Application protocols such as Simple Network Management Protocol (SNMP) and Simple Transportation Management Protocol (STMP)
Review of answers

a) Management Information Base (MIB) for each field device
   
   *Correct, because NTCIP 12xx series standards provide a device-specific MIB.*

b) Application protocols such as SNMP and STMP
   
   *Incorrect, because application level protocols are covered by NTCIP 23xx series standards.*
Summary of Learning Objective #2

Explain how the NTCIP Framework (Stack) fulfills functional requirements to meet operational needs.

- Discussed problem being addressed by the NTCIP Framework

- Discussed how **Information Level** NTCIP 12xx series device data dictionaries provide objects to meet C2F operational needs

- Discussed how **domain-specific** dictionary provides data concepts to support C2C operational needs
Learning Objective #3 — Describe Center-to-Field (C2F) applications and their related NTCIP Standards

Operational Needs

- Define SNMP Network Management Model
- Structure of SNMP Messages (Get/Get Next, SET, and TRAP), PDU format
- STMP, FTP, TFTP
Operational Needs

C2F Standards Supports Management Station for:

1. Configuring a device (parameters)
2. Monitoring a device and gathering data
3. Controlling device functions or actions
4. Retrieving logged/events reports when something “unexpected” happens

(Exception reporting by agent)
C2F Protocols

Protocols Available for Managing Field Devices:

1. Simple Network Management Protocol (SNMP)
2. Simple Transportation Management Protocol (STMP)
3. File Transfer Protocol (FTP)
4. Trivial File Transfer Protocol (TFTP)
Simple Network Management Protocol (SNMP)

- A C2F communications protocol that is simple and flexible
- Used in network management to monitor and control devices remotely:
  - Manages network devices such as routers, bridges, firewalls, switches, etc.
  - Manages ITS devices such as traffic controllers and Dynamic Message Signs (DMS)
SNMP Network Management Model

Provides Capability for Remote Management

Management Station
(Also called Network Management Station or NMS)

- Management Applications
- SNMP Manager
- MIB

Managed Device

- Management Information
- SNMP Agent
- MIB
Key Components of an SNMP Model

- **SNMP Manager**: an application program that contacts an SNMP agent to query or modify the database at the agent

- **SNMP Agent**: a software that runs on a device and maintains information about configuration and current state of database

- **MIB**: describes the information about the device being managed
SNMP Operations

- **Retrieving** the *value* of the management information accessible by an agent [Read-GET operation]

- **Modifying** the *value* of the management information accessible by an agent [Write-SET operation]

- **Reporting** an *event* or condition by the agent to the manager [Trap operation in the Internet space, but NTCIP does not support this capability at this time]
SNMP Messages

Request Messages  (Retrieval/Modification operations)
  - GetRequest message  [give me information on...]
  - GetNextRequest message  [get more information from the MIB.....get next piece of information]
  - SetRequest message  [do this action for me on...]

Response Messages  (Retrieval operations)
  - GetResponse message  [here is the information]
Exception Reporting

- Two ways to report conditions within NTCIP
  - Event logs
  - Traps (Future)

- Event logs allow user-defined events to be logged with a timestamp for later retrieval using `GetRequest`.

- Traps allow these events to be reported immediately to the management station, but this mechanism is not yet standardized by NTCIP.
To gather data from a detector station, the central SNMP Manager initiates:

**Answer Choices**

a) GetRequest message
b) SetRequest message
c) Trap message
d) GetResponse message
Review of Answers

a) GetRequest message
   Correct, because GetRequest retrieves values from the agent of the detector station.

b) SetRequest message
   Incorrect, because SetRequest message is for modifying a value.

c) Trap message
   Incorrect, because Trap message does not apply; it is not issued by the SNMP manager.

d) GetResponse message
   Incorrect, because GetResponse message only returns a value requested by GetRequest message.
Simple Transportation Management Protocol (STMP)

- A variation of SNMP, designed to work with 13 specially designed “dynamic objects.”

- Any device could use STMP, but it was only adopted by ASC devices because it allowed the more efficient use of the bandwidth for the real-time retrieval of status information.
Simple Transportation Management Protocol (STMP) (cont.)

- It has been used in wireless networks and Ethernet to allow multiple objects to be packed into a single block and retrieved with a single GET operation.

- Refer to NTCIP Guide 9001 v04, NTCIP 2301, and NTCIP 1103 v02 for more information.
File Transfer Protocol (FTP)

- FTP (NTCIP 2303) is a TCP/IP-based Protocol.
- Examples:
  - **C2F**: Environmental Sensor Stations (ESS) standard uses FTP to visually inspect weather conditions and/or verify the reported weather conditions by retrieving camera snapshots.
  - **C2C**: FTP is used in the XML-DIRECT.
Trivial File Transfer Protocol (TFTP)

- TFTP (NTCIP 2302) works with UDP/IP (User Datagram Protocol-connectionless).
- Efficient protocol for transfer of small files
Illustration

- TMC requests to retrieve the current status of a DMS.
- Agent responds with a value.

- Central system translates the response for the user who interprets the response and makes decision on the next step.
ACTIVITY
Which of the following is a preferred protocol for monitoring a DMS?

**Answer Choices**

a) SNMP  
b) FTP  
c) STMP  
d) NTCIP 2306 XML
Review of answers

a) SNMP

Correct, because **SNMP is typically used by convention to interface with the DMS in the field.**

b) FTP

Incorrect, because **FTP is only used for file transfer.**

c) STMP

Incorrect, because **STMP can be used only in ASC applications and by convention it is not typically used for DMS or other devices.**

d) NTCIP 2306 XML

Incorrect, because **NTCIP 2306 XML is a profile standard used in C2C applications.**
Summary of Learning Objective #3

Describe Center-to-Field (C2F) applications and their related NTCIP Standards

- Reviewed operational support provided by the C2F standards: configuration, monitoring, and control.
- Discussed protocols used in the C2F applications and focused on the SNMP model and services it provides.
Learning Objective #4 — Describe Center-to-Center (C2C) applications and their related NTCIP Standards

- Center-to-Center (C2C) Operational Needs
- Communications System Interface
- TMDD Data Concepts
- Components of NTCIP 2306 XML Profile
- Messaging models used in NTCIP 2306 XML
C2C Terminology

- **W3C**  World Wide Web Consortium
- **XML**  eXtensible Markup Language
  Encoding method for messages
- **WSDL**  Web Services Description Language
  Center’s Public Interface Format
- **SOAP**  Simple Object Access Protocol
  Communication method for XML Messages
- **HTTP**  Hypertext Transfer Protocol
  Web browser Transport Protocol
- **PRL**  Profile Requirements List (in NTCIP 2306)

NTCIP 2304 DATEX Application Profile Standard
NTCIP 2306 XML Application Profile Standard
Operational Needs (C2C)

System Interface Supports Information Exchange

1. Need to Share Event Information
2. Need to Provide Control of Devices, Share Status, and Data
3. Need to Provide Roadway Network Data
4. Need to Share Data for Archiving
Types of Generic Dialogs (TMDD)

Dialogs are a logical sequences of messages put together to conduct a “conversation” between centers.

1. Request/Response Information Sharing
2. Subscription Information Updates
3. Publication Published Information
NTCIP 2306 XML Application Profile

- TMDD Supplies:
  - Data Concepts in XML Format
    - Dialogs, messages’ data-frames, and data-elements

- NTCIP 1104 Naming Conventions

- NTCIP 2306 Supplies:
  - XML Schema-WSDL-SOAP
  - Transport: HTTP or XML
  - TCP/IP
Introduction to Web Service

- A web service is any service (operation equivalent to functions) that is available over the Internet/Intranet.
- Uses a standardized XML messaging system
- Independent of operating systems or programming languages
SOAP (Simple Object Access Protocol)

SOAP Encodes **XML Message**

- **Envelope**
  - **Header**
    - Carry Instruction **Optional**
  - **Body**
    - Carry Message Content **Required**

- **Carries Messages** **Required**

**Learning Objective #4**
NTCIP 2306 Implementation

- Project specification needs are listed in a conformance statement.
- Profile Requirements List (PRL) allows user to state selected sub-profile options (ref. NTCIP 2306 standard).

<table>
<thead>
<tr>
<th>Profile Requirements List (PRL)</th>
<th>NTCIP 2306 v01 Section</th>
<th>Mandatory / Optional</th>
<th>Profile Requirement</th>
<th>Project Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 SOAP over HTTP</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) WSDL Request-Response</td>
<td></td>
<td>O</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- WSDL General</td>
<td>6.1</td>
<td>M</td>
<td>PR 3.1</td>
<td></td>
</tr>
<tr>
<td>- Definitions</td>
<td>6.2</td>
<td>M</td>
<td></td>
<td>PR 3.1, 3.2</td>
</tr>
<tr>
<td>- Types/Schema</td>
<td>6.3</td>
<td>M</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
ACTIVITY
Which of the following is NOT applicable to C2C?

**Answer Choices**

a) NTCIP 2306 XML  
b) SNMP  
c) SOAP  
d) WSDL
Review of Answers

a) NTCIP 2306 XML
   Incorrect, because NTCIP 2306 XML is applicable to C2C as a profile standard.

b) SNMP
   Correct, because SNMP applies to C2F only.

c) SOAP
   Incorrect, because SOAP is the transport protocol used in NTCIP 2306 XML.

d) WSDL
   Incorrect, because WSDL is used in C2C as a language standard.
Summary of Learning Objective #4

Describe Center-to-Center (C2C) applications and their related NTCIP Standards

- Reviewed C2C Operational Needs
- Discussed C2C System Interface (SI)
- Discussed Generic Dialogs in TMDD
- Introduced NTCIP 2306 XML Profile
- Introduced Web service, SOAP, and WSDL
What We Have Learned

1. We have learned that the NTCIP Family of standards are based on the ISO’s **OSI-RM**.

2. Two categories of the NTCIP communications standards are **C2F** and **C2C**.

3. NTCIP objects are based on the **ASN.1** language representation, which is an ISO standard.

4. NTCIP 12xx series device data standards are located at the **Information Level**.
What We Have Learned (cont.)

5. **SNMP** is used for remote management of ITS devices located in the field.

6. Specifically, SNMP performs **Retrieval** and **Modification** operations to manage a field device.

7. C2C standards used in the traffic management applications include the **TMDD** and **NTCIP 2306 XML**.
Resources

- Participant student supplement provides a list of references.

- NTCIP 9001 v04 Guide, NTCIP C2F and C2C Standards documents are available in the NTCIP library at www.ntcip.org

- TMDD Standard v03 and TMDD v02 Guide are available at www.ite.org.
Additional Communications Modules

C201: Introduction to Simple Network Management Protocol (SNMP) and its Applications in the Field Devices Based on the NTCIP Standards

C202: Introduction to the Application Level Protocols for Center-to-Center Communication System Interface Implementation (NTCIP 2306 XML)