Professional Capacity Building for Communications

Curriculum Scope and Sequence

(Revised for Project Phase 3)

by

Leann A.F. Koon
Research Associate

Douglas Galarus
Program Manager/Senior Research Scientist

Western Transportation Institute
College of Engineering
Montana State University

A report prepared for the

California Department of Transportation
Division of Research, Innovation, and System Information
Sacramento, California

December 21, 2015

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data herein. The contents do not necessarily reflect the official views or policies of the State of California, the California Department of Transportation, the Federal Highway Administration, or Montana State University. This report does not constitute a standard, specification, or regulation.

Alternative accessible formats of this document will be provided upon request. Persons with disabilities who need an alternative accessible format of this information, or who require some other reasonable accommodation to participate, should contact Carla Little, Research Writer, Western Transportation Institute, Montana State University, PO Box 174250, Bozeman, MT 59717-4250, telephone number 406-994-6431, e-mail: clittle@coe.montana.edu.

ACKNOWLEDGEMENTS

The project team would like to thank those Caltrans engineers who took the time to complete the needs assessment surveys to help guide the development of the curriculum. A thank you also goes to Project Technical Advisory Panel (PTAP) members Sean Campbell, Chief, ITS Special Projects Branch, Caltrans Division of Research, Innovation, and System Information, Ian Turnbull, Chief, Office of ITS Engineering and Support, Caltrans District 2, and Steve Hancock, ITS Functional Manager, Caltrans, Office of Technology, ITS Support, for their input, support and guidance on this project. The project team also recognizes Caltrans Project Manager, Jose Perez. Dr. Bill Jameson helped to establish the curriculum and his efforts are acknowledged and appreciated. Thank you to Gary Schoep, Research Associate, and Alex Bones, Jeffrey Langemeier, Justin Livingston, Aitor Puigcerver, and Fred Vollmer, Research Assistants, for their work on researching the state of the practice for ITS communications training.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

1xRTT	One Times Radio Transmission Technology
ADN	Advanced Digital Network
ADSL	Asymmetric Digital Subscriber Line
AM	Amplitude Modulation
ARP	Address Resolution Protocol
BRI	Basic Rate Interface
Caltrans	California Department of Transportation
CAT-5	Category 5
CAT-6	Category 6
CCTV	Closed Circuit Television
CDMA	Code Division Multiple Access
CHAP	Challenge-Handshake Authentication Protocol
CSU/DSU	Channel Service Unit/Data Service Unit
CMS	Changeable Message Sign
CO	Central Office
DCE	Data Communications Equipment
DDNS	Dynamic Domain Name System
DHCP	Dynamic Host Configuration Protocol
DS1	Digital Signal at Level 1 (1.544 Mb/s)
DSL	Digital Subscriber Line
DTE	Data Terminal Equipment
EDGE	Enhanced Data rates for GSM Evolution (or Global Evolution)
EIA/RS	Electronics Industries Association/Recommended Standard
EMS	Extinguishable Message Signs
ERP	Effective (or Equivalent) Radiated Power
EV-DO	Evolution, Data Only or Evolution, Data Optimized
FCC	Federal Communications Commission
FHWA	Federal Highway Administration
FTP	File Transfer Protocol
G	Generation (e.g., 3G is 3rd Generation)
GHz	Gigahertz

GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
HAR	Highway Advisory Radio
HDSL	High bit rate Digital Subscriber Line
HTTP	Hypertext Transfer Protocol
HTTPS	Hypertext Transfer Protocol Secure
Hz	Hertz
ICMP	Internet Control Message Protocol
IEEE	Institute of Electrical and Electronics Engineers
IOS	Internetwork Operating System
IP	Internet Protocol
IPSec	Internet Protocol Security
ISDN	Integrated Services Digital Network
ITS	Intelligent Transportation Systems
ITSA	Intelligent Transportation Society of America
K	Kilobits per Second (e.g., 56k data rate), also kb/s
LAN	Local Area Network
LTE	Long Term Evolution
MAC	Media Access Control
Mb/s	Megabits per Second
MHz	Megahertz
MPLS	Multiprotocol Label Switching
MSU	Montana State University
NF	Noise Figure/Factor
OSI	Open Systems Interconnection
OSPF	Open Shortest Path First
OTDR	Optical Time Domain Reflectometer
PCS	Personal Communications System
PoE	Power over Ethernet
POTS	Plain Old Telephone Service (wireline telco services)
PPP	Point-to-Point Protocol
PPPoE	Point-to-Point Protocol over Ethernet
PRI	Primary Rate Interface

PTAP	Project Technical Advisory Panel
RF	Radio Frequency
RFB	Request for Bids
RIP	Routing Information Protocol
RSSI	Received Signal Strength Indication
RSTP	Rapid Spanning Tree Protocol
RWIS	Road Weather Information Systems
SLIP	Serial Line Internet Protocol
SME	Subject Matter Expert
S/N	Signal-to-Noise ratio
SNMP	Simple Network Management Protocol
SONET	Synchronous Optical Networking
SSH	Secure Shell
SSL	Secure Sockets Layer
TCP	Transmission Control Protocol
TDR	Time Domain Reflectometer
TKIP	Temporal Key Integrity Protocol
TMC	Transportation Management Center
TMS	Traffic Management System
UDP	User Datagram Protocol
VDSL	Very high bit rate Digital Subscriber Line
VPN	Virtual Private Network
WAN	Wide Area Network
WEP	Wired Equivalent Privacy
WiMAX	Worldwide Interoperability for Microwave access
WPA	WiFi Protected Access
WTI	Western Transportation Institute
xDSL	Digital Subscriber Line (of any type such as ADSL, HDSL, or VDSL)

1. INTRODUCTION

Rural ITS deployments are continuing to become more complex with a greater number and variety of field devices utilized to improve the safety and operations of rural travel. Design of communication networks employing devices such as Highway Advisory Radio (HAR), Road Weather Information Systems (RWIS), Changeable Message Signs (CMS), Closed Circuit Television (CCTV) cameras, Extinguishable Message Signs (EMS), and roadway sensors that communicate with Transportation Management Centers (TMC) is a critical skill in successful implementation of rural ITS projects. With any advancing technology, there is a need for a skilled workforce with an advancing skill set, which in turn requires ongoing training in new technologies. The purpose of the Professional Capacity Building for Communications Systems project is to research and develop a comprehensive training curriculum for transportation communication systems that will build the professional capacity of rural ITS engineers and technicians.

This document outlines the scope and sequence of a proposed training curriculum in transportation communication systems. The target audience includes field engineers and technicians who apply ITS technologies in rural areas to improve transportation safety and operations.

For the sake of clarity in this document and in the project as a whole, the term "curriculum" refers to the complete scope and sequence. To further distinguish the various terms, "subject areas" are the next level down in organizing the curriculum. Each "subject area" consists of several different "topics" or "modules." Finally, each "topic/module" has specific "learning objectives" associated with it. The words "course" and "class" are used interchangeably and describe an actual presentation of materials by a subject matter expert. A "class" or "course" could cover an entire "subject area" or it could cover a "topic/module" or group of "topics/modules" within a "subject area".

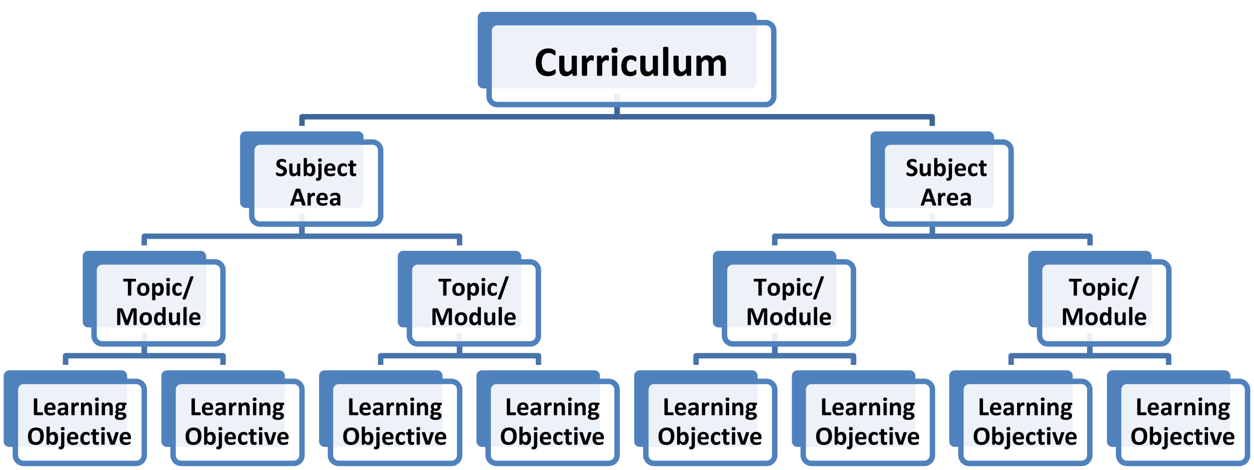

Figure 1: Curriculum terminology.

Through a comprehensive literature review and a needs assessment conducted with Caltrans engineers in Phase 1 of this project, five major subjects were identified as important knowledge and skill areas for successful rural ITS implementations. These subject areas are: Plant Wireless, Telco Wireless, Plant Wired, Telco Wired, and IP Fundamentals. The curriculum scope and sequence outlined in this document is based upon these five subject areas and includes a description, prerequisites, duration, method of presentation, and specific learning objectives. It should be noted that the scope and sequence have been developed with the idea that training courses will consist of significant time spent on realistic, hands-on problem solving and lab exercises, in addition to traditional classroom work.

The original curriculum scope and sequence developed in Phase 1 was revised in Phase 2 of the project based upon input from the Project Technical Advisory Panel (PTAP), and the development and evaluation of the two training courses delivered during that phase. In Phase 3, the curriculum was again revised based upon guidance from the PTAP, delivery of another training course, and feedback from a second needs assessment survey. The revised curriculum scope and sequence is outlined in the following sections.

2. CURRICULUM OVERVIEW

The proposed sequence for the training curriculum is based on the identified needs of Caltrans rural ITS engineers as well as the necessary prerequisite skills required to participate in and fully benefit from the subject area trainings. Five subject areas are suggested for inclusion in the ITS communications curriculum: Plant Wireless, Telco Wireless, Plant Wired, Telco Wired, and IP Fundamentals. Suggested topics are presented for each subject area.

Training in the Plant Wireless subject area, particularly the topics of plant wireless core and RF system design, was identified as a critical need for Caltrans rural ITS engineers. Therefore, it is proposed as the first subject area covered by the curriculum. Professional capacity building in Telco Wireless topics was identified as another critical need and placed second in the proposed curriculum sequence.

Generally, it is recommended that students should be trained in the Plant Wireless core module—plant wireless core and RF system design—before participating in Telco Wireless training. Similarly, it is recommended that students should receive training in plant wired core/plant wiring basics, serial connectivity, and xDSL before taking the Telco Wired courses.

In regard to the IP Fundamentals subject area, it is suggested that this be covered last so participants are better prepared to understand the enabling hardware and communications technologies that are pertinent to this subject. As with the other four subject areas, there are no prerequisites for the core module in this subject area—Understanding IP Networks/IP Networking Core. However, a working knowledge of the concepts addressed in the Understanding IP Networks/IP Networking Core module is an important prerequisite for the other four modules in this subject area.

Topics within each of the subject areas are organized so that students receive training in the basic terminology and concepts before moving on to more specific technologies. For example, under the Plant Wireless subject area, it is recommended that students cover plant wireless core and RF system design fundamentals before moving on to training in 802.11 (WiFi), microwave, and short haul radio. This helps ensure that students begin a course on a level playing field with adequate background to maximize learning. It also facilitates more in-depth training on specific topics if less time can be spent on background and terminology because students are already familiar and comfortable with the basics. Beyond this sequence suggestion, there is some flexibility based on need as to the order of the remaining topics within subject areas.

Based on these recommendations, the following curriculum sequence was developed:

A. Plant Wireless
   a. Plant Wireless Core and RF System Design
   b. 802.11 (WiFi) and Related
   c. Microwave
   d. Short Haul Radio

B. Telco Wireless
   a. Telco Wireless Core and Cellular/PCS Basics
   b. GSM Data, 3G and Next Generations
   c. CDMA Data, 3G and Next Generations

d. LTE (Long Term Evolution), 4G and Next Generations

C. Plant Wired

a. Plant Wired Core/Plant Wiring Basics

b. Serial Connectivity

c. xDSL

d. Optical Fiber

D. Telco Wired

a. Telco Wired Core

b. POTS

c. Analog Data Circuits

d. ISDN

e. xDSL

f. DS1/T1

g. Fractional DS1/T1

h. Frame Relay

i. MPLS

E. IP Fundamentals

a. Understanding IP Networks/IP Networking Core

b. Local Area Networks (LANs)

c. Wide Area Networks (WANs)

d. Network Security

e. Vendor Specific Equipment Training (e.g., Cisco, Juniper, other)

3. PLANT WIRELESS

3.1. Description

Plant wireless communication, as applied to Rural ITS, consists of systems that are user owned and installed. After taking this course (or courses), rural ITS engineers and technicians will have the skills and knowledge of telecommunication technologies necessary to design, implement, and maintain wireless communication links. Topic areas covered will be plant wireless core, radio frequency (RF) systems design, 802.11 (WiFi) and related, microwave, and short haul radio.

3.2. Prerequisites

Basic engineering skills or relevant experience

3.3. Duration

Thirteen days, to be assigned as follows:

- Plant Wireless Core—1 day
- RF Systems Design—4 days
- 802.11 and related—3 days
- Microwave—3 days
- Short Haul Radio—2 days

3.4. Method of Presentation

Instructor-led classroom and laboratory

3.5. Learning Objectives

3.5.1. Plant Wireless Core and RF Systems Design

This module is intentionally broad and covers basic knowledge of radio frequency communication. A solid foundation in RF systems is essential for building successful wireless communication links. For example, with the potential availability of wideband 700 MHz frequencies, RF systems may be an important way to connect multiple field elements to a TMC.

At the conclusion of this module, the student will be able to:

- Define and explain terminology and general concepts for plant wireless communication systems.
- Compare equipment specifications for RF systems.
- Select appropriate equipment for the site and system requirements (e.g., filters, power dividers, combiners, directional couplers).
- Evaluate tower and antenna site requirements, including availability of existing towers, tower structure (e.g., self-supporting or guyed), and potential antenna sharing.

- Calculate a link budget allowing for RF power, bandwidth, bit error rate, and channel noise among other variables.
- Calculate system losses due to path, system, and obstructions (i.e., transmission line loss, connector losses, path loss, and/or combiner loss).
- Evaluate the effects of fading using statistical fading models and distance-power (path loss) relationships in different propagation environments.
- Calculate path-related impairment such as the effects of outdoor terrain and structures on signal propagation.
- Analyze antenna polarization mismatch and apply the Power Loss Factor.
- Determine and apply antenna parameters such as antenna type and size, antenna patterns and polarization, gain, gain pattern, Effective (or Equivalent) Radiated Power (ERP), receive and transmit diversity, and proper installation to provide adequate coverage, mitigate interference, and reuse frequency.
- Optimize coverage of a radio system using propagation analysis tools such as ComStudy, and appropriate coverage calculation and verification techniques.
- Determine appropriate antenna spacing using adaptive antenna methods and techniques.
- Develop a block diagram of a radio system showing the location of all RF units in the system.
- Perform and interpret RF system measurements using test equipment such as network analyzers, spectrum analyzers, and time domain reflectometers (TDR). Example tests and evaluations include but are not limited to the following:
  - ERP
  - Received Signal Strength Indication (RSSI)
  - Noise Figure/Factor (NF)
  - Noise temperature
  - Receiver sensitivity
  - Sources and impact of external noise
  - Signal-to-noise ratio (S/N)
  - Co-channel and adjacent channel interference analysis
  - Intermodulation interference
- Use computer tools to evaluate radio links and perform propagation studies.
- Maintain and repair equipment according to system manufacturer, FCC and Caltrans guidelines.
- Evaluate the pros and cons of common alternatives.

3.5.2. 802.11 (WiFi) and Related

An 802.11 wireless network can be an inexpensive, easy, and quickly installed means of connecting ITS nodes or connecting to a gateway. However, a reliable link requires a well thought out design.

After completing this module, the student will be able to address RF issues in 802.11 technology and:

- Understand the fundamentals of 802.11 alternatives, and unlicensed high bandwidth 2.4 or 5.8 GHz communications.
- Determine when and where 802.11 can be used effectively.
- Correctly install appropriate equipment.
- Correctly configure equipment using proper antenna alignment and accurate field strength measurements.
- Carefully follow user instructions for proper equipment installation and use.
- Select and operate appropriate test equipment for troubleshooting to successfully address problems.
- Maintain and repair equipment according to system manufacturer, FCC and Caltrans guidelines.
- Evaluate the pros and cons of common alternatives.

3.5.3. Microwave

One of the fundamental requirements for Caltrans communications engineers and technicians is a working knowledge of microwave communication systems, particularly point-to-point high bandwidth radio communication. A working knowledge of programs such as Micropath is useful for performing microwave system analysis and assisting in configuring a microwave communication system.

At the conclusion of this module, the student will be able to:

- Determine when and where microwave communication technology can be used effectively.
- Perform microwave path analysis and determine proper Fresnel zone clearance.
- Apply the fundamentals of microwave path configuration to correctly install microwave communications equipment.
- Correctly configure equipment considering such factors as tower type (self-supporting or guyed), tower height, antenna type, antenna gain, antenna orientation, antenna polarization, and frequency (licensed or unlicensed).
- Carefully follow user instructions for proper equipment installation and use.
- Select and operate appropriate test equipment for troubleshooting to successfully address problems.

- Maintain and repair equipment according to system manufacturer, FCC and Caltrans guidelines.
- Evaluate the pros and cons of common alternatives.

3.5.4. Short Haul Radio

The use of short haul radio systems for short distance microwave communication (e.g., 18 and 23 GHz systems) may have potential for use in TMS-TMC and land mobile communications. Note that a microwave path analysis program such as Micropath is also appropriate for short haul radio communications systems.

By completing this module, the student will be able to:

- Determine when and where short haul radio communication technology can be used effectively.
- Perform a microwave path analysis and determine proper Fresnel zone clearance.
- Effectively install appropriate equipment with an understanding of transmit ERP requirements and limitations, siting limitations, and interference potentials.
- Correctly configure equipment, taking into consideration antenna type, gain, and siting, in addition to receiver sensitivity requirements.
- Carefully follow user instructions for proper equipment installation and use.
- Select and operate appropriate test equipment for troubleshooting to successfully address problems.
- Maintain and repair equipment according to system manufacturer, FCC and Caltrans guidelines.
- Evaluate the pros and cons of common alternatives.

4. TELCO WIRELESS

4.1. Description

Telco wireless communication, as applied to Rural ITS, consists of systems that are leased from telecommunication service providers. After taking this course (or courses), rural ITS engineers and technicians will have the knowledge and skills necessary to design, implement, and maintain systems that interface to telco provided wireless communications. In areas where wireline telco services, or other alternatives, are unavailable or cost-prohibitive, third and fourth generation (3G, 4G) GSM, CDMA, and LTE data communications between the Traffic Management System (TMS) and the TMC may be an appropriate, viable solution. As wireless systems evolve and newer technologies become more widely available, more interest is placed in the later generation technologies. In these modules, students will learn fundamentals of telco wireless communications, cellular/PCS basics, Global System for Mobile Communications (GSM) data and next generation systems, Code Division Multiple Access (CDMA) data and next generation systems, and Long Term Evolution (LTE) and next generation systems.

4.2. Prerequisites

- Basic engineering skills or relevant experience
- Plant Wireless: Plant Wireless Core and RF System Design, or equivalent experience

4.3. Duration

Eleven days, to be assigned as follows:

- Telco Wireless Core and Cellular/PCS basics: 2 days
- GSM, GPRS: 3 days
- CDMA: 3 days
- LTE (Long Term Evolution): 3 days

4.4. Method of Presentation

Instructor-led classroom and laboratory

4.5. Learning Objectives

4.5.1. Telco Wireless Core and Cellular/PCS Basics

A fundamental knowledge of the characteristics of leased wireless communication systems is important for determining how best to implement the technology to the benefit of rural transportation.

After completing this module’s exercises, the student will be able to:

- Define and explain terminology and general concepts for telco wireless communication systems.
- Discuss the concepts of wireless propagation and related theory.

- Review the history and evolution of available services and spectrum (E.g., 1X, 2G, 2.5G, 3G, 4G, etc.).
- Examine and discuss carrier supporting network infrastructure and how it operates, including capabilities, potential bottlenecks, etc.
- Determine the coverage area and signal strength at a specific location by conducting necessary field strength measurements.
- Locate and classify cellular sites using the Federal Communications Commission (FCC) data base.
- Select and effectively utilize cellular/PCS data services.
- Understand and thoroughly evaluate technical information on vendor equipment specification sheets.
- Ascertain tower and antenna requirements for the particular application (e.g., cellular modem at a fixed site for a CCTV).
- Specify and install proper antenna framework and cabling for the particular application.
- Compare, contrast and evaluate available modems and hardware and select the best alternative for specific applications.
- Successfully install and configure equipment considering such factors as modem type and data rate, and antenna requirements, gain and gain orientation for a fixed site.
- Properly implement cellular/PCS equipment, taking into account the potential for system overload and the type of site receiver (dialup or fixed).
- Conduct thorough bandwidth and throughput testing and apply the results.
- Maintain and repair the system and equipment according to system provider, accepted standards, and/or Caltrans guidelines.
- Assess and compare the pros and cons of common alternatives.

4.5.2. GSM Data, 3G and Next Generations

In areas where wireline telco services, or other alternatives, are unavailable or cost-prohibitive, third generation (3G) GSM data communications between the Traffic Management System (TMS) and the TMC may be an appropriate, viable solution.

Upon completion of this training module, the student will be able to:

- Discuss the technical characteristics and basic operation of GSM communication systems.
- Determine when and where GSM communications technology can be used effectively.
- Deduce the required and optimal data rate with a working understanding of the data rate provided by various options such as General Packet Radio Service (GPRS), Enhanced Data rates for GSM or Global Evolution (EDGE), etc.
- Select appropriate equipment necessary for specific applications.

- Successfully install and configure equipment considering such factors as modem type and data rate, and antenna requirements, gain and gain orientation for a fixed site.
- Properly implement GSM equipment accounting for the potential for system overload and the type of site receiver (dialup or fixed).
- Conduct thorough bandwidth and throughput testing and apply the results.
- Maintain and repair the system and equipment according to system provider/equipment vendor and/or Caltrans guidelines.
- Assess and compare the pros and cons of common alternatives.

4.5.3. CDMA Data, 3G and Next Generations

The rationale for training in this subject area is similar to that for learning about GSM data communications (Section 4.5.2).

After completing this module, the student will be able to:

- Discuss the technical characteristics and basic operation of CDMA communication systems.
- Determine when and where CDMA communications technology can be used effectively.
- Deduce the required and optimal data rate with a working understanding of the data rate provided by various options such as 1xRTT, EV-DO, etc.
- Select appropriate equipment necessary for specific applications.
- Successfully install and configure equipment considering such factors as modem type and data rate, and antenna requirements, gain and gain orientation for a fixed site.
- Properly implement CDMA equipment accounting for the potential for system overload and the type of site receiver (dialup or fixed).
- Conduct thorough bandwidth and throughput testing and apply the results.
- Maintain and repair the system and equipment according to system provider/equipment vendor and/or Caltrans guidelines.
- Assess and compare the pros and cons of common alternatives.

4.5.4. LTE (Long Term Evolution), 4G and Next Generations

The rationale for training in this subject area is similar to that for learning about GSM data communications (Section 4.5.2).

After completing this module, the student will be able to:

- Discuss the technical characteristics and basic operation of LTE communication systems.
- Determine when and where LTE communications technology can be used effectively.
- Deduce the required and optimal data rate with a working understanding of the data rate provided by various LTE options.

- Select appropriate equipment necessary for specific applications.
- Successfully install and configure equipment considering such factors as modem type and data rate, and antenna requirements, gain and gain orientation for a fixed site.
- Properly implement LTE equipment accounting for the potential for system overload and the type of site receiver (dialup or fixed).
- Conduct thorough bandwidth and throughput testing and apply the results.
- Maintain and repair the system and equipment according to system provider/equipment vendor and/or Caltrans guidelines.
- Assess and compare the pros and cons of common alternatives.

5. PLANT WIRED

5.1. Description

Plant wired communication, as applied to Rural ITS, comprises systems that are user owned and installed. By completing training in this area, rural ITS engineers and technicians will have the knowledge and skills necessary to design, implement, and maintain wired communications links. This type of communication technology is used in several Caltrans districts making this subject area particularly valuable for ITS communications systems training. Students will learn about plant wiring basics, serial connectivity, various types of Digital Subscriber Lines (xDSL), and optical fiber.

5.2. Prerequisites

Basic engineering skills or relevant experience

5.3. Duration

Ten days, to be assigned as follows:

- Plant Wired Core/Plant Wiring Basics: 2 days
- Serial Connectivity: 1 day
- xDSL: 2 days
- Fiber: 5 days

5.4. Method of Presentation

Instructor-led classroom and laboratory

5.5. Learning Objectives

5.5.1. Plant Wired Core/Plant Wiring Basics

This module covers the fundamentals of wired communication. Important knowledge and skill sets will be developed for different wire types, connectors and installation of wired communication systems.

After completing the activities in this module, the student will be able to:

- Define and explain terminology and general concepts for plant wired communication systems.
- Explain the differences, advantages, disadvantages, and appropriate applications for a variety of wire and cable types, for example, twisted pair (standard telephone), CAT-5, and CAT-6.
- Read and interpret equipment specifications.
- Explain and apply a variety of wire and cable topologies.

- Correctly install various wire and cable types considering connectors, terminations, and shielded versus unshielded, among other factors. Wiring related issues are standards based to insure equivalence/compatibility with telco wiring. Cable and other wiring transmission issues (e.g., transmission distance related impairments, cable and wiring types, etc.) will be carefully addressed.
- Understand, design, and install with proper workmanship structured cabling including component parts, backbone wiring structures, horizontal wiring structures, and cross-connected wiring structures.
- Successfully test, troubleshoot, and certify wiring structures.

5.5.2. Serial Connectivity

Serial connectivity is used frequently for ITS wired communication applications. Standards of particular interest to Caltrans include EIA/RS-232, EIA/RS-422, and EIA/RS-485.

At the conclusion of this module, the student will be able to:

- Technically explain the operating fundamentals for serial connections.
- Determine when and where serial connections can be used effectively.
- Establish equipment requirements for proper installation.
- Successfully install/employ serial connections considering data rate and protection requirements, and recommended standards (e.g., EIA/RS-232, EIA/RS-422, EIA/RS-485).
- Compare and contrast DTE and DCE devices and how both are utilized.
- Describe and apply proper methodology for interfacing with wireless modems.
- Select and correctly configure necessary equipment. Examples may include but are not limited to suitable modems, Ethernet to serial converters, and terminal equipment.
- Carefully follow user instructions for proper equipment installation and use.
- Select and operate appropriate test equipment for troubleshooting to successfully address problems.
- Maintain and repair equipment according to system provider, accepted standards, and/or Caltrans guidelines.
- Evaluate the pros and cons of common alternatives.

5.5.3. xDSL

Self-installed communications between field nodes with existing twisted pair over moderate distances and relatively high bandwidth can be effectively conducted with multiple types of DSL. This allows the utilization of existing telephone cable plant for moderate distance LAN interconnections.

After completing this module, the student will be able to:

- Technically explain the features and operation of xDSL communication including, but not limited to, bandwidth, modulation, bi-directional data rates, interference potentials, and point-to-point distance limits.
- Determine when and where xDSL can be used and the appropriate type of xDSL for the application (e.g., DSL, ADSL, HDSL, VDSL).
- Establish equipment requirements for proper installation of xDSL communication systems.
- Successfully install and configure necessary equipment, taking into consideration twisted pair wiring needs, shielding or burying to reduce interference, and distance limitations.
- Determine effective data rates.
- Productively utilize xDSL equipment with a working understanding of asymmetric limitations, potential interference and transmission impairment sources (e.g., AM radio, amateur radio transmissions, unterminated stubs, crosstalk, noise sources (e.g., lightning)).
- Select and operate appropriate test equipment for troubleshooting to successfully address problems.
- Maintain and repair equipment according to system provider, accepted standards, and/or Caltrans guidelines.
- Evaluate the pros and cons of common alternatives.

5.5.4. Optical Fiber

The use of optical fiber (high speed communication using glass fiber and light) for rural ITS communications is garnering wider interest as this technology becomes a more viable alternative.

Upon completion of this module's presentation and activities, the student will be able to:

- Technically explain the fundamental principles and operation of optical fiber, including, but not limited to, fiber types, data rates and optical carrier requirements, and connectivity options.
- Ascertain when and where optical fiber technology can be used effectively.
- Define the most efficient and effective fiber path, taking into consideration such variables as the number of access points and whether the system is buried (preferred) or a pole system.
- Calculate a link budget.
- Describe and design different fiber topology options.
- Establish equipment requirements for proper installation and effective operation of optical fiber communication systems.
- Select the appropriate fiber type for the application (i.e., single versus multimode, number of strands).
- Successfully install and configure necessary equipment, for example, Ethernet fiber media converters that convert a digital signal to/from an optical signal.

- Explain and demonstrate the issues, challenges, and appropriate methods for fusion fiber splicing.
- Functionally describe the various methods of connectorization, identify appropriate connector types for specific applications, and explain the advantages and disadvantages for each.
- Discuss and demonstrate splice case methods and issues associated with underground and aerial applications (e.g., use of mechanical splices and connectors as a temporary "make-good").
- Productively utilize optical fiber equipment (e.g., identify and specify receiving media converter).
- Select and operate appropriate test equipment for troubleshooting, for example, determining the location of fiber cuts using an Optical Time Domain Reflectometer (OTDR).
- Maintain and repair the system and equipment according to accepted standards, system provider, and/or Caltrans guidelines. Develop and demonstrate a working knowledge and skill set for tasks such as fiber splicing.
- Assess and compare the pros and cons of common alternatives.

6. TELCO WIRED

6.1. Description

The telco wired communication subject area, as applied to Rural ITS, consists of topics related to leased wired communications technologies. After taking this course (or courses), rural ITS engineers and technicians will have the knowledge and skills necessary to design, implement, and maintain systems that interface to telco provided wired communications. These topics are essential to training ITS professionals because virtually all are used to some degree by Caltrans. Training modules in this subject area include technologies typically operated by telephone companies including Plain Old Telephone Service (traditional analog land lines) known as POTS, analog data circuits, Integrated Services Digital Network (ISDN), Digital Subscriber Line (xDSL), Digital Signal at level 1 (DS1/T1), fractional T1, frame relay, and Multiprotocol Label Switching (MPLS).

6.2. Prerequisites

- Basic engineering skills or relevant experience
- Plant Wired: Plant Wired Core/Plant Wiring Basics, or equivalent experience
- Plant Wired: Serial Connectivity, or equivalent experience
- Plant Wired: xDSL, or equivalent experience

6.3. Duration

Thirteen and ½ days, to be assigned as follows:

- Telco Wired Core: ½ day
- POTS: 2 days
- Analog Data Circuits: 1 day
- ISDN: 2 days
- xDSL: 1 (previous training in other modules)
- DS1/T1: 2 days
- Fractional DS1/T1: 1 day
- Frame Relay: 2 days
- MPLS: 2 days

6.4. Method of Presentation

Instructor-led classroom and laboratory

6.5. Learning Objectives

6.5.1. Telco Wired Core

It is suggested that the following learning objectives be incorporated into the first section of any Telco Wired course. After reviewing the materials in this module, the student will be able to:

- Define and explain terminology and general concepts for telco wired communication systems, including best effort, committed information rate, latency, etc.
- Explain the differences, advantages, disadvantages, and appropriate applications for circuit switched, dedicated line, and packetized systems.

6.5.2. POTS

ITS professionals frequently use POTS when available and appropriate for connecting field elements to a TMC. After completing this module on POTS communication technologies, the student will be able to:

- Define and discuss the terminology, technical characteristics and basic operation of POTS communication systems.
- Determine when and where POTS communications technology can be used effectively.
- Assess performance challenges such as analog transmission impairments, line length or interference potentials from multiple users on telco cable, etc.
- Establish requirements and select equipment appropriate for specific applications, including ITS equipment, modem, and line interface, etc.
- Define modem requirements, for instance, data rates and environmental conditions, to establish modulation schemes, site equipment data rate requirements, etc.
- Carefully follow user instructions for proper equipment installation and use.
- Successfully install and configure equipment, taking into account how the system will be used (e.g., point-to-point, point-to-multipoint, etc.).
- Select and operate appropriate test equipment for troubleshooting to successfully address problems.
- Maintain and repair the system and equipment according to system provider/equipment vendor and/or Caltrans guidelines.
- Assess and compare the pros and cons of common alternatives.

6.5.3. Analog Data Circuits

An analog data circuit is a digitally modulated analog signal on an analog leased line. This service supports the transmission of data within the frequency range of 300 to 3,000 Hz, which is the filtered bandwidth for telco voice signals. Hence the data rate is limited by the digital modulator and the quality characteristics of the circuit.

By completing this module on analog data circuits, the student will be able to:

- Define and discuss the terminology, technical characteristics and basic operation of communication systems using analog data circuits.
- Determine when and where analog data circuit communications technology can be used effectively.
- Understand various voice band transmission impairments and their effect on data communications.
- Define data rate requirements.
- Establish equipment requirements.
- Correctly implement and utilize equipment, including that which is telco-provided.
- Carefully follow user instructions for proper system installation, configuration, and use.
- Effectively operate equipment.
- Select and operate appropriate test equipment for troubleshooting to successfully address problems.
- Maintain and repair the system and equipment according to Telco service provider, equipment vendor and/or Caltrans guidelines.
- Evaluate the pros and cons of common alternatives.

6.5.4. ISDN

ISDN technology is of particular interest for ITS applications because it can provide significant data rates (e.g., 128 kb/s and greater), which can support devices such as CCTV cameras and is available in many rural locations where other digital services are not. Caltrans currently uses ISDN technology for video transport from CCTV cameras to the TMC.

After completing this module in Telco Wired communications, the student will be able to:

- Define and discuss the terminology, technical characteristics and basic operation of ISDN communication systems.
- Determine when and where ISDN communications technology can be used effectively, paying close attention to local availability.
- Define and select ISDN system options, for example Basic Rate Interface (BRI), Primary Rate Interface (PRI), or other options.
- Fully understand the communications protocol between the end device and the central office switch.
- Establish equipment requirements for specific applications (e.g., user terminal does not require modem).
- Correctly implement and utilize equipment including that which is telco provided.
- Carefully follow user instructions for proper system installation, configuration, and use.
- Select and operate appropriate test equipment for troubleshooting to successfully address problems.

- Maintain and repair the system and equipment according to system provider/equipment vendor and/or Caltrans guidelines (i.e., ISDN equipment, telco provided service).
- Assess and compare the pros and cons of common alternatives.

6.5.5. xDSL

Although there are 10 different types of Digital Subscriber Line (xDSL) technologies, those currently used or that have the potential for future application for Caltrans include DSL, Asymmetric Digital Subscriber Line (ADSL), High bit rate Digital Subscriber Line (HDSL) and Very high bit rate Digital Subscriber Line (VDSL). By completing the activities in this module, the student will be able to:

- Define and discuss the terminology, technical characteristics and basic operation of xDSL communication systems.
- Determine when and where xDSL communications technology can be used effectively, taking into account distance (i.e., 18,000 ft or less to central office (CO) or optical fiber fed neighborhood cross-connect for DSL and ADSL, 12,000 ft for HDSL and 3,000 ft up to 26 Mb/s or 1,200 ft up to 51 Mb/s for VDSL), and required data rate.
- Evaluate potential interference sources and transmission impairment sources (e.g., AM radio, amateur radio transmissions, unterminated stubs, crosstalk, noise sources (e.g., lightning, distance, other digital channels).
- Define effective data rates by measuring transmission times, among other activities.
- Define acceptable upload and download speeds for specific applications and compare pricing options for different speed levels.
- Compare and discuss static versus dynamic addressing as used in ITS communications.
- Establish equipment requirements considering factors such as location and weather restrictions, modem options, and the need for wireless connections.
- Select appropriate equipment for specific applications. For instance, choose the best modem for the job based on modem documentation and current deployments.
- Correctly implement and utilize equipment, paying close attention to procedures for connecting to the standard POTS line.
- Carefully follow user instructions for proper system installation, configuration, and use.
- Select and operate appropriate test equipment for troubleshooting to successfully address problems.
- Maintain and repair the system and equipment according to system provider/equipment vendor and/or Caltrans guidelines.
- Evaluate the pros and cons of common alternatives.

6.5.6. DS1/T1

DS1/T1 technology is used by Caltrans for Wide Area Networking. A DS1 circuit is a 1.544 Mb/s signal channel, a T1 circuit is a DS1 divided into twenty-four 64 kb/s channels plus an 8 kb/s control channel by a channel bank. Since 64 kb/s is the standard data rate for a voice channel, a T1 is typically used in a telephone voice network.

After completing this module, the student will be able to:

- Define and discuss the terminology, technical characteristics and basic operation of DS1/T1 communication systems.
- Determine when and where DS1/T1 communications technology can be used effectively.
- Define data rate requirements and evaluate the need for framing, considering the data capabilities of DS1/T1 lines and framing into voice channels.
- Ascertain the availability of DS1/T1 at a site utilizing telco site information.
- Establish equipment requirements (e.g., CSU/DSU, native channel termination or channel bank (T1)).
- Correctly implement and utilize equipment, including that which is telco provided.
- Carefully follow user instructions for proper system installation, configuration, and use.
- Effectively operate equipment to achieve high speed, continuously available, and highly reliable system communications.
- Select and operate appropriate test equipment for troubleshooting to successfully address problems.
- Maintain and repair the system and equipment according to Telco service provider, equipment vendor and/or Caltrans guidelines.
- Assess and compare the pros and cons of common alternatives.

6.5.7. Fractional DS1/T1

Fractional T1 lines have less than 24 64 kb/s digital voice channels and can be a more economical solution for applications that still require the speed, security, and direct and dedicated connections of T1 communications. Fractional DS1 lines are available with 128, 256 or 384 kb/s bandwidth.

After completing this module, the student will be able to:

- Define and discuss the terminology, technical characteristics and basic operation of Fractional T1 communication systems.
- Determine when and where Fractional DS1/T1 communications technology can be used effectively.
- Define data rate requirements and evaluate the need for framing, considering the data capabilities of DS1/T1 (Fractional DS1/T1) lines and framing into voice channels.
- Ascertain the availability of Fractional DS1/T1 at a site utilizing telco site information.

- Establish equipment requirements (e.g., CSU/DSU (128, 256 or 384 kb/s fractional DS1) or channel bank (T1)).
- Correctly implement and utilize equipment, including that which is telco provided.
- Carefully follow user instructions for proper system installation, configuration, and use.
- Effectively operate equipment to achieve high speed, continuously available, and highly reliable system communications.
- Select and operate appropriate test equipment for troubleshooting to successfully address problems.
- Maintain and repair the system and equipment according to Telco service provider, equipment vendor and/or Caltrans guidelines.
- Assess and compare the pros and cons of common alternatives.

6.5.8. Frame Relay

Frame Relay is a high-speed packet switched service that utilizes a fixed-frame structure. Frame transmission rates typically range from 56 kb/s to 1.544 Mb/s. Sequential frames may be transmitted over different routes subject to network usage with error correction performed (e.g., by retransmission) at network end-points. Caltrans uses Frame Relay for a connection from a TMC to a wireless service provider's network, or to connect the TMC to a field hub (aggregation point for field elements).

Upon completion of this module, the student will be able to:

- Define and discuss the terminology, technical characteristics and basic operation of frame relay communication systems.
- Determine when and where frame relay communications technology can be used effectively.
- Define data rate requirements.
- Establish equipment requirements.
- Correctly implement and utilize equipment, including that which is telco provided.
- Carefully follow user instructions for proper system installation, configuration, and use.
- Effectively operate equipment.
- Select and operate appropriate test equipment for troubleshooting to successfully address problems.
- Maintain and repair the system and equipment according to Telco service provider, equipment vendor and/or Caltrans guidelines.
- Evaluate the pros and cons of common alternatives.

6.5.9. MPLS

MPLS technology is of interest to Caltrans for ITS applications because it may be used to connect from a provider's cloud (for example a wireless carrier that provides connectivity to TMS field elements) to the TMC field element network.

After completing this module in Telco Wired communications, the student will be able to:

- Define and discuss the terminology, technical characteristics and basic operation of MPLS communication systems.
- Determine when and where MPLS communications technology can be used effectively.
- Define data rate requirements.
- Establish equipment requirements.
- Correctly implement and utilize equipment, including that which is telco-provided.
- Carefully follow user instructions for proper system installation, configuration, and use.
- Effectively operate equipment.
- Select and operate appropriate test equipment for troubleshooting to successfully address problems.
- Maintain and repair the system and equipment according to Telco service provider, equipment vendor and/or Caltrans guidelines.
- Evaluate the pros and cons of common alternatives.

7. IP FUNDAMENTALS

7.1. Description

The IP Networking Fundamentals and Usage subject area, as applied to Rural ITS, is composed of topics related to the Internet Protocol (IP), IP networks and related technologies. After completing this course (or courses), rural ITS engineers and technicians will have the knowledge and skills necessary to design, implement, and maintain IP communication links, as well as a general knowledge of vendor specific equipment. This subject area is important to Caltrans because most of its digital communications are IP based. Training modules in this subject area include understanding IP networks, local area networks, wide area networks, network security, and vendor specific equipment.

7.2. Prerequisites

Basic understanding of the concepts of networks and Ethernet.

7.3. Duration

Nine days, to be assigned as follows:

- IP Networking Core/Understanding IP Networks: 2 days
- LAN: 2 days
- WAN: 1 day
- Network security: 2 days
- Vendor Specific Equipment Training (e.g., Cisco, Juniper, other): 2 days

7.4. Method of Presentation

Instructor-led classroom and laboratory.

7.5. Learning Objectives

7.5.1. Understanding IP Networks/IP Networking Core

In order to successfully implement new communication systems, an understanding of the fundamental principles and concepts is critically important. This module will cover these fundamentals in order to prepare students for the other four modules and provide them with a solid understanding of IP communications technologies and applications to rural transportation.

After completing this module, the student will be able to:

- Discuss the technical characteristics and basic operation of communication systems using IP networking technologies.
- Explain the OSI Reference Model and its uses.
- Describe and differentiate simple networks and varying network topologies.

- Understand and apply the fundamentals of basic routing concepts, the TCP/IP Model, and the role of various devices in TCP/IP.
- Compare and contrast networking protocols (e.g., ARP, IP, ICMP, TCP, UDP).
- Correctly implement subnetting in a network. Topics to discuss include, but are not limited to, addressing and IPv4 versus IPv6.
- Discuss IP routing and protocols (e.g., RIP, OSPF).
- Understand and explain applications for HTTP, HTTPS, FTP, SSH, and Telnet, etc.
- Properly implement DHCP and DNS.
- Explain the difference between sockets and ports and the function of each.
- Select and successfully employ appropriate tools to troubleshoot problems in a network.
- Discuss and apply basic security concepts.

7.5.2. Local Area Networks (LANs)

ITS nodes are often connected using IP technology into "roadside LANs." Upon completion of this IP Fundamentals module, the student will be able to:

- Articulate different applications for LANs in rural ITS communications.
- Understand and discuss the concepts of Ethernet and Power over Ethernet (PoE).
- Understand and discuss the concepts of a Virtual Local Area Network (VLAN).
- Discuss the functions and requirements of routers, switches, hubs, and bridges, as applied to LANs and ITS.
- Build a LAN for specific ITS applications.
- Effectively and efficiently utilize IP equipment for rural ITS applications.
- Investigate and employ available hardware and software tools to develop, analyze, and troubleshoot networks.
- Manage equipment with SNMP.
- Construct usable Ethernet cabling.
- Discuss and apply basic security concepts.
- Interpret network documentation.
- Prepare clear network documentation.

7.5.3. Wide Area Networks (WANs)

Wide area networks are often used as the connection between ITS LANs. After completing this IP Fundamentals module, the student will be able to:

- Recognize and describe WAN applications for rural ITS communications.
- Research and select appropriate WAN hardware.

- Discuss common WAN services offered by telecommunication service providers.
- Compare and contrast WAN protocols such as SLIP, PPP, PPPoE, and Frame Relay.
- Explain the concept and application for Dial on Demand networking and Multiprotocol Label Switching (MPLS).
- Understand router functions.
- Correctly set up and configure routers for specific applications.
- Discuss and apply basic security concepts.

7.5.4. Network Security

Security is necessarily a major concern when using IP networks. By completing this module of IP Fundamentals training, the student will be able to:

- Discuss and apply basic principles of encryption.
- Differentiate varying types of Virtual Private Networks (VPN).
- Explain and utilize Internet Protocol Security (IPSec) and Secure Sockets Layer (SSL).
- Explain and utilize CHAP authentication over serial WAN links.
- Comprehend, discuss, and use fundamentals of wireless security (e.g., WPA, WPA2, WEP, TKIP, MAC addresses, etc.).
- Understand and employ firewalls.
- Understand and utilize proxy servers.
- Discuss address translation, port forwarding, and active directories.
- Successfully set up a VPN.

7.5.5. Vendor Specific Equipment Training

Many Caltrans districts use Cisco equipment for ITS communications. Cisco is presented as an example vendor here. Other vendor technologies (Juniper, etc.) may be substituted as needed. At the end of this module, the student will be able to:

- Understand and operate Cisco IOS for rural ITS applications.
- Comprehend Cisco switch and router security.
- Successfully perform Cisco switch startup and configuration.
- Satisfactorily manage Cisco switches.
- Successfully perform Cisco router startup and configuration.
- Satisfactorily manage Cisco routers.
- Set up the DHCP on a Cisco router.
- Establish a point-to-point WAN connection with the Point-to-Point Protocol (PPP) using Cisco equipment.

- Establish a point-to-point WAN connection with Frame Relay using Cisco equipment.

8. SUMMARY

This document is the scope and sequence for a training curriculum in rural ITS communications. It defines the recommended courses and their content in necessary detail. It provides a suggested curriculum sequence and includes recommended prerequisites as appropriate. It also includes the recommended use of specific equipment, such as the OTDR to determine the location of breaks in optical fiber lines, and software for RF and microwave propagation/path analysis such as the RadioSoft ComStudy program for RF and a microwave analysis program such as Micropath. Other equipment and software might be substituted.

Note that while the curriculum sequence is a significant part of the document it is not intended to suggest that all qualified staff take all of the courses, but that they take those they need for their planning and implementation activities.

During Phase 3 of this project, the training needs of Caltrans ITS engineers related to ITS communications were reevaluated through another needs assessment survey. A number of comments were received relative to augmenting and refining individual objectives. They are listed below.

- One suggestion that may warrant further discussion involves further specification of the target audience: "It may be better to differentiate the training that is needed for repair/maintenance, system implementation, system design, or system administration. We would want everyone to have a basic overall understanding, but do not need to train/educate on specifics that are not needed for a particular job."
- Plant Wireless: Installation details, including racking of equipment and proper waveguide/cabling installation, were listed as important to include as core plant wireless training. One respondent said, "Proper installation of equipment is an important aspect of maintainability and reliable operation of the system." How to secure the channel against intrusion, eavesdropping, and denial of service attacks, as well as the pros and cons of the various security modes, would be useful to address generally and particularly for 802.11 (WiFi). Some attention to site survey techniques, including spectral analysis, would also be helpful to rural ITS engineers. In regard to 802.11 (WiFi) and related technologies, it was suggested to include discussion on "mixing modes of B/G/N/AC in a wifi system and the impact of the speed / bandwidth." Addressing system degradation (i.e., when using an antenna inside versus outside of a cabinet) was suggested for inclusion specific to short haul radio.
- Telco Wireless: As with Plant Wireless technologies, core training for all of the Telco Wireless technologies should include proper installation methods, including racking of equipment and proper waveguide/cabling installation. Discussion on various cost considerations for video transmission would be helpful to include.
- Plant Wired: Again, it was mentioned that "good installation workmanship is critical for robust and reliable operations and maintenance of the system." It was suggested that significant time (a day or more) be spent on how to layout/design and restructure equipment rooms as part of Plant Wired core and plant wiring basics. Some examination and review of Telco trends (e.g., phase out of technologies such as ISDN, T1, etc.) was also suggested for inclusion. Com port redirection software, USB to serial and terminal servers were objectives recommended for inclusion in a potential serial connectivity

course. Discussion on system security was suggested to augment potential courses in serial connectivity, xDSL, and optical fiber.

- Telco Wired: Discussion about security issues with xDSL systems, particularly the security ramifications for xDSL circuits that are public versus those that are vLAN, would be useful to include in a potential Telco xDSL course. Addressing framing, timing, and clock derivation, etc., were suggestions to enhance the objectives of potential training in DS1/T1, fractional DS1/T1, and frame relay technologies. Although analog data circuit technology has become somewhat deprecated, participants suggested it was still useful to know about it, and suggested adding objectives dealing with transmission and transmission impairments, test levels, and use of half-duplex/full-duplex and the pros and cons of each. In regard to MPLS technology, one person commented that it seemed more the responsibility of the Telco provider.
- IP Fundamentals: To thoroughly cover wide area networks (WANs), it was noted that router functionality should be addressed in great detail (i.e., ARP, packet forwarding, ACL's, etc.). Specific to network security, it was suggested that it would be helpful to examine potential vulnerabilities in a system, how an attacker could access the network, and what tools they might use to do so. One person stated, "Network management has become a large part of the ITS infrastructure and support skill sets." He/she suggested incorporating a training track towards CCNA certification.