Telecommunications and Information Technology Planning

The telecommunications and information technology planning function represents the highest-level system or network perspective of the Institute. This work can be characterized generally as planning and analyzing existing, new, and proposed telecommunications and information technology systems, especially networks, for the purpose of improving efficiency and enhancing the technical performance and reliability of those systems. In many cases, ITS performs this work for both wireline and wireless applications. This portion of the ITS technical program encompasses work that is frequently referred to in industry as "systems engineering."

All phases of strategic and tactical planning are conducted under this work area; problem solving and actual implementation engineering also are done. ITS engineers identify or derive users' functional requirements and translate them into technical specifications. Telecommunication system designs, network services, and access technologies are analyzed, as well as information technologies (including Internet and Internet-related schemes). Associated issues, such as network management and control and network protection and privacy, also are addressed. Integration of individual services and technologies is a common task in many projects, along with the application of new and emerging technologies to existing applications.

Areas of Emphasis

Interoperability Efforts for Justice/Public Safety/Homeland Security
The Institute conducts a broad-based technical program aimed at facilitating effective telecommunications interoperability and information-sharing among dissimilar wireless and information technology systems within the justice/public safety/homeland security community. ITS activities are sponsored by a number of Federal agencies and programs, and are planned and performed only after close coordination with local, state, tribal, and Federal practitioners. Technical thrusts within the program, which are described in separate sections below, include: **Engineering Support and Coordination**, **Information Technology Interoperability Standardization**, and **Wireless Telecommunications Interoperability Standardization**.

Emergency Telecommunications Service (ETS)
The Institute develops and verifies ETS Recommendations for ITU-T Study Group 9. A second project provides ETS expertise relating to network survivability for Technical Subcommittee T1A1. These projects are funded by the National Communications System (NCS).

Networking Technology/Interoperability
The Institute characterizes and analyzes the fundamental aspects of networks, and network interoperability. Methodologies and tools are developed to address discovery, monitoring/measurement, simulation, management, and security/protection issues. This project is funded by NTIA.

Railroad Telecommunication Planning
The Institute performs radio infrastructure system planning in support of a high-speed rail pilot program, and demonstrates digital land mobile radio technology and infrastructure, compliant with TIA-102 standards. The Federal Railroad Administration funds this project.

Voice Over IP
The Institute develops technical contributions related to Internet Protocol (IP) telephony gateways and their supporting infrastructure for the TIA TR41 Standards Formulating Group. This project is funded by NCS.

Engineering Support and Coordination for Justice/Public Safety/Homeland Security

Outputs

- Technical evaluations of industry R&D and community grant proposals.
- Interoperability and performance evaluations of Project 25 equipment.
- Summit on Interoperable Communications for Public Safety.

ITS is conducting a technical program aimed at facilitating effective interoperability and information sharing among dissimilar wireless telecommunications and information systems within the justice/public safety/homeland security community. The primary focal points of the program are: (1) Standards support, (2) Research and Development (R&D) support, (3) Test and Evaluation (T&E), and (4) Technical Coordination among local, State, and Federal departments and programs associated with interoperability activities. All efforts described here are complementary to the ITS technical programs focused on wireless telecommunications interoperability standardization and information technology interoperability standardization.

The ITS program is sponsored by a number of different Federal departments and programs that have a keen interest in public safety interoperability, including: National Institute of Standards and Technology (NIST) Office of Law Enforcement Standards (OLES), National Institute of Justice (NIJ) AGILE Program, Department of Justice Office of Community Oriented Policing Service (COPS), National Communications System (NCS), Public Safety Wireless Network (PSWN) program, Federal Law Enforcement Wireless Users' Group (FLEWUG), and NTIA.

Standards Support

ITS provides contributions to several standards development organizations supporting justice, public safety, and homeland security goals. The proposed technical solutions offered in such contributions are validated in the Institute's Interoperability Research Laboratory (IRL). This process will be especially useful in the coming year for Project 25/Telecommunications Industry Association TR-8 interface definition work.

R&D Support

At the request of several Federal Departments and Programs, ITS worked alongside practitioners from the justice/public safety/homeland security community to technically evaluate grant proposals. By acting as the Government's common "technical thread," ITS engineers helped ensure that R&D proposals from industry and telecommunications integration proposals from local and State government agencies were feasible and consistent with long-term interoperability strategies. Evaluations were conducted on behalf of NIJ's AGILE Program, SAFECOM, the COPS Program, and the Department of Homeland Security's Emergency Preparedness and Response Directorate.

Figure 1. An ITS engineer conducting performance measurements on digital land mobile radio equipment in the ITS Interoperability Research Laboratory (photograph by E. Gray).

Test and Evaluation

The IRL has been designed to accommodate a wide variety of testing requirements for public safety applications that have arisen, are occurring now, or are expected in the near future. Interoperability and performance testing of standardized products has already commenced (e.g., for Project 25 radio equipment) with portable, mobile, base station, and repeater equipment being scrutinized in the conventional mode of operation (see Figures 1 and 2). (Trunked system operation will be investigated in FY 2004.) Test and evaluation has also been done on an interim interoperability solution (a crossband technology device) and on a hybrid network product (that interconnects a radio frequency network to the Internet). T&E in all of these areas will continue in earnest during FY 2004. In addition, laboratory assessments of R&D concepts and prototypes are expected to occur next fiscal year, with some emphasis being placed on the examination of software defined radio functionality.

Figure 2. An ITS engineer making equipment configuration changes on land mobile radio base station equipment in the ITS Interoperability Research Laboratory (photograph by E. Gray).

Technical Coordination

On behalf of its sponsors, ITS planned, conducted, and documented the *Summit on Interoperable Communications for Public Safety* that was held at NIST in Gaithersburg, Maryland, on June 26/27, 2003. With the purpose of coordinating technical efforts related to wireless telecommunications and information technology interoperability, over 50 different Federally-supported programs, and 104 representatives, were located and invited, and participated in the summit. It was the first opportunity for program managers to share viewpoints regarding public safety communications and interoperability. To facilitate further coordination among participants, a briefing book was produced for all attendees that contained salient information about all of the programs, and what particular public safety requirements each program was targeting. Information on the summit is available at http://pssummit.its.bldrdoc.gov.

Other Support

In addition to the established areas of activity mentioned above, ITS frequently responds to the immediate needs of its sponsors by performing a variety of other research and applied engineering activities. These activities may include strategic and tactical planning, system engineering, technical analysis, economic benefit studies, etc. During FY 2003, ITS compared the performance and application of conventional radio systems against trunked radio systems for public safety applications. A technical report providing the results has been drafted and is undergoing internal ITS review. Once released, it will help guide agencies as to the advantages and disadvantages of each system for particular operational scenarios.

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Information Technology Interoperability Standardization for Justice/Public Safety/Homeland Security

Outputs

- Support to Global Justice Information Sharing Initiative.
- Administration of Justice Standards Clearinghouse on-line.
- XML Data Model and Data Dictionary development.

ITS is conducting a technical program aimed at facilitating effective interoperability and information sharing among dissimilar information systems within the justice/public safety/homeland security community. The primary focal points of the program are: (1) the identification and delineation of applicable information sharing architectures, (2) coordination between major Federal players and local and State public safety practitioners to collegially develop a nationwide strategic plan for information sharing, and (3) the identification and/or development of standards that address the community's requirements and are in conjunction with the strategic plan. All efforts are aimed at allowing local, State, and Federal agencies to exchange information, without requiring substantial changes to internal systems or procedures.

The ITS program is sponsored by a number of different Federal departments and programs that have a keen interest in public safety interoperability, including: National Institute of Standards and Technology (NIST) Office of Law Enforcement Standards (OLES), National Institute of Justice (NIJ) AGILE Program, and the Department of Justice Office of Community Oriented Policing Service (COPS).

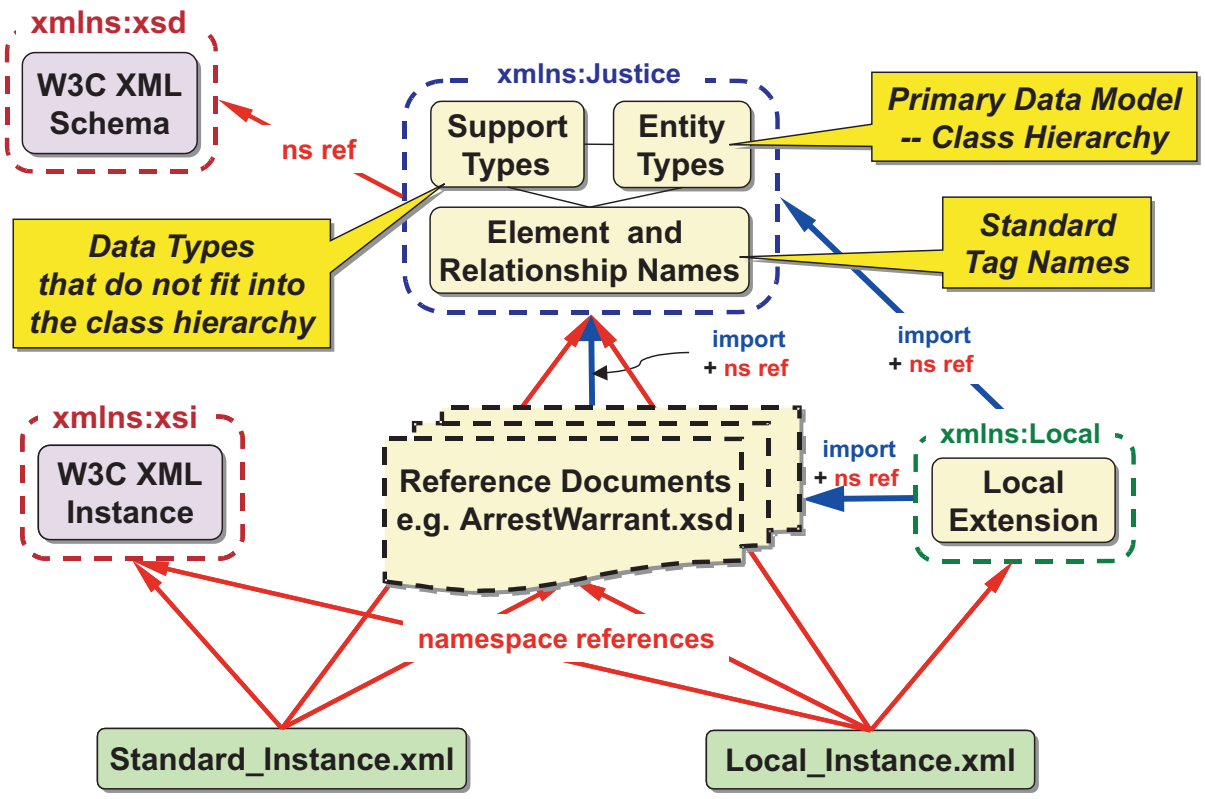
Support to Global Justice Information Sharing Initiative

The Global Justice Information Sharing Initiative (Global) is a group of groups representing all practitioners in the justice community (e.g., law enforcement, courts, corrections, prosecutors, defenders, etc.; see http://it.ojp.gov/global/index.html). In particular, ITS worked with Global's Infrastructure/Standards Working Group (GI/SWG) on a wide variety of tasks. The most significant of those is the background work needed to develop a nationwide architecture for information sharing among the justice and public safety communities. Significant progress has been made on the architectural framework and related strategic plan. The GI/SWG is currently in an iterative process to ensure that the elements of the framework can accommodate current and future information sharing requirements of the practitioners at the local, State, Federal, and tribal levels.

Administration of the Justice Standards Clearinghouse On-Line

Also in conjunction with Global, ITS designed and tested the prototype web page and search engine for the Justice Standards Clearinghouse (JSC), a repository of IT and communication standards and specifications. The JSC is designed to assist public safety agencies in sharing information and communicating productively through increased awareness and accessibility of standards. This has been achieved by making the technical specifications and standards — as well as user comments regarding those standards — available to the practitioners via an online standards clearinghouse. The clearinghouse is hosted on the Office of Justice Programs (OJP) Website at http://it.ojp.gov/jsr/public/index.jsp.

Currently there are more than 70 standards and specifications available for public access in the clearinghouse, and ITS is playing an ongoing role in the addition of new standards through administration of the site and validation of the data that is entered there.



Structure of the justice/public safety/homeland security XML Data Model.

XML Data Model and Data Element Dictionary Development

In prior years, ITS had played a significant role in providing technical assistance and coordination in the initial development of an XML Data Element Dictionary that can provide common "words" for a common "language" to be used by the justice/public safety/homeland security community. In FY 2003, the XML development work skyrocketed, with an order of magnitude increase in the size of the Data Element Dictionary and the development of an associated Data Model.

The development of an XML Data Model is a significant step forward in achieving information sharing among members of the justice and public safety community. It provides a foundation for the structure of a consistent Data Element Dictionary, documents to be exchanged, and messages to be passed. The figure above shows the structure of the justice/public safety/homeland security XML Data Model. The core of the Data Model is the XML Data Element Dictionary and the corresponding "Justice" namespace. Users and developers use the "words" of the Data Dictionary to build documents that represent a particular information exchange. Based on their requirements, they can import the words by reference and can extend or restrict the definitions.

The significantly-expanded Data Dictionary contains over 2000 elements and is expected to meet over 90% of the information sharing requirements of the justice/public safety/homeland security community. A beta version of the dictionary is currently available for public comment at http://it.ojp.gov/jxdd .

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Wireless Telecommunications Interoperability Standardization for Justice/Public Safety/Homeland Security

Outputs

- Wireless telecommunications Statement of Requirements (SOR) for Public Safety.
- Functional and performance specifications for Project 25/TIA digital radio and system standards.
- Standardized measurement methods for testing Project 25 radios and systems.

ITS is conducting a technical program aimed at facilitating effective interoperability and information sharing among dissimilar wireless telecommunications systems within the justice/public safety/homeland security community. The primary focal points of the program are: (1) the identification and delineation of wireless telecommunications functional and interoperability requirements, (2) coordination with major Federal players and local and State public safety practitioners to collegially design a nationwide strategic plan for wireless interoperability, and (3) the identification and/or development of standards that address the defined requirements and are in concert with the strategic plan. Standardization efforts are aimed at allowing local, State, and Federal agencies to exchange information, without requiring substantial changes to internal systems or procedures.

The ITS program is sponsored by a number of different Federal departments and programs that have a keen interest in public safety interoperability, including: National Institute of Standards and Technology (NIST) Office of Law Enforcement Standards (OLES), National Institute of Justice (NIJ) AGILE Program, Department of Justice Office of Community Oriented Policing Service (COPS), National Communications System (NCS), Public Safety Wireless Network (PSWN) program, Federal Law Enforcement Wireless Users' Group (FLEWUG), and NTIA.

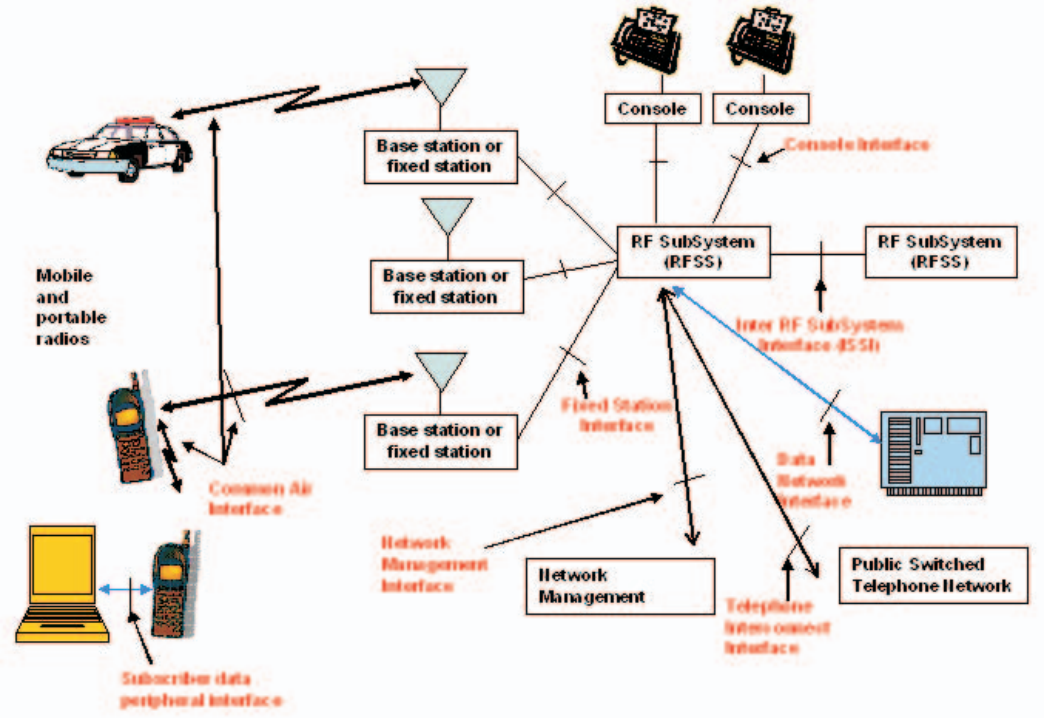
Wireless Telecommunications Statement of Requirements (SOR)

No comprehensive set of wireless telecommunication requirements has been written for public safety since the highly regarded PSWAC (Public Safety Wireless Advisory Committee) Final Report was published in 1996. Yet, the development of any far-reaching nationwide strategy for wireless interoperability (and the standards to implement it) demands that practitioners' needs be clearly understood before approaches are drawn. Therefore, on behalf of the public safety community, ITS took the lead in developing a contemporary SOR during the latter half of FY 2003. By the end of the fiscal year, several sections were drafted, with a final product targeted for practitioner review on or about January 1, 2004.

In general, this SOR is focused on the functional needs of public safety first responders — Emergency Medical Services (EMS) personnel, fire fighters, and law enforcement officers — to communicate and share information when it is needed, where it is needed, and in a mode or form that allows the practitioners to use it effectively. The communications mode may be voice, data, image, video, or multimedia that includes multiple forms of information. To keep the emphasis on functional requirements, the SOR avoids specifying either technologies or business models (i.e., whether requirements should be addressed through owned products and systems, or via commercial services).

Wireless Strategic Planning

Through its sponsors, the Institute is supporting the development of a nationwide strategic plan for wireless interoperability. Working with those in the Federal Government responsible for the final plan, most notably SAFECOM, ITS is expediting the overall Federal effort by taking advantage of background engineering work already conducted at the Institute and elsewhere. For example, ITS has investigated frameworks for high-level enterprise architectures, and is also reviewing and analyzing the wireless integration activities being performed, and being contemplated, by local, State, and regional governmental organizations to characterize common architectural elements that have been successfully applied in the field. Governance and other non-technical issues have also been researched.



Project 25 system interfaces.

Project 25/TIA TR-8 and Project MESA

The Institute contributes widely to Project 25, a program devoted to developing a comprehensive series of interoperability standards for the new generation digital land mobile radio (LMR) operating in narrowband channels for public safety applications. Comprised of representatives from the Association of Public-Safety Communications Officials (APCO) International, the National Association of State Telecommunications Directors (NASTD), industry as represented by the Telecommunications Industry Association (TIA), and local, State, and Federal governments, Project 25 is closely aligned with TIA's Standards Committee TR-8 (TR-8 is the body that formally develops, approves and releases Project 25 standards as TIA 102 series documents). While Project 25/TIA TR-8 "Phase 2" work is now addressing interoperability standards for narrowband (6.25 kHz channel) digital LMRs, the specification of interface standards for (Phase 1) 12.5-kHz digital LMRs also continues. "Phase 3" (also referred to as Project 34 and Project MESA) is a joint effort between TIA and the European Telecommunications Standards Institute and is focused on the development of standards for wideband mobile data applications.

An ITS engineer represents NCS on the Project 25 Steering Committee, and chairs the Project 25 Encryption Task Group where Information System Security (INFOSEC) standards have been developed. ITS also contributes heavily to other TIA TR-8 committees and Project 25 task groups. For example, ITS' technical and editorial efforts have enabled the completion of initial drafts of two new TIA standards that will define Inter-RF Subsystem Interface (ISSI) measurement methods and specify recommended ISSI performance objectives. ITS continues to have the responsibility for developing procedures to test the interoperability of Project 25 radio systems. To date, procedures have been developed to test radios employing conventional voice, encrypted voice, over-the-air re-keying, trunking, and data applications.

Project MESA efforts have concentrated on defining the public safety requirements for wideband mobile applications. To date, the Institute has provided user operational requirements to Project MESA. These requirements represent the United States position.

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Emergency Telecommunications Service (ETS)

Outputs

- Technical contributions to ANSI Working Group T1A1.2.
- Technical contributions to ITU-T Study Group 9.
- Report to NCS on baseline computer simulations for network survivability and ETS studies.

In the aftermath of the recent terrorist attacks, the Federal Government has become very interested in priority treatment for emergency communications. While the Government Emergency Telecommunications Service (GETS) has served emergency workers well for many years, it is limited to the Public Switched Telephone Network (PSTN) and to the United States. ETS is envisioned as a GETS-like service that will be available internationally and encompass virtually all wireless and wireline communications networks. The types of traffic to be carried include voice, video, database access, text messaging, e-mail, ftp, and web-based services.

The ETS effort at ITS encompasses several projects, including Packet-Switched Networks, and Network Survivability and Restoral. For both of these projects, computer simulation, laboratory studies, security analyses, and traffic engineering are used to support Critical Infrastructure Protection (CIP) initiatives. These two projects are funded by the National Communications System (NCS). This work supports NCS in its mission to protect the national security telecommunications infrastructure, and to ensure the responsiveness and survivability of essential telecommunications during a crisis.

In the first project, Packet-Switched Networks, ITS develops and verifies ETS Recommendations for ITU-T Study Group 9. The major goal of this project is to ensure that future ETS mechanisms will interoperate over broadband cable television networks. Additionally, the project is working to facilitate the evolution of GETS over the IPCablecom network.

The second project, Network Survivability and Restoral, provides ETS expertise relating to Network Survivability for ANSI-accredited Technical Subcommittee T1A1. Within this project, an ITS engineer served as co-editor of a new T1 technical report: T1.TR.79-2003 “Overview of Standards in Support of Emergency Telecommunications Service (ETS).” An ITS engineer is now serving as editor on three new draft Standards and Technical Reports related to ETS in T1A1.2.

Traditional analysis methods are not adequate to predict the effects of large service outages in the current and future network environments. Therefore, ITS is using network modeling and simulation tools to address the needs of T1A1.2, NS/EP, and the Nation. While modeling and simulation are powerful tools for the assessment of threats

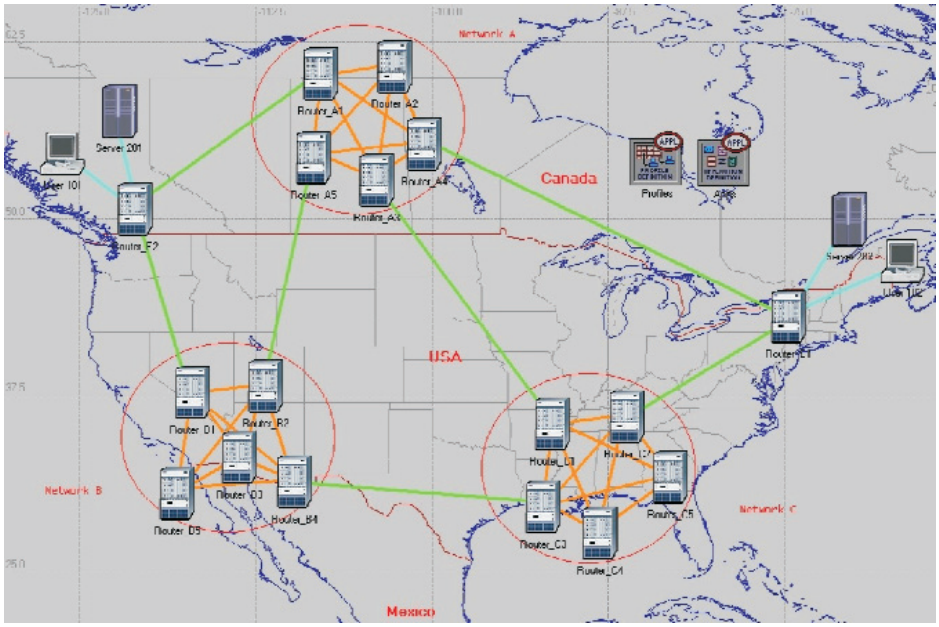

Figure 1. Simulation for testing routing protocols.

and mitigation techniques, the simulations must be well grounded in the physical measurement of important parameters. One goal of the project has been to produce baseline models for reference network architectures that can be used in standards development as well as in future network research by ITS and others. Figure 1 on the previous page shows a model developed to investigate aspects of routing protocols. In Figure 1, the orange lines represent links that are internal to a network and use an Internal Gateway Protocol (IGP). The green lines represent links that connect the different networks. These links use an External Gateway Protocol (EGP) such as BGP4. Within a network, most of the nodes will share the same network prefix, so the IGP can optimize the route that a packet takes to the destination node once it arrives in the network. An EGP exchanges higher-level information between networks so that the packets can be sent to the appropriate network for distribution. The BGP4 protocol has some convergence issues that this simulation, and similar ones, can help to identify.

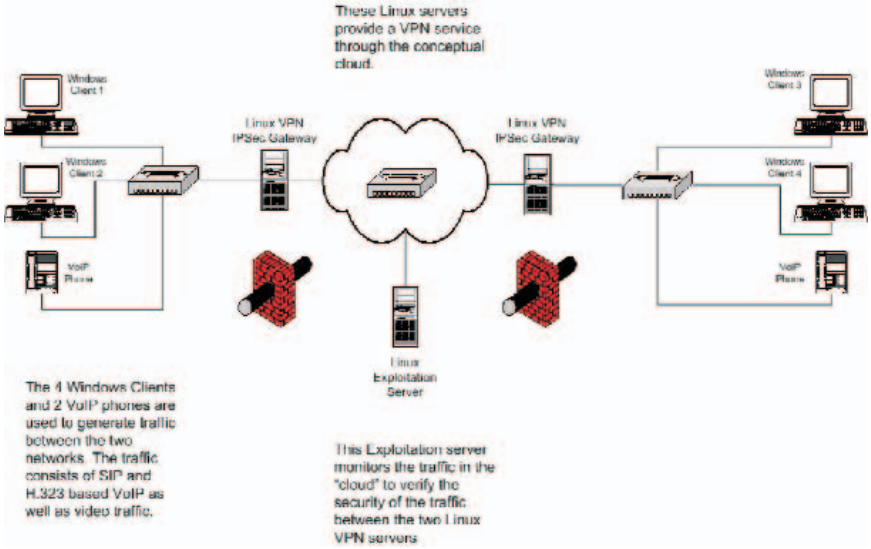

Figure 2. Laboratory setup for testing security and ETS protocols.

The standardization work in ITU-T Study Group 9 is focused on the IPCablecom family of Recommendations. These Recommendations define the protocols and signaling to be used on broadband cable television networks to support telephony, multimedia, and Internet access. The IPCablecom Recommendations have just recently been standardized and they are currently in production worldwide. One of the goals of this project is to identify where additions or changes might be needed to support the ETS. This effort also involves work with the Internet Engineering Task Force (IETF) since many of the underlying protocols used in IPCablecom (as well as some of the ETS mechanisms) are under development in the IETF. An ITS engineer serves as the Editor of Draft New Recommendation J.TDR, "Requirements and Specifications for Telecommunications for Disaster Relief over IPCablecom Networks," in Study Group 9.

Another important study underway at ITS is a series of tests of GETS over IPCablecom networks. The evolution of GETS from a PSTN-only service to one which will interoperate over the wireless, IPCablecom, and Next Generation networks (NGN) is one of the goals of NCS. Determining the security needs of ETS in IPCablecom networks is another goal of the ETS effort. Figure 2 above shows a laboratory setup to test proposed ETS mechanisms over virtual private networks (VPNs) and through firewalls. The lab setup is currently used to test the performance of videoconferencing and Voice over IP over SIP. Proposed ETS mechanisms will be coded and tested over the same network to determine if they are viable from a Quality of Service (QoS) standpoint.

In FY 2004, ITS will continue to address work on the development and standardization of ETS in T1A1, the IETF, and ITU-T Study Group 9. The projects will address technologies in the NGN and interactions with the IPCablecom networks. This work on ETS must of necessity be conducted with the help of representatives from network providers and cable television equipment manufacturers, as well as NCS. The work in FY 2004 will focus on survivability and security in the NGN ETS as well as GETS compatibility in the IPCablecom networks.

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Networking Technology/Interoperability

Outputs

- Definition of structured planning process for telecommunication and IT networks.
- Suggestions for types of tools to assist in network design and administration.
- Definition of a structured approach for applying tools and methods in the analysis of network interoperability issues.

ITS has a long history of assisting other agencies and organizations with their telecommunication planning, assessment, and interoperability studies, but the complexity of today's telecommunication and information technology (IT) requirements, and the technology available to satisfy those requirements, create demands for enhanced sophistication in the methodologies and tools used to perform these studies. The Networking Technology/Interoperability projects have defined structured methods for such studies, examined many tools and techniques that can be used in conducting such studies, and identified those tools and methodologies most likely to provide the greatest benefits. The previous two years' work focused on the selection and use of a suite of neworking tools that aid in discovering the topology of a network, the load on segments of a network, and the simulation of a network, as well as examining tools and methods useful in supporting two important aspects of network design and administration: network management and network security. This past year's efforts focused on the development of a structured approach to applying these tools, along with a systems engineering method to address the complex issue of network interoperability.

Network Interoperability

From a technical networking perspective, network interoperability involves the migration of existing (Legacy) systems which are not interoperable to current (Preferred) systems which are interoperable. Interoperability is a knowledge dimension (see Figure 2 on next page) of network systems engineering involving the technical ability of two or more cooperating networks at a given point in time to satisfy users' telecommunication needs (e.g., exchange of user information at specified quality levels). The ability to characterize and analyze network interoperability depends significantly on characterizing and understanding the following issues:
1. A complete understanding of the interoperability problem domain including an understanding of interoperability requirements and the problems generated by these requirements. An understanding of the organizations from which these requirements emerge. A thorough understanding of the

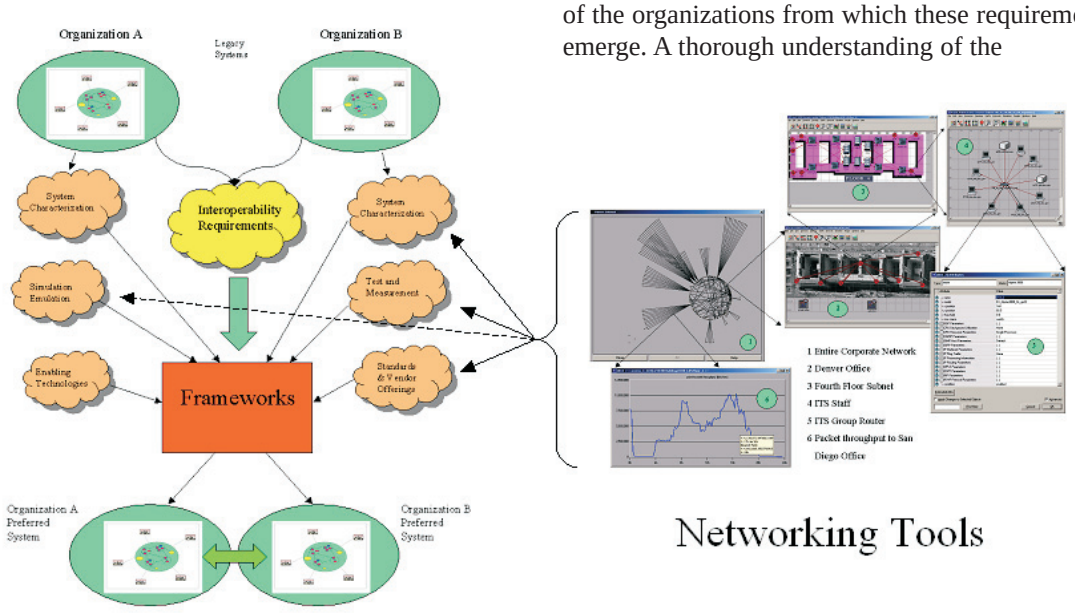

Figure 1. Graphical depiction of a structured approach to network interoperability analysis.

characteristics of the systems involved, including network type, topology, interfaces, components, services, traffic and utilization levels, and security and management infrastructures.
2. The use of existing or emerging enabling technologies to facilitate the development of interface and migration interoperability solutions.
3. The use of networking tools including test and measurement equipment and software as well as evaluation methods that aid in the design of alternative solutions and ensure that solutions meet goals and performance requirements. This includes tools for network simulation and emulation, network monitoring and management, and security assessment and protection.
4. The judicious use of frameworks within which the interoperability requirements can be described and solved using structured methods and decision-making techniques.

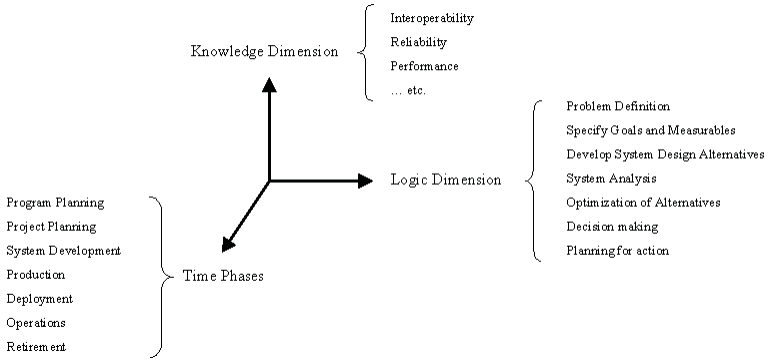

Figure 2. A three dimensional framework for systems engineering analysis.

Figure 1 on the previous page shows this structured approach to interoperability analysis in graphical form. The frameworks shown aid in developing an interoperability solution by offering a structure within which alternative solutions can be developed and compared. The systems engineering framework chosen for this project is a 3-dimensional framework of time, logic and knowledge dimensions. The time dimension consists of seven phases which describe the life cycle of most projects, the logic dimension describes steps followed in solving problems for each time phase of the project life cycle, and the knowledge dimension describes those branches of engineering and project management that guide the project staff in defining and solving problem areas. Figure 2 above shows this framework. For each knowledge dimension, the seven time phases help guide the project from inception to retirement. For each time phase, the seven logic steps aid in the definition of problems to be solved and guide the development team in the design of alternative solutions.

ITS applied this methodology to a hypothetical laboratory interoperability project involving three organizations, each of which has implemented a Voice over IP (VoIP) network using different vendor solutions and different technologies. It has now become necessary to make these systems capable of calling each other. The goal of the effort is to deploy a cost effective solution for interoperating these VoIP networks. In this simple case, we assumed that the organizations involved had similar missions so that organizational considerations did not result in any technical constraints.

Following the structured approach resulted in several alternative design solutions that satisfied the interoperability requirements. One solution was costly but had the most flexible hardware and very good customer support. A second solution was excellent for configuring and managing large networks but had significant overhead in software operation. A third solution was the least costly and simple to use but would not scale as well in large organizations. In addition, each solution had tradeoffs between voice quality and bandwidth requirements which could be a significant factor depending upon the infrastructure used (wireless or wireline). Since these VoIP networks operate over the existing IP infrastructure, it is also important to monitor the existing utilization levels on the network to ensure that the chosen solution will operate over a wide range of levels. Lastly, it is important to be able to simulate the existing system and the alternative solution designs to ensure that we can simulate scenarios which may be experienced. Using the ITS Interoperability Research Laboratory and the suite of networking tools for network discovery, monitoring, security, and management resulted in the development of excellent, well-understood, alternative solutions which could now be presented to management for final selection.

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Railroad Telecommunication Planning

Outputs

- Technical support to the Federal Railroad Administration (FRA) for all matters related to railroad telecommunications.

This project involves providing technical consulting on a continuing and as-needed basis to the Federal Railroad Administration (FRA), relative to any technical issues related to railroad telecommunications that may arise. For example, prior years' activities related to the Oregon Department of Transportation (ODOT) Pilot Project, which investigated the efficacy of utilizing TIA102-compliant radios in a railroad private land-mobile radio (PLMR) environment, and have been detailed in previous years' Technical Progress Reports, continued in FY 2003.

In FY 2003, a task that resulted from the FCC's Second Report and Order (R&O) 03-34 was undertaken by the Institute. The R&O is a matter with wide-reaching implications for the railroad industry. It concerns itself with, among other things, the mandatory migration of "wideband" (emission designator 16k0F3E) PLMR systems to "narrowband" (11k0F3E or 11k0F1E) systems. The railroad industry had raised concern that such a migration process will present significant challenges to implement.

The railroad PLMR infrastructure is comprised of more than 15,000 base stations, 45,000 mobile radios, and 125,000 portable radios nationwide. Each railroad manages its own PLMR infrastructure, and is responsible for ensuring that its base station assets provide the necessary RF coverage throughout its own territories, which are scattered nationwide.

It is common practice to find one railroad's locomotive operating in another railroad's territory, utilizing that "foreign" railroad's PLMR infrastructure. Furthermore, a locomotive could be expected to be found anywhere in the country at any given time — locomotives are not necessarily "captive" to a particular geographic area.

Hence, the dilemma in migrating to a nationwide radio infrastructure is this: with the sheer number of radios involved nationwide, owned and managed by different railroad companies, each railroad would be challenged to coordinate the simultaneous conversion of all its assets nationwide to narrowband technology all at once, and to coordinate such a massive undertaking with all the other railroad companies. Obviously, there will be a "transition" period where "mixed-mode" operation (wideband receivers operating with narrowband transmitters and vice versa) will be the norm. For example, a locomotive whose legacy radio had not yet been replaced, and that was operating in a territory whose base station had already been transitioned to narrowband technology, would be receiving a narrowband signal by its wideband receiver. Thus, the question arose as to the effects of such mixed-mode operations on the performance of land-mobile radios. It is this aspect of a migration that the railroads and the FRA wished to explore further.

Among other testing, the Institute subjected various commercial-grade radios of different manufacture to these mixed-mode operating conditions. The resultant data was provided to the FRA sponsor. The Association of American Railroads incorporated this work into comments that it filed last August in response to the aforementioned R&O.

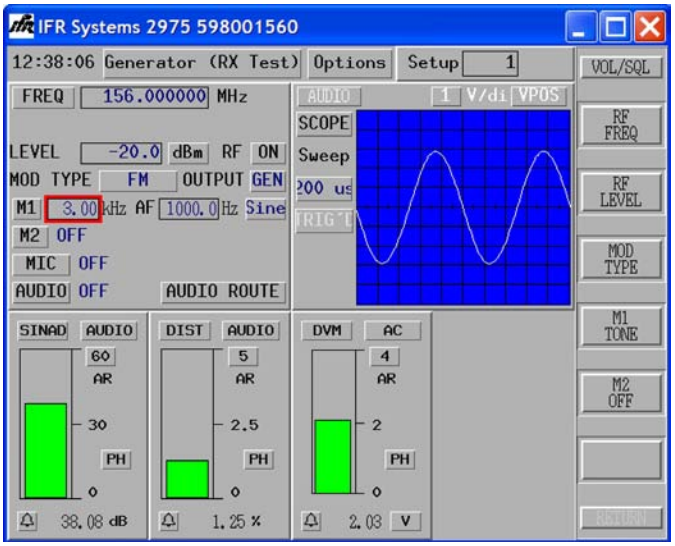

Figure 1. Wideband transmitter deviation with wideband receiver bandwidth.

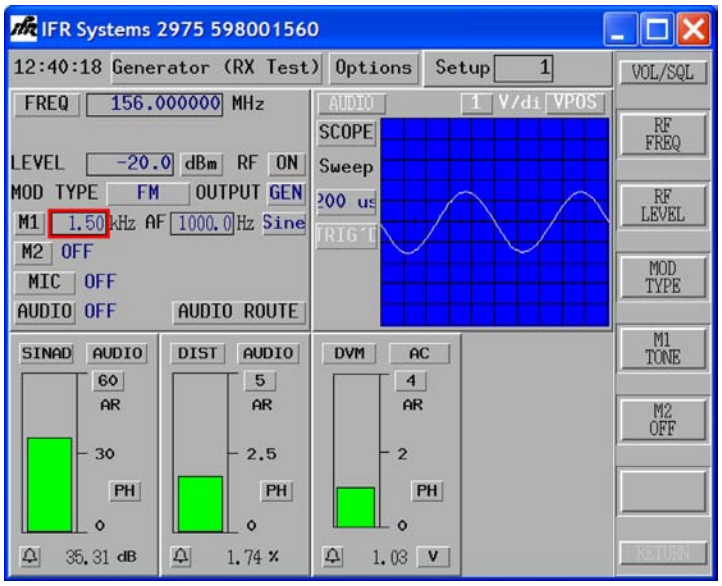

Figure 2. Narrowband transmitter deviation with wideband receiver bandwidth.

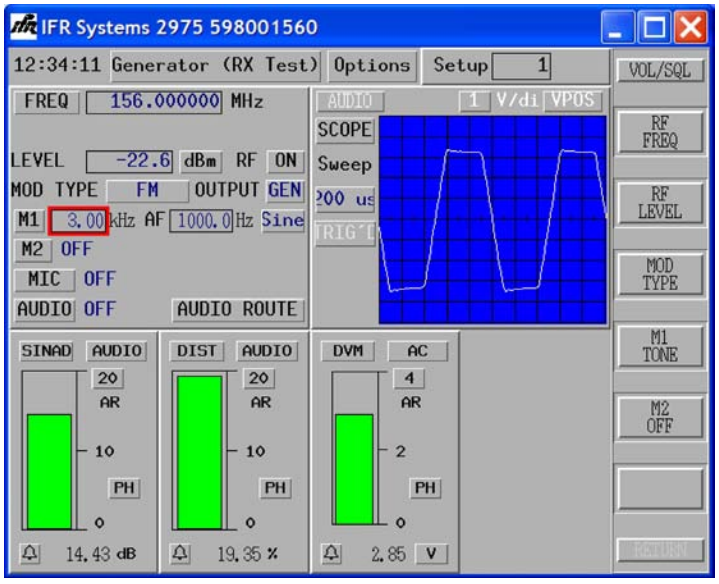

Figure 3. Wideband transmitter deviation with narrowband receiver bandwidth.

One important issue, revealed as an outcome of this work, is illustrated in Figures 1 through 3. Notice how the amplitude of the demodulated audio in Figure 1 (on previous page), the "legacy" configuration, is twice as large as the demodulated audio signal in Figure 2, an example of "narrowband transmitter/wideband receiver" mixed-mode operation.

Although an operator could simply turn up the radio's volume control to compensate for the decreased volume, the issue here is this: Suppose a locomotive roams out of a "legacy base station" region into a "narrowband base station" region. What if the engineer did not notice that at some specific milepost marker, he had entered the new base station coverage area and that therefore he had to increase the volume control setting on the locomotive radio? Is it possible, in the noisy acoustic environment of a locomotive cab, that the engineer might miss a critical radio transmission from the dispatcher?

Or consider the converse case, depicted in Figure 3, where a wideband transmitter signal is received by a narrowband receiver. It is quite clear from the figure that the demodulated audio is distorted. Could an engineer misunderstand a dispatcher's instructions because of such distortion?

It is issues such as these that the measurements revealed, and it is issues such as these that the railroad industry must now consider as it develops a wideband-to-narrowband migration strategy.

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Voice over IP

Outputs

- Metrics and measurement methods for real-time traffic over long 802.11b links.
- Standards contributions (TR-41.1) detailing the behavior of real-time VoIP traffic over long 802.11b links.

The market availability of Voice over Internet Protocol (VoIP) equipment continues to increase, due to the many advantages that this technology offers. These advantages include efficient resource utilization, a homogeneous network offering both voice and data, potential for other multimedia transmission (e.g. video), and lower data bandwidth requirements than traditional telephony.

As wireless local area networks (LANs) based upon IEEE 802.11b (Wi-Fi) technologies become more ubiquitous, attempts are being made to utilize VoIP over radio channels as well as the fixed location wired networks more traditionally associated with VoIP systems. However, propagation effects within the wireless channel can substantially degrade the Quality of Service (QoS) of a VoIP system. As VoIP and Wi-Fi technologies converge, knowledge about the type and extent of these effects assumes increasing importance.

In order to evaluate some of the potential impairments implicit in VoIP transmission over Wi-Fi channels, ITS has created a testbed with three 802.11b long links. Two of these links, of length 1 mile and 10 miles respectively, are being used to evaluate the effects of 802.11b long link transmission on network parameters related to VoIP. They simulate two different environments, rural and suburban, and also represent two slightly different radio setups.

The shorter link is essentially a peer-to-peer link that runs from the ITS Wireless Networking Research Center to a test location one mile distant on a nearby hill. This link uses directional antennas, but is otherwise unamplified. Since its path traverses open fields, it represents a rural environment.

The second link has one end node on the same hill, but it passes over a well-populated residential area, with all of the potential interferers that are implied by such a traversal. The link terminates in a node situated in the ITS field site on the Table Mountain plateau. This link utilizes amplification to achieve the distance required, in the form of a constant power 250 mW output amplifier and a standard 17 dB input amplifier. Although the shorter link runs in peer-to-peer mode, this longer link is terminated at both ends by wireless access points. Both links use 24 dBi directional antennas at each end and both are line-of-sight.

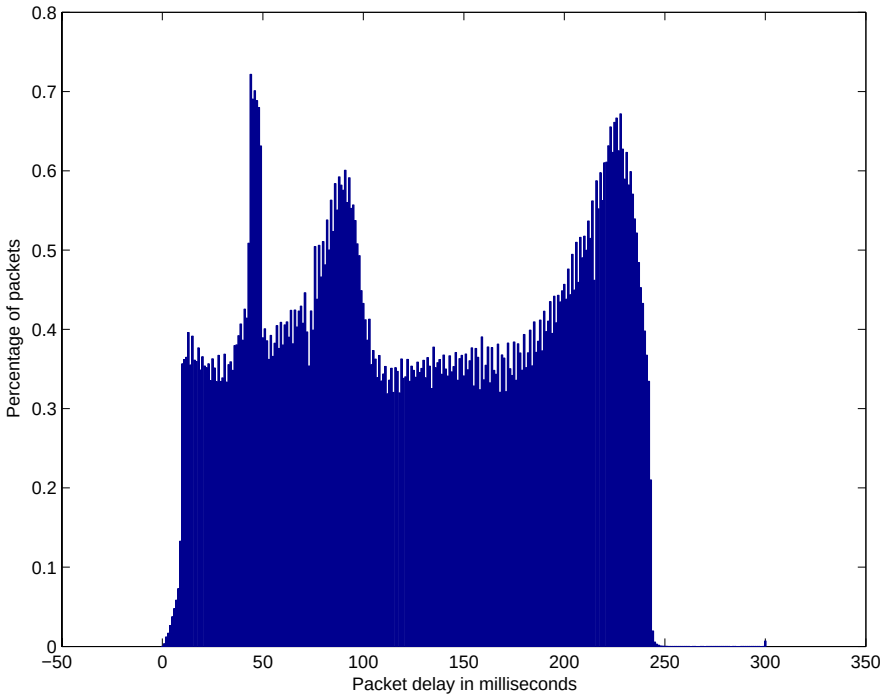

Figure 1. Packet latency distribution over a 1-mile peer-to-peer 802.11b link.

Both links achieve true realizable throughputs of approximately 4 Mbps, a value that is consistent with 802.11b technology operating at maximum burst speed. Initial experiments concentrated on the measurement of jitter and packet loss in the system. Both of these parameters are of great importance in services like VoIP that require a real-time transport capability — jitter because packets that are delayed beyond the time length of the jitter buffer must be dropped, causing gaps in the output stream, and packet loss because the real-time nature of the required transport makes it impractical to retransmit lost packets.

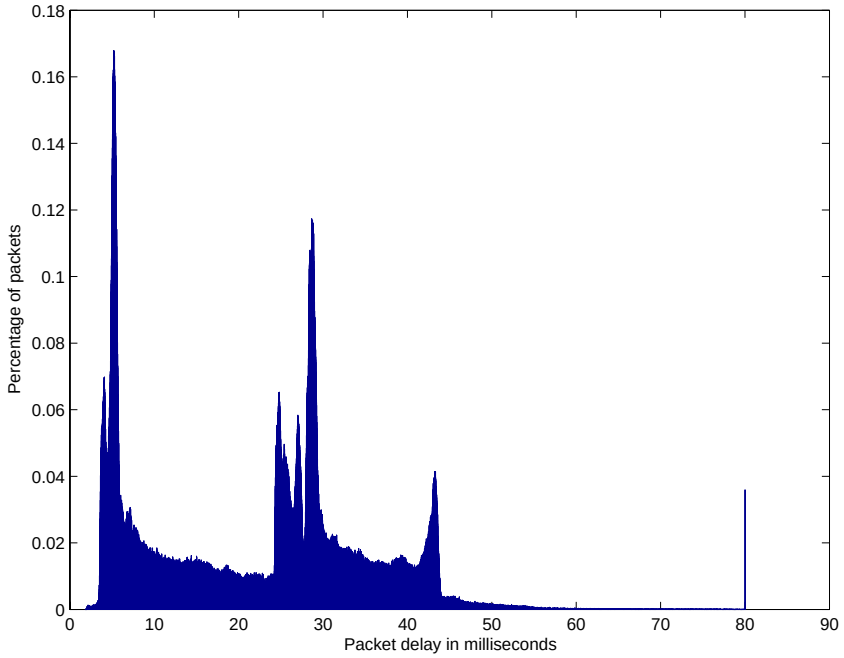

Figure 2. Packet latency distribution over a 10-mile 802.11b link.

Representative results from the two links are shown in Figure 1 (on the previous page) for the 1-mile link and Figure 2 (above) for the 10-mile link. It is immediately apparent from the figures that the shorter link has a much greater variation in latency than the longer link. Although the short link has a smaller minimum value — 0.3 milliseconds versus 1.9 milliseconds for the long link — the mean value for the short link is considerably greater than that of the long link — 129.8 milliseconds for the 1-mile link and 22.4 milliseconds for the 10-mile link. Losses for the short link also exceed those of the long link, although neither figure is high. Packet loss for this experiment was 0.11% for the short link and only 0.02% for the long link. The standard deviation of the short link delays is 94.6 milliseconds, and that of the long link delays is 45.6 milliseconds. By this metric, the jitter on the two links is similar within a factor of 2.

In real time VoIP transmission, a jitter buffer must be maintained to deal with delayed and out-of-order packets. Packets that are delivered outside the time range of this buffer are discarded. Contrary to what might be inferred from the standard deviation numbers alone, the figures show that the delay variation for the short link peer-to-peer connection is approximately six times greater than that of the long link.

A comparison using a different jitter metric, the Inter Quartile range, gives more insight into these distributions. This value expresses the time difference between packets in the third quartile of the distribution and those in the first quartile. For the short link, this metric gives 126.0 milliseconds and the long link is evaluated at 22.2 milliseconds. These somewhat counterintuitive data may indicate that the peer-to-peer mode of 802.11b transmission is a bad choice for VoIP traffic due to poor jitter characteristics. This conjecture, as well as the reasons for the multimodal nature of both delay distributions, is under current investigation.

It is clear that the wireless channel is significantly more complex than a wired channel in regard to real-time traffic. Studies of this transport mechanism must include information about the radio environment as well as traditional network parameters. In addition, new and relevant metrics and measurement methods for these information channels must be devised. ITS research is aimed at providing this information.

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