OVERVIEW OF PROTOCOL TESTING PROGRAMS, METHODOLOGIES, AND STANDARDS

Herbert V. Bertine, Wolfgang B. Elsner, Pramode K. Verma, and Kamlesh T. Tewani

Herbert V. Bertine, Wolfgang B. Elsner, Pramode K. Verma, *and* ***Kamlesh T. Tewani*** *all are associated with AT&T Bell Laboratories. Mr. Bertine is head of the Standards Planning Department at the Holmdel, New Jersey facility. He holds B.E.E and M.E.E degrees from Rensselaer Polytechnic Institute, Troy, New York. Since joining the company in 1965, he has been responsible for systems engineering in data communications planning, architecture and protocols. He is active in domestic and international standards groups and user and vendor forums. Mr. Elsner has been with Bell Laboratories since 1973, and is supervisor of the ISDN Interfaces Group at Holmdel. His responsibilities include managing the ISDN Basic Rate Interface conformance testing program. Mr. Elsner received his B.S.E.E,*
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The twin developments of sophisticated communications protocols and a multivendor environment are revolutionizing the world of data communications and telephony. Protocol testing will have a significant role in this evolving environment, for it helps ensure interoperability between and among systems from multiple vendors and service providers. AT&T, in its role of service and product provider, has a keen interest in protocol testing to ensure the interoperability of its products and services, alone and in concert with those of other vendors.

Introduction

During the past decade, two processes have revolutionized the world of data communications and telephony. One is the emergence of increasingly complex, sophisticated protocols to govern the establishment and control of paths between communicating entities, and to facilitate the transfer of information between them. For example, the X.25 packet-switching protocol has matured as a data communication standard; the Integrated Services Digital Network (ISDN) has emerged into prominence; and application layer protocols such as file transfer, access and management (FTAM) and the message handling system (MHS) have been defined. The second process is the movement toward an environment in which users communicate in a networking environment that involves multiple equipment vendors and multiple service providers, often across national boundaries.

Protocol testing plays a major role in this new environment. Protocol incompatibility between or among two or more systems can have various causes. First, different implementations of the same protocol might result from varying interpretations of the protocol specification. Second, each protocol usually provides a range of options that may result in mutual incompatibility between or among two or more systems (the terms *systems* and *implementation* are used interchangeably). Third, due to the complexity of protocols, developers may introduce errors. Finally, incompatibility may result from incompletely specified protocols and procedures that cover, for example, system administration, system management, or maintenance applicable to

Panel 1. Terms and Acronyms in This Paper

BRI	basic rate interface
CCITT	International Telegraph and Telephone Consultative Committee
COS	Corporation for Open Systems
DMI	digital multiplexed interface
FSM	finite state machine
FTAM	file access transfer and management
GOSIP	Government Open Systems Interconnection Profile
IEEE	Institute of Electrical and Electronics Engineers
IEC	International Electrotechnical Commission
ISDN	Integrated Services Digital Network
ISO	International Organization for Standardization
IUT	implementation under test
JTC1	Joint Technical Committee 1 (ISO/IEC)
LAN	local area network
MAP	manufacturing and automation protocol
MHS	message handling system
NIST	National Institute of Standards and Technology
NIUF	North American ISDN Users Forum
OSI	Open Systems Interconnection
PICS	Protocol Implementation Conformance Statement
PIXIT	Protocol Implementation Extra Information for Testing
PRI	primary rate interface
PTT	Postal, Telegraph and Telephone Authority
SC	Subcommittee (ISO)
SG	Study Group (CCITT)
TOP	Technical and Office Protocol
TTCN	tree and tabular combined notation
UIO	unique input-output (sequences)
X.25	packet-switching protocol and standard (CCITT)
X.400	Message Handling Systems (CCITT)

individual systems.

AT&T provides various network services and products. During development, they are tested to ensure they comply with their specifications and standards. The company also provides means to test products and services developed by other vendors to ensure their interoperability with AT&T products and services.

This paper emphasizes the role of testing in discussing the evolution of a product or service from concept to availability. The importance of having complete and unambiguous protocol specifications is highlighted. Finally, two testing phases—*conformance testing* and *interoperability testing*—are discussed. The importance of the different aspects of testing is based on the growing demand from the marketplace to have interoperable products and services in a multivendor environment.

The Role of Testing

To put the role of testing in perspective, it is useful to examine how a communications service (e.g., X.25 or X.400) evolves from concept to delivery to the user. (*Service* in this paper refers to services provided by public or private networks.) Figure 1 illustrates this evolution.

The first step is the *service definition*, in which all behaviors and features of the service as seen by the user are specified. This step is followed by a *specification phase* that consists of developing a complete definition of the protocol behaviors needed to produce the required service. The specification must describe what the protocol should do, what it should *not* do, and how it should react to external stimuli.

A protocol specification must be *verified* to ensure that it is complete, that it is free of logical and functional errors, and that it correctly delivers the intended service. Verification ensures that a protocol has the desired *safety* and *liveness* properties; safety insures that *bad things* (e.g., deadlocks) *will not happen*, and liveness ensures that *good things will happen* (e.g., a call will be set up; data will be transferred). Protocol verification is discussed in more detail elsewhere in this issue.

The protocol specifications are used to develop products and services. *Conformance testing* verifies that these products and services comply with their specifications. *Interoperability testing* supplements conformance testing by verifying the end-to-end behavior of specified complex configurations.

Even after the product or service has passed both conformance and interoperability tests, protocol and functional problems may occur in the field due to unexpected conditions, untested configurations, or faulty administration. Thus, *maintenance testing* may be needed to troubleshoot and resolve protocol and functional errors while installing new services or equipment, upgrading software, and performing service operations.

The remainder of this paper discusses Protocol Specification, Conformance Testing and Interoperability Testing in greater detail.

Protocol Specification

This section gives an overview of the various standards-setting organizations such as CCITT, ISO and user and vendor forums. It also discusses how AT&T uses standards to develop its interface specifications and technical references.

Standards. The objective of the suppliers of open OSI and ISDN systems is to have internationally accepted, stable standards throughout the user and vendor communities. The International Telegraph and Telephone Consultative Committee (CCITT), the International Organization for Standardization (ISO), and the International Electrotechnical Commission (IEC) are three major international organizations that play a significant role in developing telecommunications and information technology standards. CCITT is part of the International Telecommunications Union and its members are the agencies of the various governments (e.g., PTTs). The aim of CCITT is to produce standards for international interworking of telephone and other telecommunications

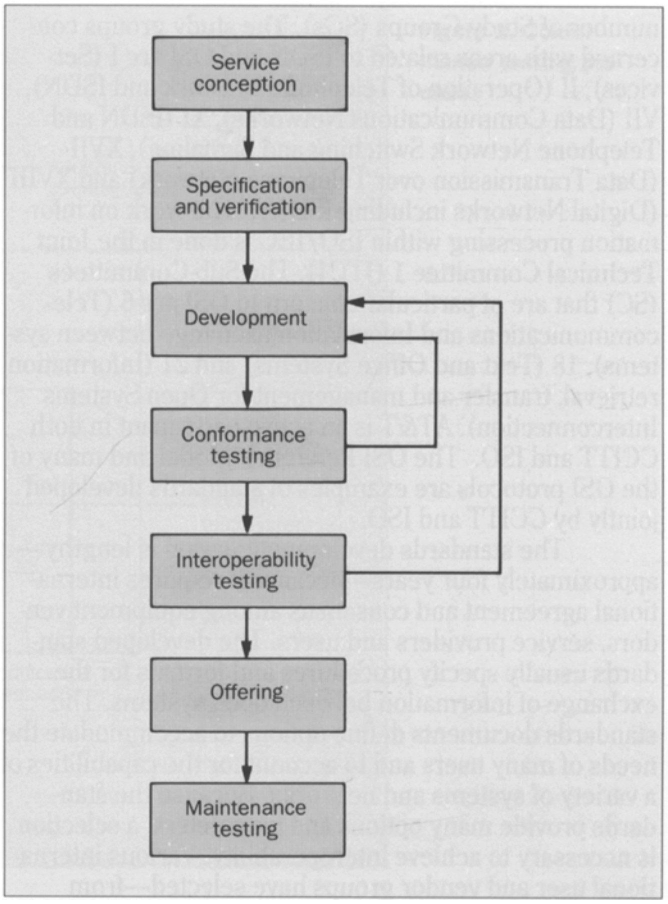

Figure 1. Communications service: from concept to delivery.

systems. ISO is concerned with standardization over a broad spectrum of subjects that include information processing. Members of ISO are the national standards organizations. IEC is the organization responsible for international standardization in electrical and eletronics fields. Members of IEC are the national committees.

CCITT divides its program of work between a number of Study Groups (SGs). The study groups concerned with areas related to ISDN and OSI are I (Services), II (Operation of Telephone Network and ISDN), VII (Data Communications Networks), XI (ISDN and Telephone Network Switching and Signaling), XVII (Data Transmission over Telephone Network) and XVIII (Digital Networks including ISDN). The work on information processing within ISO/IEC is done in the Joint Technical Committee 1 (JTC1). The Sub-Committees (SC) that are of particular concern to OSI are 6 (Telecommunications and Information exchange between systems), 18 (Text and Office Systems) and 21 (Information retrieval, transfer and management for Open Systems Interconnection). AT&T is an active participant in both CCITT and ISO. The OSI Reference Model and many of the OSI protocols are examples of standards developed jointly by CCITT and ISO.

The standards development period is lengthy—approximately four years—because it requires international agreement and consensus among equipment vendors, service providers and users. The developed standards usually specify procedures and formats for the exchange of information between open systems. The standards documents define options to accommodate the needs of many users and to account for the capabilities of a variety of systems and networks. Because the standards provide many options and parameters, a selection is necessary to achieve interoperability. Various international user and vendor groups have selected—from approved and draft base standards—a consistent set of options to ensure that implementations that adhere to the selections will work together. The Open Systems Interconnection (OSI) Workshop of the National Institute of Standards and Technology (NIST), the North American ISDN Users Forum, the Corporation for Open Systems (COS), the Manufacturing and Automation Protocol and Technical and Office Protocol (MAP/TOP) Users Group, the European Workshop on Open Systems, and Asia and Oceania OSI Workshop are examples of these groups. For example, the NIST workshop for OSI protocol implementors produces a set of implementor agreements at the end of each year.[1] The Government Open Systems Interconnection Profile (GOSIP)[2–3], which is used by government agencies for procurement of open systems computer network products and services, is based on agreements reached in this workshop. Likewise, the MAP/TOP specifications and the COS profile specifications are based on these agreements.

Work also is underway in the Special Group of Functional Standards within ISO to establish international standardized profiles, i.e., an internationally accepted, harmonized document that identifies a standard or group of standards—including options and parameters—needed to accomplish a function or set of functions.

Interface Specifications and Technical References. In AT&T, identifying a consistent set of options and parameter selections is achieved by developing and publishing *interface specifications* (for products) or *technical references* (for network services).

Interface specifications and technical references are written collaboratively by product or service managers, systems engineers, and developers. These documents are based on one or more protocol standards, on the selection of particular options and parameters and, where applicable, on extensions of the standards to support the desired service. Examples of AT&T interface specifications and technical references are the ISDN basic-rate interface specification[4] and AT&T's X.25 interface specification and packet transport network capabilities.[5] (The term *protocol specification* will be used throughout the rest of this paper to imply an interface specification, technical reference, or implementation agreement.)

Conformance Testing

Conformance testing is detailed, systematic testing of an implementation to ensure it correctly implements every applicable requirement of the interface specification. Though conformance testing alone does not guarantee product interoperability, it is a critical step.

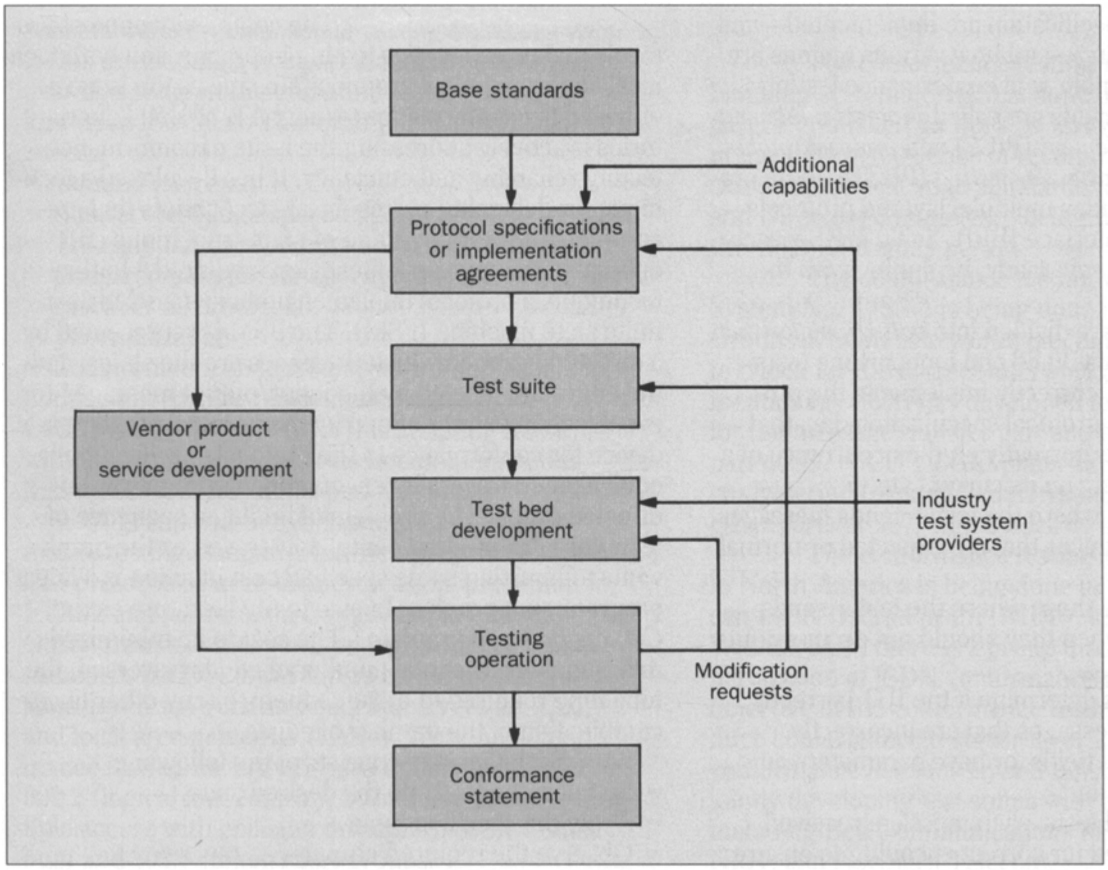

Figure 2. Conformance testing process.

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The AT&T Testing Process. The general flow of AT&T's conformance testing process is shown in Figure 2. Based on the protocol specification, a test plan is written. The purpose of the test plan is to discover, as reliably as possible, whether a given implementation meets all the requirements described in the specification. A test system is then developed to subject the implementation under test (IUT) to all tests specified in the plan. The system observes, analyzes and records the responses, and then issues "pass" or "fail" verdicts for each test. In some instances, the test system may be acquired from an outside vendor (e.g. COS). (COS develops and distributes products designed to conformance-test OSI and ISDN implementations. It has made available conformance test systems for MHS, FTAM, Transport Layer, X.25, among others.)

Once a test system is available, products or services built to a particular protocol specification are tested for conformance. When testing is completed successfully, a *conformance statement* is issued.

Before beginning conformance testing, a product developer is asked to submit statements detailing what parts of the protocol specification are implemented—and hence relevant for testing—and how various options are exercised. In the terminology of conformance testing standards, these statements are called *protocol implementation conformance statement* (PICS) and *protocol implementation extra information for testing* (PIXIT). If the protocol specification includes multiple, layered protocols—e.g., ISDN basic rate interface (BRI), X.400 MHS—each protocol layer is tested separately, beginning with the lowest.

Protocol tests are divided into *valid*, *inopportune*, and *invalid message* tests. Valid and inopportune tests determine that the IUT correctly implements the procedures defined by the protocol specification, i.e., that the implementation acts correctly on the occurrence of a specific event, depending on its current state.

- *Valid* tests are those where the tester sends messages at times and in sequences that are expected or normal for the IUT's state.
- *Inopportune* tests are those where the tester sends messages at times when they should not occur or out of sequence.
- *Invalid message* tests determine if the IUT correctly handles receipt of messages that are incorrectly encoded, have illegal fields, or have parameters outside their legal bounds.

Throughout all tests, each message received from the IUT is checked for correct encoding to ensure that all mandatory and relevant optional fields are present, and that their values are within the permissible ranges.

The experience gained during testing is always used to improve the quality of the specification and testing process. If the testing process uncovers an ambiguity in the specification, that specification is revised. If an IUT exhibits erroneous behavior for which no specific test is provided, a new test case may be added to the test suite. Thus, testing seeks to enhance not only the quality of the product but also the quality of the specification and testing processes.

Formal Methodologies. The complexity of most protocols makes exhaustive testing impractical on both technical and economical grounds. This raises the issue of efficiency in conformance testing. AT&T Bell Laboratories is actively addressing the issue of conformance testing reliability and efficiency. It has developed a technique for designing protocol-state test scripts that are complete in their coverage of state transitions and optimal in the number of test steps required.[6] In this technique, a protocol implementation is modeled as a finite state machine (FSM). The FSM is represented by a directed graph in which the nodes are the states, and the edges are labeled by the input/output messages (or event/action pairs) defined by the protocol. Testing a device for conformance to the protocol specification is equivalent to traversing successfully all edges of the directed graph. The problem of finding a sequence of tests (or a "tour") that completely traverses the graph while minimizing some specified cost function is a linear programming problem known in the literature as the *Chinese Postman* problem.[7] The cost to be minimized may simply be the total number of edges traversed, the total time required to traverse them, or any other linear combination of the number of edges.

Each test step consists of the following:

- Initialize the IUT into the desired state.
- Apply the specified input.
- Observe the required output.
- Verify that the new state is correct.

The verification step is straightforward for protocols with "status" messages that permit testing for a state without causing a state advance. For protocols without status messages, a variant of the *Chinese Postman* algorithm—the *Rural Chinese Postman* algorithm—can be applied, provided it is combined with a method called "unique input-output [UIO] sequences," in which a state is uniquely identified by a particular signature of inputs and outputs.

In conventional testing techniques, the IUT

Panel 2. Current Conformance Testing Standards Work

ISO is developing a five-part standard covering overall testing architecture and test methodology known as ISO 9646. This draft international standard covers:

- General concepts
- Abstract test suite specification
- Tree and tabular combined notation (TTCN)—the preferred notation for specifying abstract test cases for all protocols
- Test realization
- Requirements on test laboratories and clients for the conformance assessment process.

CCITT Study Group (SG) VII is adopting this work without significant change as Recommendations X.290, X.291, X.292, X.293 and X.294.

A group within ISO is working on conformance testing standards for the upper three layers of OSI protocols. These include session, presentation, FTAM, and Association Control Service Element. Other groups in ISO work on conformance testing standards for OSI lower layers including the transport layer, network and data link layers for X.25, and local area networks (LANs). Work on conformance testing for LANs is also underway in IEEE in 802.2 (logical link control), 802.3 (carrier sense multiple access with collision detection), 802.4 (token bus) and 802.5 (token ring) groups.

The conformance testing work on message handling systems (MHS) is done in CCITT SG VII. CCITT published its work on abstract test suites for in the 1984 X.400-series of recommendations. CCITT standardized test suite standards for MHS (1988) and Directory Systems are being worked on during the 1989-1992 study period.

The conformance testing work for Signaling System No. 7 (SS7) is being done in CCITT Study Group XI. SGXI also works on compatibility testing to check for the correct interworking of two implementations. SGXI has developed test specifications for the message transfer part and the telephone user part of SS7. CCITT SGXI plans during 1989-1992 study period to extend conformance testing work to other parts of SS7, e.g., the ISDN user part.

The conformance testing work for the ISDN in North America is being done in the North American ISDN Users Forum (NIUF), sponsored by NIST. Within NIUF, there is a group that addresses standardization of ISDN conformance tests. The current objective of the conformance testing group is to produce conformance tests for layer 2 (LAPD) and then conformance tests for layer 3 (Q.931). AT&T is jointly developing test suites with other participants including Bell Communications Research, IBM, NIST, and Northern Telecom.

usually is driven into a particular state, given an input, and after the output is observed, is immediately reinitialized in preparation for the next input. However, applying the Chinese Postman and the Rural Chinese Postman algorithms has led to reducing the number of test steps by factors of three to five over conventional techniques. The Chinese Postman technique easily permits certain sequences of tests to be specified, while ensuring that all remaining edges are optimally covered. In this way, operational tests, consisting of pre-specified call sequences or scenarios, can be automatically embedded in the tour.

Efforts in the Standards Arena. Conformance testing in the international standards arena requires establishing an overall testing architecture and test methodology and the development of conformance test suites for individual protocols. These steps are required because open system users and suppliers would like to have implementations that are tested for conformance against identical test suites and methods worldwide. This work is done in various committees within ISO,[8] CCITT,[9–17] and IEEE, and is reviewed in Panel 2.

Interoperability Testing

As mentioned above, interoperability testing verifies user-level functionalities in an end-to-end configuration. There are three ways interoperability testing differs from conformance testing. First, the emphasis in interoperability testing is on progressing, in a controlled (i.e., laboratory) environment, through the same sequence of steps a user would follow and verifying the observed behavior against the expected behavior under actual operating conditions. Second, interoperability testing usually involves a multiplicity of interconnected systems and networks that are functionally disparate, but have common interfaces to achieve interconnection. To the extent protocols need to be terminated at intermediate endpoints, the communicating entities between these endpoints must be compatible from a protocol standpoint. Third, interoperability testing is usually carried out with field quality systems. Issues related to operations, administration, maintenance, or other aspects of services not covered in the specifications are also discovered and resolved at this stage.

Interoperability testing by itself is insufficient because there is no known way to synthesize an application or set of applications that, if successfully executed, will guarantee the behavior of the underlying protocols for even moderately complex protocols. Thus, conformance and interoperability system tests are both necessary and complementary. There is, however, no guarantee that systems tested for conformance and interoperability will not experience any operational problems in the field. It is impossible to simulate, in a limited period, all situations that might arise in a customer environment.

Issues Addressed in Interoperability Testing. The following sections highlight why successfully executing interoperability tests enhances confidence that the tested configuration will function as expected in a customer environment. These sections also illustrate the complementary characteristics of conformance and interoperability testing.

End-to-End Protocols and Applications. By their nature, protocol specifications address only the required functionality between two systems and thus may not cover the end-to-end applications in complex configurations. In such cases, conformance testing of individual systems is not sufficient.

Options in a Protocol Specification. There often is a tradeoff between the degree of flexibility provided in a protocol and the tightness with which it is defined. An overly flexible protocol will result in implementations with diminishing chances of interoperability among two independent implementations. However, a protocol that is too narrowly defined may be inconsistent with a flexible architecture increasingly demanded in the marketplace. Thus, a useful protocol has a range of options associated with it. However, protocol options may result in inconsistency between two implementations that can either prevent the application from executing, block communication, or reduce performance (e.g., throughput and delay). Interoperability tests ensure that ***mutually compatible*** options have been selected from among the permissible ranges of choice.

Timing and Synchronization Issues. There usually are many timers associated with protocols. Some of these timers are essential to correct operation. Others, such as time-out intervals for retransmission, are related to optimum performance levels. Usually a range of timer values is specified to compensate for differences such as propagation delay and error characteristics of the medium. Synchronization patterns usually are employed to initialize a protocol process. Synchronization patterns have adjustable durations. Thus, two communicating entities relying on the pattern must be optioned to satisfy the needs of both communicating ends. Interoperability tests ensure that the time-out intervals—and durations of synchronization patterns, if any—are tested for integrity in a simulated end-to-end operating environment prior to field deployment.

Performance Characteristics. Another benefit of interoperability testing is that performance measures—such as reliability, availability, and error and delay characteristics—can be estimated. Although interoperability tests usually are conducted in under a week—compared to the multi-year operating life of a typical configuration—extrapolating the performance characteristics can be done within statistical bounds of confidence. Such estimates have proved useful in customer decisions to purchase a system.

Planning for Interoperability Tests. Interoperability tests are major undertakings for all parties, whether they are different vendors or different business units in a large corporation. The cooperating parties in a multivendor test act in good faith as customer surrogates.

A test plan is developed prior to executing the tests. In contrast to the test plan applicable to conformance testing a particular interface, interoperability test plans are specific to the application being tested, and are driven by the customer environments in which the application will be used. The interoperability test plan documents detailed information on the systems making up the configuration—e.g., model number, version, and release information—as well as all details associated with the configuration. For example, details of setting up the configuration—including wiring and cabling—must be understood and recorded. The sequence of steps necessary to execute the tests should be optimized and the results recorded. The Chinese Postman Algorithm described earlier is one approach to optimizing the sequence of steps.

If modifications are needed to achieve interoperability, the question of which party should make them is potentially difficult, because any incompatibility can usually be solved in more than one way. The choice of the least expensive alternative usually is a good guide, though a determination of which available choice qualifies as the least expensive is not easy. In practice, however, such a determination has not been a stumbling block.

Interoperability Testing: An Example. Configurations of AT&T's Definity® communications system and the 5ESS®—switch, where the communications link between any two pairs of switches was the ISDN primary rate interface—recently were tested for interoperability. The number of potential end-to-end scenarios was very large. The reasons included:

- The variety of terminal adapters these systems accommodate
- The data communications options available in each terminal adapter—e.g., digital multiplexed interface (DMI) Modes 0, 1, 2, and 3
- The applicable speed options in each data mode
- The differences resulting from the users' software environment.

Choices were made to narrow down the list of potential configurations that would result in the same substantive level of confidence. The number of steps to test these configurations was then optimized, in part using the Chinese Postman Algorithm.

Conclusion

Protocol testing is a key step to ensure end-to-end functionality of complex communications systems. AT&T, as both equipment manufacturer and service provider, has played a lead role in establishing conformance and interoperability testing programs, and in developing state-of-the-art protocol test tools and methodologies. Protocol testing at AT&T helps to provide the customer with the highest possible assurance of service quality and integrity.

References

1. *Ongoing Implementation Agreements for Open Systems Interconnection Protocol: Continuing Agreements*, National Institute of Standards and Technology, December 1988.
2. *U. S. Government Open Systems Interconnection Profile (GOSIP)*, Version 1.0, FIPS 146, U. S. Department of Commerce, National Bureau of Standards, August 24, 1988.
3. *U. S. Government Open Systems Interconnection Profile (GOSIP)*,

Draft Version 2.0, GOSIP Advanced Requirements Group/National Institute of Standards and Technology, April 1989.
4. "AT&T Integrated Services Digital Network (ISDN) Basic Rate Interface Specification," AT&T Technical Reference, Select Code 801-802-100, AT&T Customer Information Center, Indianapolis, Indiana, June 1988.
5. "X.25 Interface Specifications And Packet Transport Network Capabilities," AT&T Technical Reference, Publication TR 54010, AT&T Customer Information Center, Indianapolis, Indiana, May 1986.
6. *Information Processing Systems—OSI Conformance Testing Methodology and Framework*, ISO DIS 9646 Parts 1-5, ISO International Electrotechnical Commission Joint Technical Committee 1, Subcommittee 21, Workgroup 1, November 1989.
7. M. U. Uyar and A. T. Dahbura, "Optimal Test Sequence Generation for Protocols: The Chinese Postman Algorithm Applied to Q.931," *Proceedings of Globecom '86*, Houston, December 1986, pp. 3.1.1-3.1.5.
8. "Conformance Testing Methodology and Framework for Protocol Recommendations for CCITT Applications," CCITT Recommendation X.290, *Blue Book: IXth Plenary Assembly, Melbourne, Australia, 14-25 November 1988*, Vol. XIII, Fascicle VIII.5, International Telecommunications Union, Geneva, Switzerland, 1989.
9. "Message Handling Systems–Conformance Testing," CCITT Study Group VII Recommendation X.403, IXth Plenary Assembly, Melbourne, Australia, 14-25 November 1988.
10. *Conformance Testing Specification Manual for IPMS (P2)*, CCITT Study Group VII, IXth Plenary Assembly, Melbourne, Australia, 14-25 November 1988.
11. *Conformance Testing Specification Manual for MTS (P1)*, CCITT IXth Plenary Assembly, Melbourne, Australia, 14-25 November 1988.
12. *Conformance Testing Specification Manual for RTS*, CCITT IXth Plenary Assembly, Melbourne, Australia, 14-25 November 1988.
13. "CCITT Recommendation Q780, Signalling System No. 7 Test Specification General Description," *Blue Book: IXth Plenary Assembly, Melbourne, Australia, 14-25 November 1988*, Vol. VI, Fascicle VI.9, International Telecommunications Union, Geneva, Switzerland, 1989.
14. "CCITT Recommendation Q781, MTP Level 2 Test Specification," *Blue Book: IXth Plenary Assembly, Melbourne, Australia, 14-25 November 1988*, Vol. VI, Fascicle VI.9, International Telecommunications Union, Geneva, Switzerland, 1989.
15. "CCITT Recommendation Q782, MTP Level 3 Test Specification," *Blue Book: IXth Plenary Assembly, Melbourne, Australia, 14-25 November 1988*, Vol. VI, Fascicle VI.9, International Telecommunications Union, Geneva, Switzerland, 1989.
16. "CCITT Recommendation Q783, TUP Test Specification," *Blue Book: IXth Plenary Assembly, Melbourne, Australia, 14-25 November 1988*, Vol. VI, Fascicle VI.9, International Telecommunications Union, Geneva, Switzerland, 1989.

Biographies (continued)

M.S.E.E. and Ph.D. degrees from Clarkson University, in Potsdam, New York. Mr. Tewani is a member of technical staff in the Standards Planning Department, where he is participates in developing conformance testing standards in CCITT and ISO. He has a B.E. in electronics and communications engineering from Osmania University, India; an M.Tech. in electrical engineering from the Indian Institute of Technology, Kanpur; and an M.S. in computer science from The Johns Hopkins University, Baltimore, Maryland. He joined AT&T in 1985. Mr. Verma is supervisor of the Platform Interfaces Group at the Middletown, New Jersey facility. His responsibilities include AT&T cross-product and multivendor interoperability testing for complex configurations. He received his B. Eng. degree from the Indian Institute of Science, Bangalore, India, a doctorate in electrical engineering from Concordia University in Montreal, and an M.B.A. from The Wharton School of the University of Pennsylvania. He joined AT&T in 1978.

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