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A Brief Assessment of Engineering Issues Related to Trial Testing for IP Transition

January 13, 2014

Prepared for Public Knowledge by CTC Technology & Energy

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1. Introduction

This report considers, from an engineering standpoint, some of the tests necessary to determine the likely impact of transitioning the telephone service delivered by particular wire centers from circuit-switched analog technology to packet-switched Internet Protocol (IP) technology—what FCC Chairman Tom Wheeler has called the "Fourth Network Revolution."[1]

Specifically, this report identifies the core technical features of the public switched telephone network (PSTN); enumerates some of the IP network attributes that require testing; and identifies some of the parties that should be involved in any testing regime. This analysis was prepared by the engineers of CTC Technology & Energy to provide a starting point for planning tests. In other words, the elements we recommend here are, in our judgment, a floor for adequate trials—not a ceiling or an exhaustive list of considerations.

The basic core functionality of the PSTN holds critical importance to American citizens, businesses, and institutions. As a result, the transition to IP technology—which is an upgrade to the PSTN, not a replacement—requires verification that the new IP environment delivers the same capabilities, reliability, and other critical aspects of the old technologies upon which Americans have long relied.

New IP technologies offer myriad benefits but IP technology has never had to replace the core functionality of the circuit-switched network. Regardless of individual consumer choices to purchase IP service, the circuit-switched network has remained an option for all Americans.

Given that IP technologies will become the nation's primary telephone wire center technology as a result of this transition, these technologies must demonstrably meet the threshold of capabilities delivered by circuit-switched wire centers in order for Americans to rely on the new system for the core functionalities upon which they have always relied.

As Chairman Wheeler has said in regard to the transition, "The way forward is to encourage technological change while preserving the attributes of network services that customers have come to expect – that set of values we have begun to call the Network Compact."[2]

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[1] Tom Wheeler, "The IP Transition: Starting Now," Official FCC Blog, November 19, 2013. http://www.fcc.gov/blog/ip-transition-starting-now

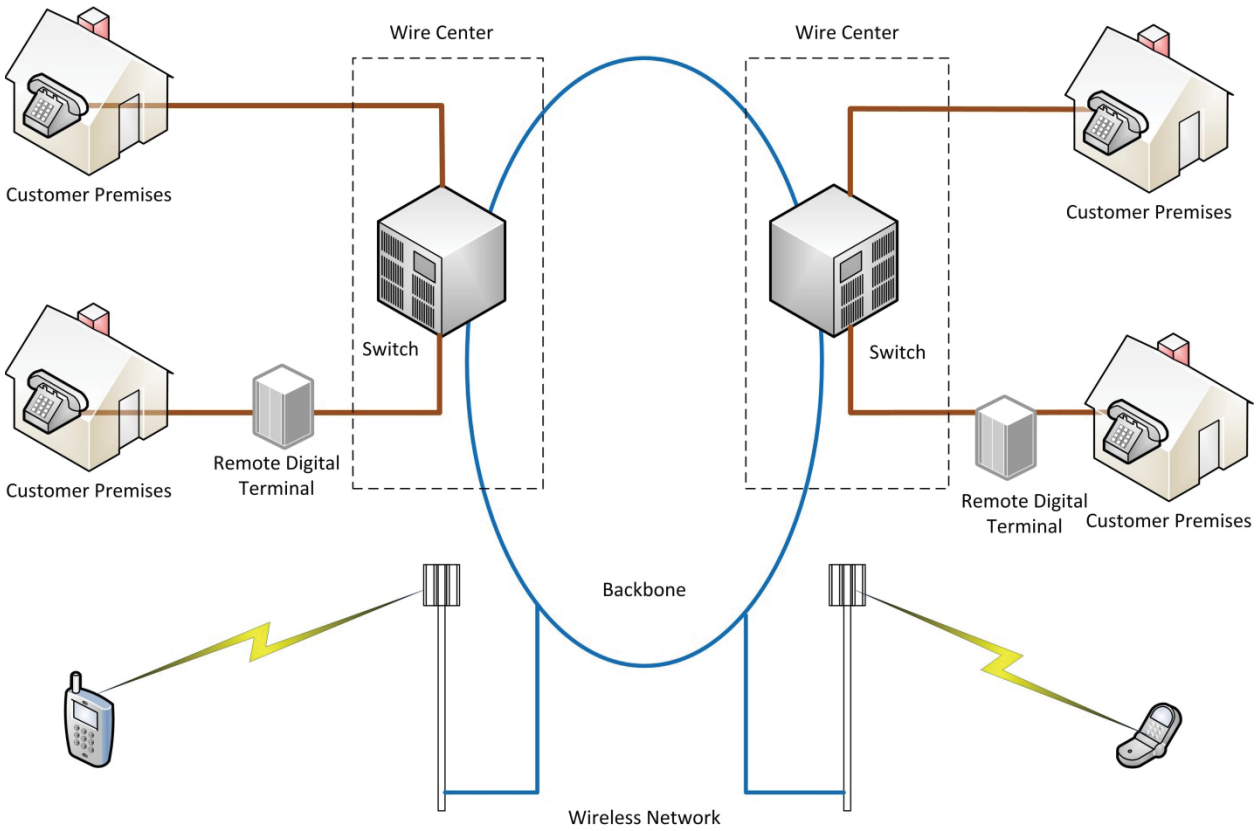
[2] Ibid.

2. Selected Core Features of the Public Switched Telephone Network and IP Networks

The public switched telephone network (PSTN) provides a reliable voice connection to almost all Americans. Subscribers hear a dial tone virtually every time they pick up their phone, and their calls—including to 9-1-1 during emergencies—are completed almost every time.

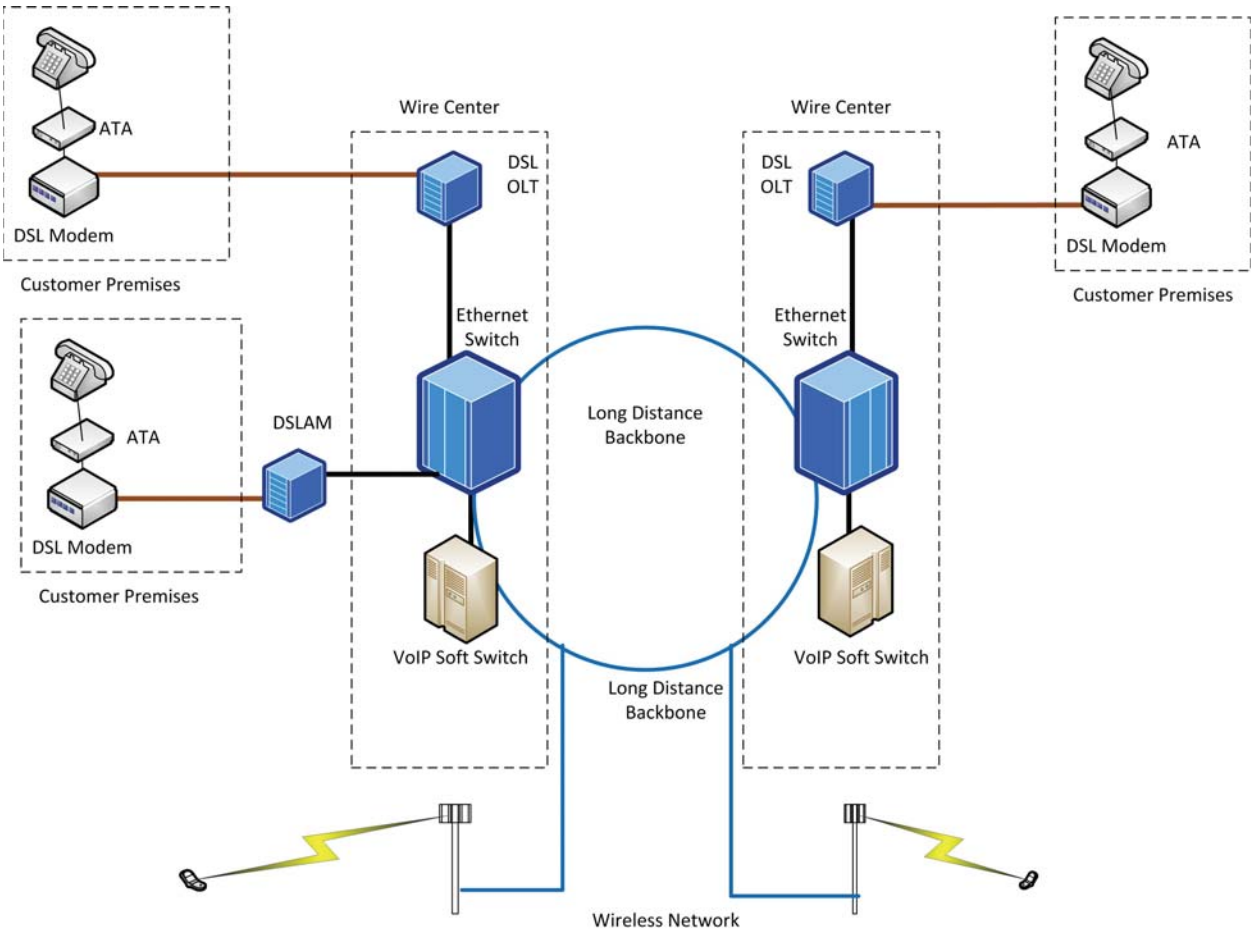
The current PSTN has a set number of lines in and out of each wire center. Some lines have a dedicated switch port at the central office and others are terminated at a remote digital terminal (RDT) (Figure 1). The switch provides the dial tone signal. The current PSTN has trunk circuits to the long distance and backbone networks. The phone company sizes its trunk circuits to provide sufficient lines for normal peak conditions. Although the network has physical limits and will eventually give a customer a busy signal or non-completion message if overloaded, the network works in a predictable way up to known limits.

Figure 1 – Typical Telephone Network



In contrast, in an IP environment, calls are converted to IP data packets at the user premises by an IP analog telephone adapter (ATA). The packets are transported over a DSL, cable modem, wireless, or fiber connection to the wire center, where they are aggregated by a high-speed Ethernet switch. VoIP call servers or "soft switches" (the IP equivalent of traditional telephone switches) connected to the Ethernet IP network set up connections between phones by communicating both with the ATAs placing and receiving the call and the switches and routers creating the connection through the IP network (Figure 2). The call quality, call completion, and other performance parameters depend on the ATA, the type of compression/encoding algorithm, the VoIP servers, the IP network, the Ethernet switches, and the multiple interfaces between them. Call quality can potentially vary greatly from provider to provider and from installation to installation. Additionally, call completion depends on mapping of the phone numbers to addresses in the IP network.

Figure 2 – Telephone in an IP Environment



3. IP Network Attributes that Require Testing

An effective testing regime will prioritize key attributes of circuit-switched wire centers, and will demonstrate that IP-based technologies can deliver comparable functionality and reliability across an appropriate range of scenarios and environments.

It is impossible to generalize about how any one sector or community is currently using traditional telephone services, or how a sector will be able to make the transition. In other words, we cannot understand the impact in a generalized way. Part of the reason for testing, then, is that the process will identify variations between communities. Robust testing will determine the real-life impact of IP migration and how much variation there is likely to be from community to community.

Testing regime must explore these 10 key network attributes:

1. Network capacity
2. Call quality
3. Device interoperability
4. Service for the deaf and disabled
5. System availability
6. PSAP and 9-1-1
7. Cybersecurity
8. Call persistence
9. Call functionality
10. Wireline coverage

In this section, we propose 10 attributes of IP telephone service delivery that should be tested—starting in a lab setting and progressing to a wire center environment and to field tests.

As a starting point, we believe that the FCC should conduct an architecture review—an examination of the current nationwide implementation by voice providers of "plain old telephone service" (POTS), IP-transitioned telephony, and transition stages between the two. The architecture review is critical for determining the number of central offices, phone lines, and other systems that should be tested, and verifying the estimates in this report. The review would ascertain the current state of the voice network—how many customers have POTS, how many phone companies and wire centers provide it, if and where communications services have already transitioned to digital and IP format in backbone network segments, and how many have been transitioned to an IP access technology (e.g., VoIP over DSL, Verizon Voice Link). The review would examine the extent to which calls are already converted to IP at the wire center or tandem switch; the use of IP "soft switches" (also known as Session Initiation Protocol (SIP) switches) versus traditional time division multiplexing (TDM) switches; and the use of IP network connections versus TDM connections.

This architecture review is also essential because much of the IP conversion in the backbone has already happened. Many voice calls may be in IP or other digital format in the backbone or elsewhere. It is necessary to understand what is being proposed relative to the current environment, and to what extent risk will increase.

3.1 Network Capacity Stress Test

Stress testing of the access network (i.e., the portion of the network that connects from the home or business back to the wire center or central office), switching, aggregation system, and connections between wire centers should be performed to quantify available network capacity and analyze the behavior of the system when it is heavily used.

These tests should identify the system's real-world "breaking point." To that end, testing must simulate worst-case traffic through all significant system components to determine the limits of those components. The traffic types and other environmental conditions should be as close to a real-life wire center service area as possible. And the results of these tests should be comparable to the standards of the PSTN in its current state. (We recommend that the stress test not be performed on a live production network; it should instead be conducted on a VoIP and IP network that is under test, before voice lines are connected, to avoid disruption to customer telephone services.)

These tests should demonstrate that the components of an IP-transitioned telephone network will work reliably even when large numbers of calls take place simultaneously, and when large numbers of calls are made in and out of the wire center. This means that:

1) Calls are routed to the correct location
2) Calls are completed
3) Call quality does not deteriorate under stress
4) Call setup does not exhibit noticeable latency

The level of stress on the network may affect the quality and reliability of the phone system, because large numbers of packets and many simultaneous requests for a call may overburden many different parts of the system. Because the IP system is complex, the problems may not be predictable. Therefore live testing is necessary in several diverse wire centers representing a wide range of environments.

Specifically, network capacity stress tests should follow certain minimum requirements:

1) Testing should be conducted at a minimum of 100 separate wire centers across the U.S. (together representing approximately 1 percent of the phone lines in the U.S.). Wire

centers under test should collectively represent urban and rural environments, large and small service areas, a range of telephone companies, and the range of equipment types and configurations that the telephone company plans to use. *If the architecture review (Section 3) indicates that the telephone system is so diverse that 1 percent cannot represent the range of environments in a statistically viable way, then a larger number should be tested.*

At each wire center, the testing should generate simulated simultaneous traffic from at least 25 percent of the lines in the wire center,[3] in advance of a cutover to IP service in the wire center area. Test traffic calls should be placed to lines internally within the wire center area; from the wire center area to several other wire centers, cellular carriers, and other carriers; and from external wire centers back to the lines in the wire center.

2) Testing should be performed while the underlying DSL, Ethernet, wireless, or fiber data network is fully utilized.

3) Testing should include the failover to alternate paths between wire centers, to verify that calls are not affected when primary routes between wire centers fail.

Carriers and enterprises commonly conduct stress tests before accepting a new network or an upgrade, so there are many established technical approaches and platforms for stress testing of IP networks, and VoIP in particular. Numerical measurements can include loss or delay of voice packets or jitter in the voice calls, call setup time, and call answer delay.[4]

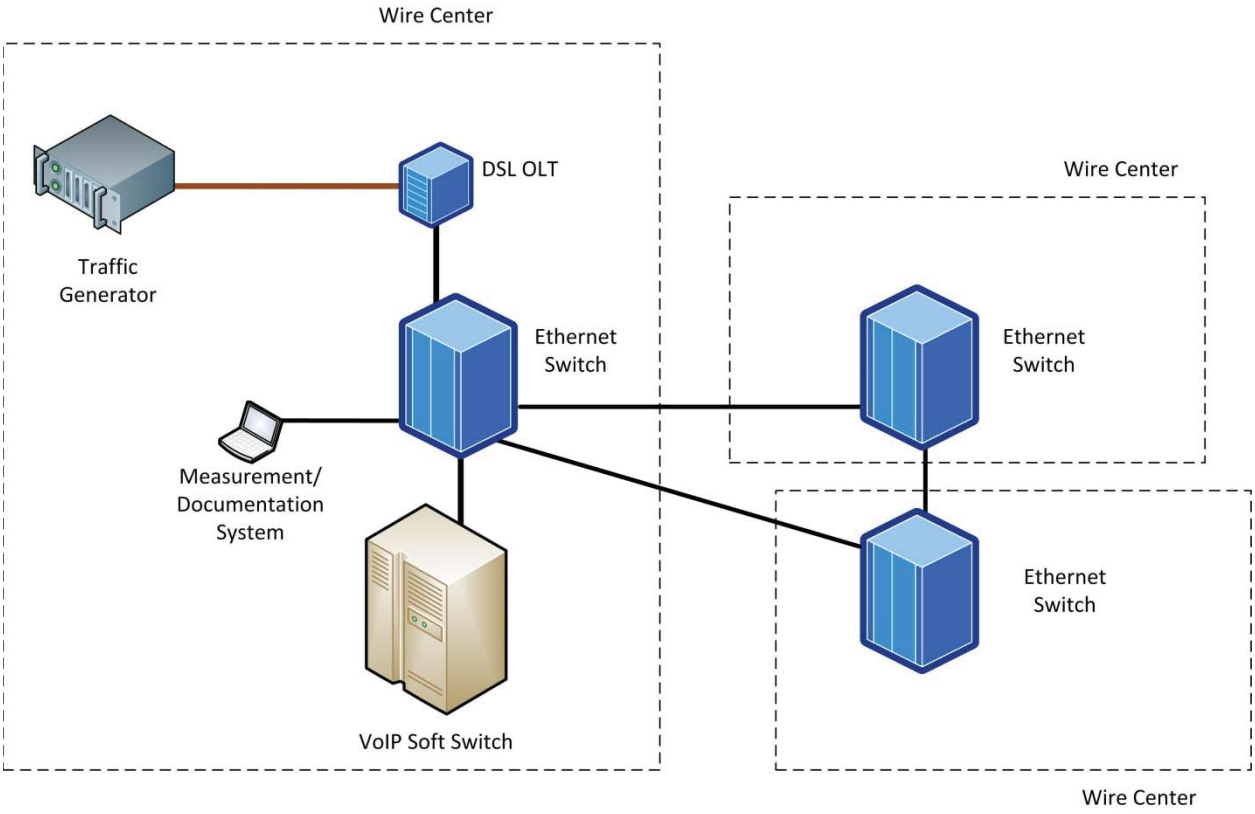
In contrast to the other tests recommended here, we do not recommend that the stress testing called for in this section be conducted from customer premises; that would be logistically complex for so many simultaneous calls. Rather, because this test is less dependent on the line to the customer premises, we recommend that calls be placed at the aggregation points entering the network—such as the DSL optical line terminal (OLT) at the wire center or the remote DSL access module (DSLAM). The calls can be simulated by test equipment specifically designed for this purpose; this equipment can generate large numbers of VoIP calls and large

[3] Remote terminals often serve 96 lines out of a T1 trunk with 24 wire center ports, so 4:1 is a common aggregation ratio in a phone network.

[4] See, for example, the IP voice stress test technology in the enterprise environment described in "Performance and Stress Testing of SIP Servers, Clients and IP Networks," StarTrinity. http://startrinity.com/VoIP/TestingSipPbxSoftswitchServer.aspx#tests, accessed December 7, 2013.

amounts of data traffic through an Ethernet port on the OLT or DSLAM, and can place calls to test equipment at the remote end, which simulates the phones receiving the calls (Figure 3).

Figure 3 – Stress Test Configuration



3.2 Call Quality

Testing the quality of calls relative to standards applicable to current POTS calls will require both quantitative and qualitative measurements. While quantitative scores are necessary for any rigorous analysis, many aspects of call quality are best measured by a human test, so the qualitative score (as assessed by a test team) will be a check on the quantitative methodology.

Qualitative criteria should include a Delivered Audio Quality (DAQ)[5] score. A suitable passing minimum score should be selected, such as 4.5 out of 5, corresponding to clear speech with

[5] Delivered Audio Quality (DAQ) is defined in TSB-88, a Telecommunications Industry Association standard for wireless systems performance. *See:* "A REPORT ON TECHNOLOGY INDEPENDENT METHODOLOGY FOR THE

only infrequent noise or distortion. A standard practice in land-mobile radio testing, which would also be applicable here, is for an odd number of individuals to evaluate the quality, with the majority determining whether the call passes or fails.[6]

Quantitative tests should measure frequency response, signal levels, distortion, and other criteria—which will be selected so that any audible problem or weakness in quality will be a failing score.

Testing must also verify that a range of standard modem types will work with access connections loaded to their full capacity. This will verify the line quality and also determine the ability of diverse non-voice devices to continue using the network (see Section 3.3.2 for more details).

Tests should be performed in two ways: Using test equipment connected to the analog telephone adapter (ATA) that dials the test equipment at the remote end (Figure 4**Error! Reference source not found.**), and with individual testers dialing a team member at the remote end (Figure 5). Other tests proposed here (e.g., device interoperability, 9-1-1, TTY/TDD) can be performed in series with this test, during the same visit, to minimize the time and customer service impact.

MODELING, SIMULATION AND EMPIRICAL VERIFICATION OF WIRELESS COMMUNICATIONS SYSTEM PERFORMANCE IN NOISE AND INTERFERENCE LIMITED SYSTEMS OPERATING ON FREQUENCIES BETWEEN 30 AND 1500 MHz," Table 1 at 80. TIA, May 20, 1997. http://www.antd.nist.gov/wctg/manet/docs/TIAWG88_20.pdf, accessed December 6, 2013.

[6] One approach can include three individuals—one from the phone company, an independent technical person and an independent layperson—a similar acceptance test approach is recommended in Jacobsmeyer, J., and Reardon, K., "Acceptance Testing in Land Mobile Radio Systems," presented at International Wireless Communications Expo 2010, http://www.pericle.com/papers/W07_ATP_for_LMR%20Slides_V2.pdf, and by Teddy Kavaleri, Chief Information Officer, District of Columbia Office of Unified Communications (discussion, December 4, 2013).

Figure 4 – Field Test from Test Transmitter at Customer Premises

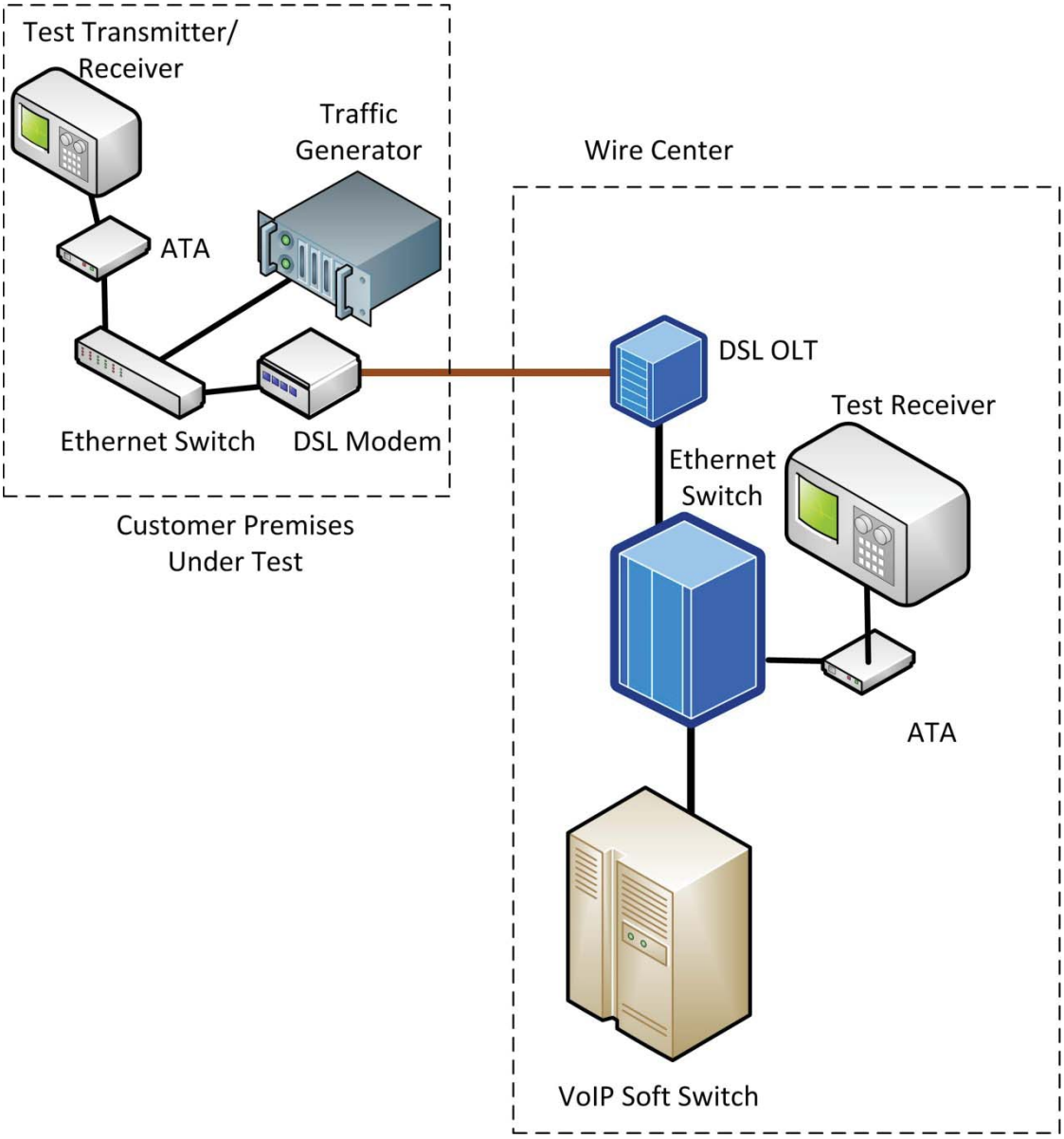
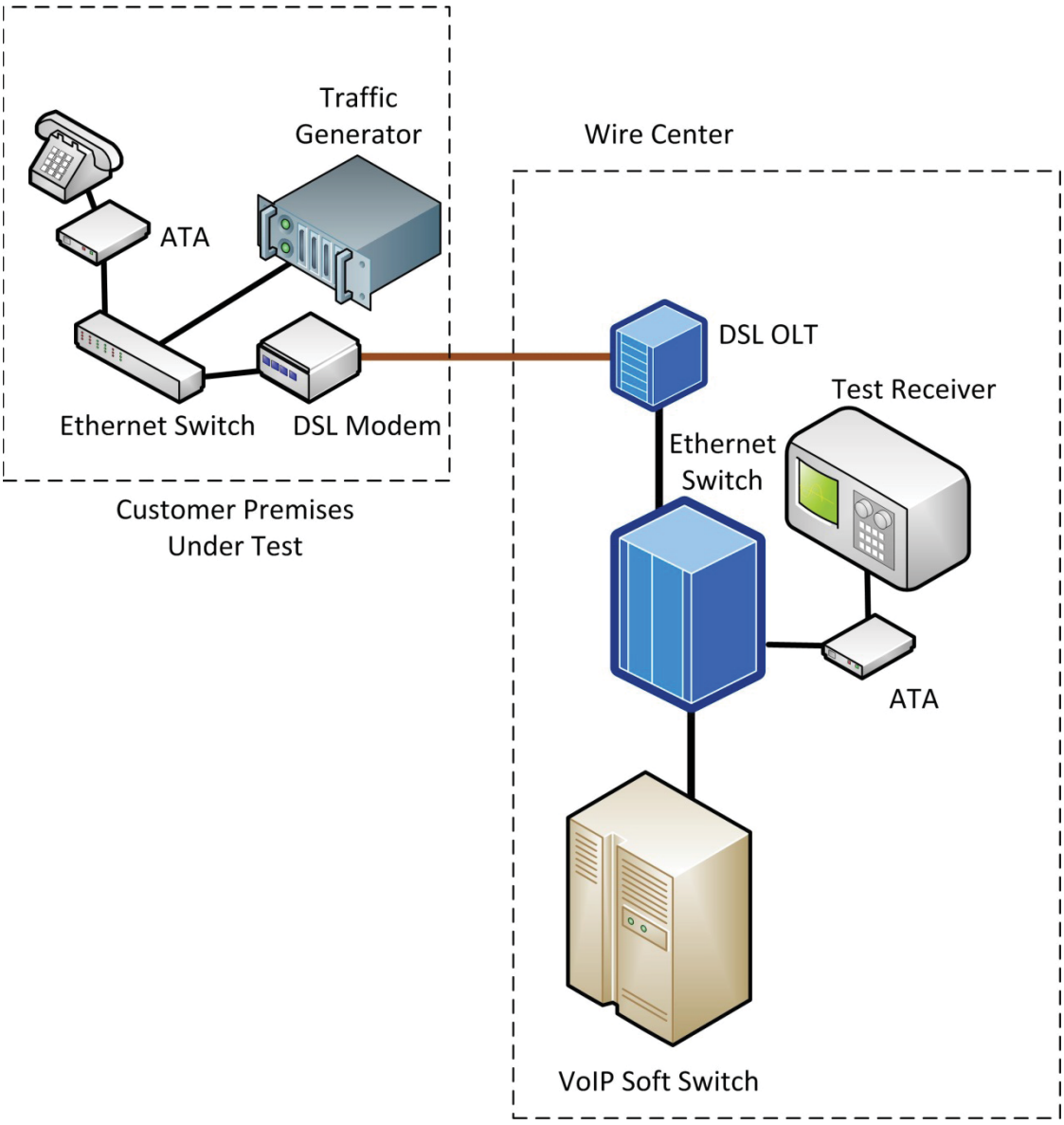


Figure 5 – Field Test from Telephone at Customer Premises



Both quantitative and qualitative tests may fail for a range of reasons. The phone company should be required to determine the root cause of the problem (e.g., ATA, copper line, DSL network, wireless network) and the means of correcting the problem. If there are systematic problems (e.g., failures in all long lines, failures in using particular types of network equipment, failures using particular types of phones or modems), these must be understood and addressed, and noted as important outcomes of the test.

Finally, the test practices and criteria should be leveraged as ongoing standards for system performance. They should be used in regular proof-of-performance tests, and as standards for

customer satisfaction—such as for determining when to send a service technician, and when to provide credits or refunds to a customer. Cable TV performance standards provide an example of commonly accepted minimum technical standards for initial and ongoing testing, and criteria under which a regulatory authority can force the operator to act.[7]

Large-scale technology transitions such as the IP transition have, as a matter of course, significant acceptance testing involving many lines and user addresses. During the E-911 upgrade of the 9-1-1 system, for example, some states required testing of 40 percent of the lines.[8] The acceptance testing of the Washington, D.C. public safety radio network upgrade, serving only a 70-square-mile area, required the work of 60 individuals over a two-week period.[9] And in the 1990s, AT&T's testing and implementation of its TrueVoice upgrade of the long distance voice system, which sought to improve call quality by boosting the levels of certain voice frequencies, required three years.[10]

Before any national implementation of the IP transition, there should be testing at a large enough number of wire center service areas to obtain a representative sample of the national network. As with the network capacity stress tests, the call quality tests should be performed in the test ensemble of at least 100 wire centers.

In each wire center, at least 10 percent of lines should be tested—and the lines should be representative of all geographic areas in the wire center service area, all types of customer (residential, business), overhead and underground service, and single dwelling and multi-dwelling units. At least one-third of the tests should have loop length in the top 25 percent of the loop lengths in that service area (as measured from the beginning of the copper loop from the DSLAM or wire center) in order to take into account the most challenging lines.[11] Tests should be performed with calls originating and terminating within the wire center, as well as with calls originating from one wire center and terminating in another.

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[7] Code of Federal Regulations, Title 47 Subpart K, 76.601 and 76.605, http://www.gpo.gov/fdsys/pkg/CFR-2010-title47-vol4/pdf/CFR-2010-title47-vol4-sec76-601.pdf, accessed December 9, 2013.

[8] Illinois Administrative Code, PART 725 STANDARDS OF SERVICE APPLICABLE TO 9-1-1 EMERGENCY SYSTEMS SECTION 725.500 TESTING PROCEDURES, http://www.ilga.gov/commission/jcar/admincode/083/083007250E05000R.html, accessed December 5, 2013.

[9] Discussion with Teddy Kavaleri, December 4, 2013.

[10] Discussions with David Isenberg and Chuck Gritton, members of the AT&T TrueVoice team, on November 26, 2013, and an article by Waring, Christine, *AT&T Bell Labs News*, August 2, 1993, accessed at http://repo-nt.tcc.virginia.edu/classes/tcc315/resources/alm/telephone/truevoice.html, 2013.

[11] This is comparable to the requirement in the cable TV proof of performance tests that one-third of cable test points be in the extremities of the cable system.

Testing 10 percent of the lines, if a representative sample is chosen, will create an acceptably sized database to understand the performance of the system, highlight trends, and identify the transitioned network's strengths and weaknesses. This level of testing will reliably identify problems in the hardware and software, call routing, installation, line quality, training, and maintenance.

3.3 Device Interoperability

Testing should verify that voice and non-voice equipment that works on the current PSTN will work consistently on an IP-transitioned phone line—and, in the process, should identify types of devices that do not work in all circumstances on an IP-transitioned phone line, or that work only in a limited way.

3.3.1 Voice Devices

Analog telephone adapter (ATA) terminal equipment should be tested to determine its ability to work with telephones designed to provide voice service and interface through a standard RJ-11 jack. Testing should include all proposed ATAs and should include verifying the ringer equivalence number (REN), which determines the maximum number of phones of various types that can be connected to the ATA. Testing should also include the ATA device's ability to transport Dual-Tone Multi-Frequency (DTMF) tones, both in-band (to dial a number) and out of band (to dial within a phone tree or to dial an extension).

Tests should be performed in the lab or in a test wire center. Any phone should have similar characteristics, but testing should include phones representative of the full range of typical consumer voice devices, such as a high-REN and a low-REN device, and a corded and a cordless phone.

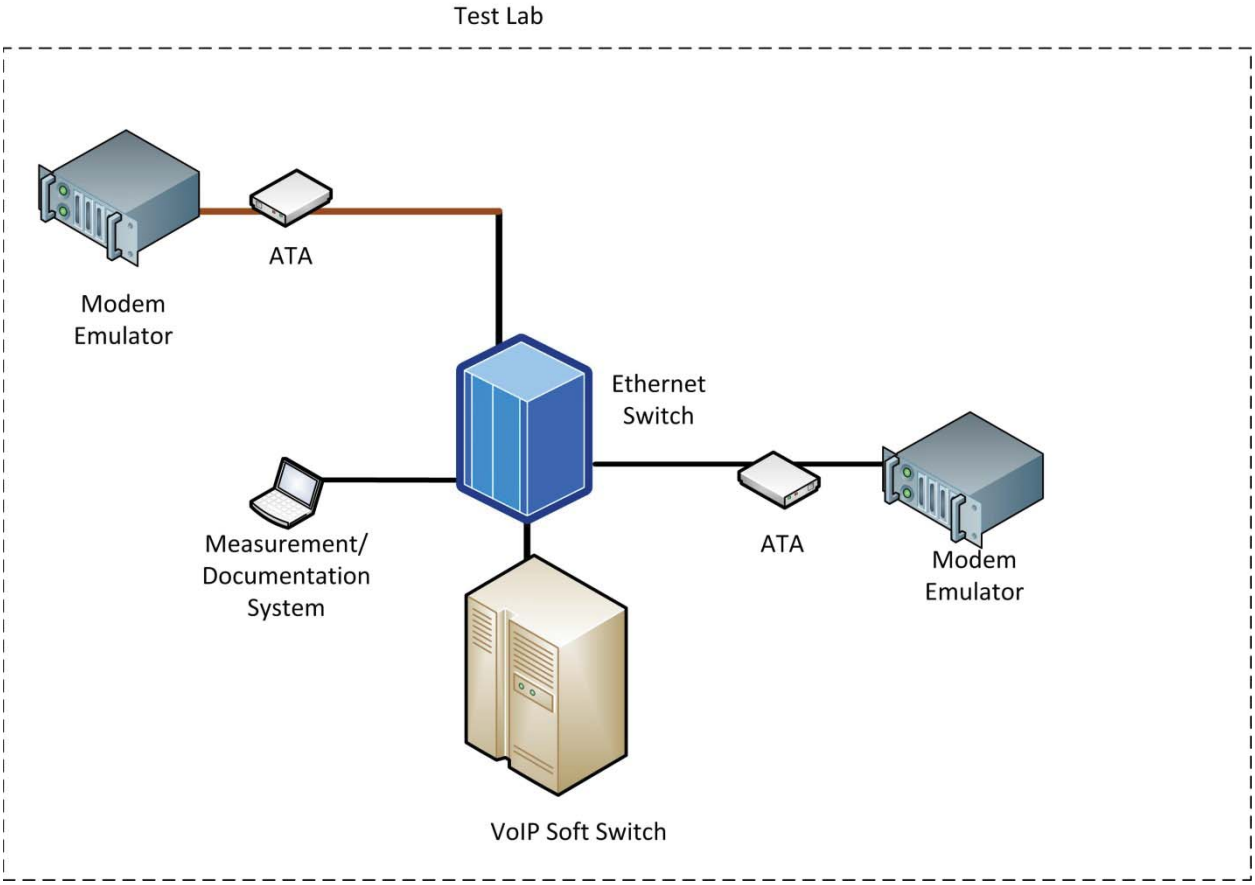
3.3.2 Non-Voice Devices

A rich variety of non-telephone devices successfully use the telephone network and have become important parts of our infrastructure. These include fax machines, credit card/point-of-sale terminals, ATMs, voting machines, medical monitoring or alert systems, burglar alarms, elevator phones, ringdown lines at fire stations, and intercoms for building access.

Despite this diversity, the majority of non-voice devices conform to a standard modem technology, such as v.32, v. 34, v.42bis, v.44, v.90, and v.92. Even where a truly proprietary device is used, the signaling and communications protocol is similar enough to a standard modem that a test of a range of standards should be close enough to determine whether many devices will work on an IP-transitioned line.

These tests should first be performed in a lab setting, to determine what types of devices (if any) are excluded by the ATAs or another part of the IP-transitioned system. The tests should be performed with the full range of standard modem protocols, and under a range of simulated operating environments (Figure 6). For example, if the ATA switches to a different type of CODEC (i.e., hardware or software in the ATA that converts the voice to a digital signal) or operating mode under conditions of congestion or low bandwidth, then the ideal and the congested/low-bandwidth modes should all be tested.

Figure 6 – Interoperability Test Setup



Systematic problems should be noted, and test results should include a checklist of modem protocols, the degree of compliance, and the performance in the range of operating modes.

This testing is necessary because the history of technological transitions and the history of phone communications include many examples of users being left behind or encountering unexpected problems. Users of older phones, users of phones with unusual features, and users

in poorly connected areas may be sufficiently outside the design use cases that they will experience more problems after the IP transition.

Unlike with phones, there may be non-voice devices that either 1) never work on the IP-transitioned network or 2) work under some conditions, but fail under certain circumstances (e.g., poor quality line, congestion, power failure).

The formerly ubiquitous dial-up modem and fax machines still exist in many business, governmental, and institutional settings; common recent versions are accommodated by many VoIP devices in most operational situations. However, unusual or older devices may not work. There is a range of possible reasons, including that some VoIP devices compress the telephone audio signal in a manner that prevents the receiving modem or fax machine from decoding the signal. This compression is generally optimized for voice audio signals, and does not reproduce the digitally encoded data in the modulated audio signal from a modem or fax machine. Technology complying with the ITU T.38 standard can mitigate this issue by allowing the VoIP ATA to decode or "read" the fax or modem signal, transmit the contents to the VoIP device at the far end as IP packets, and re-encode it for the fax or modem at the receiving location.

In circumstances where a CODEC that does not compress the audio is used, the VoIP device accurately carries the fax or modem signal, and the system appears to work perfectly even without specialized fax and modem support. However, in unusual situations such as network congestion or during a "reboot" of the network following a power failure or outage, the device may revert to a low-bandwidth mode with a different CODEC. In this circumstance, the VoIP system may again cause the modem to fail. It is this "unusual" situation that can be the most dangerous—because it could cause a critical device such as a burglar alarm or a medical alert device to fail, potentially at the same time as a major power disruption or other problem.

This is one reason that some providers of IP voice services, such as Cablevision, recommend that alarm devices not be used on their networks, even though they may appear to work properly. Cablevision states, "Cablevision does not guarantee that Optimum Voice will function as the connection between home security or emergency medical alert systems and central monitoring services, and will neither connect to such services nor provide technical support for the connection."[12] Vonage and Comcast both state that their services are not compatible with

[12] "Optimum Voice: Emergency Medical Alert Systems (ID 733)," Cablevision Optimum website, http://optimum.custhelp.com/app/answers/detail/a_id/733, accessed December 6, 2013.

all alarm systems, and recommend consulting first with the alarm company to verify compatibility.[13]

Device and protocol compatibility are a significant part of any technology transition. Extensive effort is needed to identify "marginal" uses of the phone network, and these uses also need to be included in the test. As an example, during its TrueVoice implementation, AT&T worked to identify and test the technology of diverse users, including banks, institutions, and people with disabilities. As part of the process, AT&T also replaced terminal equipment used by the AP and UPI wire agencies with equipment that was compatible with TrueVoice.[14] Through this process, AT&T was able to test the equipment in a range of environments, including over longer, low-quality lines. The testing was an important means of identifying user equipment that did not work and equipment that failed under certain ranges of conditions, as well as equipment that could be relied upon to work.

3.4 Service to the Deaf and Other Support for People with Disabilities

Tests must be performed to determine how IP migration will affect the full range of devices and services that accommodate people with disabilities in using the phone network. These include Text Telephones (TTY), Telecommunications Devices for the Deaf (TDD), and "711" Telecommunications Relay Services (TRS).

The TTY/TDD system is a telemetry-based system that enables deaf and hard-of-hearing individuals to communicate via text over the phone network. The system consists of a text terminal connected to a modem, which communicates with a similar device at the other end. The system is centered around the ITU V.18 set of standards, which incorporate a range of modem technologies.[15]

The TRS system uses a text-based system to enable a deaf individual to type a message to an operator. The operator then calls the intended recipient of the message and verbally conveys the message.

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[13] Vonage website, https://support.vonage.com/app/answers/detail/a_id/1075/kw/alarm%20system, accessed December 6, 2013; Comcast website, http://customer.comcast.com/help-and-support/phone/home-alarm-systems-phone/, accessed December 6, 2013.
[14] Discussion with David Isenberg, former AT&T engineer and TrueVoice team member, November 26, 2013.
[15] V.18 operational and interworking requirements for DCEs operating in the text telephone mode, International Telecommunications Union, http://www.itu.int/rec/T-REC-V.18-200011-I/en, accessed December 6, 2013.

Both of these technologies are well established and an important part of the lives of many deaf individuals. New technologies and applications offer similar functionality, often through a smart phone or computer, but many of those depend on the availability of a minimum quality of wireless service, which may not be available in all areas and may not be affordable to all users.

A transition to IP technology may reduce the reliability of the TTY/TDD service, because the service uses analog telephone modem technology (which, as discussed in Section 3.3.2, may be affected by the conversion to IP). The technology may become less reliable under conditions of stress or saturation of the IP network. Because the TTY/TDD system, combined with an IP conversion, is complex, the areas of potential failure need to be examined.

To the extent that the network may diminish the reliability of the system, it may compromise one of the means that many people have to communicate, with particular burden placed on individuals who for financial or other reasons have not adopted newly emerging technologies for the deaf.

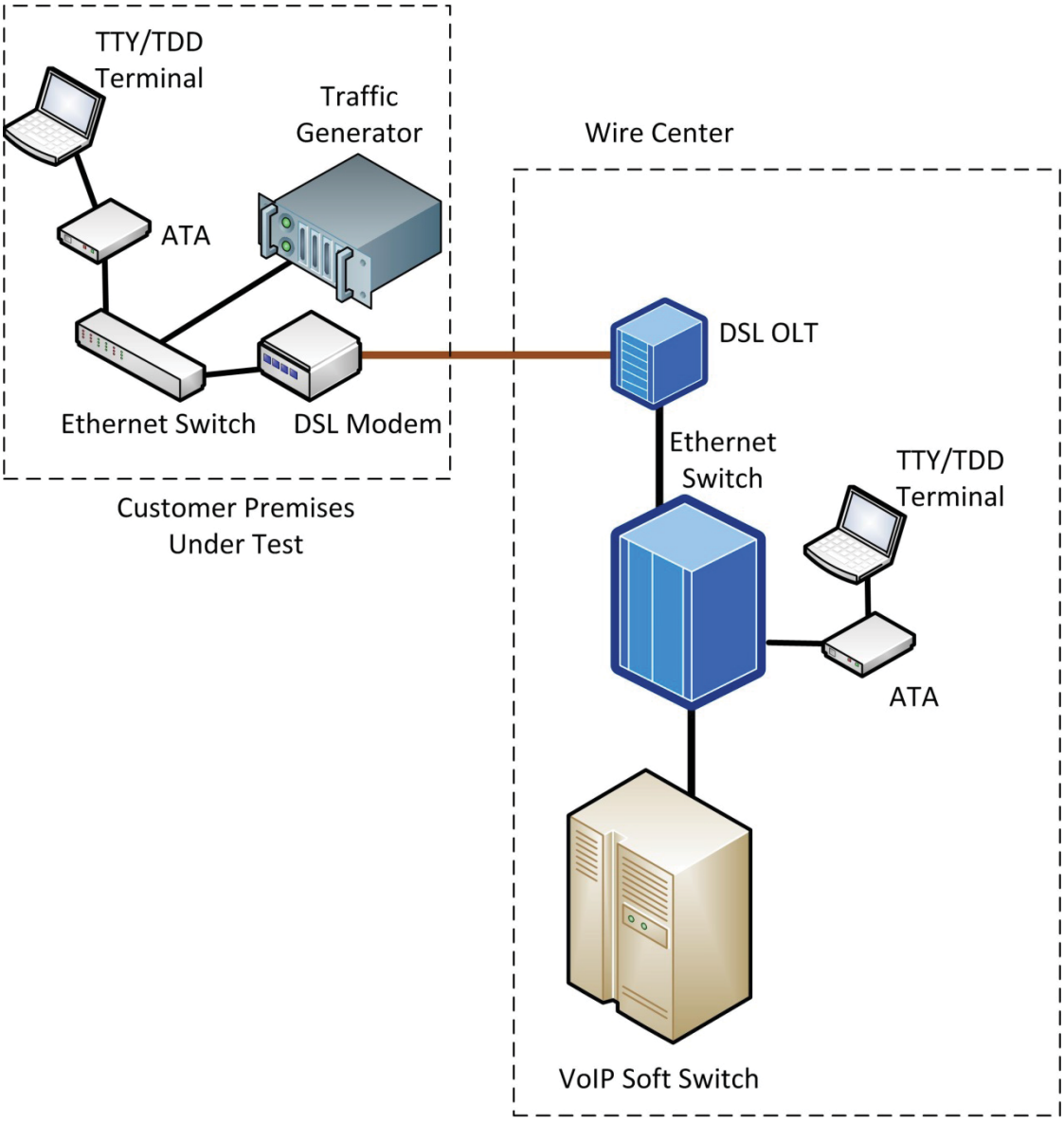
3.4.1 TTY/TDD

TTY/TDD testing should use all ATA devices under consideration, and a range of TTY/TDD devices representing the majority of devices in use (not necessarily the ones currently for sale). As with the non-voice testing in Section 3.3.2, testing should include ATA devices operating in all possible CODECs and operational modes, during a system reboot, and other possible situations. It should occur when the underlying data network is saturated, and should determine the levels of latency, jitter, and packet loss that can be tolerated by the system. Testing should include the ability to connect, place calls, deliver a message, as well as to receive a message.

As with the voice calls, there should be qualitative as well as quantitative tests, with deaf test team members evaluating the quality of the overall experience.

Testing of the TTY/TDD hardware should first be performed in a lab setting. Once it is determined which areas pose the greatest challenges, elements of the tests should be included in the wire center tests in Section 3.1. This will likely mean ensuring that the modem protocols used by the TTY/TDD hardware are tested as part of the non-voice tests performed at the 10 percent of customer locations.

Figure 7 – TTY/TDD Test Setup



3.4.2 TRS

Testing of the Telecommunications Relay Services (TRS) system should include deaf test team members, the system hardware, and the companies (including the operators) that provide the service.

As with the TTY/TDD systems, there should be extensive lab testing that, in addition to verifying the performance of the physical system under the full range of configurations, should also verify that operators receive messages accurately and reliably, and are able to call and relay the messages. To the extent that any problems are observed by operators or the TRS providers

during the lab testing, it may be necessary to include a call to the TRS as part of the procedure during the field tests.

3.4.3 Other Communications Systems

To adequately test other devices used by individuals with disabilities, such as wireless peripherals for paraplegic or mobility-impaired individuals, communications providers should be required to reach out to organizations representing these individuals (e.g., disabled veterans, AARP) as well as industry groups developing and manufacturing assistive technologies. The goals of this outreach should be to identify use cases that use the phone network, and to ensure either that assistive technologies can migrate to the IP-transitioned network or that individuals who need these devices can have the telephone company replace them with another technology that suits their needs.

3.5 System Availability

A system availability test should be conducted to ensure that an IP-transitioned telephone network maintains the level of availability that has been expected of the PSTN. Availability refers to the ability of the technology to be usable when needed, through a wide range of circumstances and network conditions.

Although not perfect, the current PSTN has demonstrated a high level of availability compared to other telecommunications technologies:

- It is designed to continue operating when power fails, even if it fails for an extended period.
- It is designed with sufficient capacity to provide dial tone and connectivity even when demand for the network is at its peak.
- It is designed so that callers can count on reaching or being reached by any other connected caller, even if that caller is distant or in an isolated part of the network.

The telephone industry is one of the best known instances of using “nines” to illustrate the percentage of time that a service is available, and the end-to-end network availability objective

for the telephone local loop is more three nines—meaning more than 99.9 percent availability, or less than nine hours per year of unavailability.[16]

In order to measure the actual availability of an IP-transitioned phone service, it is necessary to observe a sufficiently large and representative sample of phone customers to measure the availability of the service. Moreover, it is necessary to be sure that the test measures actual availability—the ability of a caller to receive a dial tone (or equivalent) and successfully complete a call with the system providing the specified level of quality and functionality.

One of the advantages of IP technology is that the status of ATA devices can be monitored by the operator in a non-intrusive way. We recommend that in the trial area of at least 100 wire centers, with hundreds of thousands of customers, all customer locations be monitored for system availability.

The operator should be required to poll the ATA devices hourly to determine status and to assess whether there is a fault condition. The operator should document all instances of the ATA device being unavailable or in a fault mode, and should document the fault.

Alternatively, if the system has another equivalent status monitoring functionality, such as an alarm mode when an ATA or DSL router experiences a fault or disappears from the network, the operator may be allowed to use that functionality.

During the trial period, the operator should be required to document the causes of all outages or faults. The operator should be required to notify the customer if a chronic problem appears to exist. If the phone is only intermittently operable, the operator should call the customer to assess whether the customer is experiencing problems and to identify a solution. If the phone is out, and the customer has not called to complain, the operator should be required to contact the customer in writing or by e-mail to assess whether the customer is experiencing problems and to identify a solution.

During the system availability test, the operator should also note any known commercial power failures, storms, Internet outages, or periods of high utilization, in order to determine how these stresses influence the network, the degree of impact they have, and how best to help the network recover.

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[16] "BOC Notes on the LEC Network," *Bellcore*, SR-TSV-002275, Issue 2, April 1994, p. 4-46, http://efile.mpsc.state.mi.us/efile/docs/13796/0442.pdf, accessed December 9, 2013.

Taken together, the documented report of hour-by-hour outages, faults, and corrective actions will be a rich resource to illustrate the capabilities and limitations of the IP-transitioned network. It will identify how many "nines" this network truly has, relative to the current network. It will identify the frequency and types of problem the new technology causes. It will create opportunities for fine-tuning the network after service has begun. It will identify potential gaps in the solution, potentially relating to power or the underlying IP network. And it will assist regulators in developing suitable approaches to protect customers.

3.6 9-1-1 and Public Safety Answering Points (PSAP)

The IP-transitioned phone network must be tested to verify that users have the same access to 9-1-1 as do users of the current public switched telephone network, and that all calls to the public safety answering point (PSAP) accurately deliver the callers' fixed locations.

The 9-1-1 system is obviously one of the most critical parts of the phone system. One of the main reasons that individuals keep a landline phone is to have a reliable 9-1-1 service in their home or business. An unreliable 9-1-1 service on wireline phones would potentially force people to depend entirely on cell phones during emergency situations. This is problematic because cell phone service is not available in isolated or very rural areas, or in areas such as basements and elevators where service is obstructed. Even ideal cell phone service only provides a position within 100 meters for an indoor 9-1-1 call where GPS signals are not available—while a properly working landline phone service will always provide an address.

Testing in the lab will identify problems that are related to the hardware and the system as a whole. Testing in the field will verify that the correct identifying information is consistently provided with each call in the correct format for the PSAP. It will also verify if any issues relating to the transport network interfere with 9-1-1, or if the qualitative sound of the system creates problems. Testing at a large number of wire center areas will confirm that a diverse set of PSAPs are tested, and that a sufficiently large ensemble of calls is tested to find unusual problems. Testing alongside other procedures will minimize the time and resources required for the test, relative to standalone 9-1-1 tests.

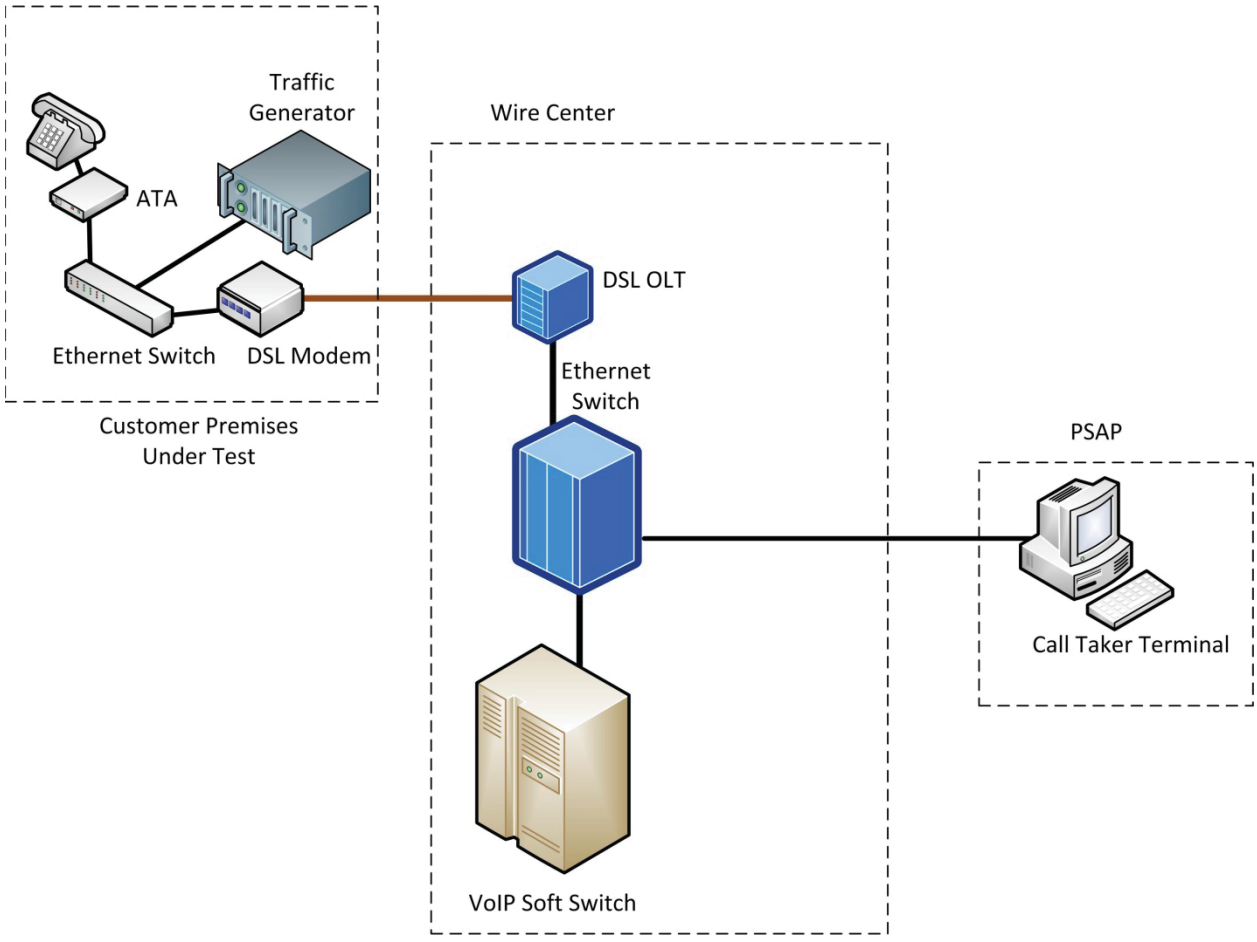
3.6.1 9-1-1

In order to test access to 9-1-1, it is necessary to 1) verify that the customers will reach the system and the correct PSAP, and 2) verify that the 9-1-1 dispatchers can provide the same quality of response to an IP-transitioned caller as a caller on the current phone network.

As in the other tests described here, this test will have both a lab and a field test component. In the lab setting, the test will need to verify that callers using all offered ATA types can reach the PSAP, and that the PSAP receives the caller's location and other identifying information.

The field component will test both the IP phone components and the phone company's customer database (Figure 8). Testing will be performed at all the locations where the tests are performed in Section 3.1. The number of wire centers should be widely representative of the U.S., a minimum of 100. Test areas should also represent a representative cross-section of PSAPs, including urban, suburban, and rural; large and small (two-person); public and private.

Figure 8 – 9-1-1 Test Configuration



As part of each field test, the test team member will alert the PSAP through a non-emergency line, then dial 9-1-1 from the test location. At the PSAP, the call will be routed to an individual

assigned to manage the test call, who will verify that the number and location information is correct, and will qualitatively verify the call.

We recommend that no more than one call at a time go to the PSAP, and that the test be suspended if the PSAP manager believes the center is too busy or there are any other issues that may interfere with 9-1-1.

We also recommended that the individual performing the test at the PSAP have training and experience as a 9-1-1 call taker. An experienced 9-1-1 call taker will be better able to verify that the call quality and experience are sufficient and to evaluate any other issues with the system. For example, some IP phone systems have been criticized by 9-1-1 operators for problems that interfere with the call—such as noise-suppression features that eliminate background noises that may be critical to managing a 9-1-1 call (e.g., sound of struggle, falling). This type of problem needs to be identified and addressed in the test stage.

The 9-1-1 testing needs to be comprehensive without interfering with 9-1-1 and without overburdening the 9-1-1 staff. We recommend that the phone company offer its own staff for the calls (including 9-1-1 trained individuals at the PSAP) and give the PSAP manager the option to use phone company staff or its own staff.

The 9-1-1 results, tabulating all passes and failures and describing in detail any problems, should be reported to the FCC and made available for review by first responder entities, such as the Association of Public Safety Communications Officers (APCO) and the National Emergency Number Association (NENA), in order that the challenges in managing emergency calls in the transitioned network be understood by the community.

3.6.2 Reverse 9-1-1

Reverse 9-1-1 is an automated system used by many local governments to quickly notify residents and businesses of an immediate public safety problem such as active shooters or gas leaks. An emergency manager selects a geographic area and calls the phones in the area to deliver a recorded message.

A typical urban reverse 9-1-1 system can make 5,000 30-second calls in less than 10 minutes. In each of the wire center service areas, each public safety entity operating a reverse 9-1-1 system should test the system to a representative area, according to its own test procedures.

The public safety entity should record the number of calls answered, as well as any anomalous behavior such as delays in completing the call and any problems reported by the public.

3.7 Cybersecurity

Another important test should assess the vulnerability of the IP-transitioned phone network to cyber attack. VoIP denial-of-service attacks have already taken place on 9-1-1 PSAPs, with large numbers of bogus calls generated overseas overloading the incoming capacity, and untraceable callers threatening 9-1-1 operators.[17]

Tests should be performed by the phone companies and independently verified by external security experts to assess the degree to which the network is vulnerable to being shut down or damaged by an attack, the presence of points of failure, the ability to impersonate other users, the ability to maliciously disconnect other devices, and the ability to generate individual or mass numbers of spoofed calls.

The phone companies should be required to describe the steps they have taken to address these and other security issues, and the testing they have conducted. These plans and steps should be reviewed for completeness and adherence to industry best practices by independent experts.

Independent security experts should then prepare interrogatories to clarify any questions and obtain more detail. If determined by the FCC, this process can be done in a manner to protect proprietary information or information that may be used to compromise the network.

Once the responses are reviewed, independent "white hat" external tests may be warranted, to determine the level of risk and strategies for remediation. As with the 9-1-1 tests, the "white hat" tests must not damage the network or compromise the service or personal information of network users.

This test is significant because IP migration of the phone network, by definition, merges the phone network with the data and Internet traffic. Prior to IP migration, the phone switches operated in a physically separate space from the data network and the communications traffic of users who are not part of the telephone company. In an IP-migrated network, the phone

[17] Kahn, David, "The Growing Threat to PSAPs from Telephony Denial of Service (TDoS) Attacks," *9-1-1 Magazine*, July 3, 2013, http://www.9-1-1magazine.com/Kahn-Threat-of-TDoS-Attacks, accessed December 10, 2013, with additional information from a briefing to first responder entities from Department of Homeland Security at time of attacks.

switch is physically connected to the IP data network, which also supports outside Internet traffic.

Best practices can help to secure the network. These include setting up separate "tunnels" for voice communications and for system management. However, managing security is complex, and individual devices, such as ATAs and switches, may have security weaknesses in their hardware or software. Moreover, internal security is also important—for example, to secure the network against rogue or careless employees or the existence of lax password practices.

Practices should be aligned, where appropriate, with the Cybersecurity Framework developed as part of *Executive Order 13636, Improving Critical Infrastructure Cybersecurity*. In the language of this Framework, the service provider would describe its current situation in various cybersecurity categories as a Current Profile, compare that Profile to a Target Profile describing industry standards and best practices, identify the gaps between that Profile and its Current Profile, and create a plan to address those gaps.[18] The risk is substantial; each ATA is essentially a computer, so each one can theoretically be spoofed or hijacked. Moreover, a single computer can pretend to be thousands of ATAs—with implications for violating customers' privacy, crashing the network, corrupting the billing, eavesdropping on calls, or generating the equivalent of voice spam.

3.8 Call Persistence

Users of the wireline phone network expect never to be "dropped" by the network—indeed, this is one of the distinguishing attributes of the wireline network, relative to wireless. Some users of the phone network also *require* persistent connectivity, such as for monitoring applications.

One way of measuring how often a caller is dropped is to see how long a call persists under a range of circumstances. Tests should be conducted both in the lab and in the field to verify that a call placed on the IP-migrated phone system stays connected indefinitely. Multiple tests of call persistence are also a means of measuring the stability of the phone network.

The test calls should stay connected for at least one week. The lab calls should be performed using the full range of ATAs on a fully utilized IP network. Calls that are dropped should be

[18] *Improving Critical Infrastructure Cybersecurity, Executive Order 13636, Preliminary Cybersecurity Framework*, http://www.nist.gov/itl/upload/preliminary-cybersecurity-framework.pdf, p. 14-5, accessed December 18, 2013.

analyzed for the root cause, and network modifications should be made accordingly, until calls stay connected in all cases.

Call persistence should be verified in a subset of the home and business field tests to verify one-week connectivity. Tests should be done at a representative 10 percent of the tested field locations[19] to other locations both within the wire office service area and to other wire centers and service providers. Again, calls that are dropped should be analyzed for root causes, and modifications made on the network, until calls stay connected in all cases.

Another benefit of call persistence testing is to identify unexpected features of the IP-transitioned network and their impact on users. Digital and computerized technologies often have new features that are not always desired. It is possible that software or hardware contains commands to disconnect calls after a period of time; these features need to be understood and, if necessary, disabled for users who need a persistent call.

3.9 Call Functionality

The local phone network has many functions that are taken for granted by its users—including that the local phone network is a network with access to any other phone network.

There is no technological reason why a user should lose basic functionality simply because of IP migration. Furthermore, there is no technological reason that the common carrier nature of the local phone network should change to a proprietary closed system in which the phone company can assert greater control over whom an individual calls or how.

For example, the Verizon Voice Link service has sharply limited callers' ability to reach outside networks. Its terms of service preclude callers from access to outside carriers, such as long distance and international phone providers and calling card numbers.[20]

Accordingly, the IP transition testing should include a test of the range of call functions that are now available to all PSTN users. These functions include transport of caller-ID information, and transport of DTMF tones (i.e., touch tones) both in-band and out of band.

These functions also include the ability to reach outside carriers—such as long distance and international phone providers, calling card, and dial-around (10-10-XXXX)—and to have full

[19] Ten percent of the ten percent of lines tested—so approximately 1% of the lines in each wire center service area.
[20] Verizon Voice Link Terms of Service, http://www.publicknowledge.org/files/VZ%20Voice%20Link%20TOS.pdf, accessed November 26, 2013.

access to any phone number desired by the caller, as well as to receive collect calls or third-number billed calls.

Tests should be performed in the lab, and in each wire center area. Tests should be performed using each ATA device. The wire center area tests can be performed at any location in the wire center service area. They should be performed once with each ATA device in each wire center area; because they are independent of the specifics of the local loop connection, they do not need to be done at many separate field locations.

3.10 Wireline Coverage

Notably after Superstorm Sandy, in Fire Island, NY and Mantoloking, NJ, but also in other locations reported by the media, telephone companies have attempted to migrate copper phone customers to wireless service, often with fewer features and lower reliability than the copper lines. In some cases, too, maintenance practices have been changed from permanent repairs to temporary patching.[21]

Testing should thus be performed to verify that, after the IP transition, service will continue to be available at all locations currently served by the phone network. Service may continue to be analog POTS or can be a migrated IP service—but where wireline service existed before the migration, wireline service should continue to be available.

Physical verification should be performed at 10 percent of addresses in the 100 wire center test areas, randomly selected from among the addresses reported served by wireline telephone service as of five years before the beginning of the trial period. Verification should include testing that analog dial tone exists, or that migrated IP service exists.

These locations may overlap with the locations in the other field tests. One scenario may be to perform the other field tests at the randomly chosen locations where service has been migrated to IP.

Each address tested should be documented as “migrated IP service,” “analog POTS,” or “service not available.” Locations where service is not available should be further investigated to

[21] Shapiro, Carolyn, “With aging infrastructure, Verizon has trouble on the line,” PilotOnline.com, http://hamptonroads.com/2011/10/aging-infrastructure-verizon-has-trouble-line, accessed December 11, 2013.

determine if the line is capable of receiving service within 24 hours (i.e., servable but disconnected by the subscriber), which would then be verified by having the phone company connect the line and perform the IP field tests (or verify POTS dial tone). If the physical plant is not capable of service within 24 hours of request, the location will be noted as service not available.

Testing of wireline coverage will also determine the extent to which copper infrastructure is being neglected or may be in the process of being abandoned by the phone company.

4 Parties that Need to Be Involved in Testing Regime

Best practices dictate that testing should be performed by independent entities, not by the companies that seek authorization for the IP Transition or by their contractors. Rather, those companies should, as has been done in the past, cooperate in and support the testing of their networks, and support the independent testing to be conducted by third parties.

Beyond the independence of the testing entities, the tests must include the involvement of three broad sets of stakeholders: Public safety, public health, and state and local governments.

Parties that must be involved in testing:

1. *Public safety*
2. *Public health*
3. *State and local government*

4.1 Public Safety

The interests of the public safety community are obviously significant—if not paramount—in the IP conversion process. This is true both in terms of their own communications and the devices upon which they rely, as well as from the standpoint of their communications with members of the public through 9-1-1 and calls placed directly to police departments, fire departments, and other first responder agencies. The local entities that represent public safety where the tests are occurring should be engaged and have the opportunity to verify the results.

4.2 Public Health

State and local public health departments will be of particular importance, much like public safety, because they are able to understand the impact of circuit-switched services on a critical sector. Implications will vary by community, because different communities use technologies in different relevant quantities. There is consistency, however, in that there is impact everywhere. Each community that is tested needs to be able to evaluate the local impact on public health, including in the delivery of emergency medical services.

4.3 State and Local Government

The IP conversion presents huge potential consequences at the local level in a variety of ways—including public safety and public health, but also in the full range of governmental operations, such as providing education, day-to-day governmental services, and regulatory functions. There are also important potential economic impacts for citizens and businesses that rely on circuit-switched technologies such as point-of-sale devices (e.g., gas stations, restaurants, retail stores).

Another way in which state and local governments have a huge stake in the outcome of the IP conversion is the quality and capabilities of government communications services in general. State and local governments constitute the largest collective user of traditional circuit-switched services in many communities, so they have standing as a major consumer group.

The possibility that thousands of devices and services will cease functioning in the event of an ineffective wire center transition means that it is essential that the state and locality where the test takes place are informed of the test, are able to plan ahead, and are able to evaluate the impact of the test.

5 Threshold for Stopping Tests

It is possible that unforeseen problems in the technological migration will be sufficiently severe that tests will need to pause or end in order to address the problems. Depending on the nature of the problem, its severity, and the individuals affected, it may be necessary to reconnect the affected members of the public to the analog "plain old telephone service" (POTS) network or end the tests altogether and return the central office area to POTS.

Therefore, it is critical that the switches, multiplexers, management system, cables, powering, and all other POTS infrastructure operate in parallel with the IP-migrated infrastructure, enabling the operator to rapidly migrate some or all of the lines and their numbers back to POTS if necessary.

We understand that no technological migration will be perfectly smooth and that there will be brief outages, variations in quality and consistency, and delays. We do not advocate halting the migration if a problem is not severe or is clearly able to be promptly solved.

However, in the event of failures affecting highly critical systems or the identification of major problems with the transitions, we believe the operator should be required to at least temporarily revert to POTS and, if no solution can be found, to potentially migrate neither the service area nor the affected users. Furthermore, if the testing demonstrates that the overall migration will be measurably detrimental to the public, the tests should be stopped altogether and the service area returned to the pre-migration configuration.

Examples of highly critical connections include systems affecting the safety or health of many people. Failures in these areas might include malfunctions in critical alarm systems at large institutions, failures of health care devices or monitoring systems, failure affecting the utilities systems, difficulties in accessing 9-1-1, reduced functionality of the 9-1-1 system for call takers (such as not properly identifying callers' locations or providing insufficient sound quality), failures of reverse 9-1-1 systems, and reduced functionality of fire station ring-down lines. *If these systems fail or lose functionality, they should be migrated back to the original system until a solution is found.* If the source of the problem extends beyond that system's direct connection to the phone network (for example, a 9-1-1 problem caused by the 9-1-1 trunks AND the customer phone connections) the entire migration should be stopped and restored to the original configuration until a solution is found.

Examples of major problems include loss or deterioration of a significant system for more than one week. As compared to "highly critical" systems, these are systems that are extremely important to individuals and businesses but do not create an imminent hazard to life or

property if they fail. These systems include credit card readers, ATMs, individual home and business alarms, TTY/TDD systems, significant cybersecurity vulnerabilities, modems, and fax machines. *If these systems fail or lose functionality for more than one week, they should be migrated back to the original system until a solution is found*.

Finally, if many of the tests fail—that is, if more than 10 percent of the tests performed consistently fail to achieve the expected results and service cannot be readily repaired or restored with minor adjustment—the operator should be required to stop the migration and restore POTS until it develops a better plan. If the IP transition creates significant deterioration within the test area that cannot be improved within one month—such as reduced call completion, call dropping, reduced access to dial tone, or deterioration of call quality (e.g., noise, echo, distortion)—the migration should be stopped and the system restored to POTS.