Web-based Expert System for Automated DSL Loop Qualification

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Abstract

Digital Subscriber Line (DSL) uses existing standard twisted-pair copper wire to supports voice and data simultaneously and delivers high speed Internet access and multimedia services. However, DSL services cannot be carried over all twisted pair copper loops that support POTS service. It takes a lot of time and expertise to figure out which lines can support DSL and which lines cannot. In this paper we describe a web-based expert system for automated qualifying lines on the basis of real-time electrical measurements and records stored in telephone company databases. Such system has been operational in GTE since January 1998.

Keywords

Web-based Management System, Digital Subscriber Line, Management of Broadband and Access Technologies, Expert System, Distributed Systems and Applications Management, Service Management

1. Introduction

The plain old telephone service (POTS) was introduced over 100 years ago. Telecommunications service providers are presently faced with the enormous challenge (and opportunity) of delivering broadband access from the residence or small office to a network provider. Digital Subscriber Line (DSL) [1] is an access technologies that can be used to provide high speed links over a twisted pair copper plant designed for POTS. There are approximately 600 million twisted pair copper lines in use today. Unfortunately, not all of these loops can support DSL services.

In this paper we discuss a web-based expert system (patent pending) [1] for automated qualifying loops on the basis of real-time electrical measurements and records stored in telephone company databases. In addition to discussing the system, we will also provide our experiences and statistics on the accuracy of the loop qualification decisions made by the system, which has been operational in GTE since January 1998.

2. xDSL Technologies

Digital Subscriber Line (DSL) uses existing standard twisted-pair copper wire. It supports voice and data simultaneously over a single pair of twisted copper wire and delivers high speed Internet access and multimedia services over the existing telephone network (Figure 1). DSL requires at least a pair of devices, one at the central office site, a Digital Subscriber Access Multiplexer (DSLAM), and one at the end user site, a DSL modem. Digital subscriber systems can provide data from 64 Kb/s in both upstream and downstream directions, to over 6 Mb/s in a single direction [2]. DSL is a dedicated copper loop technology. It supports both symmetrical and asymmetrical applications.

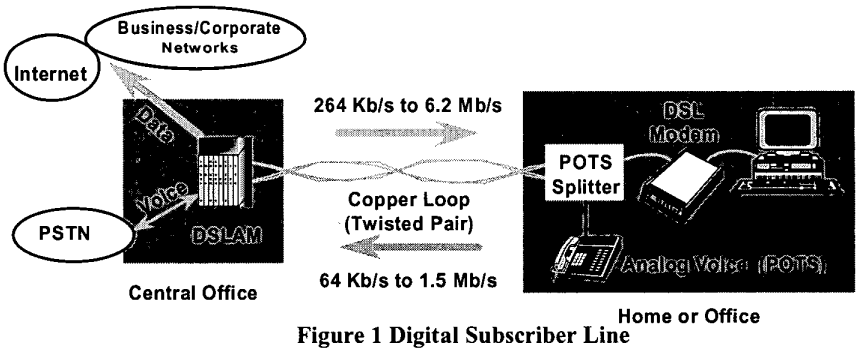

Figure 1 Digital Subscriber Line

Here are some key variants:

- ADSL, Asymmetrical DSL
- ADSL Lite, (G.Lite), lower bandwidth ADSL
- VDSL, Very high-speed DSL
- HDSL, High bit rate DSL
- SDSL, Symmetric DSL
- MSDSL, Multirate Symmetrical DSL
- IDSL, ISDN-based DSL
- RADSL, Rate Adaptive DSL

With the exception of circuit switched IDSL, all xDSL services are packet (rather than switched) technologies. This provides vastly improved and more cost effective network performance, and network manageability.

3. Outside Plant Requirements for xDSL Services

DSL services, such as ADSL, SDSL and other formats, cannot be carried over every twisted pair copper loops that support POTS service. Digital subscriber services generally have loop length and wire gauge limitations that depend upon downstream (to the subscriber) and upstream (from the subscriber) bandwidth, modulation format, and receiver sensitivity for a given chip design [3] [4].

3.1 Loop Restrictions

Digital subscriber services also have restrictions on loop topology (such as bridge taps) and presence of load coils, and services in adjacent copper pairs with overlapping frequency spectrums, such as a T1 line, will cause interference due to crosstalk between pairs.

For example, a loop is restricted to less than approximately 5.25 km of 24 gauge wire for the common 1.5 Mb/s downstream, 80 kb/s upstream bandwidth allocation using a widely used chip set for carrierless amplitude phase (CAP) modulation. For this modulation format and bandwidth allocation, if there is an analog carrier POTS service in the same 25 wire pair bundle, the ADSL modulation will interfere with the analog carrier effectively destroying the POTS service. Similarly, if the is a T1 carrier system in the same 25 pair copper pair bundle, the T1 service will interfere with the ADSL modulation nullifying the digital subscriber service (but typically not affecting the T1 system).

3.2 Spectral Compatibility

Electromagnetic transmissions over copper radiate signals to adjacent wires, commonly called cross talk. It becomes an issue when the power level of the cross talk signal becomes comparable to the power level of the primary signal. Cross talk from existing services will reduce the performance of the other services which occupy the same frequency spectrum. The effects of cross talk will reduce the loop reach and/or speed of DSL. However, the effects of cross talk from DSL into other services is generally believed to be less significant. National Standards are being developed to address spectrum management.

4. DSL Loop Qualification

Loop Qualification is the process of determining if the copper pair will support xDSL. Items to check include: DSLAM installation, loop length, wire gauge, DLC, load coils, bridge taps, loop resistances, loop dB loss, loop open, loop short. The testing should be supported from the Central Office (CO) end and not require equipment at the customer premises [5].

4.1 DSL Loop Qualification Procedures

The procedure starts by checking the existing database of cable routing and verify the distance to the CO. First check is to see if the line is copper all the way to the customer. It can not be serviced by ISDN or other digital services such as the two channel gain devices. Next, check for interferers. Some of the simple GTE limitations are no T1 or Analog Carrier in the same 25 pair binder group. Also check the adjacent binder group for interferers. The same checks need to be made on all distribution and feeder cables. If, based on this testing, there are interferers then one might consider rearrangement of some facilities or other services. For example, one may use HDSL to replace T1.

After checking the line capability, check on the quality of the facility. Two key items to check are length and load coils. Generally, the length of the loop from the CO to the customer premises is limited to 18,000ft. Loading coils are inductors placed on the loop to improve voice band quality on longer lines. However, loading coils are incompatible with DSL and must be removed. The length of the loop and the presence of load coils can be found either by measuring in real time or by checking plant records.

4.2 DSTS Loop Qualification Flow Chart

The loop qualification procedure in our DSTS (Digital Service Testing System) Loop Qualification (Figure 2), which will be described it in detail in section 5, is very similar to the loop qualification procedure described in the above section. One of the differences is that DSTS perform the database quire and the physical layer test in parallel by launching another thread to measure the loop length, cable faults, and other electrical characteristics while one thread is doing facility database lookup of cable pair information. This can greatly reduce the response the system response time. DSTS also makes a multi-database query to check if the ADSL equipment has been installed in that serving area. However, even if the ADSL service is not available in that area, the loop qualification process will continue.

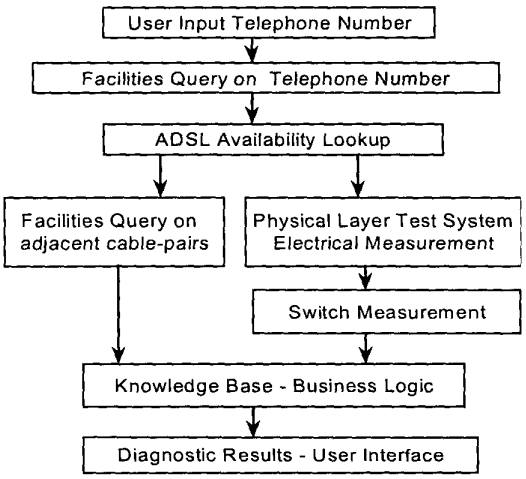

Figure 2 DSTS Loop Qualification Flow Chart

5. DSTS Loop Qualification System Architecture

A system called DSTS (Digital Services Test System) was developed to perform, among other tests [6], DSL loop Qualification automatically. DSTS does automated facility lookup, line testing and load coil check. It first gathers real-time information on a customer's line to feed into the knowledge base. These results are then analyzed by an expert engine that figures in vendor specifications for bandwidth reach, loop length and results from laboratory test to provide a Qualify/Not Qualify result to the service representative.

5.1 System Architecture

The architecture of DSTS is a scalable 3-tier client/server system [7] (Figure 3). The first tier is the client of DSTS. The client includes an interactive Web browser interface and a batch client. The interactive Web client provided access to thousands of users, such as GTE customer representatives, service and installation technicians through a web browser screen. In addition, through a secured gateway, users on the Internet, such as ISP providers, can also access DSTS Loop Qualification. The batch client also has web-based browser interface. It allows users to submit hundreds of test requests to DSTS at once. DSTS will perform this batch test request when the system is not busy or during the night. The interactive test request always has higher priority than the batch test request. Later, the user can retrieve the batch test result from the test history database. DSTS loop

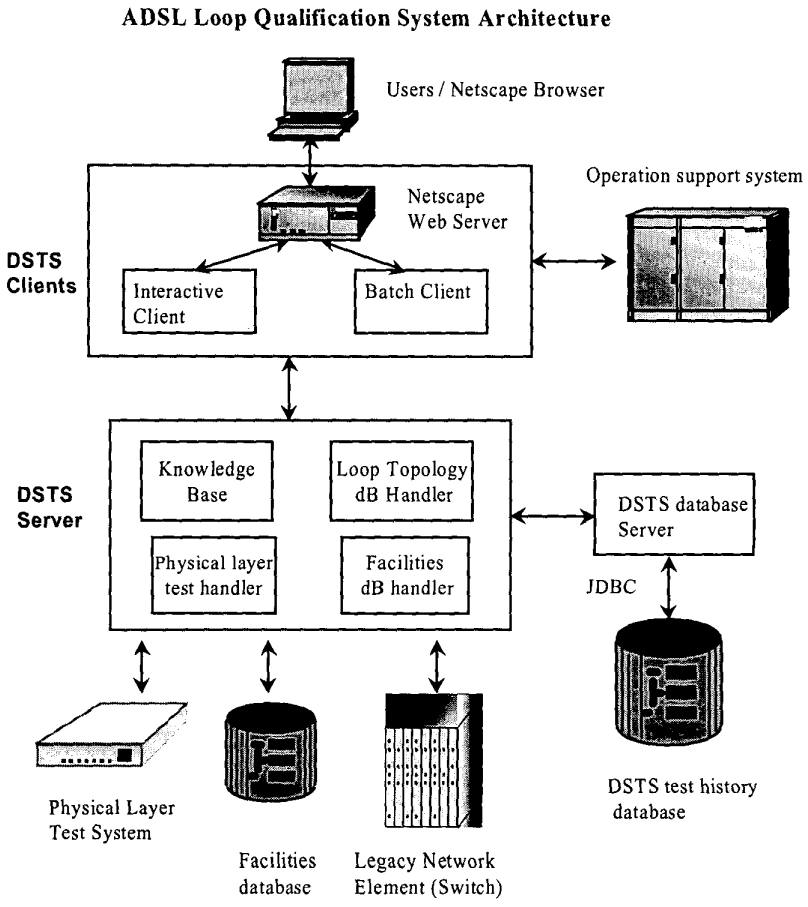

Figure 3 DSTS System Architecture

qualification can also be accessed through a machine application program interface, allowing the loop qualification process to be part of a larger flow-through provisioning system.

The middle tier of the system is the DSTS server whose main components are the knowledge base and rule-based inference engine. The server also has separate modules

that interface to some external systems, such as, legacy systems for facilities, services, and topology databases, and physical layer test systems. The server interact with the client, receiving test request from the client, gather information from the external corporate database and from the physical layer testing systems, then it implements the business logic and finally sends the result back to the client as well as to the test history database. The third tier is DSTS database and the external legacy systems that provide data sources and data storage for DSTS. The clients only interact with the user and the middle-tier server. What the clients do is to receive test requests from the users and send them to the server and then display test results when the test. They do not have to concern themselves with business logic, the external testing systems or databases. Clients never need to directly interact with the third-tier data sources. This architecture provides a lot of flexibility and scalability. More servers can be easily added without system architecture change or any code change. The clients, the server and the database can be hosted at different physical locations and the setup can be changed very easily without changing the program code.

The DSTS Loop Qualification is deployed across the United States through the GTE intranet. The DSTS server is running on IBM RS6000 servers under AIX operating system. This provides us with enough computing power to run the rules engine, perform communications, establish database insert and fetch functions and support the web server. Multiple servers have been installed in physically diverse locations across the country and that provide redundancy from an operational perspective and yet each site has it's own database of test results to provide speed of operation.

5.2 The knowledge base of DSTS

The knowledge base has been developed with extensive interviews with field personnel that captured the "best of the best" experiences. Such knowledge is built into DSTS as a set of rules. By building these experiences into the knowledge base every user can have the best knowledge at their fingertips. Along with field experience, expert system knowledge of the ADSL requirements from a physical level has been incorporated into the analysis module. This knowledge base is developed by testing of specific vendor equipment, analysis of existing Public Utilities commission requirements, theoretical models of equipment and cable models and testing results from field trials.

5.2.1 Data Gathering

Data exists in many places and part of the savings of the DSTS Loop Qualification process is in the gathering of that data from databases that have only a part of the data and combining it with other parts from other databases. When performed manually, this is a very time consuming and error prone process. Some data in databases ages very quickly while other data is predominately static. Only expert knowledge can determine

what to rely on and what to be skeptical about. Once gathered into the rules engine every user is an expert (usually without knowing it).

The database information that is not stable and must be augmented with real-time measurements. This requires communication with Network Elements and with test systems. GTE was fortunate enough to have imbedded testing systems with electronic interfaces to call upon to gather this real-time data. Some of the switch testing and some of the external test system interfaces were employed in the data gathering for a particular line.

5.2.2 Processing the Rules

Once the rules are written they need to be arranged in the appropriate order to maximize the processing flow. If, for example, the line that is being qualified for ADSL is terminated on a Dual Additional Main Line(DAML) system which can not support ADSL there is no need to continue the process of information gathering about the line. Therefore the rule that checks the kind of line being checked is placed first in the order of rules. If the line is inappropriate then processing stops. This improves the throughput of the system by avoiding unnecessary processing.

5.2.3 Analysis and Storage

A test history database is maintained as part of the system knowledge base, and also for administrative reasons. The results are made available to other GTE Service Fulfillment and Service Assurance process systems. Once all the data has been gathered and analyzed by the rules engine then the data elements are appropriately stored in a history database that records, for later recall, the important parts of the qualification data and the results of the analysis. This is available for later retrieval by the user or by statistical systems that will monitor performance of the service fulfillment process. Since all test results are stored in the DSTS history database, users can check the database to see if a qualification test has been previously done.

From the history database, GTE corporate clients can use data mining procedures to extract important information about the client base, statistically significant areas of the country that are using xDSL services, areas that are interested in using xDSL and the number of users that are requesting vs. the number that are buying services. Currently we are testing about eight times as many lines as we are providing completed service orders.

5.3 Design Philosophy of DSTS DSL Loop Qualification

The design philosophy behind the loop qualification rules have two fundamental rules: (1) To qualify loops on the basis of their measured characteristics (as opposed to qualification solely on the basis of records), and (2) The system make decision of a loop

is qualify or not qualify only when it has all the required data, otherwise, it will say "may qualify").

With this design philosophy, only loops with connections to physical layer test systems can be qualified. This in turn means that the loops must be on a working pair, in which case there is no craft intervention required, or the loop must be connected up to the test system using a test shoe. Since it is envisioned (at least in the GTE environment) that most xDSL services will be provided on the same pair and in conjunction with POTS, and since the vast majority of existing loops are presently provisioned for POTS, the real time measurements are made utilizing central office switch diagnostics, and the POTS loop testing system used by GTE.

A very common problem for all telecommunications service providers is the accuracy of records that can be many years old. The typical Regional Bell Operating Company (RBOC) and GTE have on the order of between 10 and 20 million lines to maintain. While the type of service and the cable pair attaching a given service to a given network element (such as an end office switch) is typically correct, Out Side Plant (OSP) information (such as loop length and topology, line conditioning equipment, etc.) is sometimes out of date. For this reason, we designed a loop qualification system that relies as much as possible on real-time measurements rather than OSP databases.

5.4 ADSL Availability

One of the most important features of the DSTS system is the ability to accurately identify the location of the customer and the location of the deployed DSLAM equipment. The system can match the user with the DSLAM from database information in legacy systems within GTE. A new method of combining existing legacy data and new product availability data was needed.

5.4.1 Existing Services Model

Up until this time in the telecommunications industry all services have been provided from the Central Office (CO) switch. It has been relatively easy to match the customer's NPA Nxx against a database and determine on a switch by switch basis if the customer is being served from a switch that provides a requested product. These products would be Three Way Calling, Caller ID or Centrex service as examples. Everything was based on the switch and thus on the NPA Nxx model of product offerings. This is no longer true with xDSL services.

5.4.2 Future Services Model

With the advent of the xDSL service, the CO or the switch is no longer the prime source of the "product". The ADSL service, for example, can be provided from a Remote

Switch Unit while the main or Host CO is NOT equipped. The customer's NPA Nxx exists as a component of the Host switch, not an element of the Remote.

GTE has developed a method of identifying the remote units and providing accurate correlation with the customer's serving site in order to be able to accurately identify the availability of the service for the customer. This availability is provided at the time of the customer's inquiry about the product, not after a lengthy delay of hours or days. This provides GTE customer's up front knowledge and reduces decision delays in the ordering process considerably.

As new services are deployed, not from the switch, but from the best location for the product, GTE is ready with tools for the new model.

5.4.3 Obstacles

Again, the obstacles here are not really technical but the ability to recognize the pieces of data that are scattered in databases around the company and to gather the pieces in a meaningful and time efficient manner. Once put together, the result is a considerable time saving on a per line tested basis.

5.5 System Benefits

With minimized training, every GTE service representative can simply enter the telephone number and obtain a result of qualification for the line in a few minutes without having to be a subject expert on ADSL or line conditions. Using DSTS, data from around the company have been gathered and merged with real-time data about the specific line tested to provide a comprehensive, rapid result with expert accuracy to the customer. This savings to GTE is considerable [8]. Minutes instead of hours. Expert results instead of guesses. Technical analysis for guiding deployment in existing cables that will ensure future compatibility instead of limited deployments later. All of these benefits are provided today in a completely functioning system that is saving GTE millions of dollars and providing world class service for our customers.

DSTS can qualify or disqualify approximately 90% of all 13 million loops in GTE's domestic operating regions. In the remaining 10% of loops, the operating region is within the system or measurement error, and additional (manual) testing is required to qualify or disqualify a loop.

6. Loop Qualification Examples

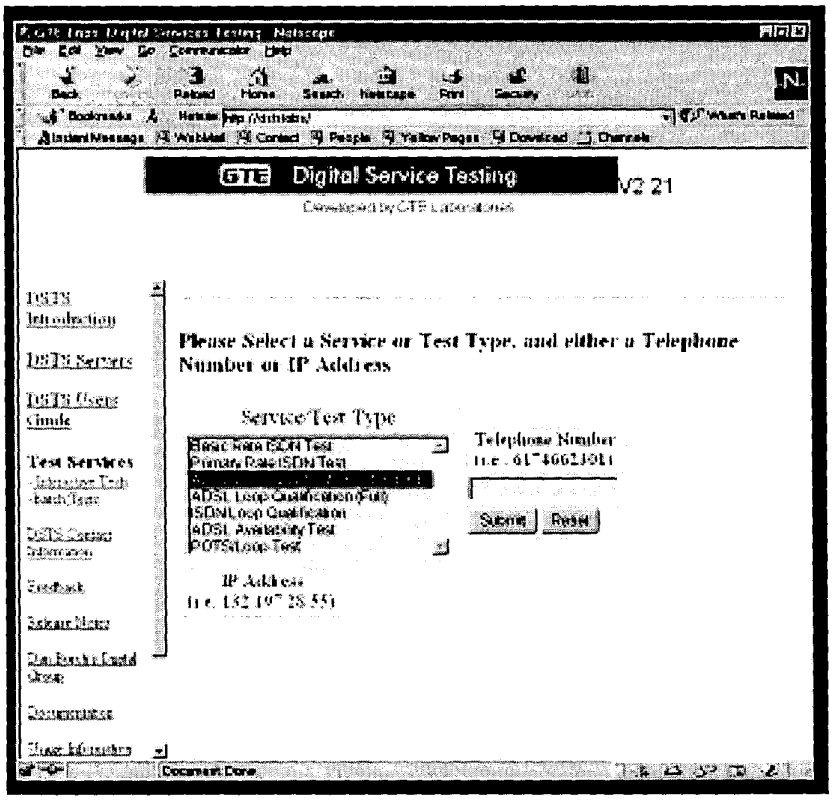

Figure 4 DSTS Web Interface

Figure 4 is the DSTS Web interface. On the DSTS web interface, the user need to select a test type, in this case, ADSL Loop Qualification is the selected test type. Then the user need to enter a telephone number and then hit the submit button. In a few minutes, he/she will see a screen of test result as shown on Figure 5. The result screen provides information on:

- service availability (is xDSL service available from location of copper pair termination (base central office, remote, digital loop carrier system, etc.)

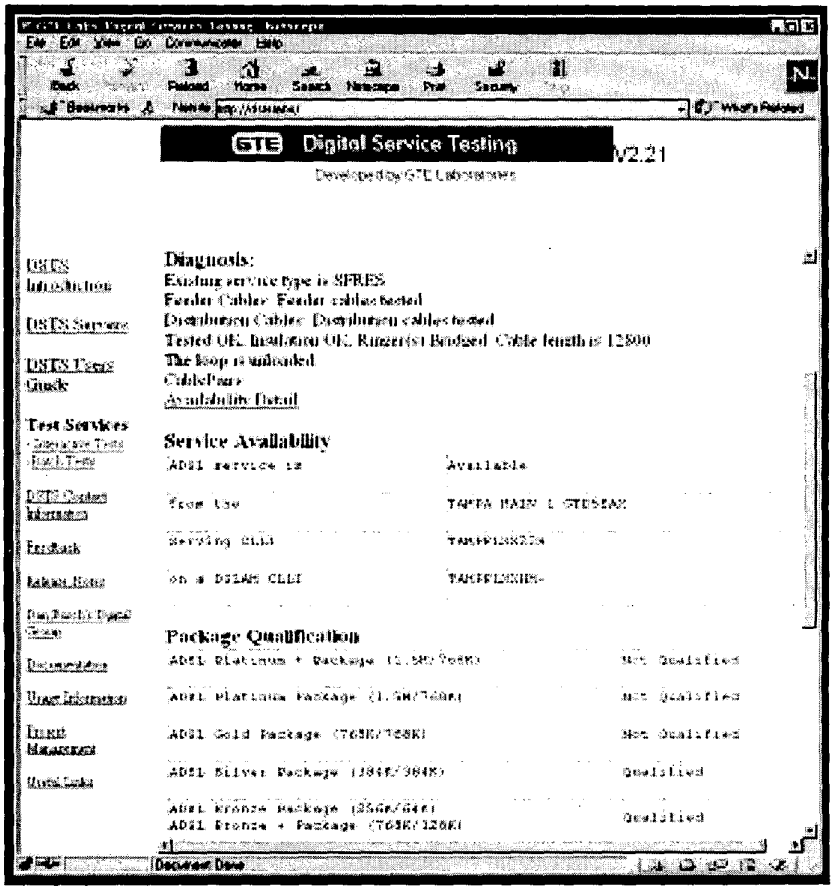

Figure 5 DSTS Loop Qualification Result

- particular xDSL service packages that can be supported (depending upon upstream/downstream bandwidth)
- diagnostic information regarding individual process threads and system reasoning.
- central office equipment, and outside plant loop data.

7. Deployment Experience and Statistical Results

7.1 Field equipment

GTE has experienced tremendous growth in the ADSL equipment in the last year. During that time GTE has progressed from the field trial stages to full deployment using

the described management system. At this time there are over 500 sites equipped with over 1100 DSLAMs installed. Customer demand is growing and there are over 20,000 subscribers.

7.2. System Users

When the system was developed the expected user was a qualified Access Design engineer or FAC clerk. With the explosive growth in number of customers inquiring about availability across the country additional users have been employed.

Due primarily to the simplicity of use and limited training required and the comprehensive nature of the reporting, there are users from Marketing who use the result information for data mining research, users from the resale side of the business who are doing qualifications for wholesale customers and there are frontline sales clerks doing real-time qualifications for customers. There are several thousand users, all successfully using the DSTS system today when it was expected that only qualified technicians would be testing.

7.3. System Volume

GTE is currently testing on the order of eight thousand tests per week on the collective server sites. Volume is limited by several factors including the access to network elements, access to test systems and access to databases. Additional volume is available as GTE continues to grow.

Test time on the DSTS systems is in the order of four minutes. In initial trials where comparisons between DSTS and manual methods were conducted the DSTS test time was on the order of four minutes while the manual method required between thirty minutes and four hours with an average of fifty minutes. The longer times were required because of record lookup times and load coil testing done manually.

7.4 System Accuracy

It is one thing to build a simple system and it is another to deliver accurate results. With the volume of business generated by GTE the statistics are impressive regarding accuracy. To date there are fewer than five percent of the tests that result in a false positive. There are two factors in this result.

One is that the access to records used in combination with real-time tests gives a superior data base from which to make the decisions. Second is that the rules reflecting the bandwidth performance have been selected such that a high percentage of lines are qualified within the margin of error of the test systems and still provide a significant

market in which to sell the product. It does no good to improve accuracy at the expense of limiting the market.

8. Summary

In summary, an intelligent, web-based system of automated loop qualification has been developed for xDSL services in GTE. This loop qualification process integrates real-time measurements of loop length and loop electrical characteristics with information from telephone company records, and is currently on-line and available on all 13 million POTS circuits in GTE's domestic loop plant. Qualifying a line with DSTS takes an average of 4 minutes, vs. 50 minutes average labor time to do it manually. Because of the speed of the system many more users have been testing than was originally expected. The system is highly accurate reducing false positives and false negative results.

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