INTERACTIVE DATA VISUALIZATION AND ANALYSIS FOR MOBILE-PHONE PERFORMANCE EVALUATION

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Abstract

In this paper, the authors introduce an interactive visualization and analysis system for Drive Test Data (DTD) evaluation designed to provide first-hand mobile-phone performance assessment for different parties—including phone manufacturers and network providers—to review phone and network performance such as service coverage and voice quality. The authors propose an integrated data-visualization system, iVESTA (interactive Visualization and Evaluation System for drive Test dAta) for mobile phone drive-test data. The objective was to project high-dimensional DTD data onto well-organized web pages, such that users can visually study phone performance with respect to different factors. iVESTA employs a web-based architecture, which enables users to upload DTD and immediately visualize the test results and observe phone and network performance with respect to factors such as dropped call rate, signal quality, vehicle speed, handover and network delays. iVESTA provides a practical test environment for phone manufacturers and network service providers to perform comprehensive studies on their products from the real-world DTD.

Introduction

Drive Test Data (DTD) evaluation [1]-[5] refers to the process of evaluating mobile phone or network performance by using the data collected from the moving vehicles driving through a prearranged area with a radius of roughly 10 miles. Because DTD evaluation can provide first-hand, real-world assessments, it plays an important role for both mobile phone manufacturers and network service providers to verify the performance of their products. For example, phone manufacturers can use DTD evaluation to compare a newly-built phone with a baseline phone such that the overall performance of the new phone can be evaluated. On the other hand, for network service providers, DTD evaluation can also be used to validate the signal coverage and frequency planning. In order to provide a reliable DTD evaluation that reveals the actual phone/network performance, the test has to be performed multiple times under complex conditions in order to increase the accuracy of the test results [1], [6].

Depending on the DTD evaluation objectives and the parties actually carrying out the test, DTD data collected from the field vary significantly. For example, DTD data collected from the phone manufacturers usually have phone performance details but lack network-side information such as the status of the Mobile Switch Center or Base Stations. Due to privacy and security issues, and the fact that mobile-phone manufacturers and network service providers may have established DTD standards, they usually do not share data with each other, which unavoidably produces a low-data integrity challenge for DTD evaluation. Low integrity means that although DTD data collected from the field can tell what happened, the data may not provide sufficient information to answer a question like why it happened, due to the limitations of the data-collection devices and the availability of network/phone status information. In summary, then, outlined here are several challenges for DTD evaluation and arguments for a DTD evaluation system that can effectively resolve all these challenges and provide a clear picture for users to answer these two questions: what happened and why did it happen?

- Establishing proper methods for evaluating a low-quality and low-integrity DTD evaluation. A DTD evaluation system must be able to decouple numerous factors such as terrain types, interference from surrounding vehicles or buildings, network variation, and phone performance.

- Deriving reliable comparisons based on a small number of significant events in DTD. Although a DTD database usually has a large volume of test data, the number of significant events, such as dropped calls, is actually very small, which makes it difficult to perform reliable statistical analyses.

- Visualizing a large number of events on the screen. Mapping DTD to a visual map can provide clear interpretation for the data, but DTDs usually have a large volume of data and events. For web-based user interfaces on which iVESTA is currently based, drawing and handling a large volume of data and providing immediate results is a challenge.

- Providing comprehensive summarized reports for DTD evaluation. DTDs usually involve a large amount of test data in which the majority of the recorded events are trivial. Consequently, it is required to provide users with comprehensive, summarized reports along with visualized presentations, such that users (possibly project managers) can gain a high-level understanding of the phone performance.

In order to resolve the above challenges, the authors propose a web-based visualization system, iVESTA, which is able to evaluate a large volume of mobile-phone DTD data and immediately provide summaries for the users. iVESTA can carry out baseline comparisons and build standardized evaluation methods from DTD, so it can help phone manufacturers and network service providers to analyze the collected data. For example, the differences between the test phone and the baseline phone can be easily evaluated when the data are displayed on a map with signal strength, signal quality, distance between a mobile phone and a base station, different operations on a mobile phone, or network traffic at different times.

The web-based visualization architecture ensures that iVESTA can rely on a centralized DTD database and provide a variety of data analyses, summarization, and visualization functionalities. More specifically, the inherent merit of iVESTA is two-fold: (1) It provides full-scale evaluation of DTD data and is able to create baseline comparisons in call performance and RF performance; and (2) It is a dynamic visualization system, where users can easily review all existing reports, generate a new report from the log files of a specific product, and provide interactive charts and tools.

iDEN [10] is a digital radio system providing integrated voice and data services to end users. The iDEN system, in which the DTD from this study were collected, uses QPSK, 16QAM, and 64QAM digital modulation, AMBE+2 (Advanced Multi-Band Excitation), and VSELP (Vector Sum Excited Linear Predictor) speech-coding techniques coupled with TDMA (Time Division Multiple Access) channel-access methodology to enhance channel capacity and system services. It is also important to evaluate QAM modulation performance versus RF measurements (RSSI: Radio Signal Strength Indicator and SQE: Signal Quality Estimation).

RSSI in dBm is measured according to Eq. (1), where P_1 is the received signal strength and P_0 is the unit signal strength (1mW).

$$P = 10\log(P_1 / P_0) \tag{1}$$

RSSI consists of three major components defined by Equation (2).

RSSI = C (Desired signal strength) + I (Inference strength) + N (Noise strength). (2)

Table 1. Summarized influence factors of DTD: this table shows the complexity of DTD evaluation, where the mobile phone or network performance crucially depends on multi-dimensional features

Influence factors of DTD					
Network	Environment	Hardware	Software	Operator	Test
- Congestion - Coverage - Handoff Delay - Interference - Color code configuration	- Terrain type - Natural Barriers - Artificial Barriers - Near Interference - Multi path - Weather	- Stability - Hardware Fault - Heat Dissipation - Antenna Setting - Antenna Pattern - RX/TX Performance	- Stability - System Fault - Mobility Management - Vocoder	- Contacting - Blocking - Voice Quality	- Car Type - Drive Route - Drive Direct - Antenna Extension - Speed

Consequently, iVESTA provides extensive functionalities for phone manufactures and network providers to understand the correlation of the cause and effect on mobile performance during the drive test [10]. General influence factors of the DTD data are summarized in Table 1. The rest of the paper outlines the iDEN background to help interested readers understand the drive-test process; introduces iVESTA system architecture; provides a detailed introduction to system functionalities, with a focus on summarization tools; and, highlights the dynamic visualization components of iVESTA.

Background

A. iDEN Characteristics

The calculation of SQE (Signal Quality Estimation) is thus given by Equation (3).

$$SQE = C / (I + N) \tag{3}$$

In iDEN systems, radio channel bandwidth assigned to 800Mhz and 900MHz is 25kHz, and a single inbound/outbound frequency pair is simultaneously shared among six users (i.e., 6 mobile radios) for dispatch voice quality and shared among 3 mobile radios for voice quality. Each time slot length is 15 milliseconds, so the communication structures of the iDEN system affect call performance during the test and require a DTD evaluation system to separate data into different call modes.

Figure 1 provides a high-level overview of the iDEN system, where DAP (Dispatch Application Processor) is responsible for the overall coordination and control of dispatch communications. An iDEN network can connect to the PSTN through a Mobile Switching Center (MSC). The Metro Packet Switch (MPS) provides one-to-many switching between the Enhanced Base Transceiver System (EBTS) and the Dispatch Applications Processor (DAP) for dispatch voice and control, so it offers users the abililty to make the Selective Dynamic Group Call (SDGC). Message Mail Service (MMS) encompasses all of the software and hardware required to store and deliver alphanumeric text messages, and the InterWorking Function (IWF) is used to manage intersystem roaming. The Base Site Controller (BSC) is the controlling element between the EBTS cell sites and the MSC that processes each type of transmission. The EBTS is the cell site that links the mobile and portable subscribers to the fixed network equipment. It is the controlling element for phone and data services. The EBTS makes it possible for subscribers to access any of the four services available in an iDEN network: telephone, dispatch, text messaging, and data.

With these dual systems, the iDEN system can be explained as a complex system, which can easily generate network delays if there is no rapid response from either the MSC or DAP system.

B. Radio Propagation Characteristics

Mobile communication is based on the propagation of the electromagnetic wave signals through the air, which follows the general laws of physics: the further the distance between the receiver and the sender, the less is the signal strength.

B.1 Signal Strength vs. Distance between the Mobile Station and the Base Station

In an open area, the power, *Po*, received at a mobile-station (MS) antenna sent from a base-station (BS) antenna is given by Equation (4) [9], where *Po* is the received power at the receiver, P_t is the transmitted power from the sender, λ is the wavelength, d is the distance between the sender and the receiver, g_b is the power gain of the BS antenna, and g_m is the power gain of the MS antenna.

$$P_0 = P_t(\lambda / 4\pi d^2) g_b g_m \quad (4)$$

B.2 Elevated Antennas

In order to increase the mobile-station coverage area, most BS antennas are placed on the top of a cell tower—about 200 feet on average. Denoting h_b and h_m the elevated height of the base station and mobile station, respectively, the signal strength reached at the receiver is given by Equation (5) [9]:

$$P_r = P_0 g_b g_m (h_b h_m / d)^2 \text{, d>> } h_b \text{ and } h_m \quad (5)$$

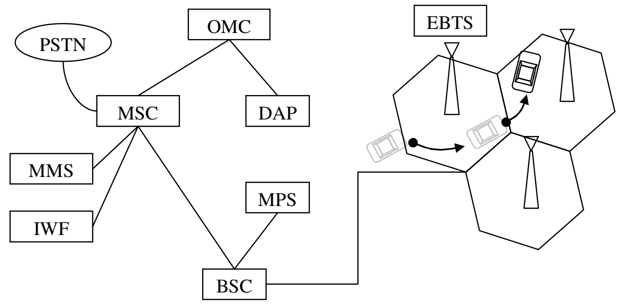


Figure 1. iDEN network system diagram

B.3 Other Factors

There are many other physical factors which have a detrimental impact on mobile communications. For instance, fading frequency is dependent on the receiver's moving speed, the reflection of the smooth objects can cause signal phase shift, diffraction can describe the modification of propagating waves when obstructed, and shadowing appears when obstacles occur in the path between the receiver and transmitter. Although DTD evaluation is assumed to consider all of these factors, in practice, the impacts of these facts are reduced through a pair of simultaneous tests: a test phone and a baseline phone are simultaneously tested in the field. Consequently, the DTD evaluation can provide evidence to indicate whether the abnormal RF signals for one particular phone are due to environmental issues, network issues, or phone issues.

C. Terrain Profile

For comprehensive evaluation purposes, the drive-test ground should cover different types of terrains. The test ground of iVESTA is shown in Figure 2, which covers a region 10 miles in diameter and includes four terrain types according to Okumura's morphology categorization [3].

- Open area: an area without any major obstacles – farmland.
- Suburban area: an area with houses, trees and low-density housing - town or small city.
- Urban area: an area with at least a two-story building - a big city.
- Mixed area: an area with one suburban side and one urban side.

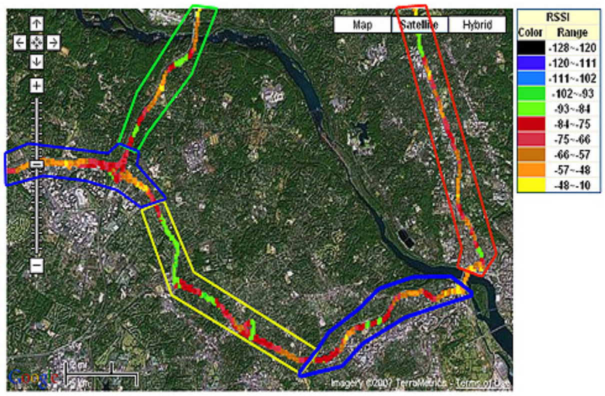


Figure 2. The four types of terrains of our drive test ground in Washington D.C (about 10 miles in diameter). Mapping tool using Google map plots RSSI data on a route in different color keys of RSSI whose table shows at the right side of the figure. The drive test area is defined into 4 different terrains: Open area in green, Suburban in red, Urban in yellow, and Mixed area in blue

D. Phone Mode Characteristics

Like many other mobile phones, iDEN phones are designed to save power, while not in use. This design generates different operation patterns for phones to listen to the BS and update its information.

D.1 Idle Mode

In the idle mode, a mobile phone will perform cell selection and reselection procedures. After a mobile phone is powered up, it performs an acquisition procedure to register to the network through a nearby base station and then listens to the paging messages broadcasted from the base station. A mobile phone in the idle mode will update its locations to the BS if necessary. Because of this, the RF measurements from scanning the neighbor cells are less accurate than the measurements of the in-call mode.

D.2 Interconnect Call vs. Dispatch Call Modes

An iDEN call mode can be separated into two types: interconnect call and dispatch. For an interconnect call, two channels—one for inbound and the other for outbound—are assigned for the call. When a call is initiated in a moving vehicle, the phone can assist the network in determining when a handover to another cell is expected. The mobile continuously monitors outbound signals from neighboring cells and measures the received power and signal quality of the signals. When the mobile determines that the neighbor measurement is higher than the measurement from the network in its currently assigned cell, it transmits a handover request to the network.

Unlike interconnect calls, which use two channels, a dispatch call uses only a single channel. The dispatch call requires the message senders and receivers to take turns sending their messages, i.e., the sender presses a button while talking and then releases the button after finishing the conversation after which the listener will press a button to make a response. In this way, the system knows the exact direction of the signal transmission.

iVESTA System Architecture

As shown in Figure 3, iVESTA mainly consists of the following ten components: drive-test log files; automatic compressor/uploader; automatic data processor; manual logs for voice defect; an integrated database; a query-driven filter/modeling; text-based summary and interactive chart; analytical mapping tools; data charts; and, replay tool.

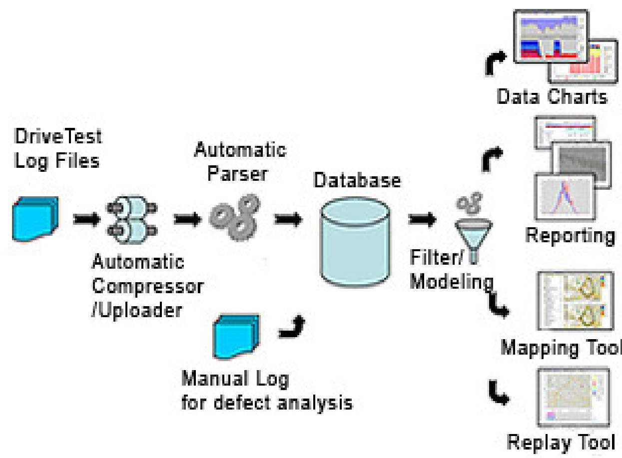


Figure 3. The main components of the iVESTA system

The structure of a log file is unique because a DTD evaluation is generated through a Radio Application Layer Protocol (RALP) device attached to the mobile phone and a computer inside a drive-test vehicle, as shown in Figure 4. In addition, iVESTA is also designed to accommodate voice quality reports, which record the voice quality of extended conversations.

To generate drive-test data, it is necessary to have a team of three people in order to operate the mobile phone, vehicle, and the base counterpart of the mobile phone. For a baseline comparison test, it is required to have a pair of two teams. Each log file mostly contains 8 hours of drive-test data, about 40 Mbytes. The cost of a drive test is expensive and the quality is poor, when compared to the in-lab simulation results. For a new product, it is required to test for several days. Therefore, web-based visualization systems play an important role in generating rapid, relevant comparison

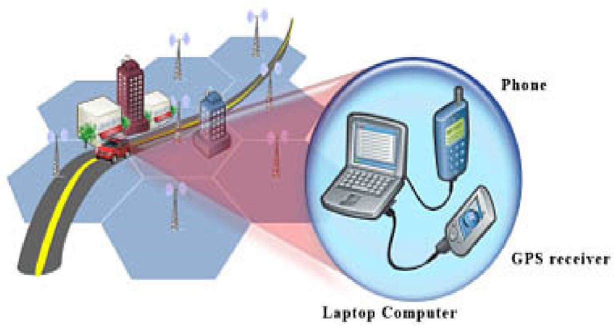


Fig. 4. The mobile drive test environment

summaries to evaluate and analyze the root cause of the defects. For the drive-test data iVESTA is dealing with, since the objective is to evaluate the new mobile phone, the baseline phone is sometimes tested with an extra antenna in order to receive a strong signal taking into consideration the vehicle penetration loss [7].

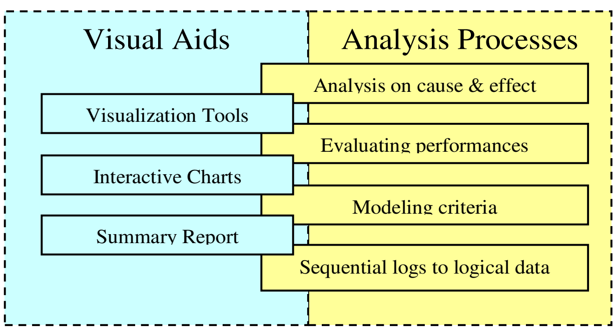


Figure 5. The Architecture of iVESTA

While the iVESTA system is intended to offer full support for the DTD evaluation, without cell site information and a channel plan from the network service providers, it is difficult to make unbiased comparisons and conclude the phone's performance. To overcome this low-data integrity hurdle, iVESTA employs a set of visual aids to bridge the gap between different levels of data understanding. As shown in Figure 5, the right side of the picture shows four layers of data analysis: (1) converting sequential logs into logical data; (2) modeling criteria; (3) performance evaluating; and (4) cause-and-effect analysis. In order to bridge the gap between two consecutive data analysis layers, a set of visual aids are employed to help users understand the data and characterize the phone's performance, such that the low-data integrity challenge can be resolved in practice.

A. DTD Format

RALP logs are sequential messages between a Mobile Station (MS) and the Enhanced Base Transceiver System (EBTS), beginning with PC time stamp and a tick count to establish ordering of additional messages within a millisecond, followed by an information log specifying the phone and conversation status. Figure 6 demonstrates the basic elements of a DTD record. Because all records and data fields are well-defined, an automatic data processor can be employed to read each single record and pull corresponding data into the database.

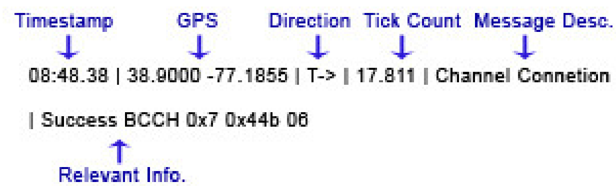


Figure 6. An example of a DTD log

B. Log Files Uploading

After DTD logs are collected by a drive test team, the files are uploaded through a web-based uploading tool as shown in Figure 7, which consists of three major parts: (1) a user information section, (2) an uploading section for DTD logs of one particular product, and (3) the uploading section for DTD logs of the baseline product. Log files are guided with proper naming conventions procedure for avoiding duplicates. In addition, all log files are automatically compressed on the local machines and sent to the server through the HTTP protocol.

The uploading process triggers iVESTA's automatic data processor to read log files and populates data into the main database (powered by MySQL), which consist of seven tables: NMS, Calls, Mobility, Events, LAPidata, Site, and Drivetest. The uploaded information, such as transaction ID and the uploader's information, is stored into the upload table. The drive-test table is a look-up table to synchronize the relationships between database tables and the log files.

The Normal Mode Summary (NMS) table contains the main DTD, such as geographical information and speed for vehicle and cell tower, PC timestamp, server color code, RSSI, SQE and measurement, the first neighbor's RSSI, SQE and measurement, the second neighbor's RSSI, SQE

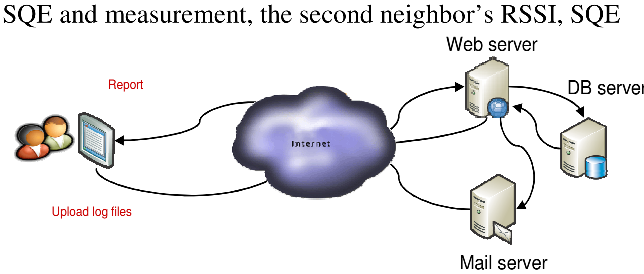


Figure 7. The upload process for log files

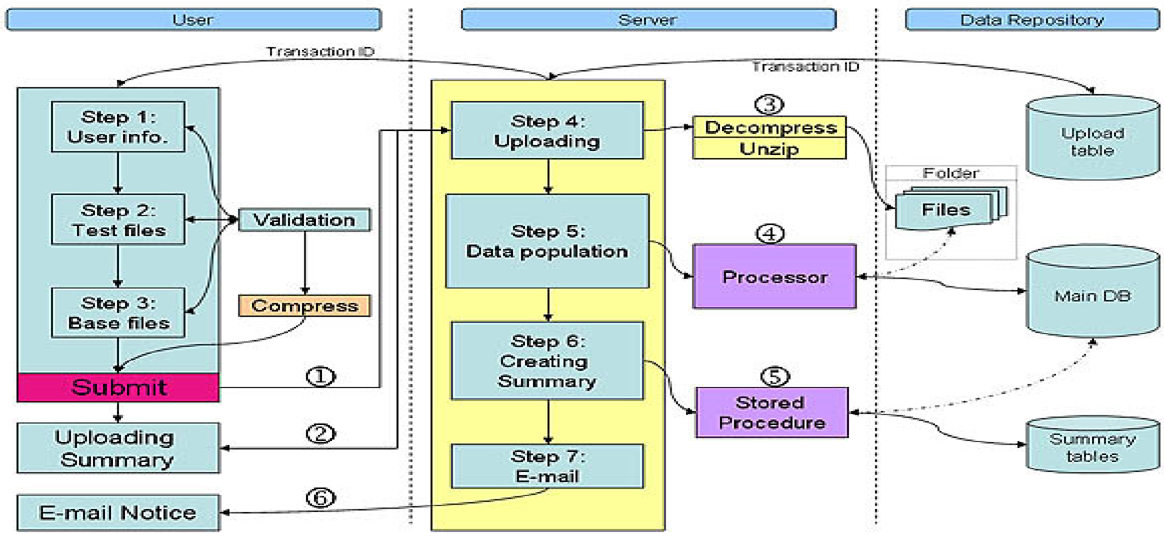


Figure 8. The data process diagram of iVESTA log file uploading

and measurement, and so on. The calls table is populated with call information such as call type, total call length and so on. The mobility table has mobility information such as the cause of handover decision, oldSitePCCH, newSitePCCH, and so on. All of the sequential event messages between MS and BS are found in the events table. Packet data information is stored in the LAPidata table. The site table places cell information such as GPS information of cell, server color code, and so on.

Following the data conversion, a summary process will create a set of charts, which may be used to help users generate a series of reports. Upon finishing the file uploading, the mail server will notify the drive-test team and their clients through an email message. A detailed diagram of the data process for uploading log files is shown in Figure 8. The uploading process starts from ① at which point a user submits the log files, which consequently triggers processing, and ② returning uploading confirmation and summary to the user. In step ③, the system decompresses the uploaded files, followed by step ④, which automatically process the log data and pulls useful information into the main database. In step⑤, the system creates a set of summary tables from the input data. Finally, then, in step ⑥, the system sends an email confirmation to the submitter and the system administrator to acknowledge the success of uploading the test data.

C. Summary Reports

The objective of the summary reports for the DTD evaluation is to provide users the statistical overview of a drive-test report: the informative summaries of events, the total calls in different modes, the average signal conditions on a route, and so on. The summary reports provided by iVESTA contain 8 main performance evaluations, which are 22 text-based summary tables, as shown in Figure 9. Users can access all of these tables by navigating the system submenus (the left panel in Figure 5.)

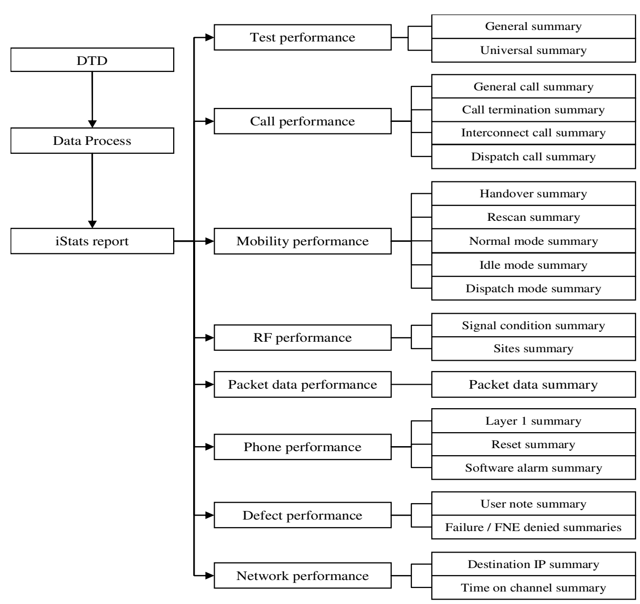


Figure 9. iVESTA performance summary diagram

In short, the summary tables cover two important components: (1) the baseline comparison form and (2) the statistical calculation based on the selected comparison attributes such as the total number of dropped calls between the test and the baseline phones. From the phone manufacturers' perspective, the most interesting parameters are listed as follows:

- Connected call percentage: number of calls connected to TCH (traffic channel) over number attempted.
- Good call percentage: number of calls ended properly over number of calls connected to TCH.
- Number of rapid handovers: two handover attempts within 10 seconds.
- Number of delayed handovers: MR sent but no handover command received within 5 seconds of the first MR sent.
- Number of Ping-Pong handovers: two handover attempts, where the radio goes from cell site A to cell site B and back to cell site A.

To provide statistical comparison analyses, iVESTA employs a two-proportion Z test with a default null hypothesis (p-value> 0.05) in all summary tables. The diagram of a two-proportion Z test is shown in Figure 10, and Figure 11 pictorially shows a summary table with statistical test results.

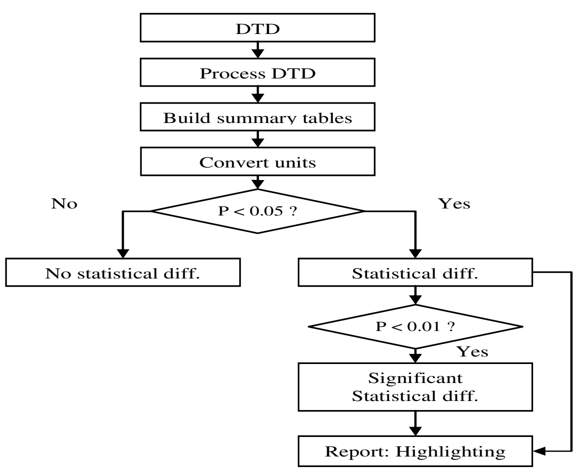


Figure 10. The diagram of a two-proportion Z test of the summary tables

D. Interactive Charts

Evaluating RF measurements of a DTD evaluation is the most important assessment in iVESTA because about 40% of abnormal events, such as dropped calls, occur in poor-signal conditions (less than -100dBm). iVESTA provides regional comparisons of RF measurements in different call modes since signal condition strongly relies on the distance and terrain type between MS and BS. In addition, interactive charts also provide spontaneous responses corresponding to a mouse position on a chart, which is shown in Figure 12.

iVESTA provides eight groups of 40 user-interactive charts and is able to let a user visually evaluate the phone performance with respect to different parameter settings. For example, the SQE (Signal Quality Estimation) charts are drawn into CDF (cumulative distribution function) and PDF (probability density function) forms and separated by five

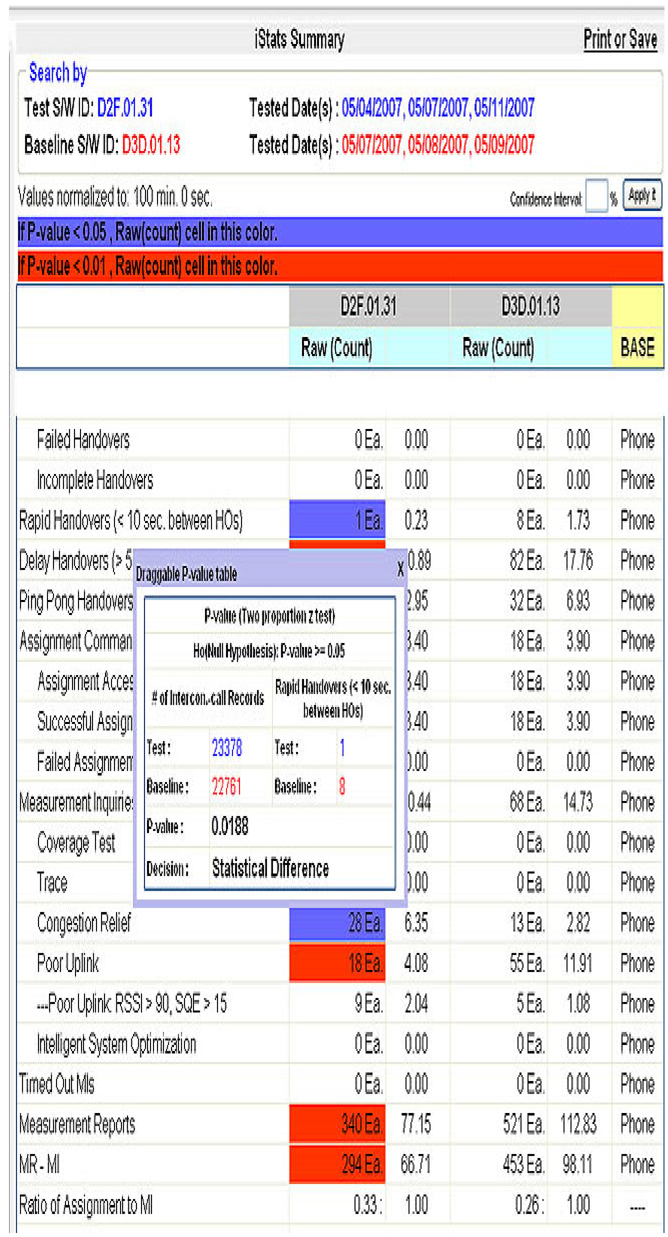


Figure 11. An example of a text summary table with a statistical information panel

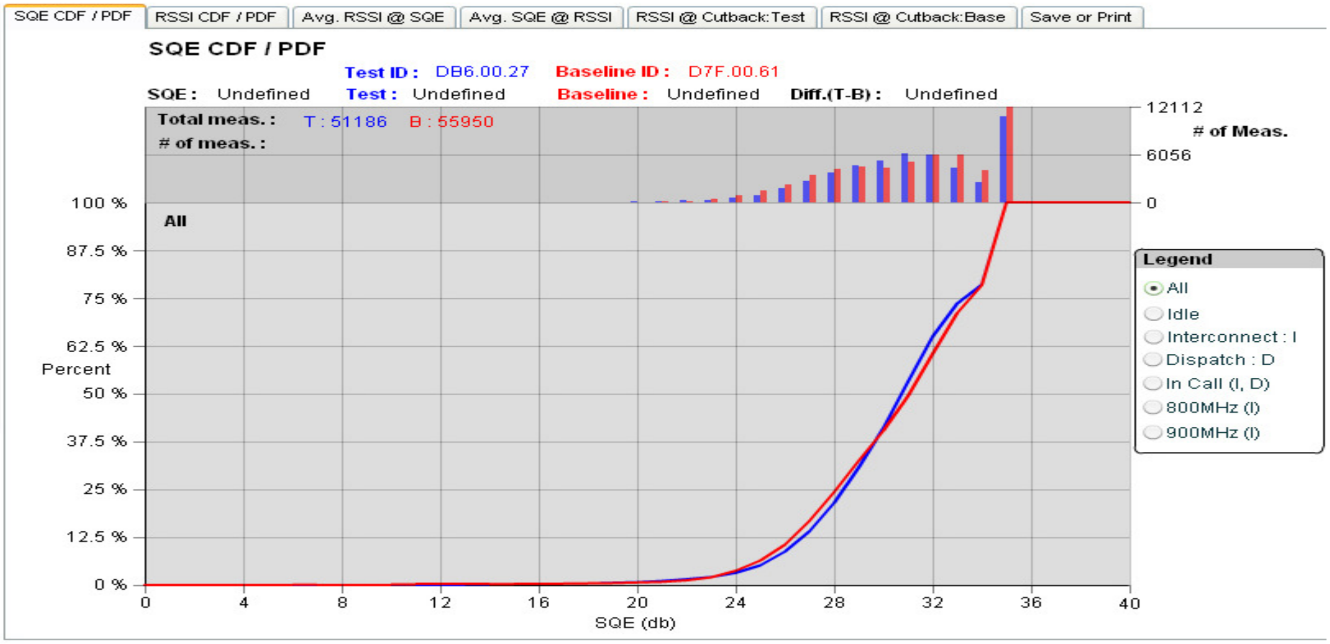


Figure 12. Interactive chart interface: all interactive charts can be navigated by selecting the menu on the left side of the figure. The lower curve graph in blue represents SQE CDF of a product under test, and the upper graph in red represents SQE CDF of a baseline product. The *x*-axis indicates SQE in the range from -10dB to 40 dB, and the *y*-axis represents the cumulative percentage in the range from 0 to 100.

different phone modes: all, in-call, dispatch, idle, and interconnect call. The interactive charts generally describe the differences between signal conditions and then evaluate the performance of the test phone with respect to the baseline phone with a particular signal condition. More specifically, if the SQE graph of a test phone is lower than a baseline phone in CDF, it means that the test phone has received a higher signal quality than the baseline phone.

E. Voice and Packet Data Evaluation Report

In addition to the evaluation at the event level, iVESTA can also provide voice and packet data evaluation reports. Consequently, the users can understand the phone performance with respect to the voice and the data transmission qualities.

During a drive test, the voice communications over mobile phones are recorded by the drive test team. To find a correlation between voice defects (unrecognized voice conversation), phone events and RF measurements, a manual process is required to compare the recorded conversation during the drive test and then store the labeled information in the defect database, as shown in Figure 13. The voice defect report is evaluated through the comparison between the test phone and the baseline phone. An example of the voice defect chart is shown in Figure 14.

Since a call communication between two users is based on the audio, voice quality is a very important factor that should be properly evaluated. Currently, iVESTA can evaluate the following types of defects: busy, choppy audio, clicks and clunks, customer unavailable, dropped call, echo, extended-muting, fading, FNE denied, freeze, garble, helicopter, iDen freeze, mute, no audio, no connect, NT, one way audio, other, and out-of-service and special codes for defects. A sample of the voice defect chat is shown in Figure 14, where the *x*-axis indicates the type of defects, and the *y*-axis represents the percentage of a defect over the total number of calls. The bars in the column indicate the defects of a product under test and baseline product. The highlighted defect in Figure 14 shows that 1.25% of calls on the baseline product have "no audio" defect, while the product under test has 0.59% only, which is clear evidence that the test phone outperforms the baseline phone with respect to the voice defects.

For a packet-switch network, the voice channels and dispatch functions are used to transmit packet data other than voice, such as emails. Due to the sharing of voice channels,

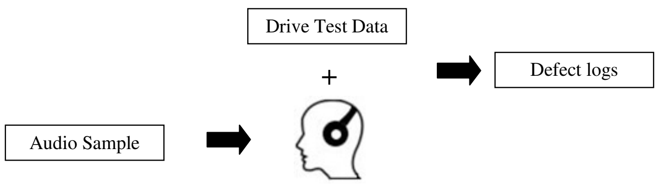


Figure 13. The diagram of voice defect labeling process: a manual process is employed to evaluate the phone conversations recorded from the drive test, and the labeled voice defects are stored in a defect database.

the actual data rate and flow will depend on the network traffic. Like iDEN, WiDEN allows compatible subscriber units to communicate across four 25 kHz channels combined, for up to 100 kbit/s of bandwidth. According to the iDEN characteristics [10], four carrier allocations for each 25 kHz bandwidth should be evaluated. For this purpose, the inbound and outbound throughputs with respect to the RF measurements are employed to indicate the packet data transmission quality. The LAPi data time chart is designed to visualize the carrier allocation performance with respect to the inbound and outbound throughputs and RF measurements. Figure 15 shows a packet data performance chart on a timeline that is placed in the middle of the chart. RSSI and SQE are shown at the top of the chart. At the bottom of the chart, four WiDEN carrier allocations and one iDEN carrier allocation are depicted with respect to the SQE timeline. This chart provides interactive and scrollable panels for test and baseline phone. From Figure 15, one can see that WiDEN carrier allocations became lower and move to iDEN carriers when the values of SQE became lower.

iVESTA Visualization Tools

The development of visualization tools for DTD evaluation is becoming an imperative demand for mobile-phone manufacturers and network providers because such tools help them analyze the collected data directly related to the customer environments. In practice, such data only make sense when interpreted in high dimensions. For example, the differences between test and baseline phones can be easily evaluated when the collected data are displayed on a map with signal strength, signal quality, distance between mobile phones and base stations, and network traffic. While the summarization tools introduced previously may indicate what happened during the drive test, e.g., dropped calls, the objective of the iVESTA visualization tools is to clearly answer why it happened, i.e., what caused the low RSSI and why the network did not properly hand over the phone to a neighbor cell.

A. Mapping Tool

The iVESTA mapping tool is a web application with selective features such as the test dates, RF measurements, and events on a map for different phones (test vs. baseline phones), as shown in Figure 16. Users can select different test dates for both phones and call modes. For all events recorded in the DTD database, some of them, such as dropped calls or rescans, are only understandable with RF measurements.

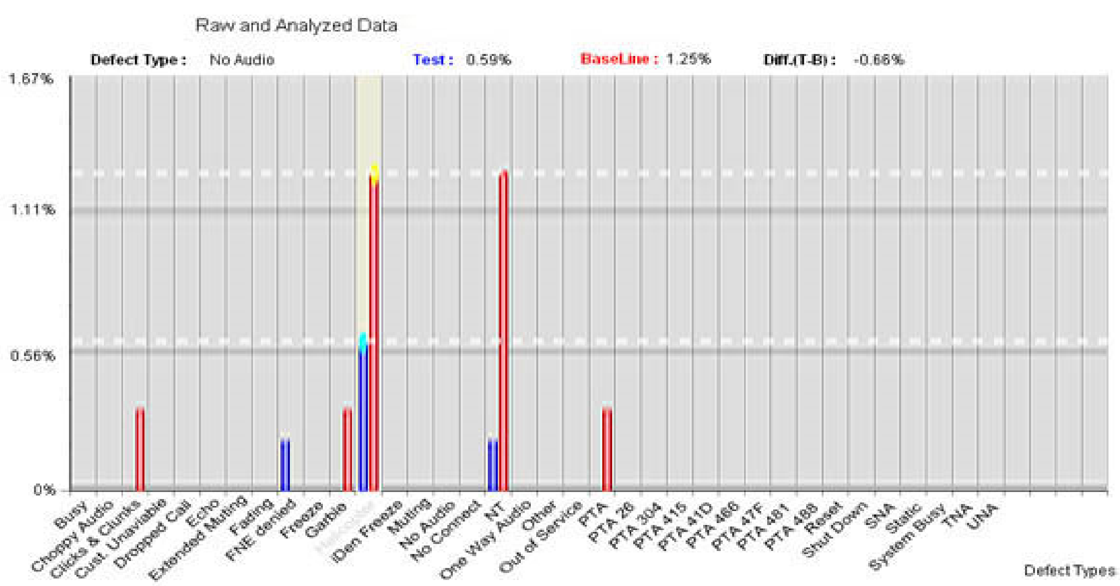


Figure 14. A sample voice defect chart

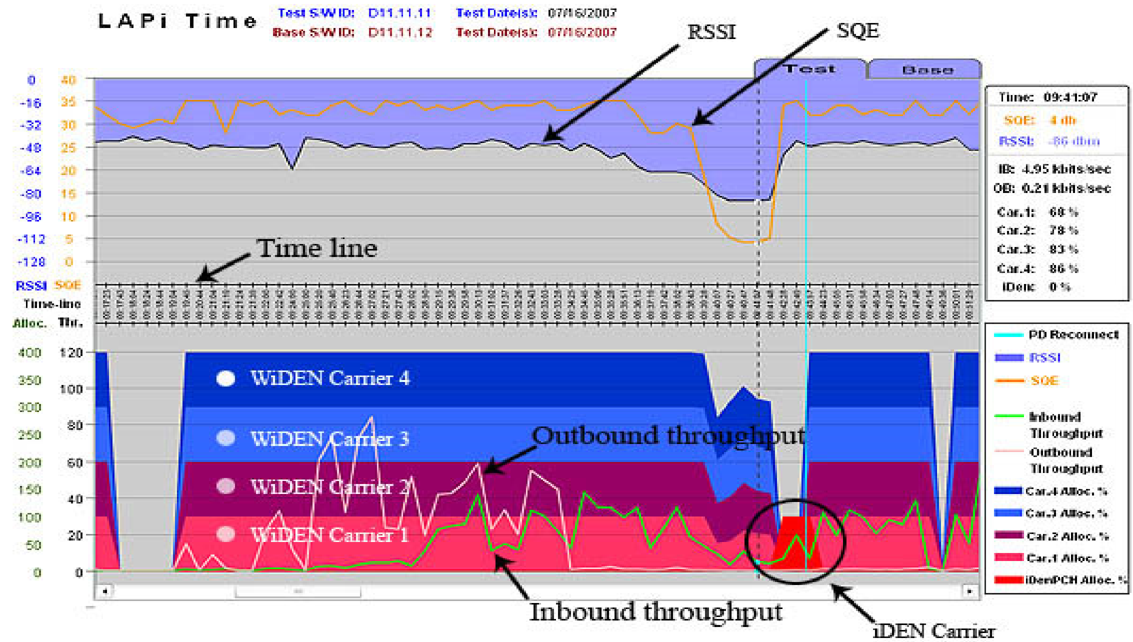


Figure 15. Sample LAPi time chart

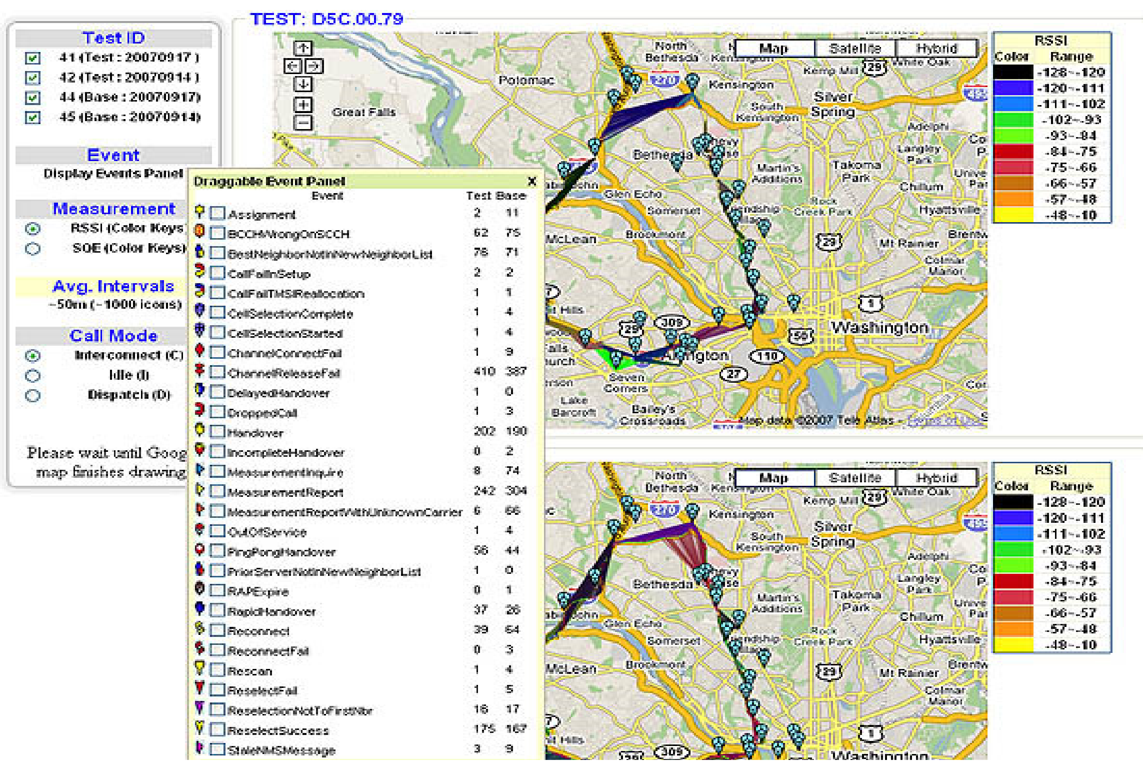


Figure 16. The mapping tool with various features: two dynamic Google maps for test and baseline phones, and moveable event panel, menu with selectable options, and icons with detailed event information.

In the iVESTA system, the RF measurements such as RSSI or SQE are visualized with color keys corresponding to the ranges of the measurements. In addition, users can selectively decide which event(s) should be displayed such that the users can review all event details. Another sample of the mapping tool is shown in Figure 17, which displays all towers and their links to the route where a mobile phone is present. In order to provide a web-based dynamic map, this tool is designed with Google map API. Instead of reviewing the coverage of the network service, this tool helps users to clearly observe abnormal mobility performances.

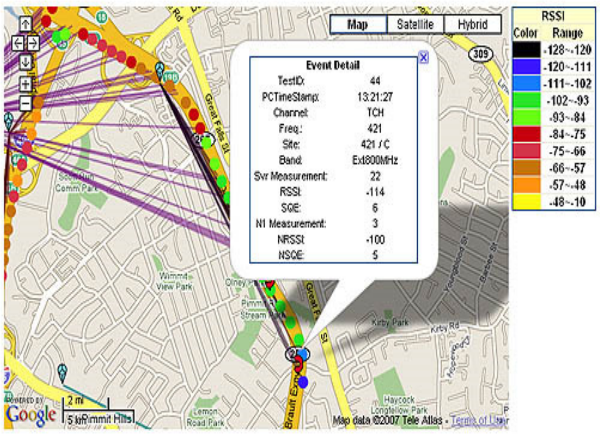


Figure 17. The detail information of a dropped call event with zoom-in state: the event detail window contains Test ID, PC time stamp, PCCH frequency and color code and RF measurements on server and foreground neighbor.

In order to reduce the time of drawing all icons on the Google map, the mapping tool is displayed in a 2-layer structure: the transparent layer is used for RF measurements and the icon layer is designed for the events. The data processing flowchart for the mapping tool is shown in Figure 18. Whenever the Google event listener catches a user event, it calls Ajax functions to retrieve data from the server and renders the map with the event icons.

B. Replay Tool

Different from the mapping tools that simply map the events to the web-pages, the replay tool helps users restore drive-test scenes with respect to factors such as the directionality and the velocity of the drive-test vehicles, through an animated web page, which dynamically shows the drive- test trail, as shown in Figure 19. In addition, the RF measurement is also dynamically visualized such that the users can understand the test environments such as signal strength, directions, handovers, and cell towers to which the phone was connecting; the bottom part of Figure 19(a) displays the

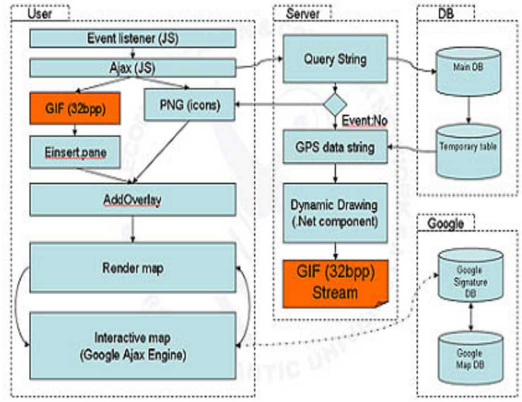
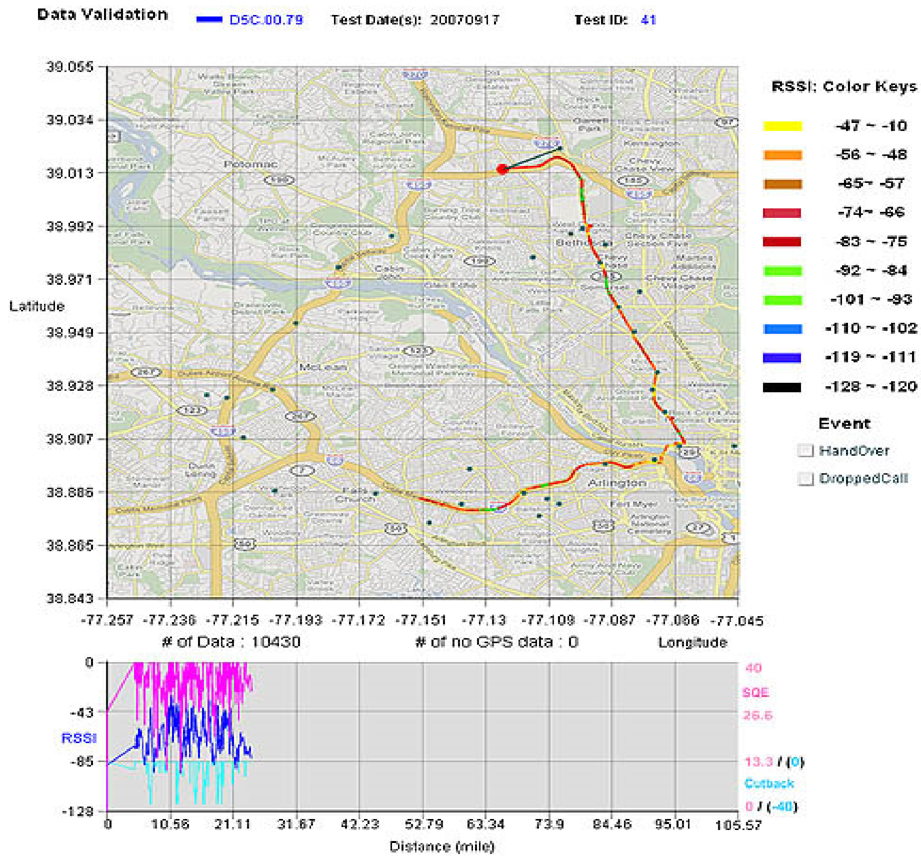


Figure 18. The data process on the mapping tool.

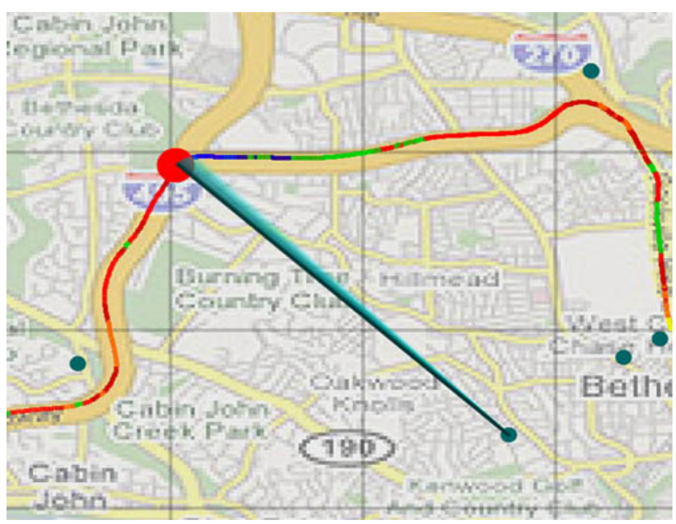
RSSI and SQE measurements along the drive-test trip. The directionality of the test route is a critical factor to the mobility evaluation because the zones of the mobility evaluation are very sensitive and dependent on this factor. At the beginning of the development of the iVESTA system, a large portion of the distinct handovers between the test and the baseline phone were observed. Later, this issue was analyzed as a cause of the vehicle directionality. This tool animates a drive-test vehicle with link lines between an MS and a BS, so it helps users to review the coverage of the network services.

Summary

Provided here was a high-level overview of the iVESTA system, which was developed for drive test-data evaluation with the objective of providing generic functionalities to help a drive-test team analyze DTD evaluations and understand the mobile-phone performance in comparison with the baseline products. iVESTA delivered a practical product for DTD evaluation, which successfully resolves the low-integrity, low-quality, high-uncertainty, and low-interpretability issues of the DTD. In short, iVESTA is a web-based reporting system which provides a full-scale evaluation of DTD through extensive comparison with the baseline phone. In addition, iVESTA provides numerous visualization tools to help users understand their DTD and essentially resolve the concerns about what happened and why it happened. This study focused mainly on the DTD evaluations from the mobile phone manufacturers' perspective. To extend this research, more efforts on scalability for a large number of subscriber clients and the extension for network service providers are highly recommended. In addition, the authors plan to focus on providing automatic scoring models for mobility and RS measurements, seamless access from chart to DTD, analysis on the cause and effect, and integrating data mining tools [8] to support intelligent data analysis in a subsequent study.



(a)



(b)

Figure 19. A screen shot of the replay tool: (a) the top part of tool illustrates the path of drive test vehicle on a map and at the same time displays the RSSI in different color keys. The bottom part of the tool plots RSSI, SQE and cutback measurements simultaneously. (b) a detailed view of the replay tool: the links between MS and BS are traced.

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References

[1] Y. Lee, X. Zhu, A. Pandya, and S. Hsu, iVESTA: an Interactive Visualization and Evaluation System for Drive Test Data, in *Proc. of the ACM Symposium on Applied Computing*, pp.1953-1957, Brazil, 2008.

[2] R. Miletic, Using Autonomous Drive Test Data to Improve Network Quality and Engineering Efficiencies, in *Proc. of the World Wireless Congress annual Conference*, 2006.

[3] Aircom Worldwide, 3G Live Network Optimised using Combined ACP and Drive Test Data, http://www.aircominternational.com/Default.aspx.locID-04vnew008.htm

[4] M. J. Flanagan, L. M. Drabeck, L. A. Cohen, A. H. Diaz, J. Srinivasan, Wireless network analysis using per call measurement data, *Bell Labs Technical Journal*, 11(4):307-313, 2007.

[5] Wu Jiao, Huang Yiling, Wei Zaixue, and Yang Dacheng, A Novel Model of Drive Test Data Processing in Wireless Network Optimization, *in Proc. of the 17th Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, 2006.*

[6] Jianming Zhang, Juanjuan Sun, and Dacheng Yang, Application of Drive Test for QoS Evaluation in 3G Wireless Networks, in *Proc. of ICCT*, 2003.

[7] Kostanic, I.; Hall, C.; McCarthy, J**.**, *"Measurements of the vehicle penetration loss characteristics at 800MHz",* Vehicular Technology Conference, 1998. VTC 98. 48th IEEE.

[8] Xingquan Zhu and Ian Davidson, *Knowledge Discovery and Data Mining: Challenges and Realities*, IGI publishing, April 2007.

[9] D. O. Reudink, Properties of mobile radio propagation above 400 MHz, in *Proc. of the 24th IEEE Vehicular Technology Conference,* Volume 24, Dec. 1973 P61 – 79.

[10] iDEN, Motorola iDEN Technical Overview, http://webaugur.com/matt/files/nextel/techover.pdf

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