Knowledge Discovery through Data Visualization of Drive Test Data

Shalini Saxena shalinisaxena1@gmail.com
Dept. of Computer Science and Engineering
Florida Atlantic University
777 Glades Road, Boca Raton, FL - 33431

Abhijit S. Pandya pandya@fau.edu
Dept. of Computer Science and Engineering
Florida Atlantic University
777 Glades Road, Boca Raton, FL - 33431

Robert Stone rstone@fau.edu
Dept. of Computer Science and Engineering
Florida Atlantic University
777 Glades Road, Boca Raton, FL - 33431

Saeed Rajput rajput@nova.edu
Farquhar College of Arts & Sciences
Nova Southeastern University
Fort Lauderdale, FL - 33134

Sam Hsu sam@cse.fau.edu
Dept. of Computer Science and Engineering
Florida Atlantic University
777 Glades Road, Boca Raton, FL - 33431

ABSTRACT

This paper focuses on the analysis of a large volume of drive test data and the identification of adverse trends or aberrant behavior of a mobile handset under test by means of drive test data visualization. The first target application was to identify poor mobility decisions that are made by the handsets in calls. The goal was to compare a set of behaviors from a baseline unit (one accepted to generally operate well). We were able to identify a particular call that was exhibiting a different path (talking to a different cell than expected or taking longer to move to a new cell). In this paper we develop a mobility tool that evaluates the handset's performance by means of mapping the handoffs on the Google Maps. The mapping of the handoffs by means of the Google Maps were very powerful in identifying the above mentioned mobility patterns.

Keywords: Mobility Patterns, Hand-offs, Drive Test, Mobile phones.

1. INTRODUCTION

In wireless communications bandwidth is always divided into smaller sub-bands. The limited availability of electromagnetic spectrum or frequency band for transmitting voice call led to the development of the cellular radio networks [1]. It essentially increases the number of simultaneous conversations (called user capacity) for mobile radio telephone service by frequency reuse [1]. In cellular networks numerous lower-power transmitters each with shorter coverage are strategically deployed to cover a large geographic area. Each cell is served by a base station that consists of an antenna, a number of transmitters, a receiver and a control unit. Within any given cell, multiple frequency bands are assigned. The number of frequency bands depends on the traffic expected. Adjoining cells are assigned different group of frequencies to avoid interference and crosstalk. However, cells that are sufficiently far apart can reuse the same frequencies since radio signals strength diminishes with distance [1]. At any given instance, a number of mobile units are active and moving in a cell, communicating with the base station. Each base station is connected to a mobile switching center, which serves multiple base stations. The mobile switching center routes the calls depending on the location of the mobile unit, assigns voice channel to each call, performs handoffs, and monitors the call for billing information [1]. We will call this mechanism mobile call management.

Handoff is an important aspect of mobile call management. During a connection when the mobile unit moves from one coverage area of a base station to another it crosses the cell boundaries. The mobile unit must switch the traffic channel assigned to the old base station to the new base station as it crosses over its cell boundary. This process is called handoff and is performed ubiquitously. The Received Signal Strength Indicator (RSSI) gets weaker as the mobile unit moves away from the base station. When a neighboring site is stronger than the serving/current cell, the mobile unit requests a handover to another site [1]. The signal strength is allocated a level from 0 to 14 with 6 dB separation between the consecutive levels [2], with 0 being the quietest and 14 being the least quiet. Therefore after the handover, the RSSI typically sees at least a 6 dB improvement.

Handoff is an important feature of mobile call management because the continuity of a call is maintained through it when the mobile moves from one cell area to another. However, cell-dragging may occur when a mobile handset moves a considerable distance into the neighboring cell area without making a handoff, resulting in an increased level of system interference [3]. A handoff scheme that utilizes two adaptive algorithms in combination; one using a relative threshold and the other an absolute threshold, has been proposed in [3]. This scheme aims at minimizing cell-dragging.

Earlier research has emphasized greatly on proposing, developing and comparing various handoff algorithms. The performance of handoff algorithms based on relative signal strength measurements has been evaluated in [4], [5], [6], [7] and [8]. In [9] a handover decision algorithm's performance is evaluated by means of a simulation that calculates expected number of handovers that occur as a user moves between two base stations. The performance of handover algorithms used in microcellular urban mobile systems is investigated in [10] by means of an analytical model that is able to take Frequency Hopping, modulation and coding schemes, fading and interference due to a multi-cell environment into account.

A new discrete-time approach has been introduced in [11] to analyze the performance of handoff algorithms based on pilot signal strength measurements. In [12] a local averaging technique for processing the received pilot signal strength, which can significantly improve handoff performance in cellular networks, has been proposed. In literature numerous papers have been published that have developed models to analyze the performance of handover algorithms [13] and [14].

Several handover algorithms have been proposed for improving the handoff performance. In [15], [16], [17] and [18] new handover algorithms and techniques to optimize the handoff algorithms' performance in cellular networks have been proposed. In [19] a survey of various channel assignment schemes has been conducted to analyze their effects on the performance of the handover algorithms. [20] provides an in depth overview of implementation of handoff schemes and analysis of their performance.

For efficient utilization of the radio spectrum, a frequency reuse scheme that is consistent with the objectives of increasing capacity and minimizing interference is required [1]. Several channel assignment strategies have been developed to achieve these objectives. In [21] an aggressive channel allocation scheme to reduce call loss due to failed hand over requests and call blocking in a multiple call hand-off context has been proposed. In [22] cellular radio channel assignment problem is addressed. They proposed a new algorithm that provides better results using the modified discrete Hopfield network.

The performance of cellular mobile communication systems such as handover priority system, with overlaying macro-cell system are evaluated and compared to that of standard micro-cellular system in [23] and [24]. In [25] for the CDMA network the effects of specific mobility parameters on base station selection using handoff algorithms are examined. They examine user mobility in the context of base station selection to study the effect of mobility parameters on connectivity and transmission quality.

Previous works [26] and [27] have proposed models to configure cellular networks based on subscriber mobility between cells. In [28] they have proposed an algorithm to dynamically determine neighboring cell lists i.e. handover candidates and their associated broadcast control channels for each cell in the system. In [29] they use knowledge of the cell terrain, the mobile trajectory, and the vehicular movements in a cellular network to predict handoff rates.

In this paper the drive test field data available for our research uses proprietary handoff algorithms for the handoff phenomenon. We do not try to evaluate or compare the performance of various handoff algorithms, but evaluate how various handsets are implementing a particular algorithm. Little has been done till date to actually analyze the performance of any of such handoff algorithms for various handsets from the user's perspective. In this paper we develop a mobility tool that measures the degree to which any handset is implementing the handoff design and it evaluates the handset's performance independent of the handoff algorithm implemented by means of mapping the handoffs on the Google Maps. The focus of evaluation is on the behavior of the handset irrespective of what handoff algorithm the service is using.

2. STRATEGY

In a drive test radios are taken in a car and calls are made while driving. Data such as the latitude, longitude, color code and RSSI is captured and collected during the duration of the call. Each day the drive test team takes a fixed route performing field test and recording the data. They have technical equipment that records the data when they make calls while driving. Separate tests are conducted for both directions – clockwise and counter-clockwise. The data collected from a baseline unit (one that is generally expected to behave well) is used to prepare a model. A test unit is the product under test whose data is compared with the baseline unit.

From the drive test data we first examine the data from the baseline unit to list all the handoffs and categorize them based on the call types which are phone, dispatch and idle. Similarly we examine the drive test data for the product under test to prepare a list of all the handoffs. These handoffs are also classified and separated based on the call types. This aggregated data of handoffs is used to identify the locations where the product under test exhibits aberrant or abnormal behavior in the sense that it communicates with a base station that serves a lower RSSI when a closer base station which can serve a better RSSI is available. A good mobility decision would be to handover to the new stronger tower as a cell phone moves from a weaker tower site to a stronger tower site.

The comparison of mobility decisions made by the product under test to the baseline unit's mobility decision is realized by means of Zones. Every time a handoff occurs in the model (data from the baseline unit) from one cell site to another cell site we construct a zone. For example, when a mobility decision is taken to handoff from color code A (radio frequency associated with the sample) to color code B, a zone is created. Similarly when the handoff occurs from Color code B to Color Code A another zone is created. Mobility decisions taken by the product under test are plotted using Google Maps but due to lack of presence of model preclude statistical evaluation. However, they are available for visual inspection on the Google Maps.

For our experiment we have primarily two phones under observation – a baseline unit and a product under test. We have learning data from the baseline unit that we use to prepare models and we have test data from the product under test.

2.1 Statistical Measure

2.1.1 Data Preparation

We will examine the drive test data collected from a baseline unit to prepare models. Drive tests produce approximately one record every second. Each record contains latitude, longitude, color code, Signal Quality Estimation (SQE) and RSSI data captured at that instance while the phone is in the call as well as when the phone is not in a call. The color code and GPS location are extracted from each record. Fig. 1 shows the mobility of a handset between two cell sites 1 and 2 that use color code A and B respectively.

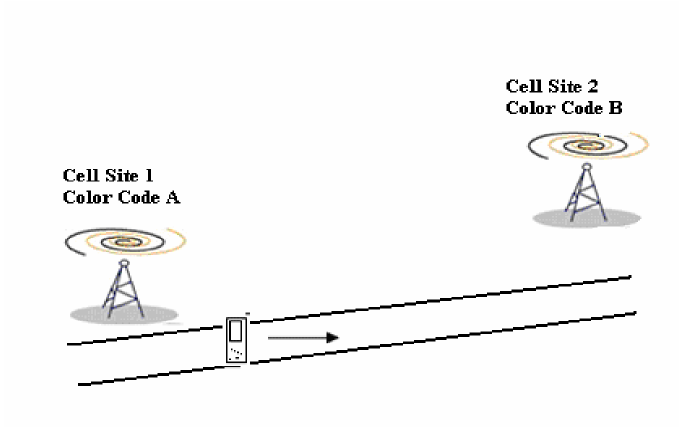


FIGURE 1 : A mobile handset moving from cell site 1 towards cell site 2

We first examine the data for the baseline unit to aggregate all the handoffs and categorize them based on the call types which are phone, dispatch and idle. Every time a handoff occurs in the model from one cell site to another cell site we construct a zone. For a handoff where the handover occurred between two cell sites such that the old and new cell sites have been recorded and a zone exists previously, then that handoff is assigned to that zone. Fig. 2 shows a portion of the route where the handoffs for the model data occurred from cell site 1 to cell site 2 such that the color code changed from A to B. Hence handoffs P, Q, R, S, T, U and V that handed-over from color code A to color code B are aggregated into one zone. In every zone using the color code and GPS data (latitude and longitude) we calculate the distance of each handoff from every other handoff. For example, the distance of P from Q, P from R, P from S, P from T, P from U and P from V is calculated and similarly the distance of each other handoff Q, R, S, T, U and V from every other handoff is calculated.

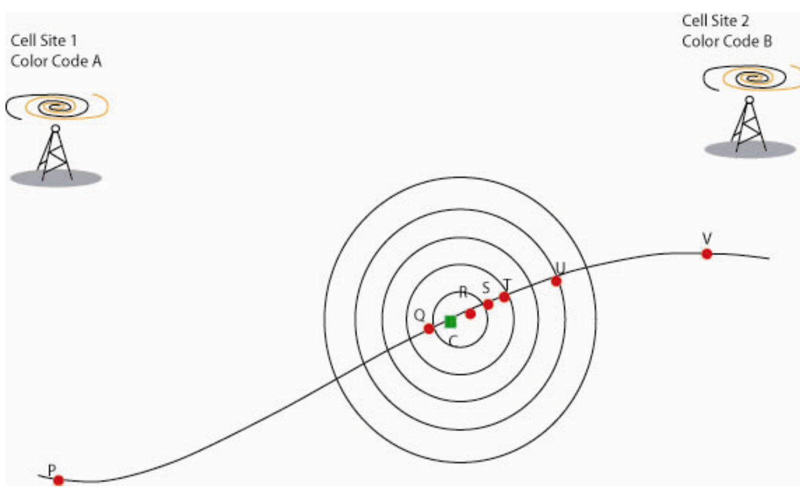


FIGURE 2 : Handoff aggregation into a Zone for the Baseline Unit

For each handoff we find the mean distance of its distance from every other handoff. After calculating the mean distance for each handoff we find the mean of all the mean distances. A standard deviation of 1.96 is calculated on the data set of means of all the means for the handoffs. Using the standard deviation we eliminate the handoffs that are outliers. An outlier is an observation that is numerically distant from the rest of the data. In Fig. 2 handoff P and V are examples of outliers. The center of the handoffs that excludes the outliers, called the center of the zone is now calculated. In Fig. 2 C is the center of the zone. We now calculate the distance of each handoff for the model from the center of the zone. For each call type of the model we calculate the

Standard Deviation for all the handoffs from the center of the zone. In Fig. 2, each concentric circle indicates the distance from the center of the zone in 0.5, 1, 1.5, 2 and 2.5 standard deviations respectively.

Similarly we examine the drive test data for the product under test for the same zone to list all the handoffs and categorize it into three different handoff lists based on the call types - phone, idle and dispatch. Fig. 3 shows a, b, c, d, e and f as the handoffs for the product under test. C1 is the center for these handoffs. Fig. 4 shows the product under test's handoffs aligned in the zone along with the baseline unit's handoffs. The distance of each handoff of the product under test from the center of the zone C is calculated. Then we use the standard deviation from the model for the model as well as the product under test so we can represent the distance of the handoffs in terms of the model. Then the distance of each product under test handoff from the center of the zone is compared to this Standard Deviation of the model. For example if 1 standard deviation from the model was equivalent to 50m and a handoff for the product under test is 91m away from the center of the zone we marked it as within 2 Standard Deviation. We do not use the standard deviation of the product under test, because we need to compare to the model and how does it perform in reference to the model. If we take the standard deviation of the product under test into consideration we will not be able to compare it to anything. By comparing to the model it compensates if the model performed poorly.

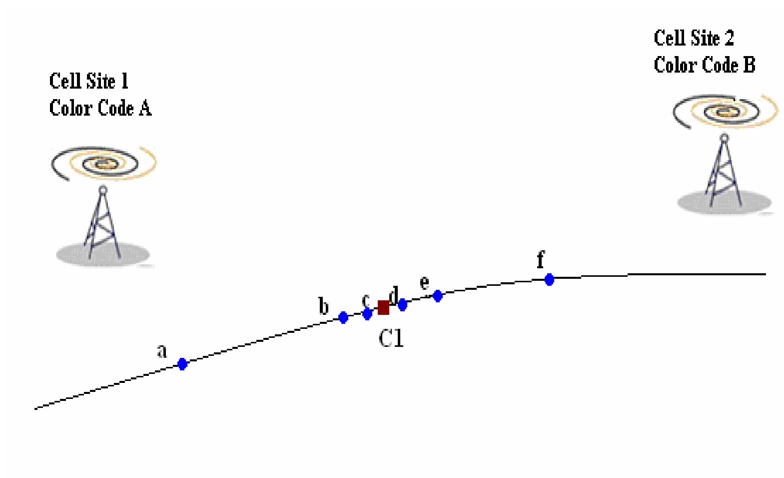


FIGURE 3: Handoffs for the Product under Test

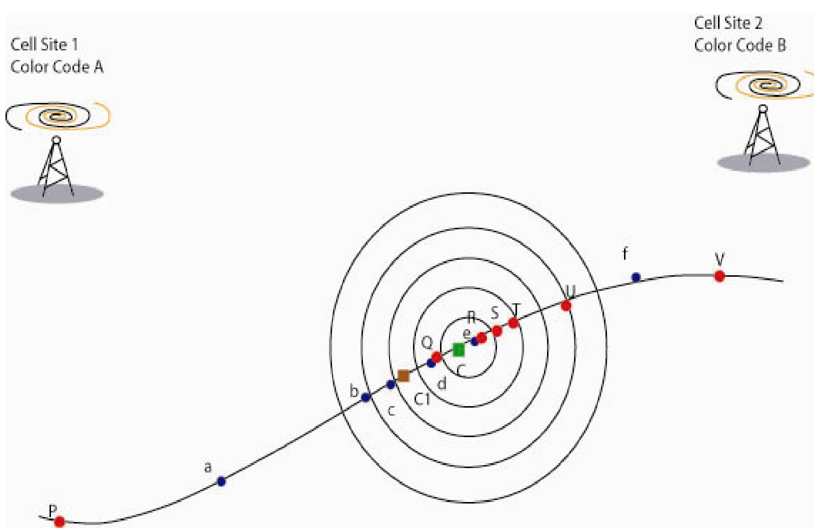


FIGURE 4: Handoffs for the Product under Test within a Zone

2.1.2 Standard Deviation as a method for comparing the behavior of product under test with baseline unit

Standard Deviation is a simple way of describing the range of a variation (usually denoted by the Greek letter sigma: σ). For our experiment we measure the deviation of the handoffs for each call type of the test unit in comparison to the handoffs for the corresponding call type in the baseline unit. Standard Deviation is the squared root of the variance. Variance (S2) is computed by taking the average squared deviation of the mean distance of all handoffs from the center of the zone (X') from the distance of individual handoff from center of the zone (Xi). For example, in a zone for the call type Idle we examine the handoffs for the model data to compute the variance and then the standard deviation. The Variance is calculated as below:

$$S^2 = \Sigma \frac{(X_i - X')^2}{n} \qquad (1)$$

Here n is the total number of handoffs for the call type Idle. Standard Deviation can now be calculated as the square-root of the variance.

For data that is "normally distributed" we expect that about 68.3% of the data will be within 1 standard deviation of the mean (i.e., in the range X' ± σ). In a normal distribution there is a relationship between the fraction of the included data and the deviation from the mean in terms of standard deviations (Table 1).

Fraction of Data	Number of Standard Deviations from Mean
50.0%	.674
68.3%	1.000
90.0%	1.645
95.0%	1.960
95.4%	2.000
98.0%	2.326
99.0%	2.576
99.7%	3.000

TABLE 1: Relationship between the fraction of the included data and the deviation from the mean in terms of standard deviations

Thus we should expect that 95% of the handoffs would be within 1.96 standard deviations of X' (i.e., in the range X' ± 1.96σ). This is called a 95% confidence interval for the sample.

3. DATA VISUALIZATION

The drive test data for the baseline unit is used to make a model. We select data from a day when the drive test team followed the route either in a clockwise or counter-clockwise direction. Similarly we select data from the product under test that we like to compare with the model for the same direction. The handoffs for the model and the product under test that have been aggregated into zones are mapped on the Google Map for visual inspection. Fig. 5 shows a map of the zones for the drive test data for the baseline unit and product under test in the counter-clockwise direction. From the map we can clearly see that a large number of handoffs occurred off the route.

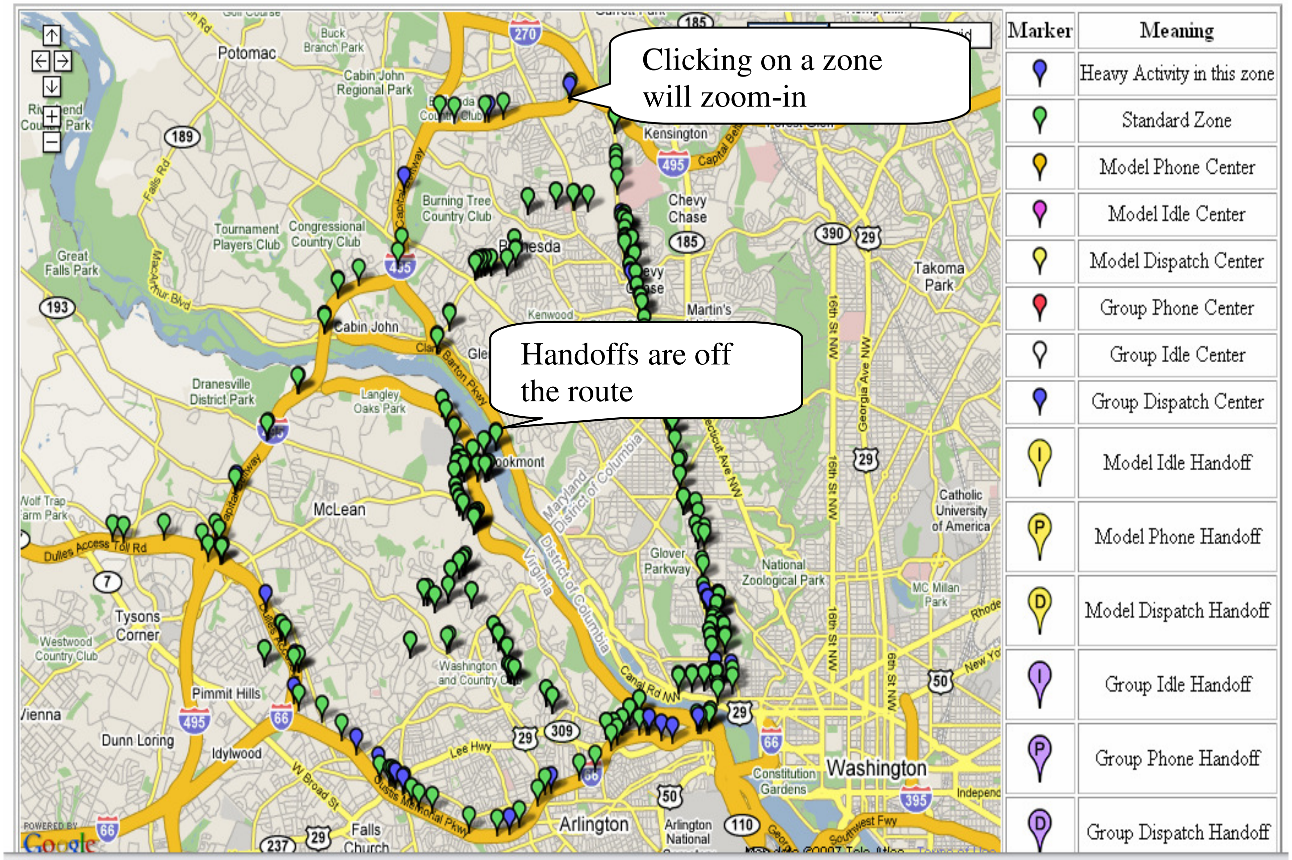


FIGURE 5 : Handoff mapping for the baseline unit and product under test on the Google Map

Zooming into a heavy activity zone (Fig. 6) we can clearly see that the product under test's handoffs for not all call types are aligned along the route with the baseline unit. This implies that the product under test has dissimilar behavior compared to the baseline. The idle-handoff for Test-ID 2869 is clearly not close to the model handoffs for idle call type. This implies that this handoff data requires further inspection. On further analysis we found that this data was mislabeled having counter-clockwise directionality. This drive test data was in actuality from a clock-wise route. The statistical analysis that is used to aggregate the handoffs into zones is represented along with the map (Fig. 7). The data for the product under test is indicated as Group and baseline unit data is indicated as Model.

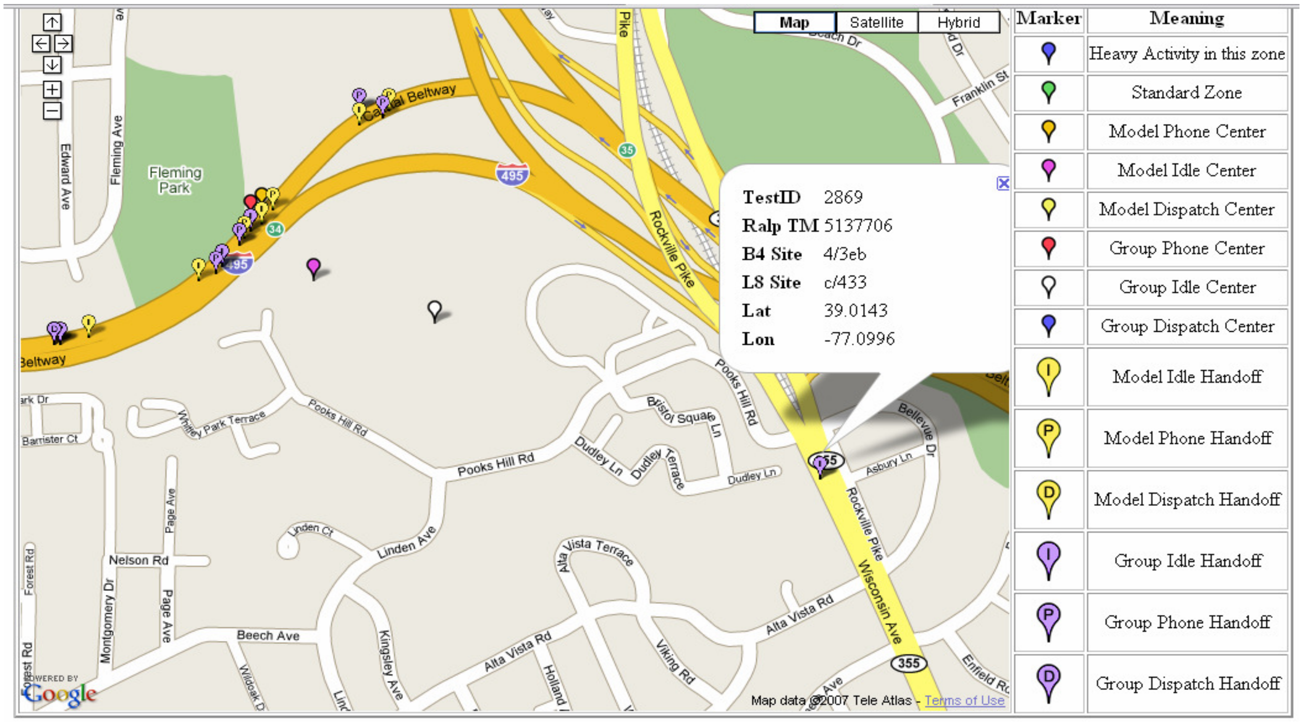
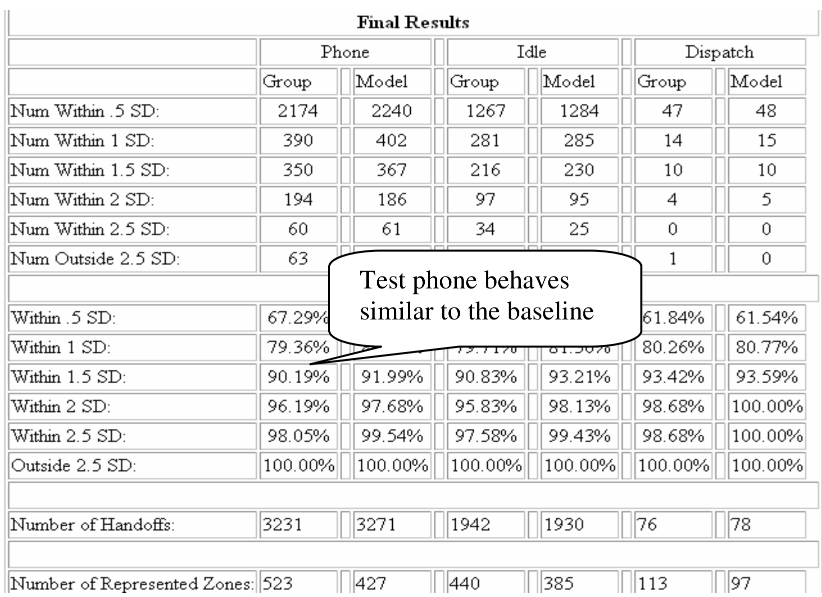


FIGURE 6: Zoomed in view of a Zone



Final Results

	Phone		Idle		Dispatch	
	Group	Model	Group	Model	Group	Model
Num Within .5 SD:	2174	2240	1267	1284	47	48
Num Within 1 SD:	390	402	281	285	14	15
Num Within 1.5 SD:	350	367	216	230	10	10
Num Within 2 SD:	194	186	97	95	4	5
Num Within 2.5 SD:	60	61	34	25	0	0
Num Outside 2.5 SD:	63	[illegible]	[illegible]	[illegible]	1	0
Within .5 SD:	67.29%	[illegible]	[illegible]	[illegible]	61.84%	61.54%
Within 1 SD:	79.36%	[illegible]	[illegible]	[illegible]	80.26%	80.77%
Within 1.5 SD:	90.19%	91.99%	90.83%	93.21%	93.42%	93.59%
Within 2 SD:	96.19%	97.68%	95.83%	98.13%	98.68%	100.00%
Within 2.5 SD:	98.05%	99.54%	97.58%	99.43%	98.68%	100.00%
Outside 2.5 SD:	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Number of Handoffs:	3231	3271	1942	1930	76	78
Number of Represented Zones:	523	427	440	385	113	97

FIGURE 7 : Final Result representation for the handoffs

The mapping of handoffs on Google Maps is very powerful in visually evaluating the data for errant handovers, cell drags, directionality and other mobility decisions. It separates the handoffs into different call types which allows for examination of each call type individually. The aggregated results generated using standard deviation provides a measure of how similar the test unit is behaving to the baseline unit.

4. CONCLUSION

The purpose of our research using data visualization of drive test data through Google Maps yielded results that helped identify aberrant mobility decisions of a product under test. This study used large volumes of real drive test data from the industry to project the behavior of the radios. Meaningful data was extracted from this enormous drive test data using data-mining and using mathematical models different call-types were analyzed for hand-over and mobility patterns. Similar work was done in [25] for CDMA networks to study the effect of mobility parameters on connectivity and transmission quality.

Other related works [26] have proposed models to configure cellular networks to study the dynamics of the mobility between single and multiple cells. In [28] they proposed an algorithm to dynamically determine neighboring cell lists i.e. handover candidates for each cell in the system. On the other hand this paper proposes a dynamic model using the data from the proprietary system iDEN (Integrated Dispatch Enhanced Network) for a baseline unit to study the existing network layout, handoff rates and mobility decisions of various call types available in this network. The Google Maps graphs were very powerful in highlighting cells drags and hand-off activity. The mobility tool developed to examine the mobility decisions of test units is technology independent and can be applied to other technologies like CDMA, GSM or WiMAX.

Unlike the previous studies which did not verify their theoretical models [27], our work utilized volumes of industrial data to suggest a model that was implemented for analyzing other products under test. In [29] they make use of knowledge of the cell terrain, the mobile trajectory, and the vehicular movements in a cellular network to predict handoff rates. However, our research is independent of the cell topography (i.e. road layout, street orientation and network layout) and is very dynamic in analyzing the mobility patterns irrespective of the network architecture and terrain layout.

Little research has been done so far to actually analyze the performance of any handoff algorithms for various handsets from the user's perspective. In this paper the drive test field data available for our research used proprietary handoff algorithms for the handover. We did not try to evaluate or compare the performance of various handoff algorithms, but evaluated how various handsets implemented a particular algorithm. We analyzed the data collected by the drive testers wherein they made calls and recorded the data pertaining to the calls almost each second. The focus was to analyze the large volume of drive test field data and develop a method that can measure the degree of adverse trends or aberrant behavior of a product under test. Data visualization of the handoffs by means of Google Maps was very effective in comparing a set of behaviors from a baseline unit and identifying a particular call that is exhibiting a different path (talking to a different cell than expected or taking longer to move to a new cell site). Hence this data visualization method was very effective in providing a method to evaluate the performance of handoffs of the mobile phones.

The mobility behavior of nodes is an important issue as discussed in [30] and in future we plan to incorporate path accumulation during the route discovery process using the Optimized-AODV protocol to attain extra routing information. Networks are being overloaded in terms of their capacity and probability of blocking being high day-by-day and in future we plan to extend our work to include a share loss analysis of internet traffic when two operators are in competition in respect of quality of service as discussed in [31].

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