

Statistical Approach for Analyzing Cell Phone Handoff Behavior

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Abstract

A handoff behavior evaluation method is proposed that uses real data collected from actual drives to evaluate the performance. This data is aggregated to perform statistical analysis. A chi-square statistical test is then presented to evaluate the performance of specific cell phone model by comparing the behavior of a test model against a well-established behavior profile. This technique can also be used to compare performance of set of models in one region to performance of same set in other region, and to determine the effect of directionality on the cell phones.

Introduction

Since the invention of wireless communications [1], innovations have continuously pushed the limit of capacity of wireless systems. First, frequency division multiplexing was used to transmit and receive multiple signals simultaneously. Then Time division multiplexing was used to further expand the capacity of communications. [2]. Ever increasing need for wireless call traffic on limited electromagnetic spectrum or frequency band led to the development of the cellular radio networks [3]. It increases the number of simultaneous conversations possible (called user capacity) in a given mobile radio telephone system by frequency reuse [3]. In cellular networks, numerous lower-power transceivers, each with shorter coverage, are strategically deployed to cover a large geographic area. Frequency reuse factor expresses the rate at which a given frequency can be used in a given network. Several low power transceivers are part of a base station that services a cell. The base station also contains a control unit that manages continuity of individual phone calls. Multiple frequency bands are assigned to each cell, so the base station is capable of communicating with cell phones in that cell on any of those frequencies. In a given cellular architecture, the number of frequency bands assigned to a cell depends on the traffic expected in that cell. 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 [3]. To achieve this, frequencies are usually bundled into colors. Thus, the problem of frequency allocation maps to the map-coloring problem [4,5]. In a real cellular network, at any given instance, a number of mobile units are moving in a cell, and they actively communicate with the base station. Several channel assignment strategies are discussed in the conventional research publications for instance, [6] discusses 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. 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 [3]. In this paper this mechanism will be called mobile call management.

When a mobile unit moves from coverage area of one base station to another it is said to have *crossed 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 [3]. After the handover, the RSSI typically sees significant improvement. Cell dragging may occur when a cell phone moves a considerable distance into the neighboring cell area without making a handoff, resulting in an increased level of system interference [7]. Cell dragging may lead to increased number of call drops. In order to measure the rate of call drops [8] has developed a method of processing information about dropped calls in a cellular network by using mobile station locations and information about locations where calls are dropped. 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 [7]. This scheme aims at minimizing cell dragging. Other works [9 and 10] have proposed models to configure cellular networks based on subscriber mobility between cells. In

[11] Magnusson, and Olofsson 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. Bansal et.al [12] propose using knowledge of the cell terrain, the mobile trajectory, and the vehicular movements in a cellular network to predict handoff rates. In [13] a system has been developed to monitor cellular telephone system that collect call performance information like signal strength and call events. This Cellular Communications Drive Test System enables mapping of the call information based on GPS information collected. Another enhancement in the field of drive test was performed in [14] for providing signal quality measurements in drive test systems for wireless networks.

This research does not try to evaluate or compare the performance of various handoff algorithms; instead it evaluates the performance of various phones models. Little has been published to-date that provides methods of analyzing the real world performance phones from the user's perspective. This work develops a comprehensive statistical test that measures the degree to which any cell phone model is implementing the handoff design and it evaluates the phone's performance independent of the handoff algorithm implemented. The focus of this evaluation is on the behavior of the phone irrespective of what handoff algorithm the service is using.

In section 2 provides the profiles of desirable and undesirable mobility behaviors. In section 3 discusses the proposed strategy in how the data is collected, and aggregated. In this section also provides a stochastic model and how the data is used to calculate the statistical chi-square test on obtained data. Section 4 presents the results and show models that made poor mobility decisions can be successfully distinguished with this approach. To protect the proprietary information, generic names for proposed models are used, even though the data was collected using actual phone cell models.

Mobility behavior

A normal decision consists of a handover to the new tower that provides the unit with higher RSSI (stronger signal) as a cell phone moves from a weaker tower site to its neighborhood. This decision process is illustrated in Figure 1. Position 1 in Figure 1 depicts the behavior of the cell phone while it is moving from one cell to another cell. At position 1 it is within the coverage region of Base station A that has assigned Color Code X. It is moving towards Base station B that uses Color Code Y. At position 2 it moves away from A it goes in the overlapping region between the two base stations. In this region the RSSI from two stations are close in values. To avoid excessive handoffs in this region the cell phones are designed to retain connection with the previous tower till the signal from tower B is at least 6dB stronger.

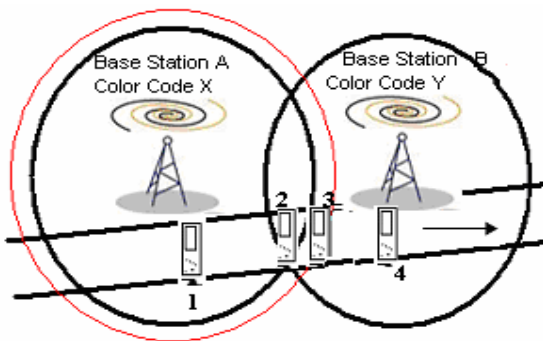


Figure 1 Mobility Behavior of phone

When the cell phone moves to position 3, the phone has moved closer to base station B and is closer to the base station B than the base station A. The phone at this point is expected to perform a handoff to cell site B with the new frequency. When the phone (position 4) crosses the range of base station A, a normal phone switches the mobile communication with the base station B and performs a handoff such that it now uses color code Y of cell site B. The base station A hands over the communication channel it allocated to communicate with the mobile to base station B so that it can establish the same communication with the cell phone.

Under these conditions if the phone fails to handoff, it is said to make a poor mobility decision. The poor mobility decision in this case would be to continue to use base station A while Base station B's RSSI is higher than 6dB. This is called cell

Data Aggregation

Proposed analysis is based on the “color code” and GPS location. Using the GPS data the drive test route is divided into 50m x 50m squares and color code information is aggregated. In a square, number of records collected is ranked based on a measure that is based on statistical techniques. The choice of 50m x 50m squares seemed to provide most consistent results for proposed analysis. Figure 3 shows a diagrammatic representation of the 50m x 50m grid that is used to divide the drive test route. In the early phase smaller grid size of 30m x 30m was tried and then larger grid size of 100m x 100m was used. Smaller grids did not have enough data in unit areas to provide significant sample sizes, while in the bigger grids data resolution reduced. One observation while analyzing smaller grids was that there are more valid grid points to use for comparison. Due to the motion of the car and the one-second delay between samples associated with moving at 60mph it was not feasible to choose squares smaller than 30m.



Figure 3 Grid drawn over the Drive test Loop Note: Grid is not drawn to scale

The aggregated data is then used to identify poor mobility decisions that are made by the cell phone.

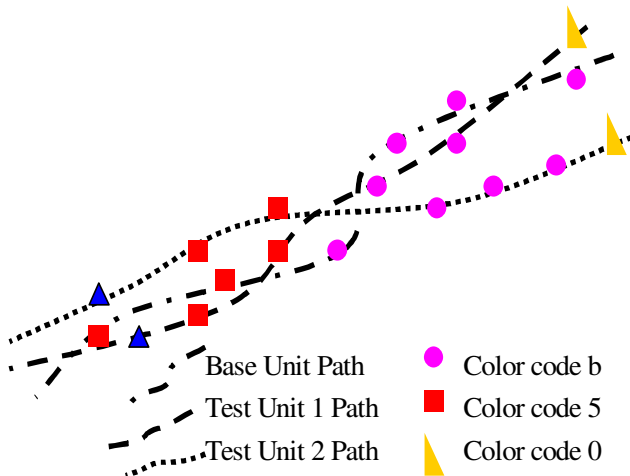


Figure 4 Color Codes observed for three drive tests

To aggregate the data for a cell the number of same color code samples for the same type of cell phone in the square was counted. This number is divided by the total number of observations in that square to obtain the frequency of that color.

When the color code is treated as a random variable, this color frequency distribution estimates the distribution of this random variable. The underlying sample space for a given square for this random variable will have all the color codes.

Figure 4 shows a sample square in the geographic grid with three drives and the colors of the observations. The paths of the drive vehicle are indicated by dashed curves while the colored symbols indicate the color observations during those drives. In this paper, different symbols have been used for each color.

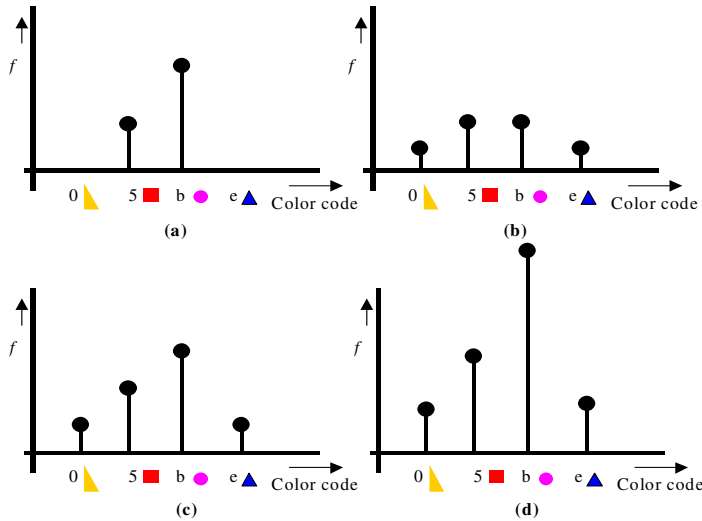


Figure 5 Frequency distribution for base model (a), test model 1 (b), test model 2 (c) and aggregated frequency distribution for all three models (d).

The resulting probability distributions are shown in Figure 5(a) for base model, (b) for test model 1, and Figure 5(c) for test model 2. To obtain a more accurate distribution, one can also aggregate data from multiple test drives that belong to the same cell phone model as illustrated by the distribution shown in Figure 5 (d).

Stochastic Model

The basic unit of this stochastic process is the square in the grid over which the observations are made. The basic experiment consists of two test drives through this square, one for the test model and the other for the base model. The color code distribution has already been discussed. That corresponds to a color code random variable for a given cell phone is used to denote this random variable with $c_{i,j,t}$, where (i,j) correspond to the longitude and latitude coordinates of the square in the grid and t corresponds to the test ID of the particular drive. The phone unit can also be treated as a random variable as well and represent it by $p_{i,j,t}$. In proposed model, this random variable has two values base model and test model. The two random variables $c_{i,j,t}$, and $p_{i,j,t}$ form a joint probability space for a given cell. Because there are 16 color codes in one cellular model and two phones, there are 32 possible outcomes. For instance (base, red) is an outcome that indicates that the base model is connected through the red frequency. The probability of this outcome is given by the relative frequency distribution observed for that color code and the cell phone. Thus, this joint probability space can be organized as a contingency table. Table 1 is an example of a 2 x 16 contingency table for the two phones (baseline and test) and 16 color codes. The column total and row total are marginal totals.

Table 1 A 2 x 16 Contingency table for Color codes and phones

	Color Code																Total
	0	1	2	3	4	5	6	7	8	9	a	b	c	d	e	f	
Model	0	0	30	38	0	0	0	0	0	0	0	0	0	0	0	0	68
Test	0	0	16	65	0	0	0	0	0	0	0	0	0	0	0	0	81
Total	0	0	46	103	0	0	0	0	0	0	0	0	0	0	0	0	149

The objective of the test was to determine if the selection of cell phone affects the color code distribution. If the two cell phones behave in a similar fashion, the color code distribution should be unaffected when the cell phones are switched. That

would imply that the color random variable is independent of cell phone random variable. However, if they have different color code distribution for that given square then the cell phones behave differently, the two random variables are dependent. Hence, this problem can be setup as a statistical Independence hypothesis test problem, where the *Null Hypothesis* being that the random variable color is independent of cell phone.

H_0 : Color code distribution is independent of cell phone selection (i.e. $c_{i,j,t} \times p_{i,j,t}$)

H_a : The variables are dependent

To establish this independence, the approach is to calculate the Chi-Square test statistic for each square and rejecting all the squares in which the null hypothesis is not rejected using the p-value test. Only the squares in which the null hypothesis is successfully rejected are kept. These are the squares where changing the two cell phones provided different color code distributions.

The next section compares the hand-off behavior of cell phones in a square using one test drive for the base model and one test drive for the test model. The hand-off behavior of cell phones using the aggregated data from multiple test-drives for the base model is compared and model in selected squares of the aforementioned grid is tested.

Results

This section also compares the handoff behavior using one test drive for the base model and one test drive for the test model. To improve the accuracy of results data aggregated from multiple drives is compared so that the number of samples in a single square is higher. Results from three squares that were studied are presented.

The first comparison for the single test drive and multiple test drives is conducted on a square with the latitude and longitude coordinates as 176 and 415 respectively.

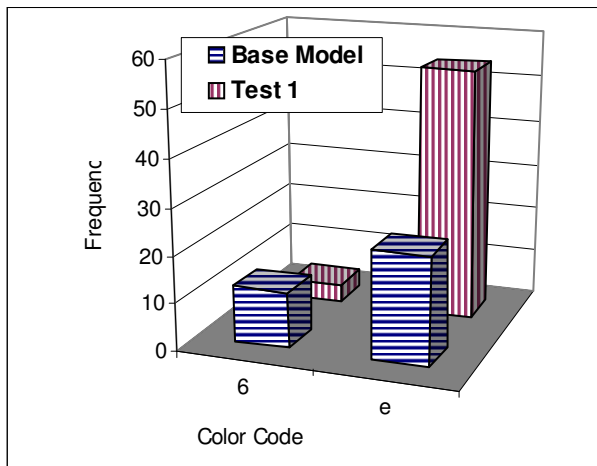


Figure 6 Test model 1 compared with the base model using data from a single test drive, Chi-Square = 11.495, degree of freedom = 1 and p-value = 0.0007

Figure 6 shows data from when a single drive test data of base model is compared with the test data of a single drive of out test model 1. In this data, there are two observed frequencies of colors 6 and e in this square so the contingency table will be of size 2 x 2). The Chi-square value for this comparison is 11.49544 and degree of freedom (DoF) is 1. At significance level 0.01 using the p-value 0.000698 it is inferred that the handoff behavior for Test 1 is significantly different from base model and requires further inspection.

Similarly, we compare base model with test model 2. Again we see the same two colors 6 and e but different frequencies as shown in Figure 7. At significance level 0.01 using the p-value 0.082346 it is inferred that the handoff behavior for Test 1 is significantly similar to the base model and should be a good cell phone model.

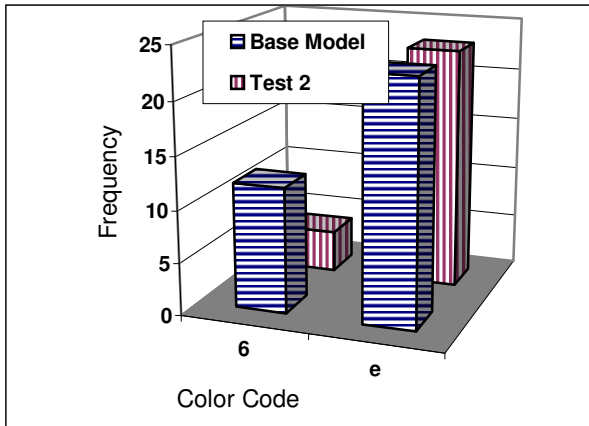


Figure 7 Test model 2 compared with the base model using data from a single test drive, Chi-square = 3.018 degrees of freedom = 1 and p-value = 0.08235

For the same square multiple test-drives can be compared for base model to multiple test-drives of test model 1, test model 2 and a phone moving in opposite direction. First comparison was base model to test model 1 (Figure 8). At significance level 0.01 the handoff behavior for Test 1 is determined to be significantly different from base model and requires further inspection.

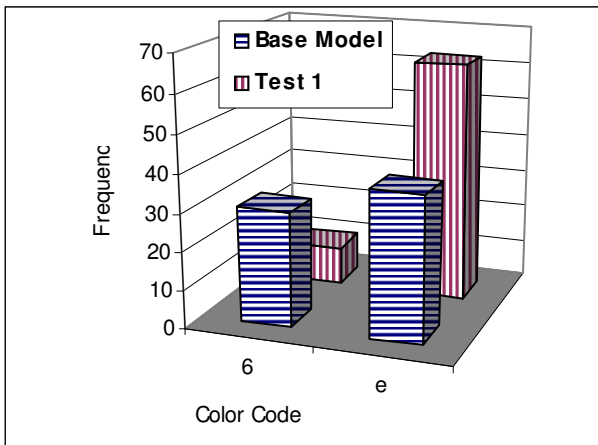


Figure 8 Test model 1 compared with the base model using data aggregated from multiple test drives. Chi-square = 16.031, degree of freedom = 1 and p-value = 6.23×10^{-5}

The comparison of multiple test-drives for the base model and Test model 2 is described in Figure 9. Using the p-value 0.618374 it can clearly be inferred that test model 2 behaves similar to the base model and this cell phone model should be a good phone. A comparison was also conducted to analyze the affect of directionality on handovers in the same square. Figure 10 shows the color code distribution for two phones moving in opposite directions. At a significance level 0.01 it can be inferred that this test model moving in direction 0 has a handover behavior that is notably different from the base model moving in direction 1.

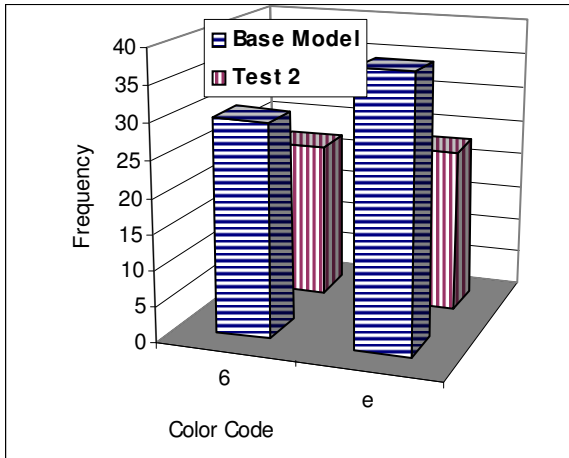


Figure 9 Test model 2 compared with the base model using data aggregated from multiple test drives. Chi-square=0.248 Degree of freedom=1 and p-value = 0.6184

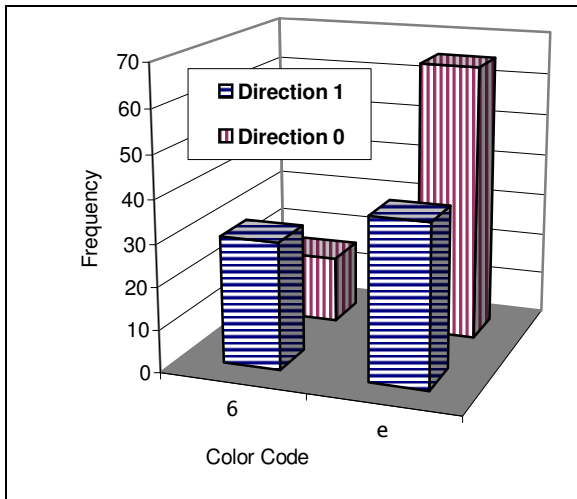


Figure 10 Comparison of same model driven in different directions using aggregated data from multiple drives. Chi-square=10.283, degree of freedom =1 and p-value = 0.001343

These results evidently show that Chi-Square Statistical Test is very powerful in comparing the handover behaviors for not only one test drive to another single test drive but also aggregated data of multiple test-drives. The comparison of a single test drive and aggregated data for the same test model yielded same results. The effects of directionality on handovers can also be examined using Chi-square Statistical Test. Table 2 shows a summary of the comparisons conducted on square (415,176).

Another Chi-Square Statistical Test was conducted on a square with the latitude and longitude coordinates as 110 and 443 respectively. The aggregated data was compared for the same multiple test drives that were studied in above square (415, 176) in this square as well.

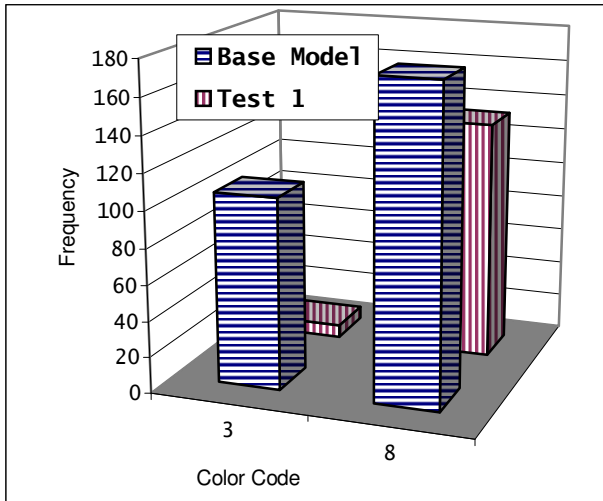


Figure 11 Test model 1 compared with the base model using data aggregated from multiple test drives. Chi-square = 51.236 Degree of freedom = 1 and p-value = 8.2×10^{-13}

We first compared base model to test model 1(Figure 11). At significance level 0.01 it was established that the handoff behavior for Test 1 is significantly different from base model.

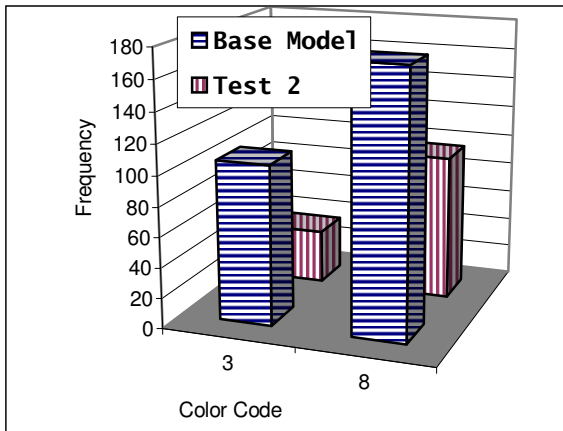


Figure 12 Test model 2 compared with the base model using data aggregated from multiple test drives. Chi-square = 4.450 Degree of freedom = 1 and p-value = 0.034912

The comparison of multiple test drives for the base model and Test model 2 as described in Figure 12 shows that Test model 2 behaves similar to base model. The p-value of 0.034912 can be used to infer that test model 2 should be a good phone.

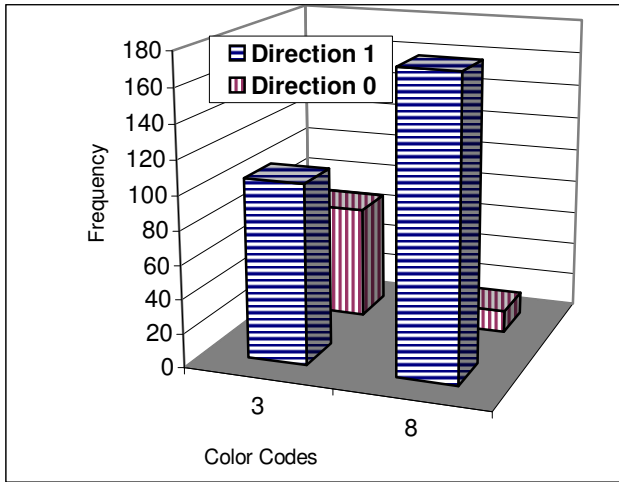


Figure 13 Comparison of same model driven in different directions using aggregated data from multiple drives. Chi-square= 52.499 Degree of freedom =1 and p-value = 4.30415×10^{-13}

Figure 13 shows the color code distribution for two phones moving in opposite directions. At a significance level 0.01 it is obvious that this test model moving in direction 0 has a handover behavior that is notably different from the base model moving in direction 1. Table 2 shows a summary of the comparisons conducted on square (443,110) is consistent with the results from square (415,176).

The results for the third comparison of the aggregated data from the same multiple test drives on a square with coordinates (449, 69) is not presented. In this square more than 2 color codes were observed.

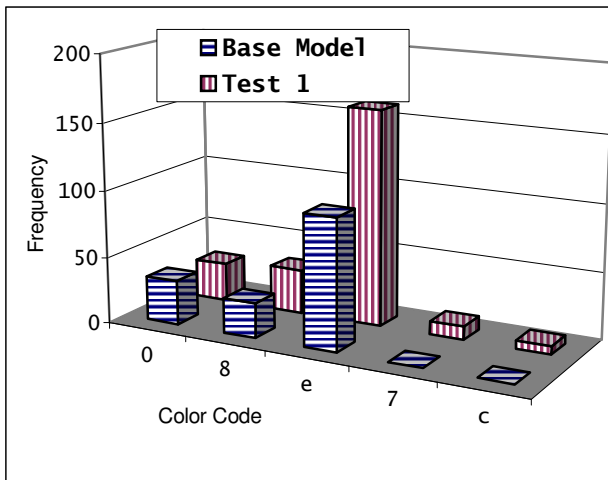


Figure 14 Test model 1 compared with the base model using data aggregated from multiple test drives. Chi-square =16.125 Degree of freedom=4 and p-value=0.002857

At a significance level of 0.01 with the p-value of 0.002857 it can be concluded that test model 1 behaved different from the baseline. Figure 14 shows the color code distribution for the two cell phones.

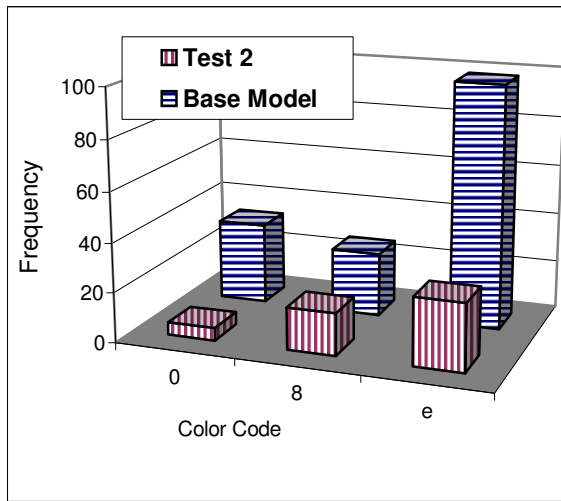


Figure 15 Test model 2 compared with the base model using data aggregated from multiple test drives. Chi-square = 8.5803 Degree of freedom =2 and p-value = 0.013703

The comparison of baseline to test model 2 conforms to the results presented earlier in this paper as well. Figure 15 describes the color code distribution for this comparison. Using the p-value 0.013703 it can be inferred that both phones behave similarly as observed in other squares.

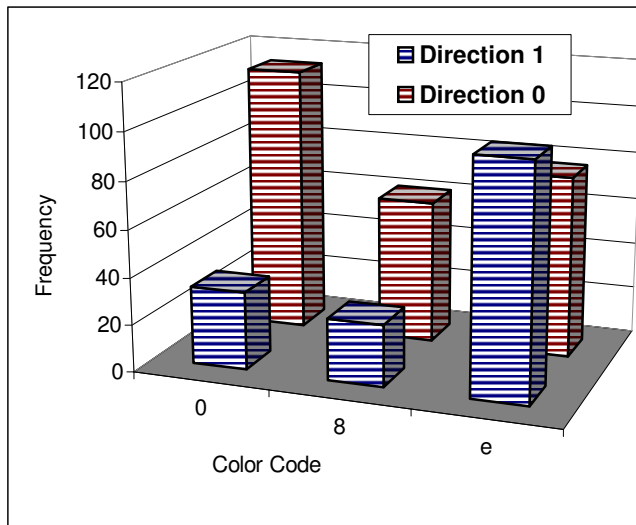


Figure 16 Comparison of same model driven in different directions using aggregated data from multiple drives. Chi-square= 40.9530 Degree of freedom = 2 and p-value = 1.27987x 10⁻⁰⁹

The comparison for directionality for two phones moving in opposite directions also yielded results as found in the other squares.

Figure 16 describes this comparison. At significance level 0.01 the p-value of 1.27987x 10⁻⁰⁹ it can be clearly determined that the two phones behave notably different.

The comparison of two phone models moving in opposite directions yielded significant results. The results as described in Figure 10, Figure 13 and Figure 16 clearly indicate that even though the same phone models are used for the drive test

but the phones behave significantly different. This is an expected behavior as the handoff behavior over a given cell for phones moving in opposite directions should be markedly differently.

The results are summarized in the Table 2. On all 3 squares, it is obvious that the behavior of test model 1 is significantly different from the base model. Therefore, it is suspected, and upon further investigation was found defective. Certainly, the test model 2 is clearly acceptable. The Chi-Square Statistical test is also very efficient in showing the difference in behavior of the same model moving in opposite directions. Finally, from the results in Table 2 it is clear that the results on the three squares are consistent.

Table 2 Summary of Chi-Square Value for Aggregated Drive Test Data

c(Lon,Lat)		Chi-Square	DoF	p-value	Conclusion
c(415,176)	Test Model 1	16.031	1	6.23E-05	different
	Test Model 2	0.248	1	0.6184	similar
	Direction 0	10.283	1	0.001343	different
c(443,110)	Test Model 1	51.23634372	1	8.19E-13	different
	Test Model 2	4.449496169	1	0.034912	similar
	Direction 0	52.49924	1	4.3E-13	different
c(449,69)	Test Model 1	16.12448968	4	0.002857	different
	Test Model 2	8.580341661	2	0.013703	similar
	Direction 0	40.95302224	2	1.28E-09	different

Given the base model that has an accepted behavior; Chi-Square Statistical Test becomes an efficient methodology in comparing two phones. The results presented in this section clearly show that it is easy to understand when the test model is a good or bad model in reference to the base model. The behavior of the phones can also be investigated based on directionality.

Conclusion

With the increasing number of subscribers for the cellular service the handoff behavior of phones is an important factor to achieve high quality of service in a cell phone system. This paper provided a practical approach that was designed to identify phone models that frequently exhibit premature, delayed or exceedingly sensitive handoff decisions also known as poor mobility decisions.

In literature till-date research has focused mostly on improving or evaluating handover algorithms using data collected under pristine laboratory conditions. Unlike these conventional this paper evaluates diagnostic data that was collected from cellular phones during the field test under real world conditions, while treating the cell phone as a black-box.

A phone that makes good mobility decisions under laboratory conditions may not behave as expected under real world conditions. Therefore for this experimental setup, we treat the test mobile unit as a black box to obtain reliable results. The tests have shown the viability of chi-square statistical test as an effective mechanism that determines the hand-off behavior of cell phones. By means of contingency tables this work compares the observed frequencies of color codes in a small geographic region for the test model and the base model. The Chi-square is calculated using these contingency tables and by means of independence hypothesis testing the handoff behavior of the two phones is compared. P-value that is calculated using chi-square is used as a threshold to accept or reject the independence hypothesis. This test is used to compare hand-off behavior in certain geographical regions. In this paper we presented the results of handover comparisons of the aggregated drive test data from the same set of multiple test drives on different restricted geographical locations. The consistent results on these tests show the efficiency of proposed statistical approach. The results also show that this statistical measure is very effective in studying the handoff behaviors of phones that are moving in different directions. In conclusion, it has been shown that this statistical approach is highly effective in studying the handoff behaviors of cell phones to determine the difference in their handover behaviors, if any.

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