The Influence of Propagation Environment in a Live GSM Network

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Abstract — This paper discusses the influence of propagation environment to the GSM cellular mobile network. Based on the propagation dependent environment, the mobile station suffered from the interference anytime and anywhere. This paper shows the measurement and analysis results for a special case in a live GSM network. The measurement-processing data from the field-strength driving test shows the enormous variances about 28% of the measured RXLEV >= -75dBm (received signal strength) between the short call case (105 seconds for conversation and 15 seconds for idle, cycling) and the long call case (1800 seconds for conversation and 15 seconds for idle, cycling). Our investigation for the GSM network is based on the GSM metrics RXLEV, RXQUAL, DTX, slow frequency hopping and handover characteristics. The problems caused by measurement instruments are not the scope of this paper.

Keywords: GSM, propagation effect, field-strength measurement, slow frequency hopping, handover, DTX, RXLEV, and RXQUAL.

1. Introduction

As the penetration of GSM (Global System for Mobile communications) cellular users increase spectral efficiency is becoming more critical. Because of frequencies are limited resources. The smaller the frequency reuse, the greater the network capacity has. High spectral efficiency is achieved by reusing frequencies over small geographic distances over the propagation dependent environment. As cellular market penetration increases even closer frequency reuses are required to support the growing customer base. However, the smaller the frequency reuse, the greater the interference levels. Techniques or mechanisms that improve the interference immunity for the cellular radio network optimization are of particular importance.

In a normal conversion, each person speaks, on average, for less than 50% of the time. Discontinuous transmission (DTX) is switching the transmitter off when speech is not present [8], so DTX is an efficiency way of decreasing the interference and thus increasing the quality/capacity. And slow frequency hopping improves network quality in two different ways, it minimizes the effects of Rayleigh fading (small-scale fading) and provides interference diversity. Frequency hopping provides a method of expanding the bandwidth used by a logical channel. In GSM, a change of frequency takes place for every new burst (every 4.615 ms), thus giving almost 217 hops per second. This is known as slow frequency hopping. Additionally, keeping continuous connections during a call conversation, good handover performance is also a key point to the success of the cellular mobile network. An Effective handover strategy scheme needs consideration in three key areas: propagation, traffic, and switching and processing. The minimization of drop call rate needs efficient schemes for making handover requests at the right place at the right time based on the propagation environment.

The following sections are organized as follows: Section 2 is the GSM concept, Section 3 investigates the propagation dependent environment effect, Section 4 is the mobile received signal, Section 5 discusses the handover mechanism, Section 6 is measurement and analysis results, and eventually Section 7 is our conclusions and future works.

2. GSM

GSM uses a TDMA (Time Division Multiple Access) channel structure [5]. On every radio channel time is divided into slots 0.577 ms in length. Eight timeslots, number from 0 to 7, form a TDMA frame of length 4.615ms. There are almost 217 bursts per second. Each of these slots can be given to a full rate traffic channel, two half rate traffic channels or one of the control channels.

In GSM the databits are coded. The channel coding introduces redundancy into the data flow, by increasing the bit rate. For the TCH/FS mode, a 3 bit CRC is at first applied to the Class 1a bits, and secondly all class 1 bits are encoded by a convolution code. The class 2 bits remain unprotected. The reordering and interleaving process mixes the encoded data block of 456 bits, and groups the bits into 8 sub-blocks (half bursts). The 8 sub-blocks are transmitted on 8 successive bursts (interleaving depth equals 8). The channel coding can be seen in Figure 1, while the reordering and interleaving can be seen in Figure 2.

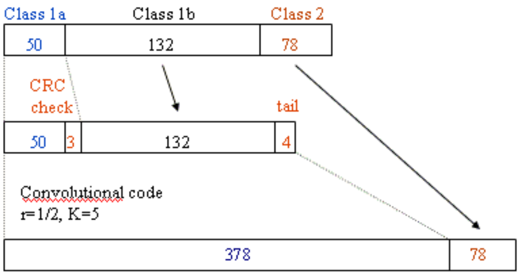


Figure 1. Channel coding of the TCH/FS

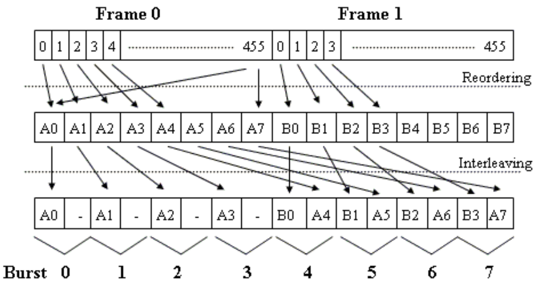


Figure 2. Reordering and Interleaving of the TCH/FS

Due to the multipath propagation, the erroneous received bits tend to appear in “bursts”. The convolution code gives the best performance for random positioned bit errors, and therefore reordering and interleaving is introduced in the GSM signal transmission flow. However, the reordering/interleaving only improves the coding performance, if the 8 successive bursts carrying the data information of one speech block are exposed to uncorrelated fading. This can be ensured by either a spatial movement (high user speed) or frequency hopping.

3. The Propagation Dependent Environment Effect

As GSM interleaves speech blocks over eight bursts, the bit error rate (BER) of the transmitted information depends upon the mean carrier to interference ratio (C/I) performance of the eight bursts rather than on that of an individual burst [1]. In general, the C/I is different for each burst. This occurs as the desired and interfering signals are continuously changing. In the radio environment the signal undergoes fading, shadowing and distance dependent path loss. In general, the Rayleigh distribution is used to model fading and the lognormal distribution to model shadowing. The Rayleigh distribution is given by [2]

$$pdf_{Ray}(\alpha) = \frac{2\alpha}{\Gamma}\exp\left[-\frac{\alpha^2}{\Gamma}\right], \tag{1}$$

where α is the received signal voltage and Γ is the average power of the fading. The average power of the Rayleigh signal is lognormally distributed and the lognormal distribution is given by [2]

$$pdf_{\log}(\Gamma) = \frac{10}{\ln(10)\sqrt{2\pi}\sigma\Gamma}\exp\left[-\frac{\left[\frac{10}{\ln(10)}\ln(\Gamma) - \mathrm{M}\right]^2}{2\sigma^2}\right], \tag{2}$$

where M is the area mean power and σ is the standard deviation of the associated normal distribution. The area mean M is the difference between the transmitted power and the path loss. The Hata model is used to calculate the path loss. In an urban environment the path loss is given by [3]

$$L_p = 69.55 + 26.16\log f_c - 13.82\log h_t - a(h_t) + (44.9 - 6.55\log h_t)\log d, \tag{3}$$

where f_c is the carrier frequency of operation in MHz, h_t is the base antenna height in meters, d is the distance between the base station and the mobile in kilometers. The effect of mobile antenna height is ignored. When modeling the signal strength in suburban environments a correction factor is added to equation (3). The correction factor is given by [3]

$$L_{ps} = -2\log\left(f_c/28\right)^2 - 5.4, \tag{4}$$

The additional path loss suffered due to the directionality of the sectorized antennas is given by

$$L_\varphi = -0.0002\varphi^3 + 0.0042\varphi^2 - 0.0134\varphi + 0.038, \tag{5}$$

where φ is the angular deviation from the center of the beam measured in degrees. Equation (5) was derived by fitting a polynomial to the horizontal antenna radiation pattern.

Rayleigh and lognormal random numbers are generated to represent the effects of fading and shadowing. As fading occurs faster than shadowing, random Rayleigh numbers are produced every burst while random lognormal numbers are generated every hundred bursts.

Intra-timeslot handover (i.e. intra-cell handover) uses idle timeslot interference measurements to select the timeslot with the least interference. When interference is experienced the mobile will be handed over to another timeslot. Frequency hopping distributes the interference over all the hopping channels and therefore intra-timeslot handover becomes less effective when used in conjunction with frequency hopping. Also the effectiveness of intra-timeslot handover reduces as the probability of channel occupancy increases. Note that intra-timeslot handover is not responsive enough to react to the effects of Rayleigh fading, and therefore only the effect of shadowing and distance dependent path loss is taken into account for intra-timeslot handover.

Intra-timeslot handover is assumed to only occur on the serving base station. In an actual system, intra-timeslot handover will occur on both the serving and interfering cells. As a result collisions may occur and additional intra-timeslot handovers will be attempted. The intra-timeslot model used here does not incorporate the effect of timeslot collisions between different cells. The C/I at the mobile is given by

$$C/I = \sum_{i=0}^{n} {}^{n}C_i p^i (1-p)^{n-i} S_d / I_i, \tag{6}$$

where S_d is the carrier signal strength, I_i is the signal strength of the ith interferer and p is the probability of channel occupancy. Equation (6) uses the binomial distribution to models channel occupancy.

The mentioned above assumed that the fading of consecutive hopping channels is uncorrelated. As most cellular networks have limited bandwidth the fading characteristics of consecutive hops in actual systems are often found to be correlated. The performance improvement when hopping over more than eight channels was assumed to be negligible as information is interleaved over eight bursts in the GSM system [1]. This is only valid if the correlation between consecutive hopping channels is zero. If the bursts are correlated, improvement may be experienced when more than eight hopping frequencies are used.

4. The Mobile Received Signal

The received signal by an MS could be considered as consisting of three components, namely, a free-space path loss component, a slow fading component due to shadowing, and a fast fading component due to vehicle velocity. However, when determining handover necessities, the received signal is averaged, and over the normal averaging periods, the fast fading component of the signal is averaged out. The shadowing component of the signal is a function of the cell propagation environment, and is a random variable that conforms to lognormal distribution. Therefore the propagation characteristics of the cell environment could be represented by the statistics of the lognormal distribution.

The free space path loss component that gives rise to the mean value μ_L of the received signal can appropriately be described by the empirical formula given by Hata [3]. With σ_L as the variance of the shadowing component the composite received signal that determines handover would then be a random variant X with pdf,

$$f_X(x) = \frac{1}{x\sigma_L\sqrt{2\pi}} e^{-\frac{(\ln x-\mu_L)^2}{2\sigma_L^2}}, x > 0$$

5. Handover

In the GSM cellular mobile system the handover process is identified as a combined operation of the mobile station (MS), base station (BS), and mobile switching center (MSC). Handover mechanism occurs when a mobile station crosses a cell boundary. In GSM Recommendations [7], the measurement reports (Figure 3, [6]) are combined to generate seven criteria for handover. These are, in order of priority:

- Intra-cell (i.e. Intra-timeslot): where the RXLEV is still high but the RXQUAL is poor, a handover to another channel on the same base station cell is requested.
- Downlink and uplink RXQUAL: where a handover is requested due to poor RXQUAL.
- Downlink and uplink RXLEV: where a low RXLEV triggers a handover request.
- Distance: where a handover request is triggered when the mobile station travels beyond a certain maximum distance from the base station. This condition is very less.
- Power budget: where a mobile station requests a handover to a neighboring cell if it detects that the received signal budget from the neighbor is better than its current cell by a given margin.

The last priority is also called better cell handover, the others are belong to survival handovers.

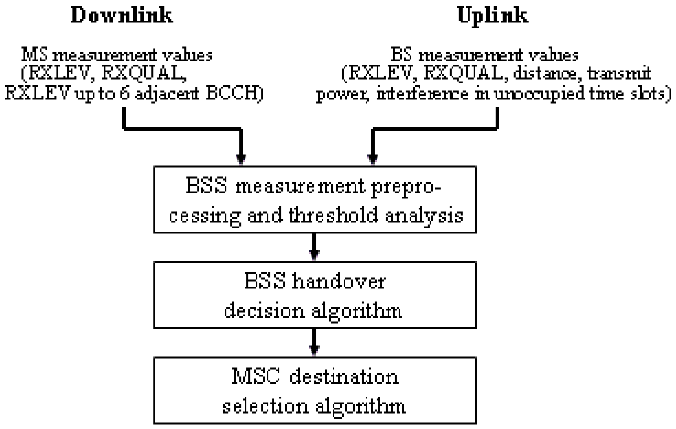


Figure 3. Decision steps in a GSM handover

6. Measurement and Analysis Results

6.1 Measurement Parameters

In principle, GSM uses two parameters to describe the quality of a channel: the Received Signal Level (RXLEV), defined as the R.M.S. received signal level at the receiver input and absolute MS-BS range obtained from the timing information for frame alignment and measured in dBm, and the Received Signal Quality (RXQUAL), measured as bit error rate (BER) in percent before error correction [7] (Table 1 and Table 2). These two values are averaged over a SACCH interval (480 ms) and transmitted to the base station on the SACCH as a measurement report/measurement information. The way the downlink quality of the channel assigned to the mobile station can be judged. In addition to these measurements of the downlink by the mobile station, the base station also measures the RXLEV and RXQUAL values of the respective uplink.

Table 1. RXLEV values and corresponding received signal level

RXLEV	Received signal level (dBm)
0	< -110
1	-110 ~ -109
⋮	⋮
62	-49 ~ -48
63 Strongest	> -48

Table 2. RXQUAL values and corresponding BER

RXQUAL	BER (%)	Assumed value (%)
0 Best	< 0.2	0.14
1	0.2 ~ 0.4	0.28
2	0.4 ~ 0.8	0.57
3	0.8 ~ 1.6	1.13
4	1.6 ~ 3.2	2.26
5	3.2 ~ 6.4	4.53
6	6.4 ~ 12.8	9.05
7	> 12.8	18.1

6.2 RXLEV/RXQUAL Estimation Accuracy

It is measured by mobile station for the downlink and by the base station for the uplink. The estimated RXQUAL values can be averaged before they are used in the power control and handover algorithm. The estimation is done by evaluating the BER before decoding over a SACCH multiframe (0.48 sec.) and then maps the value over to an RXQUAL in the way, which was shown in Table 2. The way the BER is estimated is not specified by the GSM Recommendations, but is free to implement in any way, as long as the accuracy's of [7] are fulfilled.

Since an RXQUAL value is calculated for every SACCH multiframe, the BER is estimated over 100 TDMA bursts in case of not being in DTX mode, and 12 TDMA bursts if in DTX mode. The first is called RXQUAL-FULL and the second RXQUAL-SUB. If this is RXLEV estimation in DTX non-active and DTX active, called RXLEV-FULL and RXLEV-SUB respectively. In the power control and handover algorithm these two kinds of different quality measures can be weighted differently.

6.3 Measurement System and Analytic Tool

The measurement system is a TS9951 system of Rohde & Schwarz. The professional system includes a global positioning system (GPS) receiver and supports a number of GSM test handsets that output the system information and measurement reports to a notebook computer with positional information. The windows based software interprets the handset signals and displays the system information in both alphanumeric, scrolling chart, and map forms in real time. Furthermore, logged data including the time and position information can be exported for detailed analysis. Analytic tool is a TORNADO v2.8 of PLANET system. TORNADO provides a mobility model and a radio propagation model, delivering the measurement reports. The measured data can be processed statistically. If a sufficient number of routes is measured, the field strength pattern of the area is clearly visible, and entered along the digitized routes can plot out with the aid of a plotter.

6.4 Measurement Results and Analysis Results

Totally, it took about 15 minutes to complete the driving test about 17.3 km long from the west to the east in Freeway no. 8, which belongs to suburban environments, in Taiwan on the third September, 2001. The MS was assumed to be traveling at a constant speed of 69 km per hour. Figure 4 to Figure 9 is the measurement-processing map by TORNADO. The comparison for the measured RXLEV and RXQUAL lists respectively in Table 3 and Table 4. The detailed cell-by-cell test mobile route analysis is also included in Figure 4 for the short call case, and Figure 5 for the long call case. The results analysis of field-strength driving test shows in the following:

- The signal levels during the entire driving run had coverage which was well above the GSM reference sensitivity level of -104 dBm for the MS.
- In the short call case (105 seconds for conversation and 15 seconds for idle, cycling), there are eight calls, including many better cell handovers, ten survival handovers and one handover failure during that periods. In the long call case (1800 seconds for conversation and 15 seconds for idle, cycling), only one call has many better cell handovers, 17 survival handovers during that periods. No handover failure happened.
- The results show that the long call case gets more handovers than the short call case, no matter in survival handovers and better cell handovers. The short call case gets one handover failure, but not happened in the long call case. This is due to the seizing different frequencies, so the related BSC, MSC made the different decision to deal with the propagation dependent environment in order to get better RXQUAL or RXLEV.
- Due to the propagation effect, the radio signal varies from time to time, varies from place to place. Even these two MSs inside the measurement car and against the window, but they suffered from the different propagation effect. If seize the same frequency band at the same time, the RXLEV, RXQUAL maybe not equal, i.e. the mobiles with the different antenna location suffered from the different propagation effect. It is possible for these two MSs to use the different serving cell and frequency band at the same time especially if that area has no dedicated cell/site to serve. The results show that during the curve terrain road no dedicated site make the radio signal reaching the MS is not strong enough and sometimes is very similar, so at that time co-channel/adjacent interference easily takes place if frequency planning considers not well especially in such closer frequency reuse situation, therefore these will lead to many

handovers (survival handovers mostly due to bad quality). According to the result analysis, co-channel /adjacent interference often occurred along the road of freeway no.8.

- As mentioned earlier, the frequency seizing in the similar signal strength is a random probability. The probability will be very similar if driving-test time is longer. But this case it just takes about 15 minutes to field-strength driving test about 17.3 km long. And the SUB value emphasizes the performance of conversation time in dedicated mode if the DTX (Discontinuous Transmission) is active. The FULL value takes the same weighting to speech/silence time in dedication mode and idle time in idle mode. In this case, the short call case idle mode get very good RXLEV (detailed please see Figure 4), therefore, from the below Test Mobile Route Analysis of TORNADO between the short call case and the long call case, this is why the RXLEV_FULL (>=-75dBm; the short call case:49.1, the long call case:77.3) better than RXLEV_SUB (>=-75dBm; the short call case:48.8, the long call case:76.8) in both short call and long call case, and this is also the variances between RXQUAL_FULL(0~3)=89.54 and RXQUAL_SUB(0~3)=90.95 in the long call case.

Table 3. RXLEV comparison

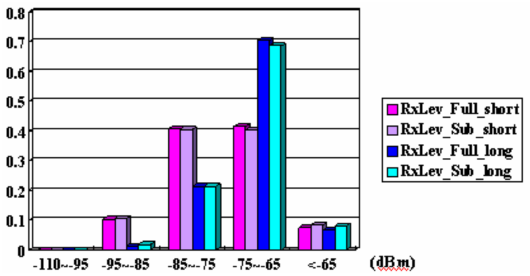
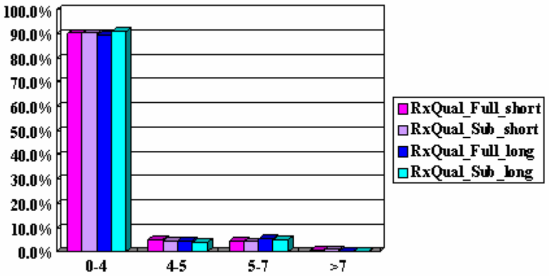


Table 4. RXQUAL comparison



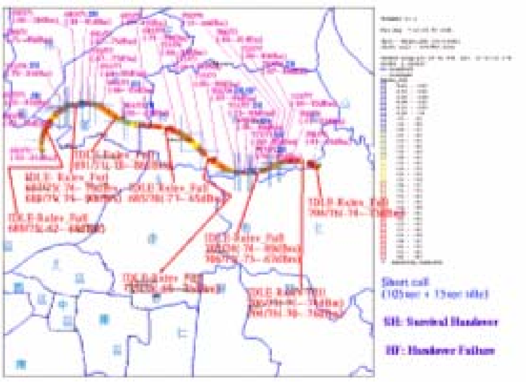


Figure 4. RXLEV_SUB for the short call case

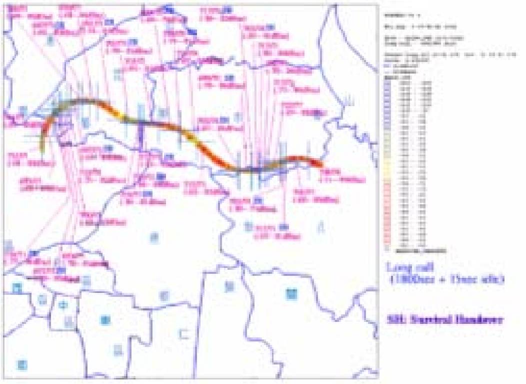
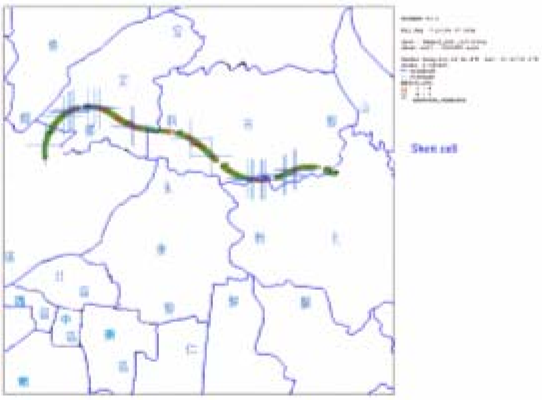


Figure 5. RXLEV_SUB for the long call case



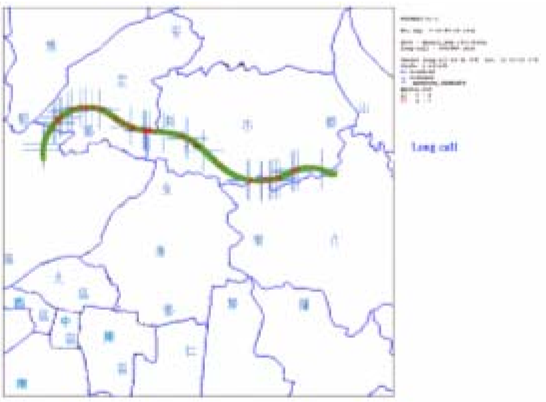
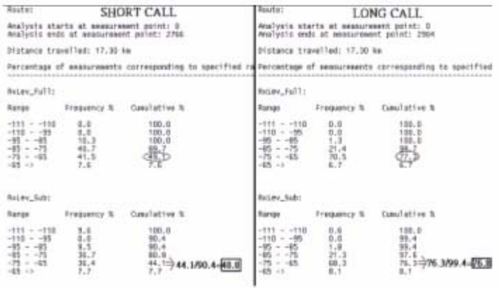


Figure 6. RXQUAL_SUB for the short call case **Figure 7**. RXQUAL_SUB for the long call case



```
Route:              SHORT CALL
Analysis starts at measurement point: 0
Analysis ends at measurement point: 2766

Distance travelled: 17.30 km

Percentage of measurements corresponding to specified ra
=========================================================

RxLev_Full:

Range          Frequency %    Cumulative %

-111 - -110       0.0            100.0
-110 - -95        0.0            100.0
-95 - -85        10.3            100.0
-85 - -75        40.7             89.7
-75 - -65        41.5             49.1
-65 ->            7.6              7.6


RxLev_Sub:

Range          Frequency %    Cumulative %

-111 - -110       9.6            100.0
-110 - -95        0.0             90.4
-95 - -85         9.5             90.4
-85 - -75        36.7             80.9
-75 - -65        36.4             44.1 ⇒44.1/90.4=48.8
-65 ->            7.7              7.7
```

```
Route:              LONG CALL
Analysis starts at measurement point: 0
Analysis ends at measurement point: 2904

Distance travelled: 17.30 km

Percentage of measurements corresponding to specified
=========================================================

RxLev_Full:

Range          Frequency %    Cumulative %

-111 - -110       0.0            100.0
-110 - -95        0.0            100.0
-95 - -85         1.3            100.0
-85 - -75        21.4             98.7
-75 - -65        70.5             77.2
-65 ->            6.7              6.7


RxLev_Sub:

Range          Frequency %    Cumulative %

-111 - -110       0.6            100.0
-110 - -95        0.0             99.4
-95 - -85         1.8             99.4
-85 - -75        21.3             97.6
-75 - -65        68.3             76.3 ⇒76.3/99.4=76.8
-65 ->            8.1              8.1
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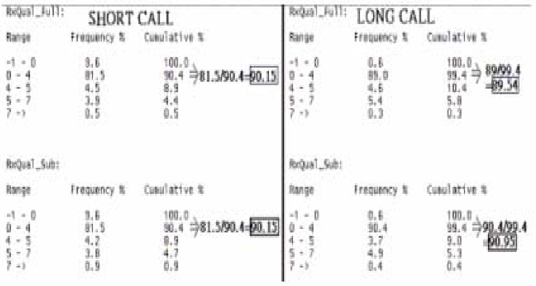

```
RxQual_Full:     SHORT CALL
Range          Frequency %    Cumulative %

-1 - 0            9.6            100.0
0 - 4            81.5             90.4 ⇒81.5/90.4=90.15
4 - 5             4.5              8.9
5 - 7             3.9              4.4
7 ->              0.5              0.5


RxQual_Sub:

Range          Frequency %    Cumulative %

-1 - 0            9.6            100.0
0 - 4            81.5             90.4 ⇒81.5/90.4=90.15
4 - 5             4.2              8.9
5 - 7             3.8              4.7
7 ->              0.9              0.9
```

```
RxQual_Full:     LONG CALL
Range          Frequency %    Cumulative %

-1 - 0            0.6            100.0
0 - 4            89.0             99.4 ⇒ 89/99.4
4 - 5             4.6             10.4    =89.54
5 - 7             5.4              5.8
7 ->              0.3              0.3


RxQual_Sub:

Range          Frequency %    Cumulative %

-1 - 0            0.6            100.0
0 - 4            90.4             99.4 ⇒90.4/99.4
4 - 5             3.7              9.0    =90.95
5 - 7             4.9              5.3
7 ->              0.4              0.4
```

Figure 8. RXLEV value analysis **Figure 9**. RXQUAL value analysis

7. Conclusions and Future Works

In this case, we can easily find the case in the enormous variances about 28% of the measured RXLEV >= -75dBm (received signal strength) is also normal situation based on the propagation effect for a live GSM network. No enough dedicated base stations there and the propagation environment effect caused many handovers occur. Based on the propagation dependent environment, cellular mobile network can be optimized. Of course, firstly by good frequency planning in such limited frequency band, and by using DTX [8] to improve the network quality, setting less collision hopping sequence for slow frequency hopping really increase the interference immunity. The simulation result [4] shows that, Intra-timeslot handover (i.e. intra-cell handover) provides better interference immunity than two channel frequency hopping when the mean C/I is less than approximately 16 dB in both the urban and suburban environments. In addition, setting appropriate hysteresis value (handover margin), threshold and other parameters such as averaging time length, weighting factor for the different propagation environments can optimize the behavior of the handover strategy.

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