

TETRA Outdoor Large- Scale Received Signal Prediction Model in Riyadh Urban Area¹

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Abstract- TETRA outdoor large scale received signal prediction model is presented here. The model follows log-distance model. It is derived based on received signal strength survey measurements of a TETRA system, operating in the 300-400 MHz band, in Riyadh city. The model is aimed to assist practicing engineers in the estimation of received power, or electric field strength as well as path-loss at any given distance from the base station or vice versa. The model exponent (n) for the selected routes is found to be 3 ± 0.7 . However, the overall value of n for urban area in the Riyadh city is found to be 3.22. It is noted that the value of n obtained here is low, compared to values obtained in several European cities, as the streets are wider and the buildings are lower in most part of the route in Riyadh.

I. Introduction:

Received signal prediction models play an important role in the RF coverage optimization and efficient use of the available resources in wireless communication. As the demand of location based services (LBS) increases in non-line of site (NLOS) environment, a robust received signal prediction model is needed to enhance the accuracy of the LBS techniques that are not based on GPS receivers. This paper presents a large scale received signal prediction model for various types of terrains. The model will be used to develop a mobile station location estimator on a cellular private mobile system which is called Terrestrial Trunked Radio system (TETRA). TETRA was specified by the European Telecommunications Standards Institute (ETSI) as an open standard trunking radio system and is used by Public Safety and Security Organizations for services such as Emergency Services, Police, Fire Fighting as well as Services Utilities Providers. Table 1 contains the main TETRA features and parameters [1-3].

Large scale path loss model for TETRA Network implemented in Athens has been presented in [4]. The model follows log distance model and the path loss exponent n , for the urban environment is found in the range $n = 4 \pm 0.5$. whereas, the standard deviation 1 for small scale fading fluctuations is equal to $1 = 8.6 \pm 0.2$ dB. The model found for two TETRA base stations only and is restricted to separation distance above one km and less than five km. The Root Mean Square Error (*RMSE*) was not calculated to measure the variation between the median in small scale window data.

A tuning of “Bertoni-Walfisch” path loss model for GSM-900 MHz Network implemented in Turkey has been presented in [5]. The model is based on measurements for several areas in Istanbul. The path loss exponents n for these areas were found in the range from 2 to 4.4. Statistical analysis parameters

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such as Cumulative Fade Distribution (CFD), Average Fade Duration (AFD), and Level Crossing Rate (LCR) have been calculated. However, *RMSE* values are quite large.

A comparison of different prediction methods with the observed path losses have been presented in [6] for VHF and UHF bands. The comparison showed that Hata's prediction method gave better agreement in all targeted areas. This is due to the fact that Hata incorporates correction factors for various environments. COST 231 Walfisch– Ikegami method is in agreement in urban and suburban areas in VHF band. The path loss exponents obtained in [6] for urban, suburban and open areas are 3.3, 2.5 and 2.2 respectively. The standard deviations of observed path loss values in urban and suburban areas at 200 MHz are 3.4 and 4.6 dB respectively, and the standard deviations of the observed path loss values in suburban and open areas at 400 MHz are 6.0 and 7.7 dB respectively.

It has been observed that the information available in the literature for various propagation terrains, are not compatible with the Middle East environments due to its geographical conditions. For this reasons the model obtained here achieves better prediction compared to the model available in [4-6].

This paper is organized as follows. In section II, Field measurements procedure and locations are discussed. Section III presents hardware and software tools that have been used. Received signal prediction model and statistical analysis are presented in section IV. In section V, Measurement analysis, results and discussions are given. Conclusions are summarized in section VI.

Table 1: The main TETRA features and parameters[1-3]

No.	System parameters/features	Parameters values/descriptions
1	Up link frequency bands(MHz)	380-390, 410-420, 450-460
2	Down link frequency bands(MHz)	390-400,420-430, 460-470
3	Digital Modulation Format	$\pi / 4$ <i>DQPSK</i> , 2 bits per symbol
4	Carrier Bandwidth	25 KHz, (25/4 = 6.25 MHz per channel)
5	Multiple access	TDMA, with 4 channels(time slots) per carrier
6	Max. Data rate	28.8 kbps (7.2 kbps per time slot)
7	Symbol rate /gross bit rate	18 K symbol/sec. or 36Kbps
8	Base station power classes	40W (46dBm), 25W (44dBm), 15W (42dBm), 10W (40dBm), 6.3W (38dBm),.....,0.6W (28dBm) 10 power classes.
9	Handheld power classes	3W (35dBm), 1W (30dBm), 0.3W (25dBm).
10	Handheld sensitivity for 2% BER.	-103 dBm
11	Max. vehicle speed	200 kmph
12	Coverage cell radius	Up to 45 km for open area coverage.

II. Field measurements

TETRA survey propagation measurements have been conducted for the existing Saudi Arabia National Guard (SANG) TETRA system in Riyadh city. The system consists of several base stations covering the whole of Riyadh city. Base stations number 2, 5, and 9 cover urban areas, whereas the other base stations cover suburban areas. The main physical characteristics of the urban areas base stations are listed in Table 2. The selected part of Riyadh city for the survey measurements is shown in the digital map copy of Fig.1. The following factors were considered in selecting the measurement area:

1. Measurement route is determined based on radio signal coverage and other propagation parameters conditions. These are: a) The route should go through metropolitan areas as long as it can; b) The route must pass through the suburban area as well as open areas; c) It must also pass through different types of terrains. This route is marked with red color on the city map. On this route, 17 outdoor fixed points have been selected and labeled with numbers enclosed in small white circled boxes. Military and commercial GPS based on the World Geodetic system 1984 (WGS 84) have been used to determine the coordinates of these points.
2. Tunnels were also chosen and labeled with numbers enclosed in small white rectangular boxes as shown in Fig.1.
3. Indoor measurements were carried out in the Department of Electrical Engineering building, King Saud University at different floor levels. However, tunnels and indoor measurements analysis and prediction models will not be covered in this paper.

Recording of the measurements was started on 4th December 2005, and was completed by 3rd January 2006. To increase the reliability, each measurement was carried out twice a day (morning and evening). Measurements were carried out using Motorola Scout software². Different radio coverage conditions, i.e., outdoor, and indoor have been also considered. The effect of mobility in different radio coverage conditions has been investigated as well. Strenuous efforts were laid in performing the measurement, first in erecting the setup and then conducting it. General Directorate of Military Survey (GDoMS) also participated in these measurements by providing accurate estimation the location of 17 fixed points distributed along the selected route, in addition to the TETRA network base stations locations.

While traversing the selected route, recording of the measurements at 17 fixed points were made in standstill condition whereas between fixed points measurements were made in moving condition at an approximate speed of 40 km/h. For high density urban area, measurements were recorded on the move. Inside tunnels, measurements were recorded in almost standstill conditions. This enables us to study the propagation behavior of TETRA radios under different outdoor propagation conditions i.e., inside tunnels, urban (metropolitan), suburban, rural (open) areas with different vehicular speed. In addition to the above, indoor measurements were conducted as well. Moreover, the effect of the small scale fading was also investigated. This is done by recording data every second with TETRA handheld radio which was mounted in a survey vehicle at a height of 1.5 m above the ground level. Enormous amount of data was collected while performing the measurements.

² Motorola RF survey engineer also participated in conducting these measurements.

Table 2: The main physical characteristic of the urban areas base stations

Quantity	BS 2	BS 5	BS 9
The altitude of the measurement area range(m)	576-645m		
Area Type	High Density Urban		
The frequency band	380-400 MHz		
Base station type	Type 1		
Transmitter's Power(W)	39.33	40.1	38
Transmitter's Power(dBm)	45.95	46	45.78
Cable Length(m)	62	30	62
Cable Losses(dB)	1.645	0.796	1.645
Antenna Gain(dBi) Whip-type / Omni- directional	6		
Antenna Height (m)	53	12.5	53
Building Height (m)	0	111 (37- story Building)	0
$EIRP_T$ (dBm)	50.305	51.204	50.135



Fig.1: Copy of part of Riyadh Digital Map, downloaded from Google Maps website.

III. Measurements tools: - Hardware and Software

1. Military Survey equipments

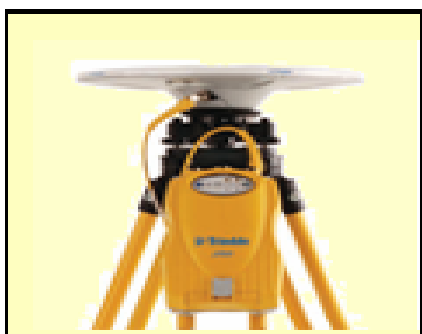
As mentioned previously, General Directorate of Military Survey participated in these measurements. Their staff used the Trimble GPS Total Station 5700 system which is shown in Fig.2 (a). This system is based on a control surveying principal. It is used to determine the coordinates of selected reference marks in certain geographic region. The station is integrated with GPS, radios, survey controller, and office software so as to achieve very accurate coordinates. The Trimble system (fast static type) yields baseline components that are precise to better than $1 \text{ cm} \pm 1 \text{ ppm}$. From these measurements, it is found that the difference between the coordinate's located using Trimble system and the commercial GPS is in the range of $\pm (10-25)$ meters. More technical details about Trimble system can be found in [7].

2. TETRA Signal Propagation Survey Equipments

Fig.2 (b) shows the equipments and the tools that have been used to conduct these measurements. The equipments used are:

1. IBM compatible Laptop.
2. Dongle for running measurement software.
3. MTP 700 Motorola TETRA handheld radio (TETRA Mobile Station "MS").
4. Programming Stand PMLN4510.
5. Programming Cable FLN9636 with serial port to connect between the stand and the Laptop.
6. Garmin 176C GPS.
7. Attached GPS antenna.
8. External GPS antenna.
9. Serial (RS232) to USB adpoter cables.
10. USB connector.
11. GPS Data and power connector.
12. GPS DC connector.
13. DC to AC adapter.
14. Motorola Scout software version 5.6.1, for TETRA network measurements.

The propagation survey equipments were connected and data acquisition software was loaded in the Laptop. Motorola TETRA handheld radio and GPS were connected to the Laptop through FLN9636 cable and USB adapter cable respectively. GPS receiver was programmed on NMEA Mode whereas MTP700 radio has been programmed on Air Tracer Mode. The measurements emphasized on recording a) latitude, longitude, and altitude of the TETRA MS radio, b) vehicular speed and c) Receive Signal Strength Indicator (RSSI) for serving base station and the strongest three foreground stations in dBm.



(a)



(b)

Fig.2: Survey equipments, (a) Trimble GPS Total Station 5700,
(b) TETRA Signal Propagation Survey Equipments

IV. Received signal Prediction Model and Statistical analysis

1. Received signal Prediction Model

Based on the above findings, the received signal prediction model has been constructed in the metropolitan area of Riyadh city. Generally, the log-distance propagation model was used to estimate path loss model parameters from the measured data. The large-scale path loss model $PL(d)$ in *decibel* for an arbitrary T-R separation (d) is expressed as following [4,5,8]:

$$PL(d) = A \log(d) + C \quad (1)$$

Or it can be written in the known following form:

$$PL(d) = 10 .n. \log\left(\frac{d}{d_o}\right) + PL(d_o) \quad (2)$$

where n is the path loss exponent, and $PL(d_o)$ is the reference path loss at distance d_o .

Now, The predicted signal $PD(d)$ can be obtained as

$$PD(d) = EIRP_T - PL(d) \quad (3)$$

$$\text{And } EIRP_T = P_T - L_C + G_T \quad (4)$$

Where, $EIRP_T$ is the effective isotropic radiated power of the TETRA base station, P_T is the base station transfer output power, L_C is antenna cable loss, and G_T is transmitting antenna gain. These powers, loss, and gain are added in dBm.

From the fitting parameters, $PD(d)$ can be obtained as follows

$$PD(d) = -A \log(d) + C = -10 .n. \log(d) + C \quad (5)$$

Similar to equation (2), the large-scale received signal prediction model $PD(d)$ in *decibel* for an arbitrary T-R separation (d) can be expressed as following:

$$PD(d) = PD(d_o) - 10.n. \log\left(\frac{d}{d_o}\right) \quad (6)$$

Where, $PD(d_o)$ is the reference predicted signal at distance d_o and it is written as:

$$PD(d_o) = C - 10 .n. \log(d_o) \quad (7)$$

2. Statistical Analysis

a. Model goodness of Fit Statistics:

In order to examine the goodness of logarithmic fit, the root mean squared error (*RMSE*) and the coefficient of determination (R^2) have been calculated. These two statistical parameters are defined as:
i) **RMSE:** This statistic measures the mean deviation (error) of the measured RSSI values to RSSI predicted values which estimated using the fitting model. RMSE value closer to 0 indicates a better fit. RMSE is defined as:

$$RMSE = \sqrt{\frac{\sum_{i=1}^m (y_i - \hat{y}_i)^2}{m}} \quad (8)$$

Where, m is the raw length of measured data matrix, y_i is the measured RSSI and \hat{y} is the predicted RSSI.

ii) **Coefficient of determination (R^2):** This statistic measures how successful the fit is in explaining the variation of the data. So, it is defined as the square of the correlation between the measured RSSI values and RSSI predicted values. R^2 always takes values between 0 and 1. As R^2 reaches 1, the regression points tend to align more accurately along the model curve. Mathematically it is defined as follows:

$$R^2 = 1 - \frac{\sum_{i=1}^m (y_i - \hat{y}_i)^2}{\sum_{i=1}^m (y_i - \bar{y}_i)^2} \quad (9)$$

Where \bar{y} is the mean of the measured RSSI.

b. Channel Fading Characteristic:

There are two different types of fading: the small scale and the large scale fading. To test the measured RSSI values fluctuations, variance (*VAR*) and standard deviation have been recommended. The *variation* (*VAR*) and the *standard deviation* (σ) are defined as:

$$VAR = \sigma^2 = \frac{m \cdot \sum_{i=1}^m (y_i)^2 - \left(\sum_{i=1}^m y_i \right)^2}{m \cdot (m - 1)} \quad (10)$$

Small scale fading variance (1_s) is defined as the variation of the measured RSSI values (blue spots) around the window median RSSI value, which is calculated for the predefined interval of 40 . Its standard deviation distribution is considered to be normal. Whereas, the large scale fading variance (1_L) is described by the variation of the window median RSSI value with respect to the distance. The total fading variance (σ_{TM}) is defined as the variation of the measured data. Also, it can be calculated using the following equation [4]:

$$\sigma_{TE} = \sqrt{\sigma_S^2 + \sigma_L^2} \quad (11)$$

V. Measurement Analysis, Results and discussions

In this section, we present the measurement analysis based on the data collected from base stations 2, 5, and 9 with omni-directional antennas, for the selected route passing through the urban area of the Riyadh city. The selected route was divided into four sub-parts; (i) Olaya Main Street, (ii) Khurais Road, (iii) King Abdulaziz & Prince Faisal Roads, and (iv) King Fahd Road. The details of these parts are given in Table 1. The data collected while traversing these routes from the above mentioned base stations are presented in Figures 2 (a)-(e). Figures 2 (a), (b), (c), and (d) present the RSSI data collected for the sub-parts, whereas figure 2 (e) presents the RSSI data collected for the overall parts.

The x-axis presents the distance between the base stations and the mobile station (TETRA hand held radio). This distance is calculated from the coordinates obtained from the commercial GPS, for the mobile station and the base stations locations, whereas the y-axis presents the corresponded RSSI (from the above three base stations) at that distance. Curve (1) "Black color" is a logarithmic fit to the window median RSSI values. The median of measured RSSI of the small scale window is obtained at every 40 intervals using a sliding window of 80. Curve (2), presented in red color passes through these window median values. The measured data having T-R distances less than or equal to 9 km have been considered, as on an average 9 km radius corresponds to a cell-edge (in the urban area) where the received power has fallen close to the dynamic sensitivity level of a TETRA receiver (set at -103 dBm, according to the ETSI standards [3]). Also, the targeted area is located within 9 km from all Base Stations. This distance is almost twice the distance that has been gotten in [4].

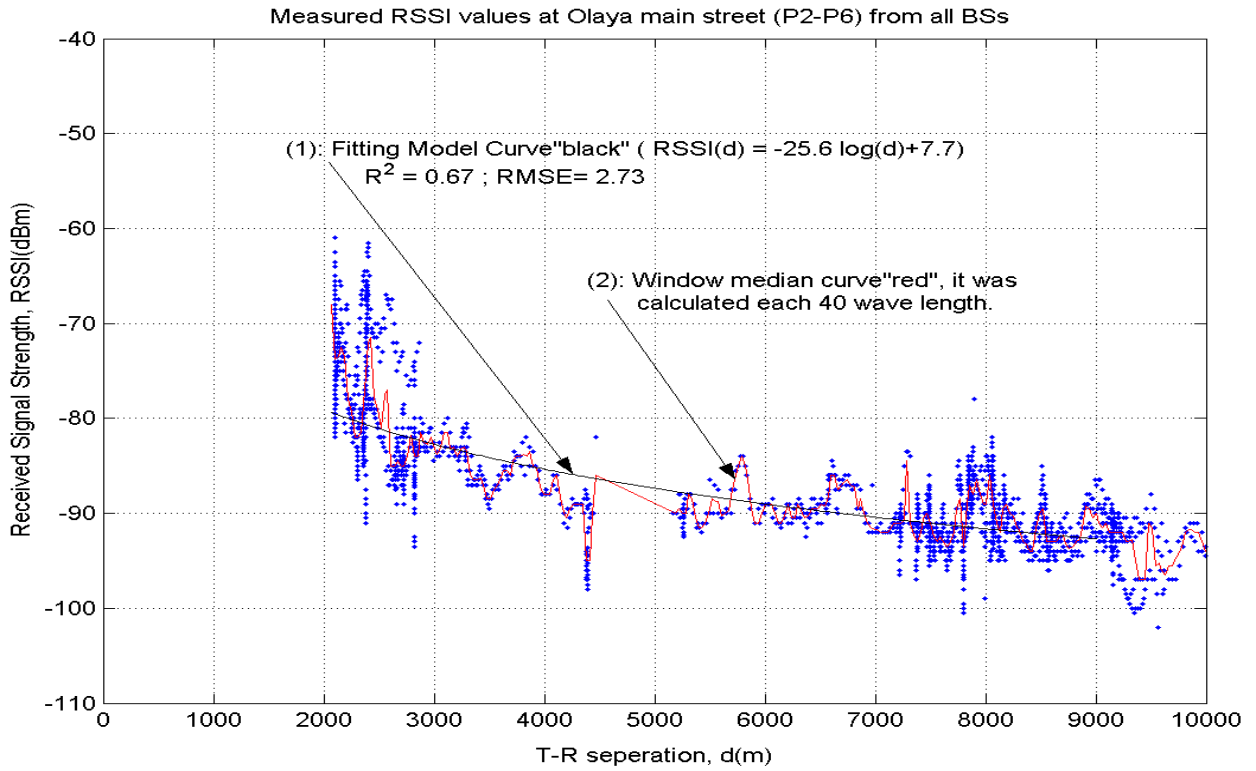
The near zone of propagated measured signal is found in the range of 1km from the base station. In this zone the RSSI does not comply with the log distance model, thus limiting the data fitting of the RSSI measurements in the range of 1-9 km.

Using the aforementioned expressions (section IV), the details of the model parameters (n , and C) with 95% confidence interval and the statistical analysis for the sub-routes as well as the overall route are presented in Table 2. From Table 2, we can say that the predicted model, equation (5), fits well with the measured data for the high density urban areas routes (King Abdulaziz & Prince Faisal Roads) than for urban areas routes (Olaya street and Khurais Road). In spite of Olaya main street passing through the highest towers in the city, the value of n is low compared with other roads that pass through the urban areas. This is due to two reasons: firstly, Olaya street has an open area in some parts. Secondly, the nearest TETRA base station is located at 2km from this street, and we found that the decay of the received signal strength in the 1-2 km, in general, is higher than other portions. Thus with no data present in 1-2 km at this street (Fig. (a)) reduces the value of its n . The value of n for the overall selected route is found to be 3.22 with the best fitting. This exponent is low compare to the European cities, as the streets are wider and the buildings are lower in most part of the route. This result enhances the hypothesis that states, "Each environment has its effects on the wireless communications propagation".

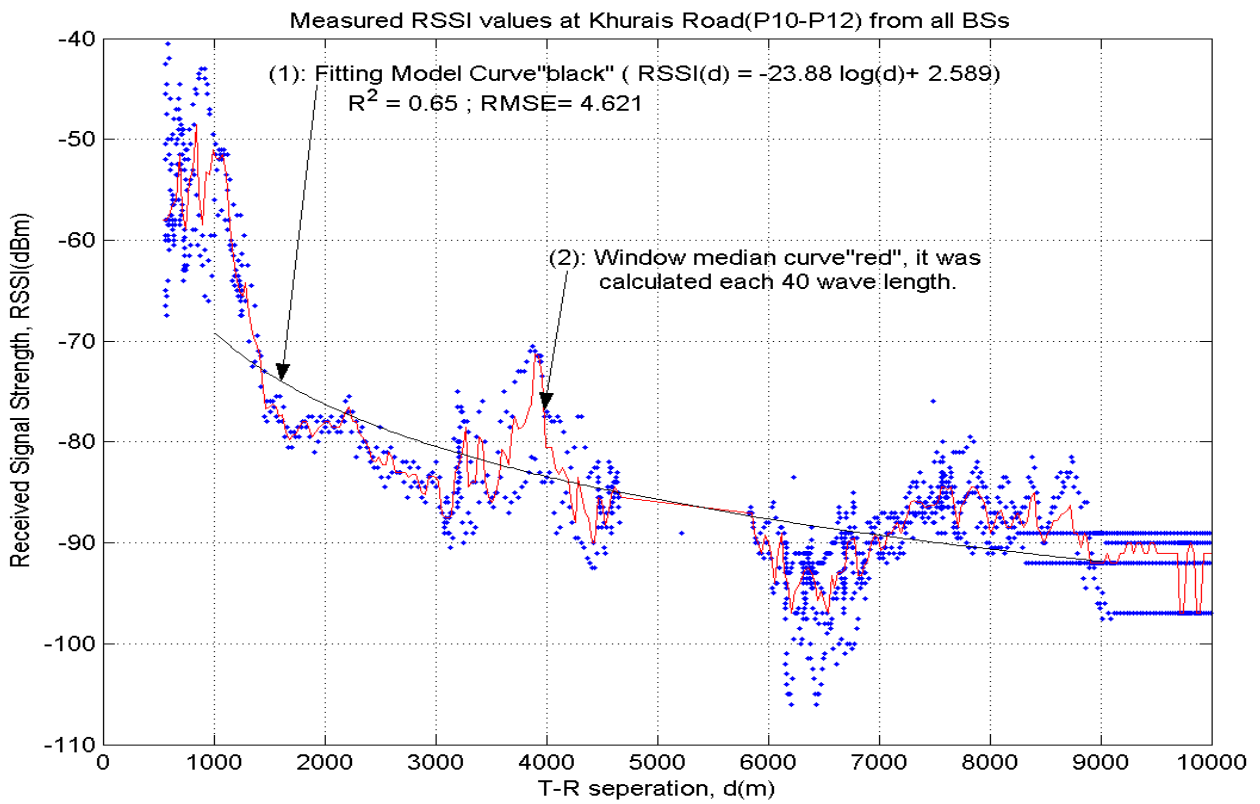
VI. Conclusion:

The paper concludes that TETRA outdoor large-scale received signal prediction model follows log-distance model. In Riyadh City the model exponent (n) is equal to 3 ± 0.7 . The average value of standard deviation for small scale fading fluctuations over a short period of travel distance (40) is found to be in the range of (2.5-4.7).

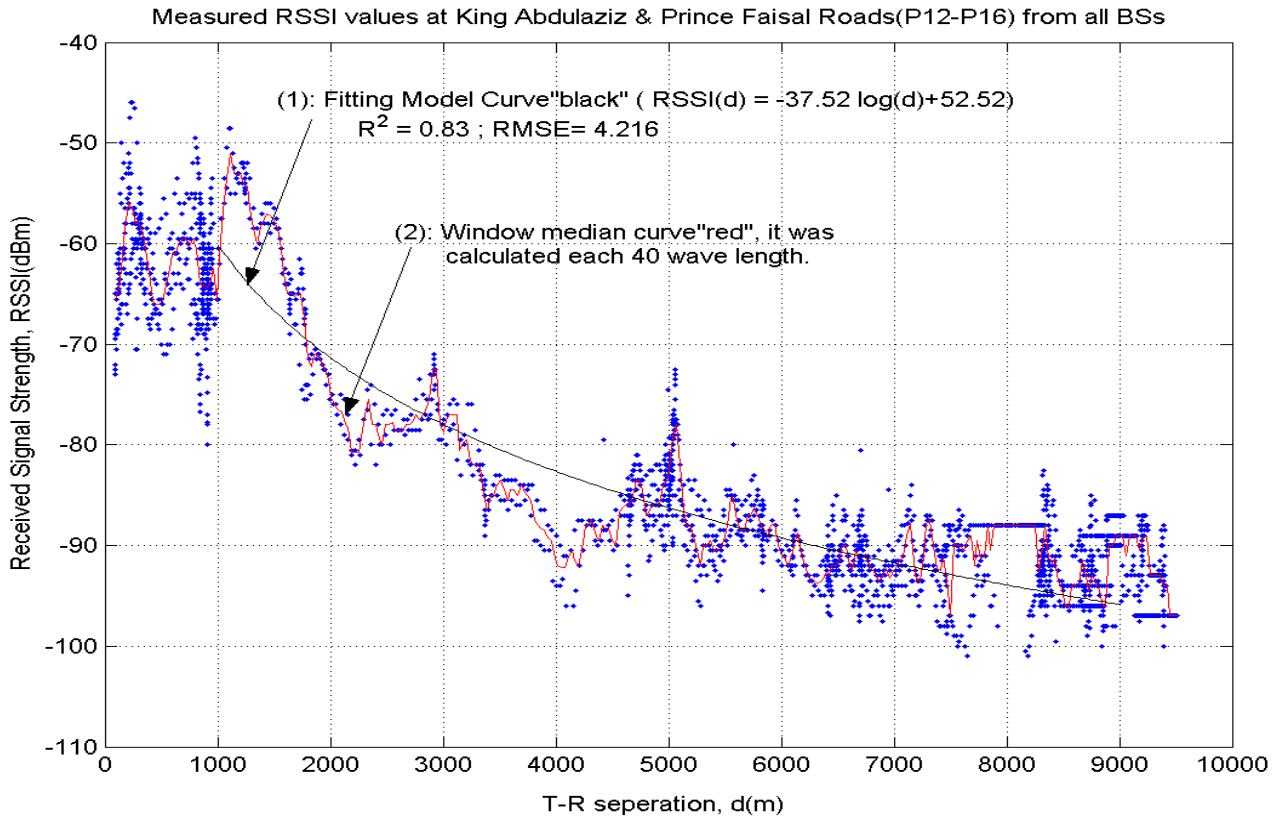
In this study, the presence of antenna height, heights of the nearby buildings and terrain profile have not been considered. The effect of these correction factors to the log-distance prediction model may increase the accuracy of prediction. Log-distance prediction model alone has its limitation when used in high density urban areas, as the correction factors are dominant in such environments. The effect of these factors will be considered in our future work.



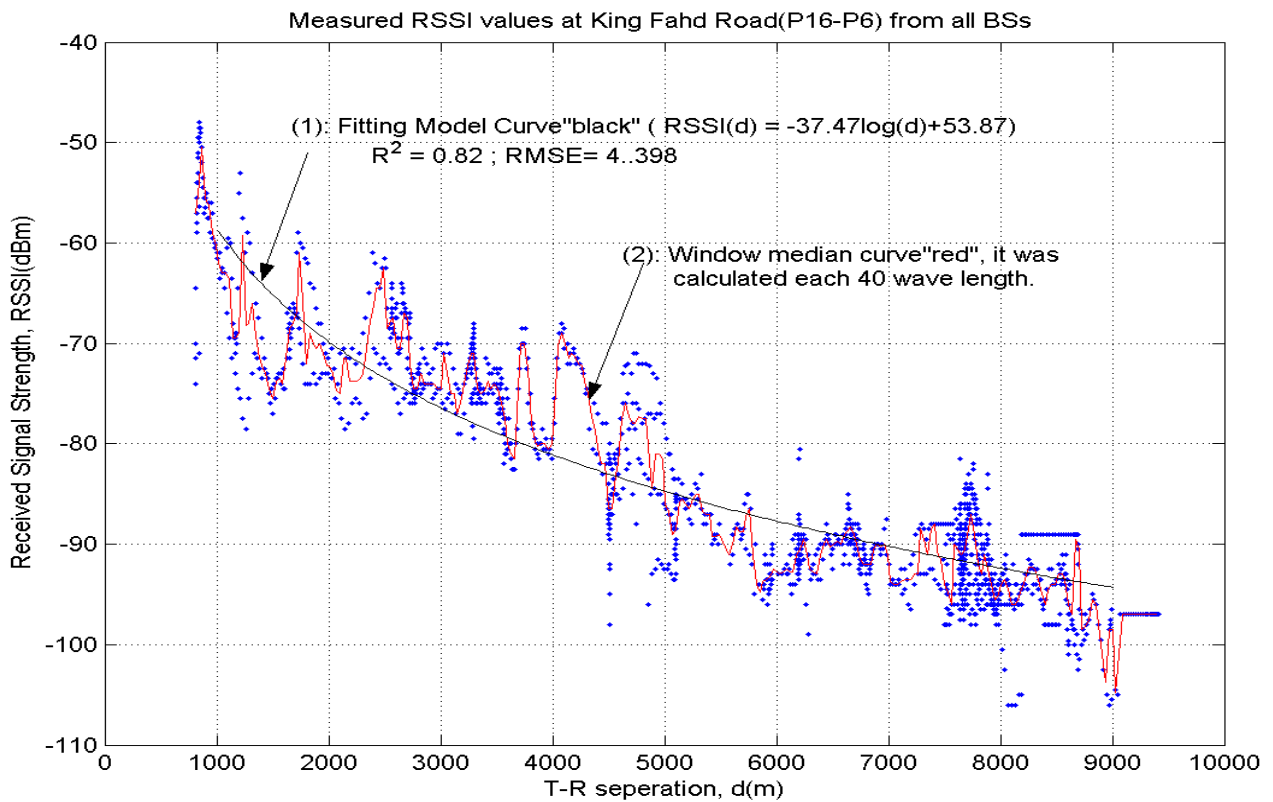
(a)



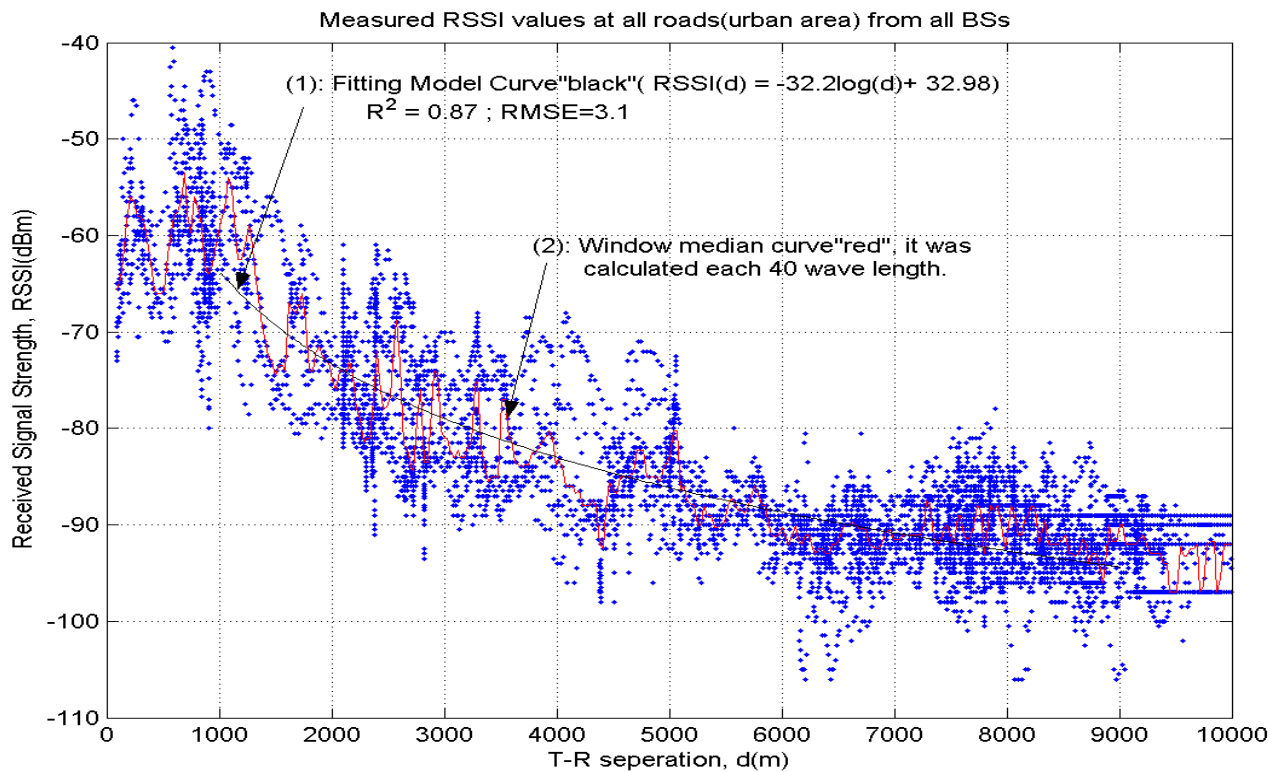
(b)



(c)



(d)



(e)

Figure3: (a), (b), (c) and (d) show the data collected for the sub-routes parts, whereas (e) depicts the data collected for the overall sub-routes.

Table 3: Details of the selected route parts

Sub-parts Between points	Name and Description	Ave. Street Width	Street/Roads length	Average Building Height	No. of collected data
2-6	Olaya Main Street; one of the most commercial streets in Riyadh City. This street has many towers. However, it has several open areas. In addition to that, the nearest TETRA base station that covers this road is 2km far from it.	60m	7km	25m	1743
10-12	Khurais Road, part of the north side of this road is open, although this part has a long bridge.	50m	8km	20m	1046
12-16	King Abdulaziz and Prince Faisal Roads. These roads pass the most high density urban area in Riyadh City (Riyadh downtown)	40m	8km	20m	1934
16-6	Part of King Fahd Road, this road is surrounded by building separated with narrow streets.	80m	7km	20m	1091
All the above parts		58m	30km	22m	5814

Table 4: Details of model parameters with the statistical analysis

Sub-parts Between points	Description	$n = A/10$	C	$RMSE$	R^2	σ_s	σ_L	σ_{TE}	σ_{TM}
2-6	Olaya Street	2.56	7.7	2.73	0.67	2.5	4.88	5.48	7.46
10-12	Khurais Road	2.388	2.589	4.621	0.65	3.51	10.27	10.85	8.81
12-16	King Abdulaziz and Prince Faisal Roads	3.752	52.52	4.216	0.83	2.722	11.74	12.10	8.952
16-6	King Fahd Road	3.747	53.87	4.398	0.82	3.24	11.24	11.7	10.10
All the above	Part of the selected route	3.22	32.98	3.1	0.87	4.71	10.93	11.90	8.82

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