# LEVEL CROSSING RATE AND AVERAGE FADE DURATION CALCULATION SCHEMES BASED ON TETRA RECENT MASUERMENTS

FAIHAN D. ALOTAIBI and ADEL A. ALI
Electrical Engineering Department, King Saud University
P.O. Box 800, Riyadh 11421, Kingdom of Saudi Arabia
falotaibi@tel.moi.gov.sa
adelali@ksu.edu.sa

*Abstract* — **Two important statistical properties associated with TETRA channel fading level have been calculated using suggested calculation schemes. These are the level crossing rate (LCR) and the average fade duration (AFD). The suggested calculation schemes are aimed to assist practicing engineers and researchers in the calculation of LCR and AFD for measured wireless signal that follows any distribution. A comparison of measured signal LCR and AFD curves with similar Nakgami curves has been performed. The comparison illustrates that most of the selected route parts have a dominant direct wave path within a range of 2.5km from the base station whereas, the over all fade distribution could be considered as Rayleigh fading distribution.**

*Keywords* — **Average Fade Duration, Level Crossing Rate,TETRA.**

## I. INTRODUCTION

In the propagation environment of digital mobile communication, the signal received by the mobile may consist of a large number of multipath components due to reflection, diffraction and scattering between the transmitter and the receiver. The randomly distributed phase, amplitudes, and angles of arrival of multipath components combine at the receiver give a resultant signal strength which can change rapid over a small travel distance or time interval and named fast fading. When there is no line of sight (NLOS) component between mobile station(MS) and base station (BS), received signal consist of reflection and scattering wave from different directions and follows Rayleigh distribution. When there is a dominant stationary signal component present, the small-scale fading envelop distribution is Rician. The power ration between LOS and NLOS can be obtained by estimating Rician *K*- factor or Nakagami *m* parameters [2]. The system performance changes rapidly when the signal falls below some noise-related threshold and this causes bursts of errors to occur [3]. The rates of occurrence and average length of these error bursts can be estimated from the level crossing rate (LCR) and average fade duration (AFD) of the received signal strength.

The LCR is defined as the rate at which the envelope (received signal strength) crosses a specified level (fading level) in the positive (or negative) slope, and the AFD is the average time duration that the fading envelope (received signal strength) remains below a specified level [3-5].

In spite of existing numerous researches utilizing LCR and AFD for many approaches and techniques such as diversity [5], none of these researches gives an insight on how to calculate LCR and AFD for measured received signal. The changes in the received signal strength depend on two factors. Firstly, the received signal strength changes due to the change in the traveling distance between the BS and the MS (i.e., path loss effect) and secondly due to the fading. Effect of path loss has been studied in our paper [1], whereas this paper deals with TETRA channel fading analysis based on the measurement[1] mentioned in [1]. In order to mitigate the effect of path loss, we divide the total distance into small windows (local areas), and calculated LCR and AFD for measured received signal falling within these windows. The values obtained are then averaged over the total number of windows.

## II. LCR AND AFD SCHEMES CALCULATION

Probability Density Functions (PDF) and Cumulative Fade Distributions (CFD) are first-order statistics and are used when the speed of the mobile exerts no influence. Systems engineers, however, need to study the received signal variations in more detail, for example, for a quantitative description of the fading rate and the distribution of fades. This kind of information is of great importance when deciding what binary rates, word lengths, or coding schemes should be used for optimum transmission through the mobile channel (i.e., to better protect the system form possible error bursts). The required information is provided LCR, AFD parameters [3,5]. These parameters depend on the speed of the mobile station and known as the second order statistics. Cumulative Fade Distributions Function (*CFD*) is defined as the probability that the fade envelop is less or equal a given level.

$$CFD = p(r \le R) \tag{1}$$

And for measured data it is the number of data equal or less than the given level divided by the total number of the data. Where, the number of level crossings ($N_R$) per second is expressed theoretically as follows [3]:

$$N_R = \int_0^\infty \dot{r}\, p(R,\dot{r})\, dr \tag{2}$$

1 The received signal measurements were conducted on Saudi Arabia National Guard (SANG) TETRA system with assistant of General Directorate of Military Survey (GDoMS), Motorola and Nasco Companies.

Where, $\dot{r} = \frac{dr}{dt}$ is the time derivative of $r(t)$ ( i.e. the slope), $p(R, \dot{r})$ is the joint probability density function of the $r$ and $\dot{r}$ at a given fading level $R$. On the other hand, AFD ( $\tau(R)$ ) is computed by adding up the duration ( $t_i$ ) of individual fade below level $R$ and dividing by number of fades ( $N_R$ ). This is given by

$$\tau(R) = \frac{\sum_{i=1}^{N} t_i}{N_R} \quad (3)$$

Also it can be obtained theoretically by dividing CFD by LCR. Normalized of the Received Signal Strength Indicator (*RSSI*) and fade level to local Root Mean Square (*RMS*), mean or median have been used to calculate the first and second order statistical analysis. As mentioned previously, LCR and AFD are presented in many literatures for known fade distribution functions like Rayleigh, Rice, Nakagami, and log normal in a closed form [3-5] but for measured data case, it is not presented in mathematical form. However, based on the data PDF, the suitable form is used. But if the data distribution does not follow known distribution, the manipulation is not clear. This drawback motivates us to formulate these calculations here.

### A. *LCR calculation scheme :*

To calculate LCR for received signal the following steps are suggested:

Step 1: Divide the data distance into small window (*W*), each window with length equal to tens(*n*) of wave length ( $\lambda$ ).This is done to study the LCR in a local area. $80\lambda$ (60 m) is used here with sliding window equal to $40\lambda$ .

$$W = \frac{D\max}{n\lambda}$$

Where, $D\max$ is the maximum distance that corresponds the measured received signal.

Step 2: Normalize each window data ( $RSSI_{W(i)}$ ) to its *RMS* or median or mean. Here we normalized to the *RMS.*

$$RSSI_{W(i)-Normalized} = \frac{RSSI_{W(i)}}{RSSI_{W(i)\_RMS}}$$

if $RSSI$ in m Watts. Or

$$RSSI_{W(i)-Normalized} = RSSI_{W(i)} - RSSI_{W(i)\_RMS}$$

if *RSSI* in *dBm* and $W(i = 1,2,3,......,M), M$ is the window numbers.

Step 3: Select fade levels (*R*) base on the maximum and minimum normalized window data

Step 4: For fade levels $R$ ( $j = 1$) to $R$ ( $j = L$ ), count $RSSI_{(W(i),k)}$ & $RSSI_{(W(i),k+1)}$ , in each window, that satisfy the following condition:
$RSSI_{(W(i),k)} \geq R(j) > RSSI_{(W(i),k+1)}$
$k = 1,2,3,..g(i)$ ; $g(i)$ is the number of data in each window and *L* is the number of fade levels. Then; $LCR_{(W(i),R(j))} = N_{(W(i),R(j))}$ is the total number of these pairs.

Step 5: Repeat step 4 for all windows $W(i = 1,2,3,...,M)$.

Step 6: Finally; $LCR_{R(j)} = N_{R(j)} = \frac{\sum_{i=1}^{M} N_{(W(i),R(j))}}{M}$

where, $j = 1,2,3..., L$

### B. *AFD calculation scheme :*

The following steps are suggested for AFD calculation:
Step 1: Repeat *LCR's* steps1 to 3.
Step 2: For fade levels $R$ ( $j = 1$) to $R$ ( $j = L$), count $RSSI_{(W(i),k)}$ & $RSSI_{(W(i),k+1)}$ , in each window, that satisfy the following condition
$RSSI_{(W(i),k)} \geq R(j) > RSSI_{(W(i),k+1)}$
followed by
$RSSI_{(W(i),k+q)} < R(j) \leq RSSI_{(W(i),k+q+1)}$
where, $g(i) \geq q > k + 1$ then, calculate its corresponding time duration ( $t_C$ ) as follows:

$$t_C = \frac{1}{2}(t_{(W(i),k+q)} + t_{(W(i),k+q+1)}) - \frac{1}{2}(t_{(W(i),k)} + t_{(W(i),k+1)})$$

Where, $t_{(W(i),k)}$ is the corresponding time of the $RSSI_{(W(i),k)}$ .This needs to convert the window distance length to window time duration using mobile speed ( $W_t = \frac{n\lambda}{MS_{speed}}$ ). The first window data should be observed and if it is less than the given fade level; it must consider as starting point of fade duration. As a result of this step *AFD* for fade level *R*(*j*) in window *W*(*i*) is given by

$$AFD_{(W(i),R(j))} = \tau_{(W(i),R(j))} = \frac{\sum_{f=1}^{S} t_{C(f)}}{S}$$

where, S is the number of sub-time durations.

Step 3: Finally; $AFD_{R(j)} = \tau_{R(j)} = \dfrac{\sum_{i=1}^{M} \tau_{(W(i),R(j))}}{M}$

where, $j = 1,2,3...,L$

## III. RESULTS AND DISCUSSIONS

Using the aforementioned schemes, LCR, and AFD curves have been plotted for the collected data from base stations 2, 5, and 9, 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 and measurements are given in [1].

The x-axis presents fade levels normalized to the *RMS*, whereas the y-axis presents the corresponded LCR and AFD in separate figures. To compare these statistical parameters with known distribution, Nakagami LCR and AFD for different value of *m* (*m* = 0.5, 1, 5, 10) have been plotted [4]. Also, CFD for measured data and for Nakagami distribution have been plotted.

Generally, when *m*<1 then the PDF of the received signal follows distribution worse than Rayleigh distribution. While when *m*=1, then the PDF of the received signal follows Rayleigh distribution and that means there is NLOS between BS and MS. The received signal envelop PDF follows Rician Distribution when there is LOS (*m*>1) between BS and MS (better than Rayleigh). Nakagami *m*-parameter for overall selected route parts is plotted with respect to the BS and MS separation distance using proposed method in[2]. Exact values of do not follow the decreasing trend with the increase in the distance strictly. However, the argument is correct on an average basis as illustrated from Fig.1.

Fig. 2(a), 3(a) and 4(a) show the CFD, LCR, and AFD for the four above mentioned sub-parts, where Fig. 2(b), 3(b) and 4(b) show the CFD, LCR, and AFD of Nakagami distribution. CFD, LCR and AFD of the overall of the selected route were added to these two groups for comparison purpose. LCR and AFD figures depict that, most of fades in selected route parts follow Rician distribution within a range of 2.5km from the base station. However, the fade distribution of the overall route is considered as Rayleigh distribution.

## IV. CONCLUSION

The schemes proposed here to calculate LCR and AFD for the measured data will help the practicing engineers in studying the wireless channel fading. Applying the suggested LCR and AFD calculation schemes to the measured data conclude that SANG TETRA system channel fading follows Rician distribution within a range of 2.5km from the base station. However, the over all fade distribution is considered as Rayleigh distribution.


## ACKNOWLEDGMENTS

The authors wish to thank the following agencies, companies and individuals who either participated or supported the propagation survey and data acquisition: SANG, GDoMS entities, Motorola, and Nasco companies, Cap. M. Al-sultan from SANG, Mr. S. Al-Shehree and Mr. K. Al-otaibi from GDoMS, and Mr. Abdel Nasser Abu Zaid from Motorola. Special thanks go to Dr. Saud Al-Semari for his support throughout.


## REFERENCES


[1] Faihan D. Alotaibi and Adel A. Ali, "TETRA Outdoor Large- Scale Received Signal Prediction Model in Riyadh City-Saudi Arabia", submitted to 8th annual IEEE Wireless and Microwave Technology Conference (WAMICON 2006). Will be held on 4-5,Dec.2006,USA.

[2] L.J.Greenstein, D.G. Michelson, and V. Erceg "Moment-Method Estimation of the Ricean K-factor", IEEE communications letters, Vol.3,No.6,June 1999.

[3] Jose M. Hernando and F. Perez-Fontan, Introduction To Mobile Communications Engineering, Artech House,685 Canton Street, Norwood, MA 02062, 1999.

[4] Li Tang and Zhu Hongbo, "Analysis and Simulation of Nakagami Fading Channel with MATLAB", Proceeding of Asia-Pacific Conference on Environmental Electro-Magnetic (CEEM'2003), pp.490-494, Nov. 2003.

[5] F. Adachi, M.T. feeney, and J.D. Parsons, "Level crossing rate and average fade duration for time diversity reception in Rayleigh fading conditions" , IEE proceedings, Vol. 135, Pt.F, No.6,pp.501-506,Dec.1988.

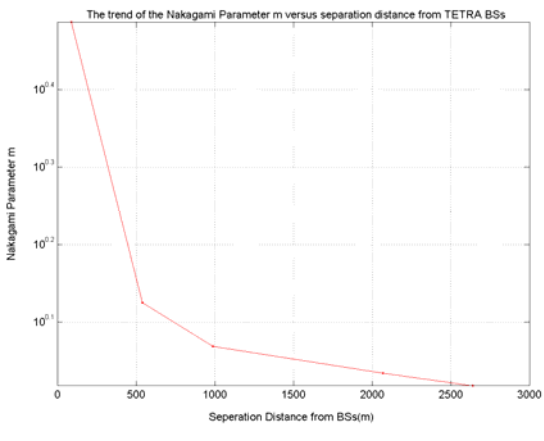
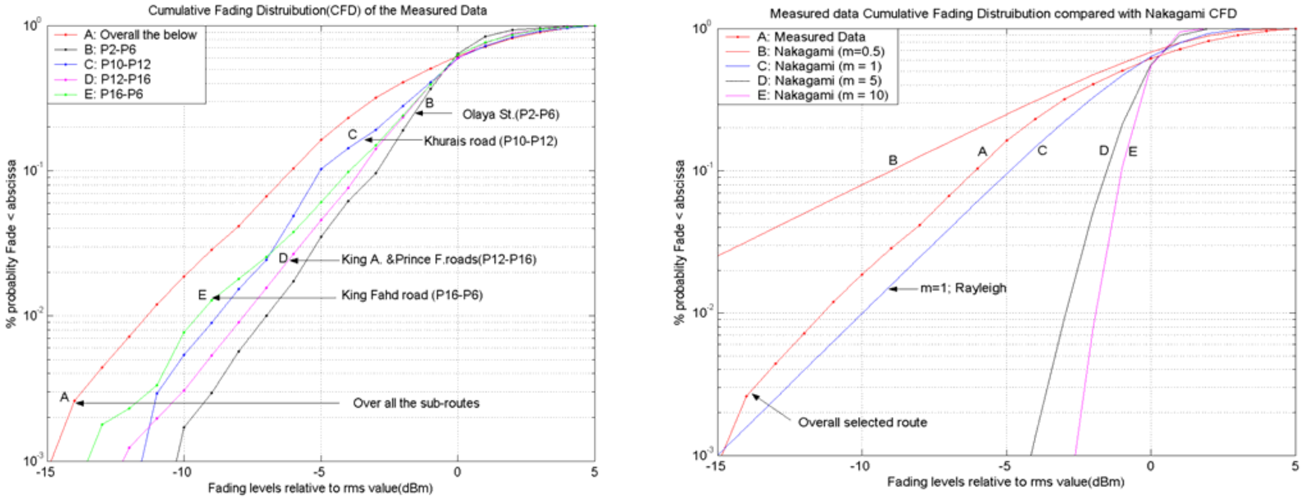
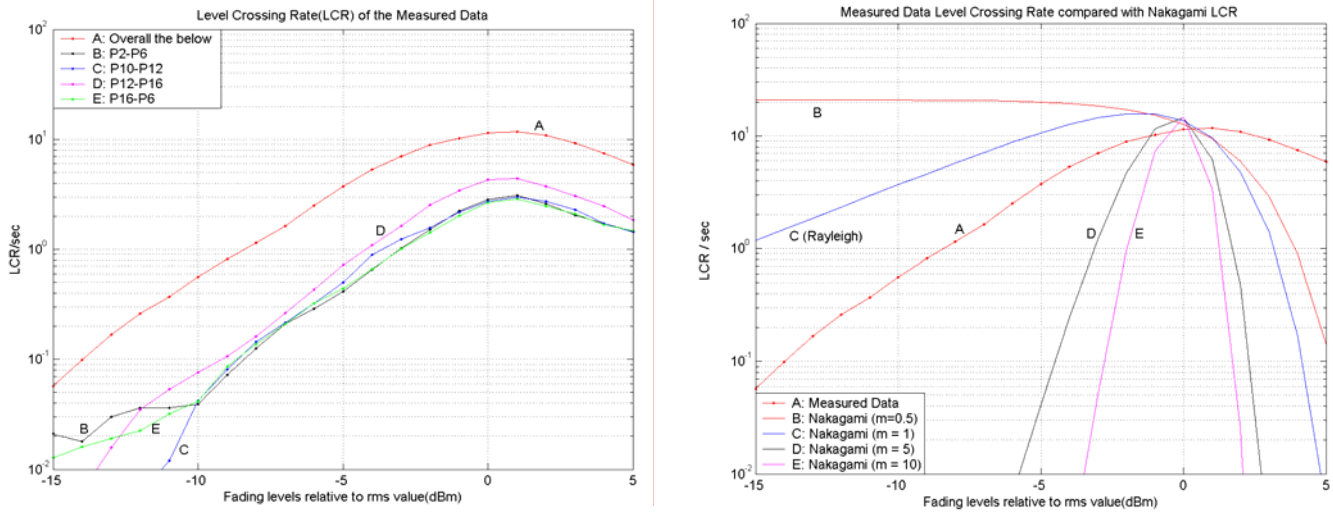




Fig. 1: *m*-parameter trend versus BS, MS separation distance.



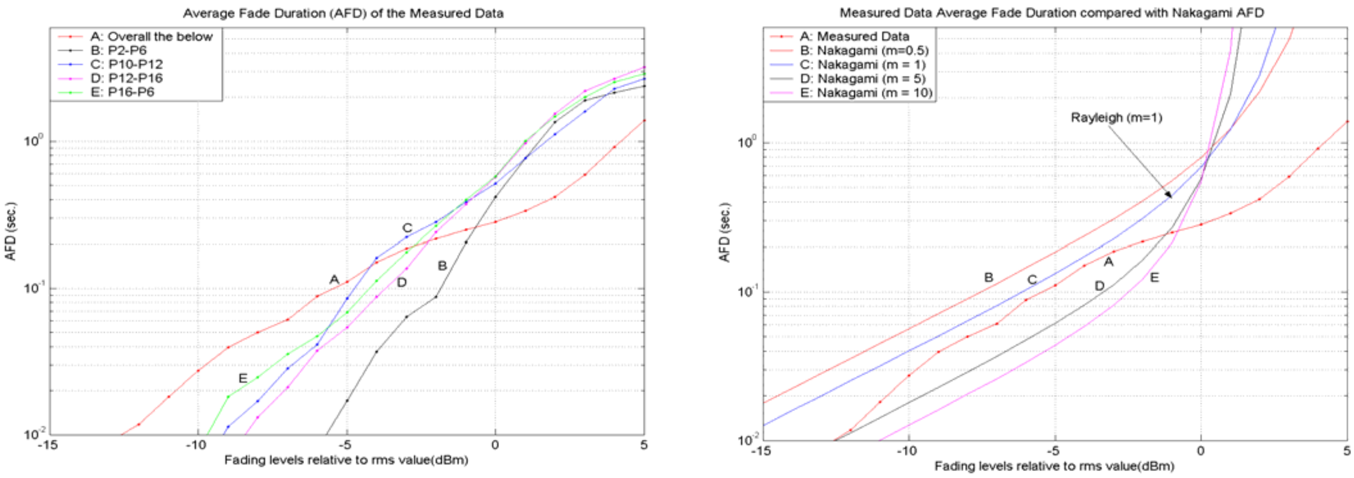

(a) (b)

Fig. 2: TETRA channel fade CFD curves. (a): CFD of the selected route parts. (b) All over the selected routes compare with Nakagami CFD.




(a) (b)

Fig. 3: TETRA channel fade LCR curves. (a): LCR of the selected route parts. (b) All over the selected routes compare with Nakagami LCR.




(a) (b)

Fig. 4: TETRA channel fade AFD curves. (a): AFD of the selected route parts. (b) All over the selected routes compare with Nakagami AFD.