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Mitigation of ISI for Next Generation Wireless Channels in Outdoor Vehicular Environments

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Abstract**—**In order to accommodate various multimedia services, next generation wireless networks are characterized by very high transmission bit rates. Thus, in such systems and networks, the received signal is not only limited by noise but - especially with increasing symbols rate often more significantly by the intersymbol interference (ISI) caused by the time dispersive radio channels such as those are used in this work. This paper deals with the study of the performance of detector for high bit rate transmission on some worst case models of frequency selective fading channels for outdoor mobile radio environments. This paper deals with a number of different wireless channels with different power profiles and different number of resolvable paths. All the radio channels generated in this paper are for outdoor vehicular environments with Doppler spread of 100 Hz. A carrier frequency of 1800 MHz is used and all the channels used in this work are such that they are useful for next generation wireless systems. Schemes for mitigation of ISI with adaptive equalizers of different types have been investigated and their performances have been investigated in terms of BER measured as a function of SNR.

Keywords**—**Mobile channels, Rayleigh Fading, Equalization, NMLD.

I. INTRODUCTION

RADIO waves arrive at the mobile radio receiver from the base station via many different paths, with different time delay. The time difference between first and last replica of the signal reaching at the receiver is known as delay spread. Signals from these paths will have considerable phase differences and will vectorially combine at the receiver. Furthermore, when the receiver moves from one location to other, there is a change in the phase relationship among the various components of the incoming signal, and this gives rise to fading in the received signal. Along with this, when a receiver or transmitter moves in standing waves, the receiver experience random variation in the signal level and phase and also Doppler shifts of the frequency component within the received signal due to the relative motion between the transmitter and receiver. As a consequence of the standing waves characteristic, the minimum distance between two signal level drop is one half of the wavelength [1]. This microscopic deviation of the received signal is called fast fading [1]. Also, when the time delay spread is large, an appreciable amount of intersymbol interference (ISI) is caused. The ISI becomes more serious when the delay spread is approximately 30% or more of the duration of the signal duration [2].

In indoor environments, the time delay spread is usually very small, according to Saleh [3] it is 10-50 ns for office environments. This leads to small ISI, and thus the ISI mitigation methods are much simpler as already reported by various researchers earlier [4-6]. However, in the work being presented in this paper, the authors are considering the case of outdoor urban environments where the ISI can be too severe, which could be order of ten microseconds [7]. The Doppler spread, which is due to the relative motion between mobile terminal and base station is considered as 100 Hz. The aim of this research is to study of the performance of the detector thus all the cases of the channels are worst i.e. these channels having maximum phase and maximum ISI. Use of channel coding techniques has also been investigated in the past, but they are known to perform well only in those systems which are noise-limited only [2].

In this paper ISI is mitigating with the help of two types of equalizations i.e. linear and nonlinear equalization. Near Maximum likelihood detector (NMLD) is very nearly an optimal detection technique and may be employed for the mitigation of ISI in outdoor environments with severe ISI. However due to the extremely high complexity of NMLD, the issue which would come into the picture will be of higher power consumption and larger memory requirements of mobile terminals [8-11]. Thus NMLD based receivers will require frequent battery charging which is an important limitation [12]. Such a limitation would not be present in the equalizer based systems being studied in this paper which will obviously have smaller power consumption.

The remainder of this paper is organized as: Section 2 describes the wireless channel generation for the power controlled communication system. Section 3 gives basic architecture and description of the equalizer used in this work. In section 4 description of a number of channels used in this paper is given. In sections 5, simulation results have been given. Finally in section 6 the research work has been

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concluded.

II. MODEL OF THE CHANNEL GENERATION

A number of techniques published in various literatures for the generation of wireless channels. Modeling mobile radio channels by using a tapped-delay-line structure with time-variant coefficients gives a deep insight into the channel distortions caused by scattering components with different propagation delays. Thus, it is recognizable that the received signal, for example, is composed of an infinite number of delayed and weighted replicas of the transmitted signal [13].

In this paper, tapped delay line (TDL) which is simplest as well as very accurate for the generation of wireless channel for mobile application, it has been given in figure 1. The number of taps in this model indicates the reflected path of the wireless channel [14]. In digital communications, a mobile system referred as wideband. Particularly, the channel generated in this paper is for next generation wideband applications.

In this figure, the symbols $Q_0(t)$ $Q_1(t)$ $Q_2(t)\cdots\cdots Q_g(t)$ are presenting as g+1 independent fading paths present in the mobile channel. Each of the fading paths is generated using two independent Gaussian random variables which are passed through five pole low pass Bessel filters such as given in equation 1, which has been written for first fading path of the channel. Here, Five Bessel filter is used for Gaussian shaping of the signal. Each $q_1(t)$ and $q_2(t)$ are two statistically independent real-valued, Gaussian random waveforms, each with zero mean and the same power spectral density [15-16]. Here $q_1(t)$ and $q_2(t)$ are generated independently by passing Gaussian noise source from two separate but identical Bessel low pass filter (LPF). In general, any Rayleigh fading path $Q_0(t)$ will be given by:

$$Q_0(t) = q_1(t) + j\,q_2(t) \tag{1}$$

The carrier frequency used in this paper is 1800 MHz, thus the wavelength of the transmitted signal wave 16.67 cm. thus the minimum distance between two signal level drops will be 8.34 cm, this microscopic deviation in the received signal is tends to undergo fast fading. Relative motion between mobile station (MS) and base station (BS) calculated with the help of the equation (2-4). The five poles Bessel filter is used in this work, for making the spectral shape of the signal as Gaussian. It is to be noted that the filter transfer function depends on the Doppler spread (f_{sp}), sampling frequency and the variance of the channel components.

$$c = 3\times10^8 \text{ m/s} \tag{2}$$

$$\lambda = c / f_c \tag{3}$$

$$v = f_{sp}\times\lambda \tag{4}$$

From these equations (2-4), it is to be found that the relative motion between transmitter and receiver is 60 km/hour (16.66 m/s) for this particular research.

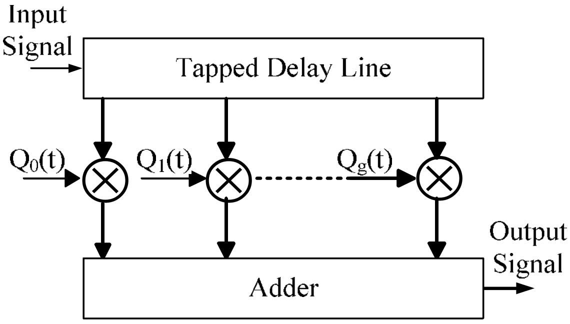

Fig. 1 TDL Model for wideband Channel

III. ISI MITIGATION TECHNIQUES

The basic components of the data transmission system simulated in this work have been shown in Fig. 2. Equalization used in this work is adaptive, since the channel is time varying [12-14]. The ISI can be removed by means of linear or nonlinear (decision-feedback) transversal equalizer, which is inserted between the sampler and threshold level detector. One important result also comes in the light from the observations and it is that the linear equalizers can work well when the ISI is not too severe in the channel. Ideally, the equalizer is adjusted such that channel and equalizer together introduce no distortion into the signal at the detector input [14]. This paper is concerned with applications of digital data transmission over a wireless fading channel. A synchronous serial 4-QAM data transmission system is considered in this work. Signal at the input to the transmitter filter is $\sum_i s_i\delta(t-iT)$, where s_i=±1±j represents the data symbol. If the impulse response of the linear baseband channel is y(t), sampled impulse response will become $y_h\delta(t-hT)$. It can also be written for g+1 component vectors.

$$V = [y_{i,0} \quad y_{i,1} \quad y_{i,2} \quad y_{i,3}\cdots\cdots y_{i,g}] \tag{5}$$

where $y_i = y(iT)$ and $y_i = 0$ for $i<0$ and $i>g$. In the form of z-transform, it is given as:

$$Y(z) = y_{i,0} + y_{i,1}z^{-1} + \ldots\ldots.. + y_{i,g}z^{-g} \tag{6}$$

The signal at the receiver input will be

$$r(t) = \sum_i s_i y(t-iT) + w(t) \tag{7}$$

where $w(t)$ represents the additive white Gaussian noise waveform with zero mean and variance σ_w^2. At the input the of equalizer, $r(t)$ is sampled at $t = iT$ to give the received signal samples $\{r_i\}$ given by equation (7).

$$r_i = \sum_{h=0}^{g} s_{i,h}y_{i,h} + w_i \tag{8}$$

These samples $\{r_i\}$ are fed to the equalizer whose output goes to the threshold detector.

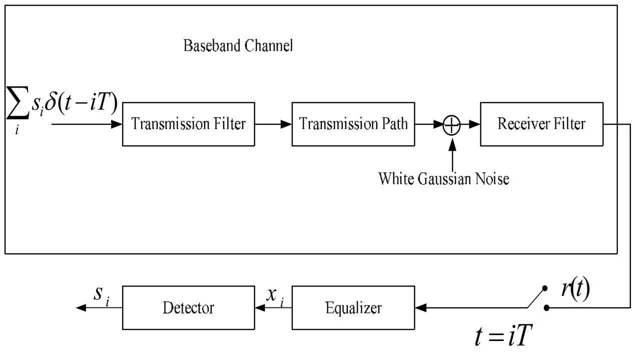

Fig. 2 Model of the data transmission System with Equalizer

A. Linear Equalization

Linear equalization is a process of linear filtering of the distorted signal by a finite impulse response (FIR) filter, or transversal filter. In this work, a 10 tap linear equalizer was implemented in the form of a feed forward transversal filter as shown in Fig. 3. The authors of this paper have found that by increasing the number of taps, no significant improvement was obtained. The sampled impulse response of the filter with m number of taps is given by

$$C = C_0\ C_1\ C_2 \ldots\ldots\ldots\ldots\ldots C_{m-1} \tag{9}$$

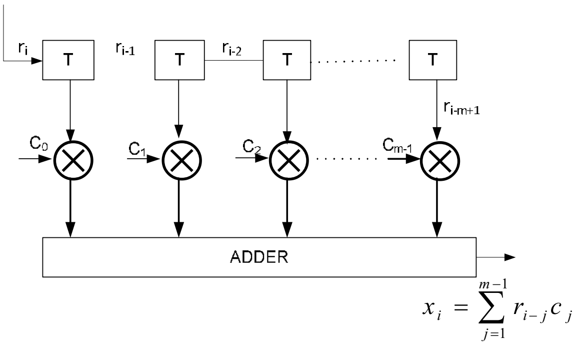

Fig. 3 Model of linear feed forward transversal equalizer

The z-transform of the equation (9) can be written as

$$c(z) = c_0 + c_1 z^{-1} + c_2 z^{-2} + \ldots\ldots + c_{m-1} z^{-m+1} \tag{10}$$

For accurate equalization of the channel the z-transform of the channel and equalizer is

$$y(z) * c(z) \approx 1 \tag{11}$$

The output signal of Fig. 3, at time $t = iT$, will be $\sum_{j=0}^{m-1} c_j r_{i-j}$

The equalizer minimize ISI from the received samples $\{r_i\}$ such that the signal at the input of threshold detector becomes $x_i \approx s_i + u_i$, where u_i is a function of the noise samples, and s_i is the data symbol to be detected. The resultant signal at the output of the equalizer i.e. x_i is then easily detected by a threshold detector.

B. Nonlinear Equalization

Nonlinear Equalizer (NLE) is implemented as a feedback transversal filter feed from the output of the detector, as shown in Fig. 4. Since the detector is a highly nonlinear device, therefore equalization becomes nonlinear. Non-linear equalizer uses decision directed cancellation of intersymbol interference (ISI) [14-15]. The received sample value at the input to the multiplier in Fig. 4, at time $t = iT$, is

$$r_i = s_i y_{i,0} + \sum_{j=1}^{g} s_{i-j} y_{i,j} + w_i \tag{12}$$

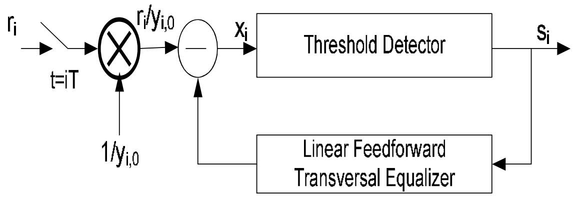

Fig. 4 Receiver using Nonlinear Equalizer

The basic architecture of the Nonlinear Equalizer and detector is given in the Fig. 5. Each of the received signal is multiplied by the inverse of the first path of the channel $(1/y_{i,0})$ as shown in Fig.4. Then the equation (12) modified as

$$r_i/y_{i,0} = s_i + \sum_{j=1}^{g} s_{i-j}(y_{i,j}/y_{i,0}) + w_i/y_{i,0} \tag{13}$$

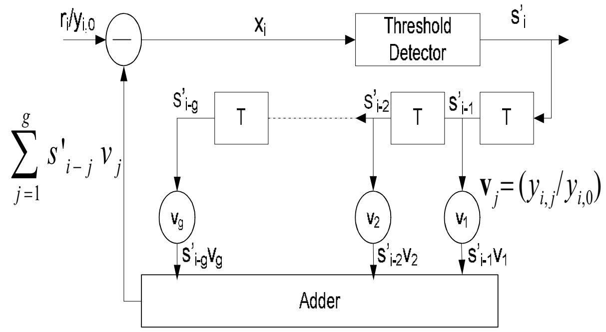

Fig. 5 Nonlinear feedback transversal filter with detector

$$r_i/y_{i,0} = s_i + \sum_{j=1}^{g} s_{i-j} v_j + w_i/y_{i,0} \tag{14}$$

where $v_j = y_{i,j}/y_{i,0}$ for $j = 1\ \ 2\ \ 3\ \ 4 \cdots\cdots g$ the channel impulse response of the baseband channel and multiplier is given as $g+1$ component row vector.

$$V = [1\ \ v_1\ \ v_2\ \ v_3 \cdots\cdots v_g] \tag{15}$$

Assuming that V and the two possible initial values of s_i are known at the receiver, the output signal from the linear feed forward transversal filter in Fig. 5 is $\sum_{i=1}^{g} s'_{i-j}\, v_j$, where s'_{i-j} is the detected value of s_{i-j}. Thus, the signal at detector input at $t = iT$ is

$$x_i = r_i / y_{i,0} - \sum_{j=1}^{g} s'_{i-j}\, v_j \qquad (16)$$

$$x_i = s_i + \sum_{j=1}^{g} s_{i-j}\, v_j + w_i / y_{i,0} - \sum_{j=1}^{g} s'_{i-j}\, v_j \qquad (17)$$

And with the correct detection of each s_{i-j}, such that $s'_{i-j} = s_{i-j}$ for j=1,2,….g , then equation (17) becomes

$$x_i = s_i + w_i / y_{i,0} \qquad (18)$$

IV. Data Transmission Over Mobile Radio

In outdoor mobile radio channels, the delay spread of the channel is typically few tens of a microsecond which may lead to severe ISI and that is the motivation behind this work. For this particular case of the outdoor mobile communication system, the data rate is fixed to be 19.2 Kbits/sec or 9.6 Kbaud/sec. The speed of mobile unit is kept at 60 km/h. This leads to about 73.74 number of fades/sec.

In this work, seven different cases of the wireless channels have been generated and these are tested by checking their mean, variance and fading rate. The mean and variance of the channels and its parameters i.e. of all $q_i(t)$s have been checked. The power of ISI can be controlled in the channel with the help of mean and variance of the channel parameters. Detailed nomenclature of these channels is given below in Table I that also includes the average power present in various independent fading paths. All these channels generated are with the frequency spread of 100 Hz.

TABLE I NOMENCLATURE OF THE CHANNEL USED IN THIS WORK

Channel Name	Remarks
CH10	Single-path fading channel
CH55	Two-path fading channel with Power distribution [50% 50%]
CH73	Two-path fading Channel with power distribution [70% 30%]
CH82	Two-path fading Channel with power distribution [80% 20%]
CH721	Three Path fading channel with power distribution [70% 20% 10%]
CH811	Three Path fading channel with power distribution [80% 10% 10%]
CH333	Three Path fading channel with equal power distribution

V. Simulation Results

The channels generated through computer simulation have been thoroughly verified, details of which are given below. This section is divided in two subsections, first for the results of the channel verification and the second for the performance of ISI mitigation over these channels.

The wireless channels used in the work have been verified by comparing various parameters of the channel from their theoretical counterparts. These results have been shown in the tables II to VIII. Table II shows the results for the flat fading channel (CH10), whereas tables III, IV, V, VI, VII and VIII showing the verification for the channel numbers CH55, CH73, CH82, CH721, CH811 and CH333 respectively. It can be seen in these tables that the all parameter of the channel: those have been generated, have a close relationship with their theoretical counterparts.

Table II is showing the case of flat fading channel, therefore it is with only a single path and thus it can be generated with the help of two independent Gaussian noise sources. The output of the Gaussian noise source should be the input of low pass Bessel filter. And variance at the output of the Bessel filter should be 0.5 at each. It could be seen from the table II that the very close to the theory, only a slight difference due to the statistical error.

Fig. 6 shows the performance of the linear Equalizer on various channels listed above. CH10 represents a flat fading channel and is studied here with an objective that the performance on other channels (which are frequency selective) may be compared with it. The linear equalizer performs reasonably when the ISI is moderate such as that present in channels CH73, CH82, CH721 and CH811. The performance of linear equalizer is very poor over channels CH55 and CH333 because of the presence of severe ISI representing worst case channels. On the other hand, the nonlinear equalizer is found to perform reasonably well even in cases of severe ISI channels as shown in Fig. 7.

TABLE II PARAMETERS OF CH10

Parameters	Theoretical Values		Simulated Values	
	Mean	Variance	Mean	Variance
q1	0	0.5	-0.0122	0.4742
q2	0	0.5	-0.0201	0.5337
y0	0.8862	0.2142	0.8800	0.2268

TABLE III PARAMETERS OF CH55

Parameters	Theoretical Values		Simulated Values	
	Mean	Variance	Mean	Variance
q1	0	0.25	-0.0012	0.2500
q2	0	0.25	0.0039	0.2500
q3	0	0.25	-0.0012	0.2500
q4	0	0.25	0.0039	0.2500
y0	0.6267	0.1073	0.6247	0.1098
y1	0.6267	0.1073	0.6247	0.1098

TABLE IV PARAMETERS OF CH73

Parameters	Theoretical Values		Simulated Values	
	Mean	Variance	Mean	Variance
q1	0	0.35	-0.0310	0.3500
q2	0	0.35	0.0034	0.3253
q3	0	0.15	-0.0106	0.1500
q4	0	0.15	0.0137	0.1653
y0	0.7415	0.1502	0.7327	0.1395
y1	0.4854	0.0644	0.4957	0.0699

TABLE V PARAMETERS OF CH82

Parameters	Theoretical Values		Simulated Values	
	Mean	Variance	Mean	Variance
q1	0	0.40	-0.0036	0.4000
q2	0	0.40	0.0244	0.4507
q3	0	0.10	-0.0108	0.1000
q4	0	0.100	0.0151	0.0924
y0	0.7927	0.1717	0.8190	0.1804
y1	0.3963	0.0429	0.3906	0.0402

TABLE VI PARAMETERS OF CH721

Parameters	Theoretical Values		Simulated Values	
	Mean	Variance	Mean	Variance
q1	0	0.35	0.0045	0.3500
q2	0	0.35	-0.0104	0.3184
q3	0	0.10	-0.0042	0.1000
q4	0	0.10	-0.0161	0.1028
q5	0	0.05	0.0012	0.0505
q6	0	0.05	0.0239	0.0483
y0	0.7415	0.1502	0.7234	0.1453
y1	0.3963	0.0429	0.4010	0.0423
y2	0.2802	0.0215	0.2783	0.0219

TABLE VII PARAMETERS OF CH811

Parameters	Theoretical Values		Simulated Values	
	Mean	Variance	Mean	Variance
q1	0	0.40	0.0045	0.4000
q2	0	0.40	-0.0104	0.3591
q3	0	0. 05	-0.0042	0.0500
q4	0	0.05	-0.0161	0.0564
q5	0	0.05	0.0012	0.0498
q6	0	0.05	0.0239	0.0509
y0	0.7927	0.1717	0.7792	0.1583
y1	0.2802	0.0215	0.2878	0.0237
y2	0.2802	0.0215	0.2802	0.0222

TABLE VIII PARAMETERS OF CH333

Parameters	Theoretical Values		Simulated Values	
	Mean	Variance	Mean	Variance
q1	0	0.1667	-0.0212	0.1667
q2	0	0.1667	-0.0240	0.1667
q3	0	0.1667	-0.0111	0.1667
q4	0	0.1667	-0.0130	0.1661
q5	0	0.1667	0.0011	0.1766
q6	0	0.1667	-0.0161	0.1658
y0	0.5117	0.0715	0.5116	0.0726
y1	0.5117	0.0715	0.5115	0.0714
y2	0.5117	0.0715	0.5198	0.0725

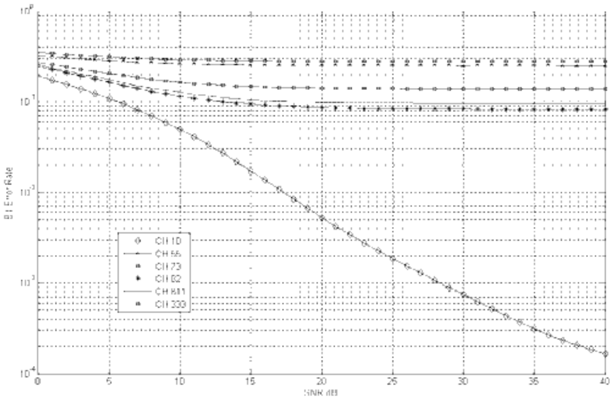

Fig. 6 Linear Equalizer Performance over high speed mobile radio channels

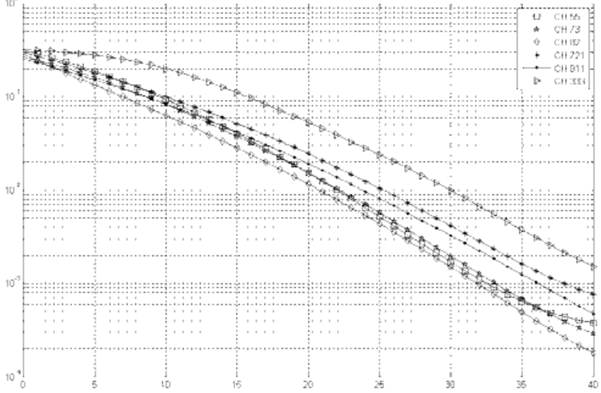

Fig. 7 Performance of Nonlinear Equalization

VI. CONCLUSION

A number of different cases of the channels have been generated and verified successfully. Performance of the communication system with linear equalizer as well as nonlinear equalizer over the channels generated in this paper has been assessed in terms of the BER versus SNR. It is found that the performance of the linear equalizer is not satisfactory for the worst cases of channel but it shows improved performance when the channel intersymbol interference is relatively smaller. However, for further improvement in performance, non-linear equalizer is investigated in this work which shows good performance even for the worst case channel. It may be noted here that the worst case ISI channels studied here are really those which are less likely to occur in practice. However, the idea here is that if the ISI mitigation methods work well for these worst case wireless channels, then they are likely to perform better in practical channels with lesser degree of ISI.

It may be mentioned here that the data rates of 19.2 kbps used in this work may possibly appear to be small for future and next generation wireless systems under study. But a lot of next generation and future systems are likely to use OFDM where an incoming serial bit stream is split up into multiple parallel bit streams each of which then travels over a separate carrier. The reduced signal element duration on any of these individual carriers would however be of the same order as that used in this work, which is also another motivation behind this work. Thus the ISI mitigation methods studied here will be of relevance to future systems also.

REFERENCES

[1] Yoshihiko Akaiwa, Introduction to digital mobile communication. Canada: John wiley and sons 1997.

[2] M. Bhat and M. Salim Beg, “Computer simulation and modeling of high speed data transmission over mobile radio links”, *Journal of Institution of Engineers (I)*, vol. 77, pp. 20-23, Sept. 1996.

[3] A.A.M. Saleh and R.A. Valenzeula, “A Statistical model for indoor multipath propagation” *IEEE Journal on selected area in communication*, Vol. JSAC-5, No.2, pp. 128-133, 1987.

[4] M. Israil and M. Salim Beg, “Performance Assessment of Adaptive equalizers for indoor mobile Channel”, paper is presented in the National *Conference on Modern Trends in Electronics Communication System (MTECS-2008)*, 8-9 March, 2008, AMU Aligarh pp. 230-234.

[5] M. Salim Beg and M. Israil, “Adaptive Equalization for Indoor Fading Channel”, Paper presented in the National *Conference on Emerging Trends in Communication and Computing (ETCC-07)*, 27-28 July 2007, NIT Hamirpur, pp. 382-385.

[6] T.A. Sexton and K. Pahlavan, “Channel modeling and adaptive equalization of indoor radio channels”, *IEEE Journal Selected Areas in Communications*, vol. 7, January 1989, pp. 114-121.

[7] T. S. Rappaport, Wireless Communications Principles and Practice. New Jersey: Prentice Hall, 1996, pp. 197-216.

[8] A. P. Clark, “Near-Maximum-Likelihood Detections Process”, *Jordan International Electrical and Electronics Engineering Conference*, April 28- May 1, 1985, pp 132-136.

[9] A. P. Clark, “Techniques for simplifying some Near-Maximum-Likelihood Detectors”, *IEE Proc*., Vol. 137, Pt I, No. 5, October 1990.

[10] M. N. Muhayiddin and M. Salim Beg, “Performance Analysis of NML Detection for Next Generation Wideband Mobile Radio Applications”, *Proc. Int. Conf. on Information, Communications, and Signal Processing (ICICS2001)*, Oct. 2001, Singapore, paper no. 1A3.3 (in CDROM).

[11] A. P. Clark, S.G. Jayasinghe, “Channel estimation of land mobile radio systems”, *IEE Proc.* Vol. 134, July 1987, pp. 383-393.

[12] M. Israil and M. Salim Beg, “Performance of some detectors for outdoor mobile radio channels with severe distortion” *The Mediterranean Journal of electronics and communications*, vol. 5, No. 2, pp. 58-65, 2009.

[13] Matthias Patzold, Mobile fading channels. USA: Johan Wiley and Sons Ltd, 2002.

[14] A .P. Clark, S. G. Jayasinghe, “Channel estimation of land mobile radio systems”, *IEE Proc*. Vol. 134, July 1987, pp. 383-393.

[15] M. Salim Beg, S.C. Tan and H. Hazemi, “Performance Assessment of Some Adaptive Equalizers in Mobile Radio Environments”, *Proc. International Symposium. on Wireless Personal Multimedia Communications*, Bangkok, Thailand, 2000, pp. 761-766

[16] J. Fuhl, J. P. Rossei, E. Bonek., “High-resolution 3-D direction-of-arrival determination for urban mobile radio”, IEEE Trans. Antennas Propagation, Vol. 45, No. 4, 1997, pp. 672–682.