Performance Analysis of Differential BLM Detector in AF Relay Networks with Time Varying Channels
Omar Gatera, Haci Ilhan, Ahmet H. Kayran
Pages 213-219
DOI: http://dx.doi.org/10.21700/ijcis.2016.125

Performance Analysis of Differential BLM Detector in AF Relay Networks with Time Varying Channels

Omar Gatera[1], Haci Ilhan[2] and Ahmet H. Kayran[3]
Department of Electronics and Communication Engineering
Istanbul Technical University[1, 3]
Yildiz Technical University[2]
Istanbul, Turkey
[omargatera, kayran]@itu.edu.tr, ilhanh@yildiz.edu.tr

Abstract: *In this paper, we investigate the performance of differential Bayesian linear model (BLM) detector in AF relay networks with time varying channels. A first order autoregressive (AR) model is utilized to characterize the time varying nature of channels. We assume that channel state information (CSI) is available at the receiver. We consider that the original transmitted signal is corrupted by noise and other interference signals during transmission due to the nature of wireless channels and multipath fading effects. In this paper, differential BLM detector is proposed in multiple relays network with time varying channels in order to enhance the receiver detection performance. Analytical and simulation evaluations on receiver operating characteristics (ROCs), bit error rate (BER), capacity and outage probability of the system are presented. Comparative results have shown that the time varying channels affect the system performance compared to static channels. The proposed detection method can be effective and resistant on the channel variation, can provide minimum bit error rate, minimum outage probability and higher channel capacity when the number of relays increases.*

Keywords: *Amplify and forward (AF) relay networks; differential Bayesian linear model (BLM) detector; channel capacity; outage probability; receiver operating characteristics (ROC); and time varying channels.*

Received: May 01, 2016 | ***Revised:*** August 12, 2016 | ***Accepted:*** September 10, 2016

1. Introduction

Wireless communication networks are always challenged by noise, multipath propagation fading and low spectral efficiency, particularly when the distance between the transmitter and the receiver is quite long. In addition, networks with mobile terminals are faced by time varying aspect which constitutes a potential constraint in wireless communication networks. Over the last years, many studies have been conducted in order to find out solutions that meet the current and next generation wireless communication goals such as high data rates and quality of service (QoS) with all conditions [1]-[3].

Among the promised solutions, diversity techniques have attracted too much attention in research for their capability to enhance the wireless network capacity, to facilitate reliable transmission, to mitigate directly the effects of multipath fading and to improve the recovery of the transmitted signal without additional infrastructure or power consumption [1]-[7]. Multiple inputs and multiple outputs (MIMO) systems have been one of the techniques to provide diversity gain in wireless networks. They use multiple antennas at the transmitting and/or receiving stations which create spatial diversity between the transmitter and the receiver. Even though, theoretical studies have proved out that MIMO systems are powerful in providing diversity gain, practically, they are not quite appropriate for some wireless terminals such as mobile stations due to their size and capacity to pack many antennas and to ensure their spacing. Therefore, cooperative communications have emerged as an alternative technology that uses single antenna at the transmitting and receiving stations and creates virtual MIMO systems [5]-[7]. Cooperative communication systems operate in different forms of cooperation in wireless networks such as multicell processing cooperation (MCP), mobile stations (MSs) cooperation and relaying cooperation. In MCP, the cooperation is done at the base stations (BSs) level, in which BSs cooperate between them to enhance the received signal at the destination. In MSs cooperation, neighboring MSs cooperate to increase the received signal strength at the destination. In relaying cooperation, the signal from the source is transmitted through the relaying stations in order to enhance the quality of the signal received at the destination. Relaying stations may be additional equipment in the network or MSs can act as relaying stations [6]-[7].

Relay networks have been an interesting topic in today's research works due to their easy implementation and their advantages to solve coverage issues in many wireless applications such as WLAN, WiMAX, 3GPP-LTE, vehicle-to-vehicle communications, wireless sensor networks, etc. [8]. They use protocols for signal processing and the most common protocols are Amplify & Forward (AF) and Decode & Forward (DF). AF which is also known as non-regenerative relaying scheme, the relay retransmits a scaled copy of the received noisy signal. The main advantage of this protocol is its low latency and low implementation complexity. In DF or regenerative relaying scheme, the relay decodes the received signal and then re-encodes it for retransmission at the destination [9].

Even though, cooperation systems can solve the problems of channel impairments, the receiver is still challenged by the signal corrupted by noise and other destructive signals. In this paper, differential Bayesian linear model (BLM) detector is proposed for its capability to recover the signal from noise, low implementation complexity and feasility. BLM detector is based on computing the energy signal for each link in the network, combining them and comparing the obtained test statistic with the predetermined threshold. The problem of energy detection is traced back in the research conducted in [10], where deterministic signal with unknown structure in Gaussian noise is considered. The same study is carried out and extended in [11] by considering random amplitude signals with different fading channels such as Rayleigh, Nakagami and Rician model. Data detection with diversity combining techniques such as equal gain combining (EGC), selection combining (SC) and switch & stay combining (SSC) is investigated in [12], square law combining and square law selection in [13], maximum ratio combining (MRC) in [14-15]. In [16-17], they consider M-relay AF cooperative system with MRC at the destination and investigate the outage probability, bit error rate and system Shannon capacity. In [18], differential M-PSK modulation and non coherent detection is investigated, [8] is concerned with differential AF relaying for multi-node wireless communications over time varying Rayleigh fading channels and [19] investigates the BER performance of AF relaying cooperative communication system with differential binary phase shift keying (DBPSK) modulation in time selective (fast) Rayleigh fading channels.

Based on the above literature review, none of the work reported has been studied out the performance of the differential BLM detector in AF relay networks with time varying channels. This paper proposes differential BLM detector in a practical scenario whereby mobile nodes in cellular wireless network are considered. The paper evaluates the effect of time varying channels and investigates the system performance in terms of ROC, BER, capacity and outage probability. The rest of the work is organized as follows; section II presents the system model, section III deals with performance analysis, section IV discusses simulation and results analysis, and finally, section V concludes the paper.

2. System model

2.1 Network model

The proposed network model comprises of single stationary source (S), multiple mobile relays (R_M) and single mobile destination (D), and all nodes are equipped with single antenna as provided in Figure 1. An example of this network model could be a wireless cellular network with a fixed base station (BS), mobile stations (MSs) and other MSs act as relay stations (RSs).

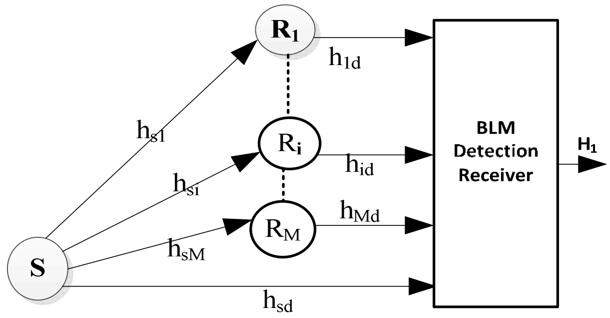

Figure 1. Network model

We denote the channel gain between the source & destination, source & relays, and relays & destination as h_{sd}, h_{si} and h_{id} respectively, with i=1, 2, …, M relays. We consider that the transmission is done in two phases: In the first phase, the source broadcasts the signal to the destination and all relays in the network. The received signals are described as follows:

$$y_{sd}(k) = \sqrt{P_s}\, h_{sd}(k) S\ (k) + n_{sd}(k)\ . \quad (1)$$

$$y_{si}(k) = \sqrt{P_s}\, h_{si}(k) S\ (k) + n_{si}(k)\ . \quad (2)$$

Where P_s is the power at the source, $S(k)$ is the signal generated and encoded differentially by the source and transmitted to the destination and relays, $n_{sd}(k)$ and $n_{si}(k)$ are zero mean circular symmetric complex Gaussian (ZMCSCG) noises with variance N_0 at the destination and relays respectively.

During the second phase, the source is silent and each relay amplifies the received signal from the source only and forwards it to the destination. In this case, orthogonal transmission is required in order to transmit M symbol without interfering each other. This can be realized by using time division multiple access (TDMA) or frequency division multiple access (FDMA) [16]. Therefore, the received signal at the destination is described as follows:

$$y_{id}(k) = \sqrt{P_i} G_i h_{id}(k) y_{si}(k) + n_{id}(k) . \quad (3)$$

This can be simplified as:

$$y_{id}(k) = \sqrt{P_i} h_{id}(k) S_{id}(k) + n_{id}(k) . \quad (4)$$

Where $S_{id}(k) = G_i y_{si}(k)$ indicates the generated signal at each relay, $n_{id}(k)$ is the ZMCSCG noise with variance N_0, P_i is the power at the relay, G_i is the fixed amplification gain that is given by: $G_i \le \sqrt{1/\{\sigma_{si}^2 P_s + N_0\}}$ where σ_{si}^2 is the variance of the channel between the source and the relay.

2.2 Channel Model

The channel link between two nodes in the network is modeled by first order autoregressive AR (1) process in order to characterize the time varying nature of links. The channel link between the source & destination, the source & relay, and the relay & destination can be represented by:

$$h_{sd}(k) = a_{sd} h_{sd}(k-1) + \sqrt{1-a_{sd}^2}\,\varepsilon_{sd}(k) . \quad (5)$$

$$h_{si}(k) = a_{si} h_{si}(k-1) + \sqrt{1-a_{si}^2}\,\varepsilon_{si}(k) . \quad (6)$$

$$h_{id}(k) = a_{id} h_{id}(k-1) + \sqrt{1-a_{id}^2}\,\varepsilon_{id}(k) . \quad (7)$$

Where $\varepsilon_{sd}(k), \varepsilon_{si}(k)$ and $\varepsilon_{id}(k)$ are ZMCSCG noise processes, a_{sd}, a_{si} and a_{id} are the temporal correlation coefficients with values between 0 and 1. These can be approximated by using Jake's autocorrelation model as: $a_{sd} = J_0(2\pi f_d T_s)$, $a_{si} = J_0(2\pi f_i T_s)$ and $a_{id} = J_0(2\pi f_i T_s) J_0(2\pi f_d T_s)$ where J_0 is the zero order Bessel function of the first kind, $f_d = f_i = f_c \upsilon / c = \upsilon / \lambda$ is the Doppler frequency shift due to the destination and relay mobility with carrier frequency f_c, mobile speed υ, speed of light c and T_s is the symbol duration.

The received signals and associated channels can be grouped in matrix form as follows:

$$\begin{bmatrix} y_{sd} \\ y_{1d} \\ \cdots \\ y_{id} \\ \cdots \\ y_{Md} \end{bmatrix} = \begin{bmatrix} \sqrt{P_s} h_{sd} & 0 & \cdots & 0 \\ 0 & \sqrt{P_1} h_{1d} & \cdots & 0 \\ \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & \sqrt{P_i} h_{id} & 0 \\ \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & \cdots & \sqrt{P_M} h_{Md} \end{bmatrix} \begin{bmatrix} s_{sd} \\ s_{1d} \\ \cdots \\ s_{id} \\ \cdots \\ s_{Md} \end{bmatrix} + \begin{bmatrix} n_{sd} \\ n_{1d} \\ \cdots \\ n_{id} \\ \cdots \\ n_{Md} \end{bmatrix} . \quad (8)$$

Assuming that signals are transmitted orthogonally, therefore, the received signals at the destination can be represented in a simple linear form as follows:

$$\boldsymbol{y} = \boldsymbol{Hs} + \boldsymbol{n} . \quad (9)$$

Where $\boldsymbol{y}$ indicates the column vector of the received signals, $\boldsymbol{H}$ denotes the channel matrix, $\boldsymbol{s}$ is the column vector of the transmitted signal and $\boldsymbol{n}$ refers to the noise vector received at the destination.

3. Performance analysis

In this work, the performance analysis is done in terms of the receiver operating characteristics (ROC), bit error rate (BER), capacity and outage probability.

3.1 Performance analysis of the ROC of the system

In general, the decision problem at the receiver is governed by the following hypotheses [20]:

$$\boldsymbol{y} = \begin{cases} \boldsymbol{n} : H_0 \\ \boldsymbol{Hs} + \boldsymbol{n} : H_1 \end{cases} . \quad (10)$$

The received signal may be the noise only or absence of the signal which corresponds to the hypothesis H_0 . Otherwise, the received signal is a combination of the transmitted signal and the noise which corresponds to the hypothesis H_1 that indicates the presence of the signal.

The ROC is defined as the probability of detection against the probability of false alarm. Theoretically, the probability of detection and false alarm are defined as follows:

$$P_d = P\left(Z(y) > \psi \mid H_1\right) . \quad (11)$$

and,

$$P_{fa} = P\left(Z(y) > \psi \mid H_0\right) . \quad (12)$$

Where $Z(y)$ is the test statistics of the system and ψ is the predetermined threshold. In Bayesian linear model (BLM) detection, the test statistics is determined by [21]:

$$Z(y) = \boldsymbol{y}^T \boldsymbol{HC}_h \boldsymbol{H}^T (\boldsymbol{HC}_h \boldsymbol{H}^T + N_0 \boldsymbol{I}) \boldsymbol{y} . \quad (13)$$

Where $\boldsymbol{C}_h = diag[\sigma_{sd}^2, \sigma_{1d}^2, ..., \sigma_{id}^2, ..., \sigma_{Md}^2]$ is the covariance matrix and $N_0 I = diag[N_0, ..., N_0]$ is the noise variance matrix. In a non-fading environment, the probability of detection and false alarm are respectively given by:

$$P_d = Q_u\left(\frac{\sqrt{2\gamma}}{N_0}, \frac{\sqrt{\psi}}{N_0}\right) . \quad (14)$$

And

$$P_{fa} = \frac{\Gamma\left(u, \psi/2N_0\right)}{\Gamma(u)} . \quad (15)$$

Where $Q_u(.,.)$ is the u[th] order generalized Marcum Q-function, γ is the instantaneous SNR and $\Gamma(.,.)$ is the upper incomplete Gamma function. The parameter u defines the bandwidth product u=N/2 with N degree of freedoms (DoFs).

In fading environment, the probabilities of detection and false alarm can be derived as follows:

$$P_d = \int_{\psi}^{\infty} P\left(Z(y); H_1\right) dZ(y) . \quad (16)$$

And

$$P_{fa} = \int_{\psi}^{\infty} P\left(Z(y); H_0\right) dZ(y) . \quad (17)$$

Where $P(Z(y); H_1)$ and $P(Z(y); H_0)$ are probability density functions (Pdfs) of the test statistics according to the hypothesis H_1 and H_0. And the probabilities of detection and false alarm in (6) and (7) are derived as follows [20]-[23]:

$$P_d = \frac{1}{\sqrt{\pi}}\Gamma\left(\frac{1}{2},\frac{1}{2\alpha_{(1)}}\psi\right) + \sum_{i=1}^{M}\frac{1}{\sqrt{\pi}}\Gamma\left(\frac{1}{2},\frac{1}{2\beta_{i(1)}}\psi\right). \quad (18)$$

And,

$$P_{fa} = \frac{1}{\sqrt{\pi}}\Gamma\left(\frac{1}{2},\frac{1}{2\alpha_{(0)}}\psi\right) + \sum_{i=1}^{M}\frac{1}{\sqrt{\pi}}\Gamma\left(\frac{1}{2},\frac{1}{2\beta_{i(0)}}\psi\right). \quad (19)$$

Where; $\beta_{i(1)} = \gamma_i\sigma_i^2$; $\beta_{i(0)} = \gamma_i\sigma_i^2 / (\gamma_i\sigma_i^2 + 1)$; $\alpha_{(1)} = \gamma_{sd}\sigma_{sd}^2$; $\alpha_{(0)} = \gamma_{sd}\sigma_{sd}^2 / (\gamma_{sd}\sigma_{sd}^2 + 1)$ and i=1,2,...,M relays.

3.2 Bit error rate (BER) performance analysis

The BER is a metric that describes the nature of the system behavior and the quality of the signal detected at the receiver. In our network model, the receiver is equipped with BLM detector, whereby the minimum mean square error (MMSE) estimate of the transmitted signal is given by [21]:

$$\hat{s} = \boldsymbol{HC}_h\boldsymbol{H}^T(\boldsymbol{HC}_h\boldsymbol{H}^T + N_0\boldsymbol{I})\boldsymbol{y}. \quad (20)$$

Using (8) and covariance values in (13), (20) is derived as follows:

$$\hat{s} = \frac{P_s|h_{sd}|^2\sigma_{sd}^2}{P_s|h_{sd}|^2\sigma_{sd}^2 + N_0}y_{sd} + \sum_{i=1}^{M}\frac{P_i|h_{id}|^2\sigma_{id}^2}{P_i|h_{id}|^2\sigma_{id}^2 + N_0}y_{id}. \quad (21)$$

The mean square error can be derived as follows:

$$MSE_{\hat{s}} = E\{(s-\hat{s})^2\}. \quad (22)$$

The expression (22) gives the Bayesian MSE which can be deduced in BER performance.

3.3 Channel capacity performance analysis

Channel capacity is one of the performance metric in wireless communication networks that measures the maximum rate achievable between the transmitter and the receiver with arbitrary small error probability. It is often derived from the mutual information between the input and output of the system as follows [24]-[25]:

$$C = \max_{p(s)} I(s;y). \quad (23)$$

The output of the BLM detector is: $\hat{s} = y$. Assuming that $P_s = P_i = P$ and $SNR = P/N_0$. Therefore, the channel capacity can be derived as follows:

$$C = \max_{p(s)} I(s;\hat{s}) \le \frac{1}{M+1}\log_2\left(1 + \frac{SNR|h_{sd}|^2\sigma_{sd}^2}{SNR|h_{sd}|^2\sigma_{sd}^2+1} + \sum_{i=1}^{M}\frac{SNR|h_{id}|^2\sigma_{id}^2}{SNR|h_{id}|^2\sigma_{id}^2+1}\right). \quad (24)$$

Where M is the number of relays in the system.

3.4 Outage probability performance analysis

Given the channel capacity and the average transmission rate, the outage probability is defined as [25]:

$$P_{out}^{BLM}(SNR,R) = \Pr\left(C(SNR) < R\right). \quad (25)$$

Substituting (24) into (25), we find:

$$P_{out}^{BLM} = P_r\left(\frac{1}{M+1}\log_2\left(1 + \frac{SNR|h_{sd}|^2\sigma_{sd}^2}{SNR|h_{sd}|^2\sigma_{sd}^2+1} + \sum_{i=1}^{M}\frac{SNR|h_{id}|^2\sigma_{id}^2}{SNR|h_{id}|^2\sigma_{id}^2+1}\right) < R\right). \quad (26)$$

By rearranging terms in (26) we have:

$$P_{out}^{BLM} = P_r\left[\left(\frac{SNR|h_{sd}|^2\sigma_{sd}^2}{SNR|h_{sd}|^2\sigma_{sd}^2+1} + \sum_{i=1}^{M}\frac{SNR|h_{id}|^2\sigma_{id}^2}{SNR|h_{id}|^2\sigma_{id}^2+1}\right) < \left(2^{(M+1)R} - 1\right)\right]. \quad (27)$$

4. Simulation and results analysis

In this paper, simulation results are presented in order to investigate the performance of the differential BLM detector in terms of ROC, BER, capacity and outage probability analysis. Three scenarios are considered; in the first scenario, we evaluate the probabilities of detection of the differential BLM detector for M-relays in time varying channels with similar mobile speeds and compare the results with the upper and lower bound of the probability of detection in [14]. In the second scenario, we evaluate the BER in M-relays with differential BLM detector and compare it with the AF differential detector and MRC detector in [25]. In the third scenario, we evaluate the effects of node mobility on the capacity and outage probabilities. In our simulations, we consider that the source is stationary while relays and destination are in motion.

At the source, the signal is generated and modulated in differential QPSK, where $S(k) = d(k)S(k-1)$ with $d = \{e^{j2\pi m/M}, m = 0,..,M-1\}$ which denotes the set of M-PSK symbols and $S(0) = 1$ as initial reference symbol. Thereafter, the transmission is done block by block in order to avoid multiple switching between the transmitter and the receiver. The source broadcasts the encoded signal to all relays and destination node in the network. The relay amplifies the received signal from the source only and forwards it to the destination. The amplification is done by only multiplying the received signal with the amplification factor or gain. At the destination terminal, the differential BLM detector computes the signal energy for each link, combines all signal energies from different links and then determines the test statistic which is compared with the predefined threshold as given in Figure 1. The threshold is determined by using the expression in (15) that represents the probability of false alarm in non fading environment. In this formula, the P_{fa} is taken between 0 and 1 and the bandwidth product u is 2.

In Figure 2, the ROC is analyzed in multiple relays (R=1, R=3 and R=5) with differential BLM detector at the destination. The results show that the probability of detection increases when the number of relays increases. The differential BLM detector results are almost equivalent to the results of the upper & lower bound of the probability of detection when MRC detector is applied in fixed relays network [14].

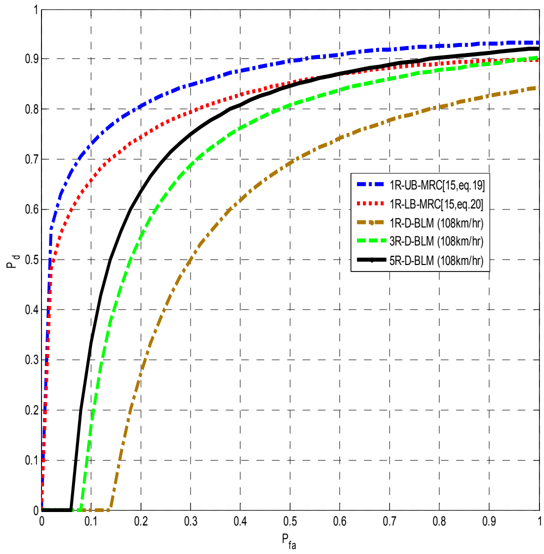

Figure 2. ROC analysis in M-Relays

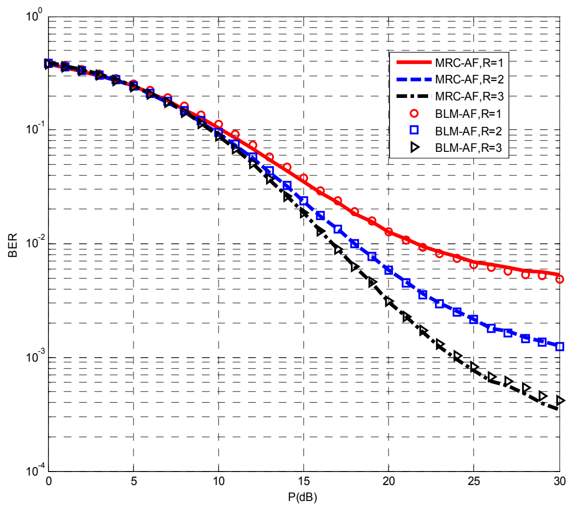

Figure 3. BER analysis in M-Relays with D-BLM detector and D-MRC detector

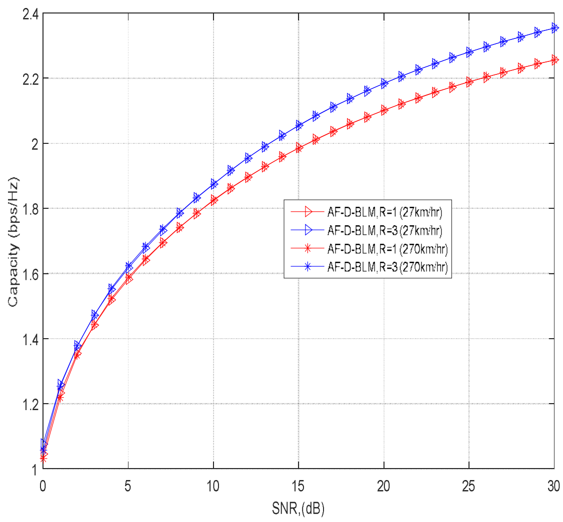

Figure 4. Channel capacity analysis in M-Relays with fD=500Hz, 50Hz, fc=2GHz, Ts=0.1 ms, V1=270km/hr and V1=27km/hr.

In Figure 3, the bit error rate (BER) is analyzed in multiple relays (R=1, R=3 and R=5) with differential BLM detector at the destination. The results have shown that the BER performance of the differential BLM (D-BLM) detector is almost equivalent to the differential MRC (D-MRC) detector as given in [25] and the BER performance improves when the number of relays increases.

In Figure 4, the effect of relays and destination mobility is analyzed when differential BLM detector is applied at the destination with multiple relays in the network. In this analysis, we consider multiple relays (R=3 and R=5) in the system, carrier frequency $f_c = 2GHz$, symbol duration $T_s = 0.1ms$ and consider two different nodes speeds $v = 270km/h$ and $v = 27km/h$ which are equivalent to normalized Doppler frequency $f_{sd}T_s = f_{si}T_s = f_{id}T_s = 0.005$ and $f_{sd}T_s = f_{si}T_s = f_{id}T_s = 0.05$. We found that the capacity increases as the number of relays increases. In Figure 5, the outage probability improves when the number of relays increases at low speed of mobile nodes.

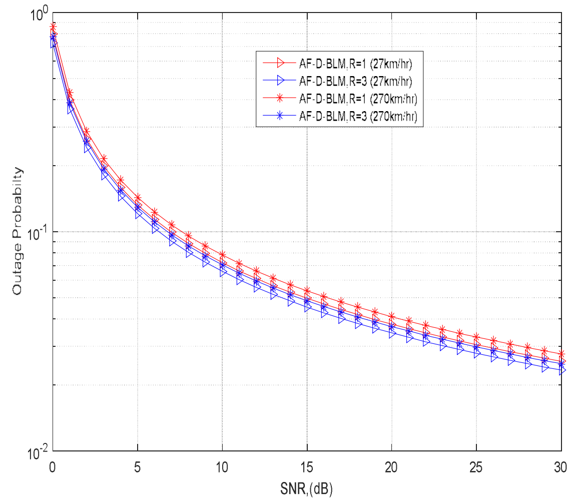

Figure 5. Outage probability analysis in M-Relays fD=250Hz, 25Hz, fc=2GHz, Ts=0.1 ms, V1=270km/hr and 27km/hr.

5. Conclusion

This paper has the aim of investigating the performance of differential BLM detector in multiple relays with time varying channels. Three scenarios are considered; the first scenario is based on evaluating the receiver operating characteristics (ROC) and comparing it with the upper & lower bounds of the probability of detection as given in [14]. The second scenario evaluates the BER performance of differential BLM detector and compares it with differential MRC detector as given in [25]. The third scenario evaluates the effect of MSs mobility on the channel capacity and outage probability when differential BLM detector is used at the destination. The simulation results of the ROCs have shown that the differential BLM detector provides good performance results of probability of detection almost equivalent to the upper and lower bounds of the probability of detection in [14]. The results of BER have shown that the differential BLM detector provides the similar results as the one with MRC detector in [25] which we justify the feasibility of our proposed detector. The results of channel capacity and outage probability have shown that the node mobility affects the performance of the system which can be compensated when the number of relays is increased in the network.

References

[1] I. F. Akyildiz, D. M. Gutierrez-Estevez and E. C. Reyes, “The evolution to 4G cellular systems: LTE-Advanced,’’ Elsevier, Physical Communication, vol. 3, pp. 217-244, 2010.

[2] M. K. Simon, M. S. Alouini, Digital communication over fading channels, A unified approach to performance analysis, John Wiley & Sons, Inc. 2000.

[3] A. Goldsmith, Wireless Communications. Stanford University, 2004.

[4] A. Sendonaris, E. Erkip, and B. Aazhang, ‘‘User cooperation diversity-part I: system description,’’ IEEE Trans. Comm., vol. 51, no. 11, pp.1927-1938, Nov. 2003.

[5] J. N. Laneman, D. N. C. Tse, and G. W. Wornell, ‘‘Cooperative diversity in wireless networks: efficient protocols and outage behavior,’’ IEEE Trans. Inf. Theory, vol. 50, no. 12, pp. 3062-3080, Dec. 2004.

[6] O. Simeone, N. Levy, A. Sanderovich, O. Somekh, B. M. Zaidel, H.V. Poor, S.Shamai (Shitz), Cooperative wireless cellular systems, An information-theoretic view, Now Publishers Inc., 2012.

[7] K. J. Ray Liu, A. K. Sadek, W. Su and A. Kwasinski, Cooperative communications and networking, Cambridge University Press 2009.

[8] M. R. Avendi and H. H. Nguyen, ‘‘Performance of differential amplify and forward relaying in multi node wireless communications,’’IEEE Transactions on Vehicular Technology, Vol.:62, Issue:8, pp.: 3603-3613, May 2013.

[9] R. U. Nabar, H. Bölcskei and F. W. Kneubuhler, “Fading relay channels: performance limits and space-time signal design,” IEEE J. Sel. Areas Commun., vol. 22, pp. 1099-1109, 2004.

[10] H. Urkowitz, “Energy detection of unknown deterministic signals,’’ Proceedings of the IEEE, vol.3, pp. 523-531, 1967.

[11] V. Kostlev, “Energy detection of a signal with random amplitude,’’ in Proceedings of the IEEE International conference on communications, vol.3, pp. 1606-1610, 2002.

[12] F. F. Digham, M. S. Alouini, and M. K. Simon, “On the energy detection of unknown signals over fading channels,’’ in the Proceedings of the International Conference on Communications (ICC’03), vol.5, pp. 3575-3579, May 2003.

[13] F. F. Digham, M. S. Alouini, and M. K. Simon, “On the energy detection of unknown signals over fading channels,’’ IEEE Trans. Commun., vol.55, pp.21-25, 2007.

[14] S. P. Herath, N. Rajathera, C. Tellambura, “Energy detection of unknown signals in fading and diversity reception,’’ IEEE Trans. Commun., vol.59, 2011.

[15] M. O. Mughal, L. Marcenaro, C. S. Regazzoni, “Asymptotic detection performance of energy detector in fixed gain cooperative relay networks,’’ The 5th International conference on Information, Intelligence, Systems and Applications (IISA) 2014, Chania.

[16] Y. Khattabi and M. M. Matalgah, ‘‘Performance analysis of AF cooperative networks with time varying links: Outage probability,’’ Wireless Communications symposium (WTS), Washington, DC, April 2014.

[17] Y. Khattabi and M. M. Matalgah, ‘‘Performance analysis of AF cooperative networks with time varying links: Error rate and Capacity,’’ Wireless Communications symposium (WTS), Washington, DC, April 2014.

[18] M. R. Avendi and H. H. Nguyen, ‘‘Differential dual hop ralaying over time varying Rayleigh fading channels,’’ 13th Canadian Workshop on information Theory (CWIT), pp.: 133-137, Toronto, June 2013.

[19] C-H.Yih,‘‘Differential BPSK modulation for cooperative communication systems in time selective Rayleigh fading channels,’’ IEEE International conference on communication, Networks and Satellite (ComNetSat), pp.: 88-92, Bali, July 2012.

[20] M. Barkat, Signal detection and estimation. Artech House Inc. Second edition, 2005.

[21] S. M. Kay, Fundamental of statistical signal processing: Detection theory. Prentice Hall, vol. II, 1998.

[22] H. Bateman, Tables of Integral Transforms, Volume I, McGraw-Hill Book Company, inc. 1954.

[23] I. S Gradshteyn and I. M. Ryzhik, Table of Integrals, series and products, 7th ed. San Diego, CA: Academic Press, 2007.

[24] M. –S. Alouini and A. J. Goldsmith,‘‘Capacity of Rayleigh fading channels under different adaptive transmission and diversity – combining techniques,’’ IEEE Trans. On Vehicular Technology, Vol.: 48, No.4, July 1999.

[25] K. G. Seddik, A. K. Sadek, W. Su, K. J. R. Liu,‘‘Outage Analysis of Multi node Amplify and Forward Relay Networks,’’ IEEE WCNC 2006, vol.:2, pp: 1184-1188, Las Vegas, NV. 2006.

Omar Gatera received his B.Sc. degree in Electronics & Communication Engineering and M.Sc. degree in Telecommunication Engineering from University of Rwanda, Huye, Rwanda, in 2006 and 2008, respectively. He is currently a Ph.D. candidate in Telecommunication Engineering program at Istanbul Technical University, Istanbul, Turkey. His current research interests include signal processing for communications, adaptive filtering, detection, estimation, MIMO communication techniques and cooperative communications.

Haci Ilhan received the B.Sc. degree in electronics and communication engineering from Yildiz Technical University, Istanbul, Turkey, and the M.Sc. and the Ph.D. degree all in electronics and communication engineering from Istanbul Technical University, Istanbul, Turkey. From 2001 to 2011 he was a research and teaching assistant in communication department at Istanbul Technical University. Since 2011, he has been with the Department of Electronics and Communication, Yildiz Technical University, Istanbul Turkey, where he is an Assistant Professor. His general research interests lie in communications theory and signal processing for communications with particular emphasis on wireless applications. Specific research areas include MIMO communication techniques, space-time coding, cooperative diversity, multicarrier communication. Dr. Ilhan is an IEEE member.

Ahmet H. Kayran was born in Kayseri, Turkey, in 1955. He received the B.S. degree with high honors from the Istanbul Technical University, Istanbul, Turkey, in 1977, the M.S. degree from the University of California, Berkeley, in 1979, and the Ph.D. and D.I.C. degrees from the Imperial College of Science and Technology, University of London, London, U.K., in 1982, all in electrical engineering.
From 1982 to 1984, he was a National Research Council Research Associate with the Naval Postgraduate School, Monterey, CA. In 1985, he joined the Istanbul Technical University, where he is now a Professor of Electrical Engineering. He served as the Dean of the Faculty of Electronics and Electrical Engineering from 1996 to 1999. He was acting as the Dean of International Education from 2010 to 2012. His current research interests include two-dimensional lattice filters, adaptive filtering, nonlinear and multirate systems, and MIMO networks. He has been an Associate Editor of *Multidimensional Systems and Signal Processing* since 2007.