Comparison of SCM and Rayleigh Channel Models by Exploitation of Diversity in Time and Spatial Domain Using Opportunistic Communication Technique

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Abstract

This paper exploits the concept of diversity using adaptive antenna at BS, where different users are communicating with BS from different locations but at same frequency in flat fading and frequency selective environments. In this paper in the simulations it is assumed that there is one jammer whose direction is known in advance. Therefore it uses the known direction of the jammer to calculate the interference plus noise correlation matrix $\mathbf{R}_{i+n}$ so that it can place a null in the direction of jammer. When user-1 is communicating with the BS a composite signal is received using the optimal beamformer that forms main beam towards user-1, while placing a null towards user-2 considering it as a jammer. The interference plus noise correlation matrix $\mathbf{R}_{i+n}$ is used to find the weight of an optimal beamformer. The opportunistic communication method has been implemented using Matlab Rayleigh and Spatial channel model (SCM) developed by 3rd generation partnership project (3GPP). The main focus is on comparison of results using SCM and Matlab Rayleigh channel and is shown with the help of simulations that SCM provides an improvement in terms of bit error rate (BER) as compared to Matlab Rayleigh Channel. The BER performance of SCM systems is much better thereby showing an improvement of about 5dB in flat fading environment which is achieved because of exploitation of spatial diversity offered by SCM. In case of frequency selective fading environment there is an improvement of 2-3 dB for two users while using SCM as compared to Matlab Rayleigh channel by exploitation of diversity in both spatial and time domains.

Keywords - *Spatial channel model (SCM); Signal to Noise ratio (SNR); Additive white Gaussian noise (AWGN); Base station (BS); Mobile station (MS); Uniform Linear Array (ULA); Bit Error Rate (BER)*

1. Introduction

The opportunistic communication system is implemented that uses a novel network protocol, that only transmits to a user when the channel conditions to that particular user are good, whereas in case of traditional communications systems the resources are allocated according to the demands of user without considering the quality of a channel as a result channel capacity is lost when the channels get faded. Different cooperation protocols like amplify-and-forward, decode-and-forward [1], [2] have been introduced for wireless networks. In most of the existing cooperative communication in wireless systems the communication is based on the multi-hop systems, where the information from source is carried to the destination through other mobiles that acts as relay. This relaying operation overcomes the problem of path-loss that occurs because of large distances. This relay channel was introduced by Van der Meulen [3] and then investigated by Cover and El Gammal [4]. The research work carried out the analysis of three nodes such as source, relay and destination. Since in case of mobile channel the fading is considered to be a source of unreliability that needs to be mitigated at all cost and communication is considered to be a source of mitigating the fading in wireless networks by achieving spatial diversity. Relays are used to help the source by transferring the information to the destination but source needs to decide when to cooperate by taking the ratio between source-destination channel and source-relay channel conditions [5].

Here in this paper concept of multiuser diversity is exploited by opportunistic communication, where multiple users are communicating with common BS in the time varying fading channels while remaining in the same cell. It is assumed that channel state information is tracked at the receivers and fed back to the transmitters and then scheduling is based on the basis that a user with good channel conditions is only allowed to transmit to the BS. Here the diversity gain is achieved in a sense, that since many users are communicating with common BS via an independent varying channel so there are all the chances that a user may get a channel at an instant of time when the channel is at its peak. Traditionally the fading in a channel is considered to be a source of unreliability which must be mitigated. When multiple users are communicating simultaneously then transmission is scheduled by allocating a channel to users only when their channels are at peaks [6]. Therefore an opportunistic communication may be used to exploit the channel fluctuation where transmission only takes place when the channel is at its peak. So here the performance of the system is then related to a channel condition when it is at peak rather than average conditions of the channel.

From Figure-1 it is seen that opportunistic communication system allocates bandwidth dynamically based on conditions of the channel to individual users and all users with good channel conditions are dynamically allocated lots of bandwidth while users in deep fades are allocated little bandwidth. Since the fading is random so all users get their fair share of the bandwidth, hence the opportunistic communication systems can provide more capacity in fading channels as compared to traditional approach. In this case, a number of algorithms in various fading environments using Matlab Rayleigh and spatial channel models using adaptive antenna at the BS have been developed that allow the users to communicate with common BS, depending upon the condition of the channel allocated to that particular user.

2. Channel Allocation Based On Quality

Here in this case a communication system considered dictates the environmental conditions where multiple users equipped with single antenna are communicating with common BS that is equipped with ULA of antenna elements. The opportunistic communication system provides the idea of multiuser diversity in the sense that in this system

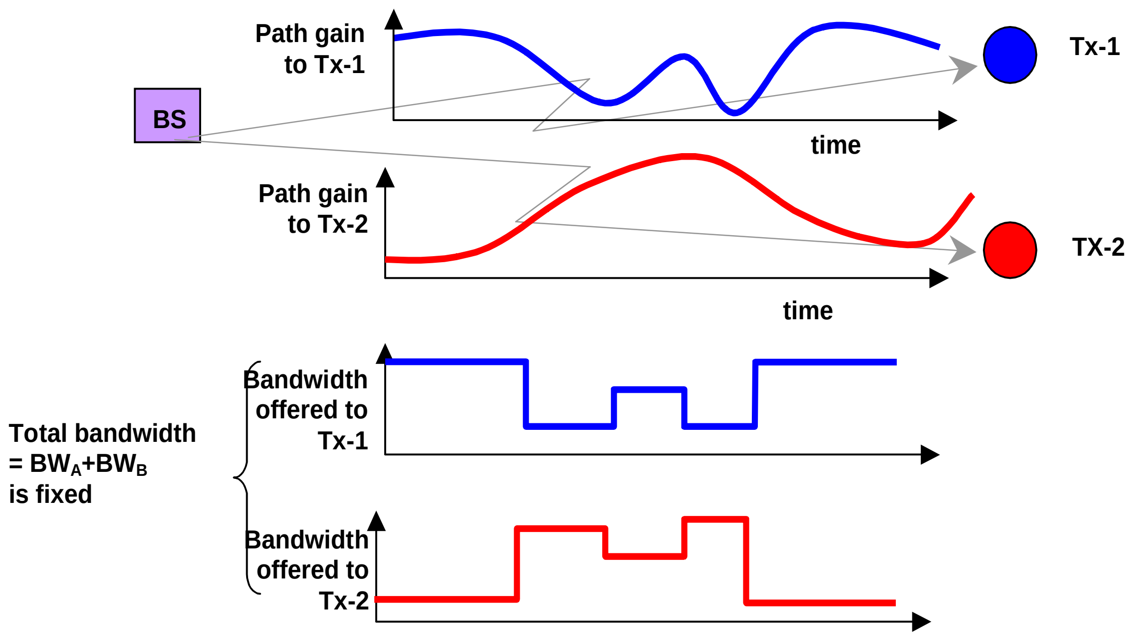

Fig. 1: Allocation of Bandwidth

different users are operating over an independently fading channel, there is a chance that one of the users is likely to have very good channel condition at the instant of time. Whenever a particular user with good channel condition has been allocated a channel for the duration it remains at its peak, then that user has a chance of transmitting the maximum data to the BS. The resultant SNR of that particular user at the instant of time when the data is transferred can be written as:

$$SNR\,(t) = \max\,|h_k\,(t)|^2 \tag{1.1}$$

Where, $k = 1 \cdots\cdots K$ i.e. is the total number of users in a system. The resultant output of the system can be expressed as

$$y(t) = \sum_{k=1}^{K} h_k(t)x_k(t) + \mathbf{w}(t) \tag{1.2}$$

Where, $h_k, x_k, \mathbf{w}$ are the channel gain, data transmitted and the additive white Gaussian noise respectively. Here in Fig.2 it is seen that both the users are placing a request to the BS for fair scheduling of resources depending on the Bandwidth and allocation of channel. So in this case the channel quality of the user k at the instant of time based on the requested data rate is represented as $R_k(t)$. This is the data rate that a user can support at the instant of time. The scheduling algorithm works on the principle that it keeps track of the average throughput denoted as $T_k(t)$ of every user in the previous interval of time *t*. In time slot *t*, the scheduling algorithm transmits with highest ratio of request to the throughput represented as: $\frac{R_k(t)}{T_k(t)}$,

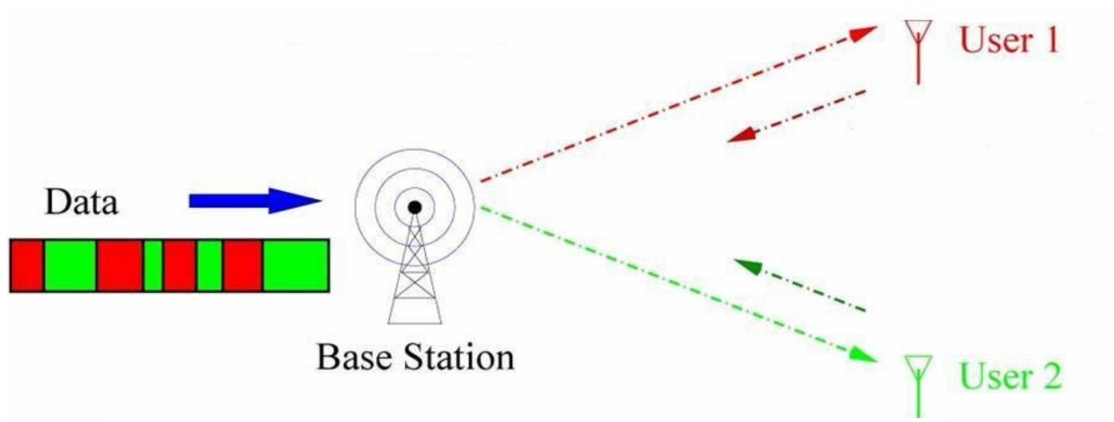

Fig. 2: Channel Allocation Based On Quality

Where R_k is the request of the user placed to the BS while T_k is the throughput transferred to BS. This scheduling of the users is done on the basis that whichever user has good channel conditions is allowed to transmit to the BS. The total throughput increases with the number of users in both the fixed and mobile environments. As the channel fades in both cases, the rate of variation is more in case of mobile channel as compared to fixed channel as a result the peaks are going to be higher in case of mobile channel environment, which determines the scheduling of the users. It can be stated that multiuser diversity is variable in case of mobile channel as compared to fixed channel where it is limited. The amount of multiuser diversity depends on the dynamic change in the fluctuation of channel characteristics.

Consider a system having *N* transmit antennas at the BS and let $h_{n,k}(t)$ is the gain from antenna *n* to the user *k* at the instant of time *t*. The block of symbols *x(t)* is transmitted in time slot *t* and the signal received by the k^{th} user during the time slot *t* is given by:-

$$y_k(t) = \sum_{n=1}^{N} \sqrt{\alpha_n(t)} e^{j\theta_n(t)} h_{n,k}(t) * x(t) \tag{1.3}$$

Where $n = 1 \cdots\cdots N$ is the number of transmit antennas, and overall channel gain seen by the receiver *k* is given by

$$h_k(t) = \sum_{n=1}^{N} \sqrt{\alpha_n(t)} e^{j\theta_n(t)} h_{n,k}(t) \tag{1.4}$$

Where, $\alpha_n(t)$ is the power allocated to each of the transmit antenna and $\theta_n(t)$ is the phase shift applied to the signal at each antenna. The fluctuation in the channel is achieved by varying these quantities ($\alpha_n(t)$ from 0 to 1 and $\theta_n(t)$ from 0 to 2π) over a time period *t*.

In case of single transmit antenna system, every receiver k feeds back the overall SNR i.e. $|h_k(t)|^2$ of its own channel to the BS and accordingly BS schedules the transmission to all users depending upon the quality of channel of a particular user. There could always be a possibility that the channels are symmetric having same quality with equal SNRs or asymmetric with different properties. The analysis for both types is carried out with the help of simulations to see the effect on BER performance. Moreover the weight of an optimal beamformer is calculated by the formula as:

$$\mathbf{w}_o = \frac{\mathbf{R}_{i+n}^{-1}\mathbf{v}(\phi_s)}{\mathbf{v}^H(\phi_s)\mathbf{R}_{i+n}^{-1}\mathbf{v}(\phi_s)} \tag{1.5}$$

Where, $\mathbf{R}_{i+n}^{-1}$ is the correlation matrix of the interference plus noise and $V(\phi)$ is the steering vector in the direction of wanted user given as

$$\mathbf{v}(\phi) = \mathbf{v}(u) = \frac{1}{\sqrt{M}}\begin{bmatrix}1 & e^{-j2\pi u} & \cdots & e^{-j2\pi(M-1)u}\end{bmatrix}^T \tag{1.6}$$

SCENARIO - I (Flat Fading Environment)

Here this scenario dictates that two Mobile users MS-1(user 1) and MS-2(user 2) moving at a speed of 1.25m/s corresponding to a Doppler shift of 10Hz and carrier frequency of 2.4GHz are communicating with a common BS, each mobile user is operating at independent path with BS. Two Rayleigh dice are rolled that determine which channel should transmit. When the channel is allocated to one transmitter, he is allowed to send across the data in frames depending upon the condition as to when the channel is allocated to that particular user and AWGN is added to it. In this case the phase estimation is performed at receiving end to compensate for the phase distortion that occurs during transmission in the channel. The schematic diagram of two users communicating with common BS is shown in Figure-3, whilst the design parameters for implementation of the scenario are given in the Table-1

RESULT ANALYSIS

a. Here two users are communicating with common BS having a dedicated link and one path/link depicting a scenario of Rayleigh flat fading environment

b. Characteristics of the channel coefficients remain constant while frame of data is being transmitted and channel coefficients are generated on the basis of frame and time period is also defined on per frame basis.

b. From Figure-4 it is observed that the curves of opportunistic (Cooperation) communication system using flat fading Rayleigh channel model have better BER performance as compared to the case of non-opportunistic communication system. Hence.

Table - 1: Rayleigh Flat Fading Parameters

Parameters	Value	Parameters	Value
Antenna elements	8	Carrier frequency (f_c)	2.4GHz
Number of frames sent	20,000	λ	c/ f_c
Number of bits/frame	10	C (m/sec)	3.0E8
Total bits sent	200,000	FFT resolution points	2048
Modulation scheme	PSK	Modulation order (M)	2
Sampling time/frame (t_s)	3.75msec	Number of Paths	1
Doppler (f_d)	10 Hz	Number of Users	2

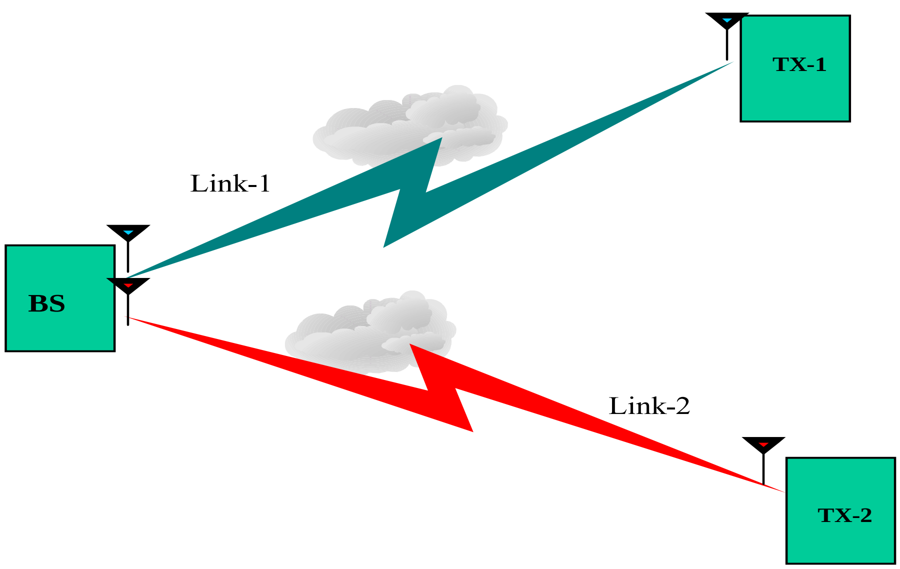

Fig. 3: Two Users Communicating With Common BS

the users communicating under the environment of an opportunistic communication system get fair share of bandwidth allocation.

c. The BER performance of an opportunistic communication system (Cooperation) is measured depending upon the condition of channel as to when the channel is given to User-1 or to User-2. The simulation results shown above dictate that if a data of about 0.2 million bits is sent across Rayleigh channel, BER of 10^{-2} at SNR of 7dB in case of opportunistic communication system as compared to non opportunistic system where

BER of 10^{-2} at SNR of about 14dB is achieved. So there is an improvement of 7dB SNR in case of Opportunistic communication system having same BER rate.

d. The BER performance is very poor and degraded when channel selection is not made and there is no cooperation amongst different users.

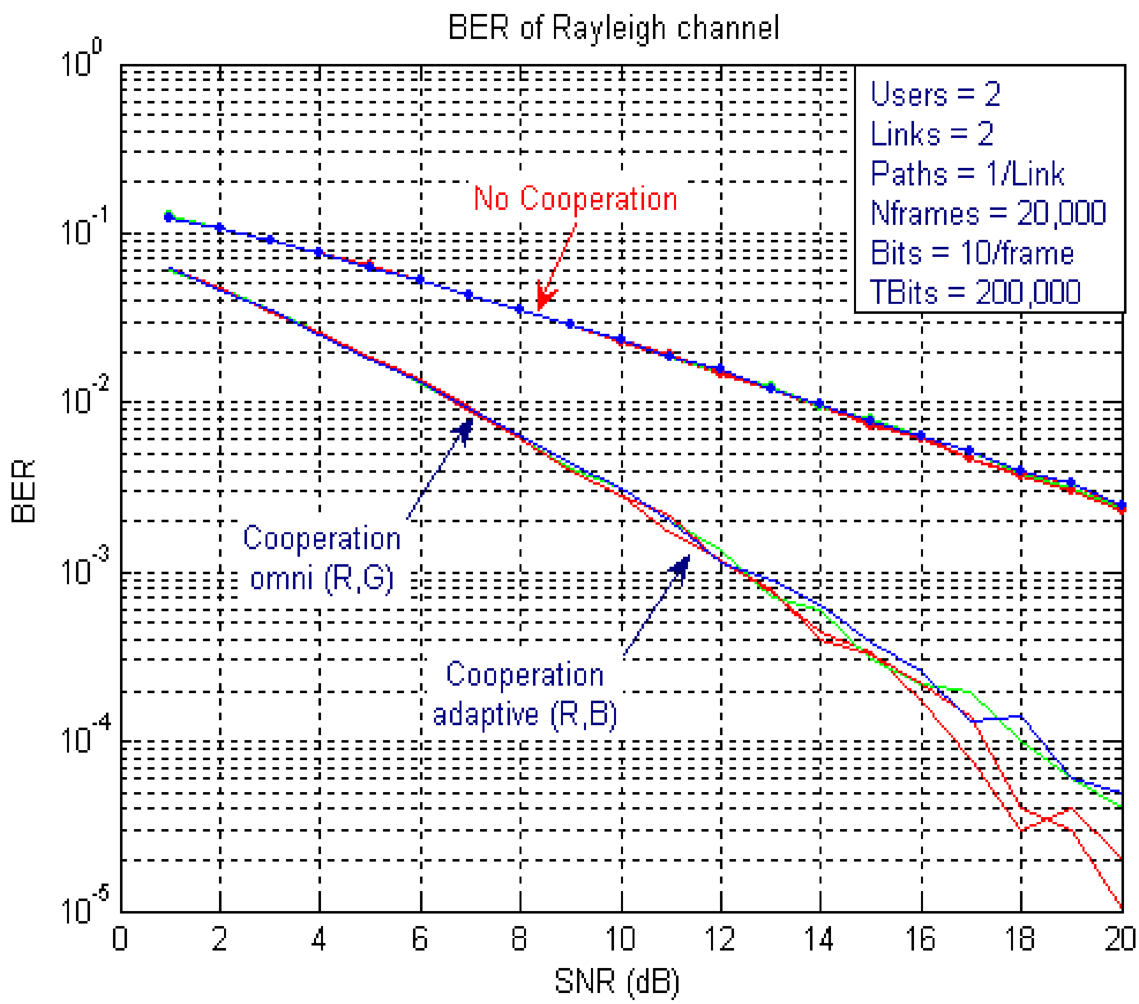

Fig. 4: BER with Opportunistic Communication in Rayleigh Channel

SCENARIO-II (Frequency Selective Fading)

Here in this case two Mobile users MS-1 (user 1) and MS-2(user 2) moving at a speed of 1.25m/s corresponding to a Doppler of 10Hz and carrier frequency of 2.4GHz are communicating with a common BS, each mobile user is operating at independent link but having two paths/link with BS. Two Rayleigh dice are rolled that determine which channel should transmit. When the channel is allocated to one of the transmitter, only that user is allowed to send across the data in frames depending upon the condition as to when the channel is allocated to that particular user and AWGN is added to it. In this case also an equalizer at receiving end is used to compensate for the phase distortion that occurs in the channel.

Table - 2: Rayleigh Freq Selective Fading Parameters

Parameters	Value	Parameters	Value
Number of Users	2	Carrier frequency (f_c)	2.4GHz
Number of frames sent	20,000	λ	c/ f_c
Number of bits/frame	10	C (m/sec)	3.0E8
Total bits sent	200,000	FFT resolution points	2048
Modulation scheme	PSK	Modulation order (M)	2
Sampling time/frame (t_s)	3.75msec	Number of Paths	2/link

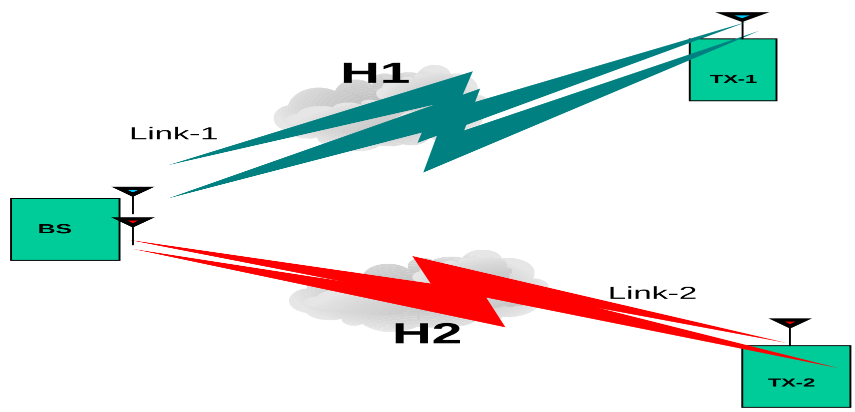

Fig. 5: Two Users Communicating with Common BS in Multipath Environment

RESULT ANALYSIS

a. Characteristics of the channel coefficients are assumed to be constant while frame of data is being transmitted.

b. Here the results of opportunistic communication system are compared with non-opportunistic case using frequency selective Rayleigh fading channel model.

c. The BER performance of an opportunistic communication system (Cooperation) is measured depending upon the condition of channel as to when the channel is given to Mobile user-1 or to Mobile user-2. The simulation results shown above dictate that if a data of about 0.2 million bits is sent across multi-path Rayleigh channel, BER of 10^{-2} is achieved at SNR of 8dB in case of opportunistic communication system as compared to non-opportunistic system where BER of 10^{-2} is achieved at SNR of more than 20dB. So there is a difference of 12 dB having same BER rate under non-opportunistic environment.

d. The BER performance is very poor when no channel selection is made and there is no cooperation between the users.

e. Here BER performance is degraded due to Inter-symbol interference that occurs because of multipath effect.

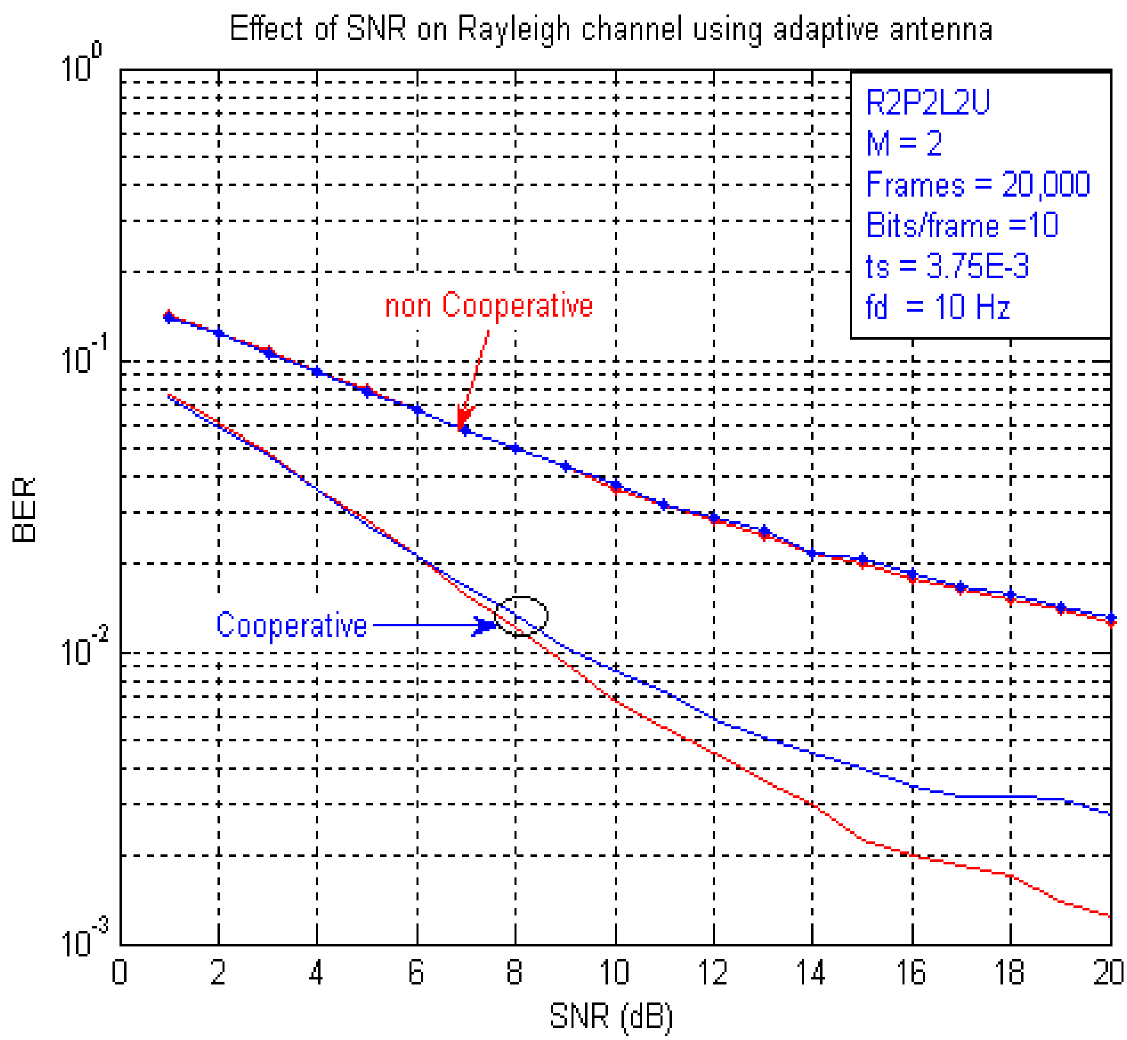

Fig. 6: Two Users Communicating with Common BS in Multipath Environment

3. Simulation Of SCM

Here spatial channel model (SCM) is used in uplink case where a signal transmitted from MS is received by the BS that forms beam in the direction of user thereby indicating the angle of arrival of that signal coming from particular MS. During each simulation run the fast fading of the channel is dictated by the mobility of MS. The information regarding state of the channel is given to BS from MS and then BS uses the schedulers to determine the direction of user where to transmit.

SCENARIO-I (Flat Fading Environment)

This scenario dictates that two Mobile users MS-1(user 1) and MS-2(user 2) moving at a speed of 1.25m/s corresponding to a Doppler of 10Hz and carrier frequency of 2.4GHz are communicating with a common BS and each mobile user is operating at an independent path with BS. Two dice are rolled that determine which channel should transmit. When the channel is allocated to one transmitter, only that user is allowed to send across the data in frames depending upon the condition as and when the channel is allocated to that particular user and then AWGN is added to it. Here phase estimation is done at receiving end to compensate the phase distortion in the channel. The design parameters for simulation are given as:-

Table 3: SCM Flat Fading Parameters (Two Users)

Parameters	**Value**	**Parameters**	**Value**
Antenna elements	8	Carrier frequency (f_c)	2.4GHz
Number of frames	20,000	λ	c/ f_c
Number of bits/frame	10	C (m/sec)	3.0E8
Total bits sent	200,000	FFT resolution points	2048
Modulation scheme	PSK	Modulation order (M)	2
Sampling time/frame (t_s)	3.75msec	Number of Paths	1
Doppler (f_d)	10 Hz	Number of Users	2

RESULT ANALYSIS

a. Characteristics of the channel coefficients are assumed to be constant while transmission of every frame.

b. In Figure-7 the curves of opportunistic communication system are compared with curves of non-opportunistic communication system.

c. The BER performance of an opportunistic communication system (Cooperation) is measured depending upon the condition of channel as to when the channel is given to User-1 or to User-2. Simulation results shown above dictate that if a data of about 0.2 million bits is sent across SCM, the BER of 10^{-4} is achieved at SNR of 9dB in case of opportunistic communication system as compared to non-opportunistic system where BER of 10^{-4} at SNR of about 17dB is achieved. So there is an improvement of 8dB with opportunistic system having same BER.

d. The BER performance of opportunistic communication system is made depending upon the condition of channel as to when the channel is allocated to User-1 or to User-2, which is far better than that of non-opportunistic case and same is obvious from simulation results shown in Fig. 7 above.

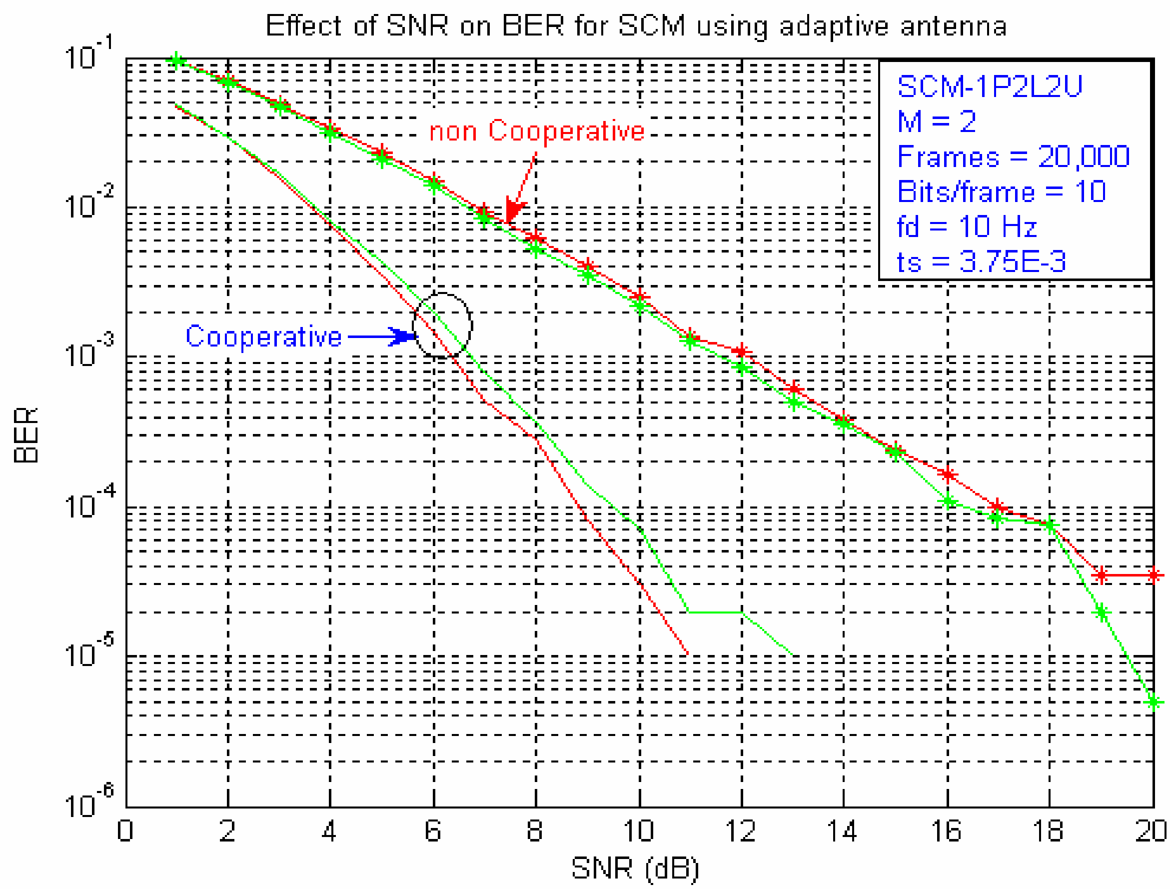

Fig. 7: BER of Two Users with Opportunistic Communication Using SCM

Compared with Rayleigh channel results in Figure-4, The BER performance of SCM systems is much better, where BER of 10^{-3} is achieved at SNR of 12dB in Rayleigh channel whilst in case of SCM channel, same BER of 10^{-3} is achieved at 7dB, so there is a difference of about 5dB when using SCM because of spatial and time diversity being exploited by Opportunistic communication technique in SCM.

SCENARIO-II (Multi-Path Frequency Selective Environment)

Here in this scenario three Mobile users MS-1(user 1), MS-2(user 2) and MS-3(user 3) moving at a speed of 1.25m/s corresponding to a Doppler of 10Hz and carrier frequency of 2.4GHz are communicating with a common BS, each mobile user is operating at independent link with symbol spaced delayed two paths/link with BS. Three dice are rolled that determine as to which channel should transmit. When the channel is allocated to one transmitter, which user is allowed to send across the data in frames depending upon the condition as to when the channel is allocated to that particular user and AWGN is added to it? Here equalizer is used at receiving end to compensate the phase distortion in the channel.

Table - 4: SCM Frequency Selective Fading Parameters (Two Users)

Parameters	Value	Parameters	Value
Number of frames sent	20,000	Number of Paths	2
Number of bits/frame	10	Number of Users	3
Total bits sent	200,000	Modulation scheme	PSK
Sampling time (t_s)	3.75E-3	Modulation order (M)	2
Doppler frequency (f_d Hz)	10	Carrier frequency (f_c)	2.4GHz

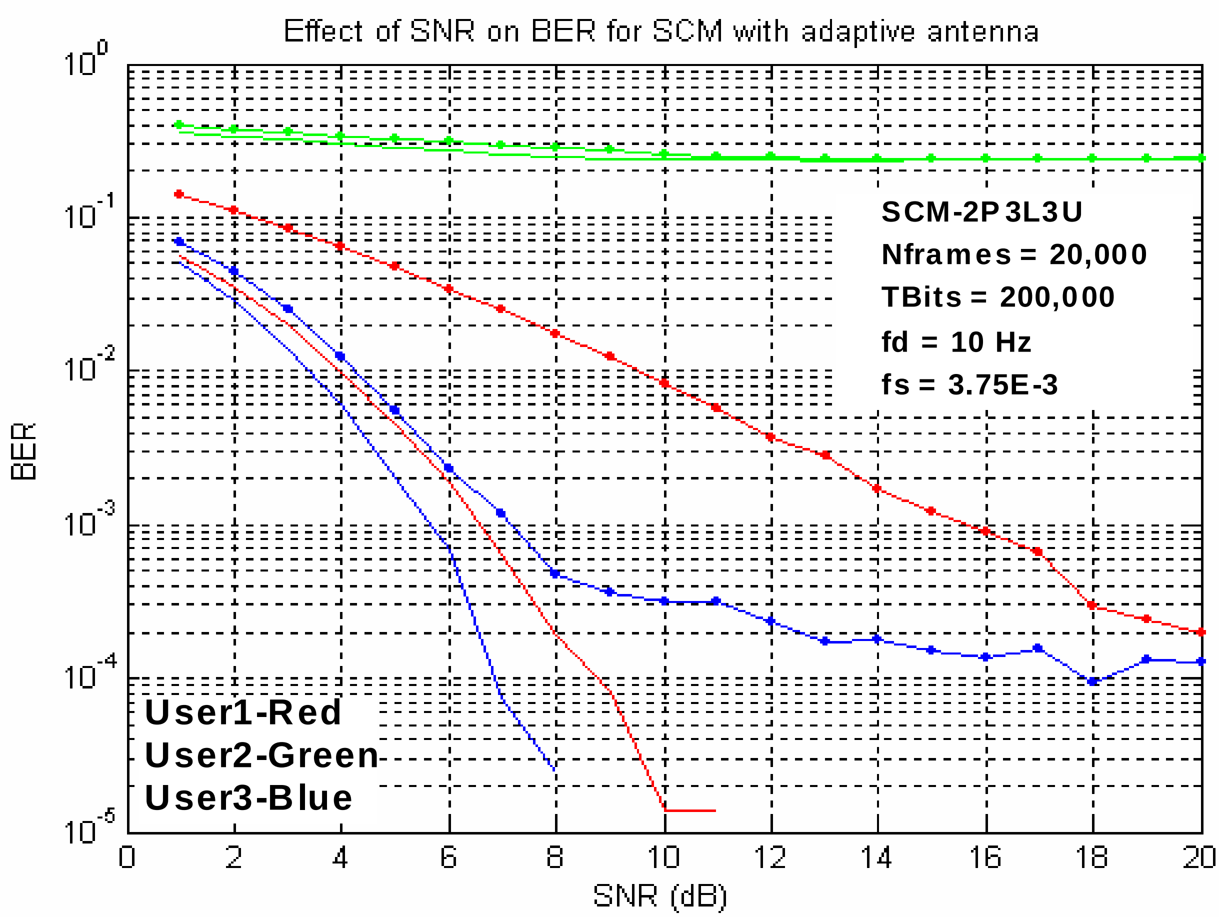

Figure - 8: BER of Three Users Using SCM

RESULT ANSLYSIS

a. From Figure-8 above it is observed that BER characteristics curves of all three users are better in opportunistic case than that of non- opportunistic environment as all users get the fair share of channel bandwidth allocation.

b. Amongst three users the BER performance of user-3 in Blue curve is better than user-1 and user-2 providing a BER of 10^{-4} at SNR of 7dB, because of good channel conditions. The user-2 in green curve does not get the good channel conditions, so its performance in terms of BER is poor as compared to other two users.

c. From the simulation results it is seen that with opportunistic conditions the user 3 and 1 has BER of 10^{-4} at SNR of 7dB and 9dB respectively as compared to non opportunistic case where same user has BER of 10^{-4} at SNR of above 20dB is being achieved. So there is an improvement of more than 13dB when using an opportunistic communication system.

d. Comparing the results of Rayleigh channel in Figure-4, where BER of 10^{-2} is achieved at 8dB, whereas while using SCM channel same BER of 10^{-2} is achieved at SNR of 4dB when operating in multipath, multiuser environment. Hence there is an improvement of about 4dB while using SCM along with Opportunistic communication technique.

4. Effect Of Spatial Correlation On Ber Performance

Here in this case frequency selective STBC OFDM-MIMO (2x2) system is implemented using SCM model with carrier frequency f_c as 2.4GHz and mobile user traveling at speed of 63.720kmph. Spatial correlation is simulated by varying antenna spacing at MS while spacing between antenna elements at BS is kept constant. The design parameters for simulation of the system implemented are given in the Table-5.

RESULTS ANALYSIS

Figure-9 shows the simulation of STBC OFDM-MIMO (2x2) system implemented using spatial channel model with different spacing between antenna elements at transmitting end, while keeping the spacing of received antenna elements constant. It is seen from the simulation results that when the MS antenna spacing is 0.5λ then BER performance of the 10^{-3} is achieved at SNR of 3dB as shown in red curve that is because of the fact that both antennas at MS are widely spaced and signals received are de-correlated and BER performance is better.

When the antenna spacing is decreased the BER performance is deteriorated as indicated in simulation results with different curves having different antenna spacing values, if the antenna spacing is 0.25λ then same BER of 10^{-3} is now achieved at SNR of 8dB thereby deteriorating the BER performance by almost 5dB. This degradation in BER performance mainly happens due to the reason that when antennas are closely spaced, signals received by the antennas are severely correlated and both antennas at MS see the same fading channel. Hence by decreasing the spacing between antennas the bit error rate gets worse due to the effect of correlated received signals.

Table - 5: Simulation Parameters of OFDM-MIMO Systems

PARAMETERS	VALUES	
Channel	**SCM**	**Rayleigh**
N_blocks	20,000	20,000
FFT bins	64	64
Symbols/block	64	64
Environment	flat/freq selective fading	flat/freq selective fading
Antenna spacing	0.5	λ /2
SNR	1: 40 dB	1: 40 dB
Carrier frequency	2.4 GHz	2.4 GHz
Doppler frequency	10/50/100/141.6 Hz (63.720kmph)	100/141.6 Hz (63.720kmph)
Sampling time/symbol	0.2 μsec	0.2 μsec
Bandwidth	10 MHz	10 MHz
Modulation order (M)	2,4,16	2,4,16
Modulation type	PSK/QAM	PSK/QAM
Paths/link	2	2/3/4/5
Sub-paths/path	20	-
GI bits	10	10
Maximum delay	5μsec	5μsec
Coding rate	½ Rate convolution	½ Rate convolution
Constraint length	3	3
Trace back length	5* Constraint length	5* Constraint length

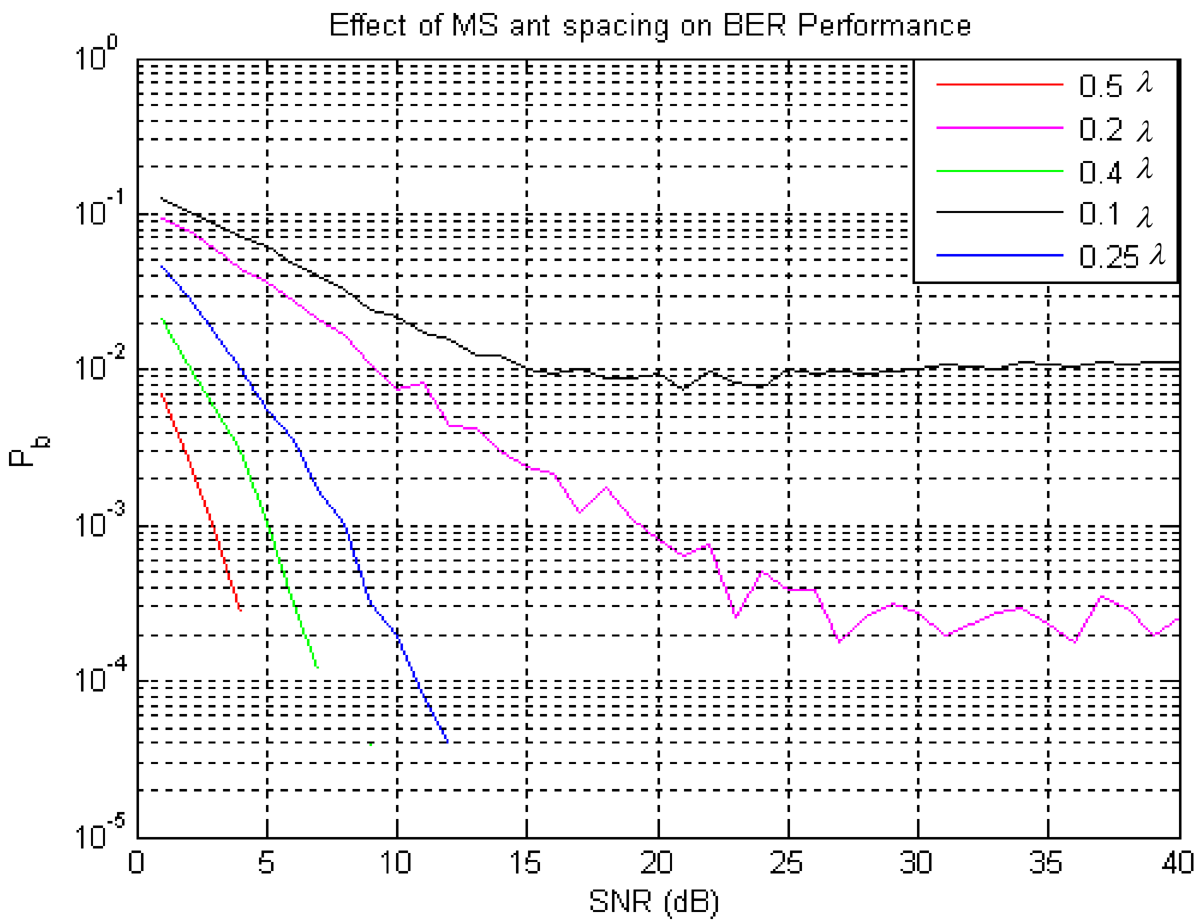

Figure - 9: Effect of Spatial Correlation on BER

The effect of Doppler and spatial correlation on BER performance of OFDM system has also been demonstrated with the help of simulations. It has been shown that by increasing Doppler the BER performance of the system is degraded. If the antenna spacing between the antenna elements is decreased the degradation in BER performance is observed which mainly happens due to the reason that when antennas are closely spaced, signals received by the antennas are severely correlated and both antennas at Mobile user see the same fading channel. Hence by decreasing the spacing between antennas the bit error rate gets worse due to the effect of correlated received signals.

5. Conclusion

The performance of Matlab Rayleigh and Spatial channel models is compared by analyzing the BER of two systems using Opportunistic communication and non-Opportunistic communication techniques under flat fading and frequency selective fading environments using Adaptive antenna at BS. It has been observed from simulation results analyzed above that SCM outperforms the Matlab Rayleigh channel by exploiting the channel diversity in spatial and time domain using Opportunistic communication technique, where BER of 10^{-2} is achieved at SNR of 4dB in case of SCM as compared to Rayleigh channel where same BER of 10^{-2} is achieved at SNR of 8dB. So there is an improvement of about 4dB due to spatial and time diversity being exploited by opportunistic communication technique in SCM.

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