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CP-FREE OFDM SYSTEM USING SUCCESSIVE MULTIPATH INTERFERENCE CANCELLATION

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Abstract - In an OFDM system Cyclic Prefix (CP) is added to reduce the Inter symbol Interference (ISI) and Inter Carrier Interference (ICI). Cyclic Prefix is added at transmitter side and removed at receiver side without checking for errors. An SMIC is a CP-free OFDM system in which the CP bits are again regenerated by Cyclic Prefix Regenerator (CPR) and ISI is reduced by Stored Feedback Equalization (SFE) and by CPR. With these two operations interferences can be reduced and with this it will be checking for errors. Decision Feedback Equalizer (DFE) is used to remove random phases before the decision device. OFDM systems high peak to average power ratio (PAPR) than compared to single carrier systems.

With the use of SFE, CPR and DFE equalizer Bit Error Rate (BER) and Symbol Error Rate (SER) performance of SMIC-OFDM system performance is improved than compared to without equalizer. MIMO-OFDM channel capacity is improved and Average Signal to Interference Noise Ratio (SINR) is reduced. So, with using equalizer SMIC-OFDM system performance is improved.

***KEYWORDS*:** OFDM, SMIC, SFE, CPR, DFE, BER**.**

I. INTRODUCTION

Wireless communication has gone through major changes in the last few decades. While it mostly had been used for satellite, terrestrial links and broadcasting until the 1970s, cellular and wireless networking and other Personal Communication Systems (PCS) presently dominate the technology of modern wireless communications but the rapid growth of Mobile Communication started to replace the complex wired telephone system. In this scenario, the wired technology became outdated and got replaced by wireless communication. OFDM has been used in many high data rate wireless systems because of the many advantages it provides Spectrum efficiency, Simpler channel equalisation, Resilient to ISI. OFDM technology is shown as one of the effectual techniques to conflict frequency selective fading through multi-path propagation.

In wireless communication, Orthogonal Frequency Division Multiplexing (OFDM) is that the hottest technique. When the information is transmitted at high data rates over wireless radio channels, the symbols may overlap with one another which may result in inter symbol interference (ISI). OFDM may be a multicarrier transmission technique during which the high data rate is transmitted over variety of low rate parallel subcarriers. Due to the low rate parallel subcarriers, the symbol duration increases which can reduce the effect of multipath delay spread on the signal.

To induce inter symbol interference (ISI), the receiver may observe a train of signals and sum of their delayed replicas which are created on multipath. Thus, to avoid ISI and ICI, cyclic prefix (CP) has to be appended between two OFDM blocks. CP is a duplicated copy of the tail of an OFDM block. The user data in a block can be protected by the CP from frequency-selective fading because the bandwidth of each subcarrier becomes narrower than the coherence bandwidth. At a receiver, CP must be removed before applying FFT operation, which creates transmission overheads. In some applications, because of the CP, spectral loss can go up to 25%, which is a significant loss. Length of a CP is decided by the length of channel impulse response (CIR), which is a technique to reduce CP. The third-generation partnership project long-term evolution (3GPP-LTE) standard defines two types of CPs, namely normal CP and extended CP, whose lengths are 7.04% and 25% of a block length respectively.

In [6] has proposed a CP-free OFDM system with Pulse Amplitude Modulation (PAM). To construct the conjugate symmetric OFDM block PAM is used at transmitter. In an OFDM block only partial samples involves in SCSE algorithm at a receiver side, which includes Decision Feedback Equalization (DFE) and CP restoration**.** DFE mainly involves with the previously recovered symbol block and it is followed by M-point IFFT. The convolution result may include feedback errors that can be termed as ISI of OFDM block. If the signal is reliable, it can completely remove ISI. PAM modulation in SCSE-OFDM is to reduce computational complexity in SCSE algorithm, but there will be loss in BER. In [7] have proposed a method for the effect of varying the cyclic prefix length on OFDM system performance over different multipath channel models. The estimated variable CP length is based on the RMS delay spread of the channels power delay profile (PDP). In this method, it optimizes the estimated CP length and system capacity and improves the system performance. In [8] has proposed to eliminate the residual ISI introduced by the channel impulse response that exceeds the length of the guard interval. The algorithm uses decisions to estimate the residual ISI by FFT and IFFT with a very low computational complexity. The ISI introduced by the multi-path channel can be eliminated by using a cyclic prefix whose length exceeds the length of channel response. It can be applied to non sample spaced channel. In [9] has proposed a suppression scheme that linearly combines the ISI-free part of a CP and its corresponding part in an OFDM signal to the ICI effect caused by a time varying channel. In this method the length of CP is larger than channel delay spread therefore, a number of ISI free part exists. There are three sets of optimum combining weights in different aspects. In [10] have proposed a CP-free OFDM/OFDMA system design without the need to use CP. This system does not insert CPs between symbols at transmitter. In frequency selective fading channel the neighbouring symbols will overlap at receiver and DFE is performed before FFT operation for ISI removal. After DFE operation, each symbol consists of multipath return of different linear shifts that may result in ICI. The output symbols from DFE will be sent to CP restoration for linear shift to cyclic shift conversion. It offers much higher SET (Spectrum efficiency, Energy efficiency and Transmission rate) than traditional OFDM/OFDMA system in frequency selective fading channel.

Because of using CP, OFDM systems will have high BER performance. So, to reduce BER performance, the proposed system uses SMIC and CPR algorithm to reduce interference and DFE is used to remove random phases before decision device. The results show comparison of BER and SER for with and without equalizer. MIMO channel capacity and average signal to interference noise ratio is also evaluated.

II. METHODOLOGY

System Model of SMIC-OFDM

The block diagram of SMIC-OFDM system is shown in Fig1. The signals to be transmitted are first mapped accordingly and then converted to serial data into parallel streams by using Serial to parallel (s/p) conversion block. These parallel streams of data are IFFT modulated and transformed from time domain to the frequency domain. And the frequency domain signals are converted to parallel data into serial streams by using parallel to serial conversion block. After that it is passed through a channel with the addition of noise. And then it is converted to serial to parallel. After then the parallel data is sent to SMIC block. In SMIC block it consists of a buffer, CPR and SFE. This all operations are done before FFT operation. After M-point FFT, the parallel data is converted to serial via parallel to serial conversion. After then the serial data is passed through DFE and decision device and then the data is de-mapped. Finally, the data or signals obtained at the receiver are decoded and the original data is recovered at the receiver. The system model is shown in figure 1.

Assume the ith data block, binary inputs b_i^T is mapped into a M-ary modulated symbols q_i^T. Quadrature Amplitude Modulation is used. q_i^T is sent in to serial-to-parallel (s/p) conversion. Then q_i is sent into M-point IFFT. S_i is sent into parallel-to-serial convertor. Then s_T^i is sent into a wireless channel. After that W_i is noise term added. Then r_i^T is sent in to parallel to serial convertor. Then r_i is sent into SMIC block, SMIC block consist of SFE, CPR and buffer. The $ŕ_i(n)$ is the summation of different circularly shifted OFDM block plus noise. The $ŕ_i(n)$ is sent into M-point FFT, the output of M-point FFT is sent into serial-to-parallel convertor. The output q'^T_i is sent into DFE and decision device for removing random phases. Then demodulated data will be obtained without any error.

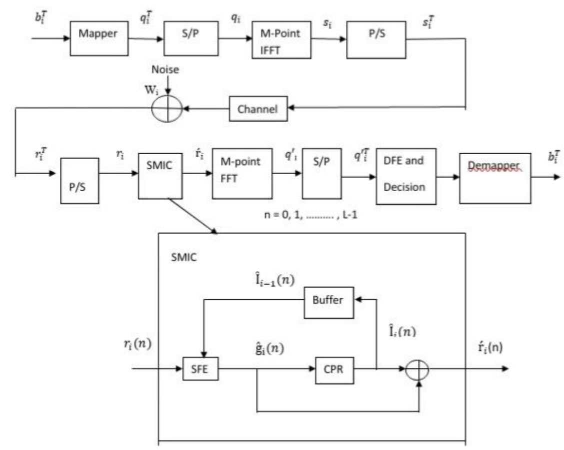

Fig: 1 Block Diagram of SMIC-OFDM System

The received signal r_i consist of ISI term (I_{i-1})

$$\begin{aligned} r_i &= [r_i(n)]_{n=0}^{M-1} \\ &= H_{si} + I_{i-1} + W_i \\ &= [g_i(n)]_{n=0}^{M-1} + [I_{i-1}(n)]_{n=0}^{M-1} + [W_i(n)]_{n=0}^{M-1} \end{aligned}$$

Where,

W_i - Additive white Gaussian noise term

SMIC algorithm is performed on r_i which includes SFE and CP, before FFT operation. To suppress ISI, SFE is performed first which gives $[\hat{g}_i(n)]_{n=0}^{L-2}$ and calculation of $\hat{I}_i(n)$ is done by CPR reconstruction block.

$$ŕ_i = \{[\hat{g}_i(n) + \hat{I}_i(n)]_{n=0}^{L-2} \ ; [g_i(n)]_{n=L-1}^{M-1}\}$$

After SMIC operation, the output of SMIC is sent into FFT block and then to serial to parallel block which gives q'_i and q_i^T. $ŕ_i$ Consist of noise term of OFDM block which consist of summation of circularly shifted symbols. On q_i^T perform frequency domain operation, which remove random phases before decision device. A demapper will translate the recovered data block q_i^T into recovered binary bits b_i^T. With the help of SMIC algorithm, a CP-free OFDM block can reduce interference effect. With the help of DFE equalizer random phases can be removed and at the end the data will be a error free data.

SMIC ALGORITHM

Assume that the delay spread is shorter than the CP-free OFDM block. In an OFDM block partial samples suffer from ISI/ICI and the segment in which it occurs called as ISI/ICI zone, and the length is L-1. Thus r_i can be written as

$$r_i = \{[g_i(n) + I_{i-1}(n) + W_i(n)]_{n=0}^{L-2} \ ; [g_i(n) + W_i(n)]_{n=L-1}^{M-1} \quad (1)$$

← ISI/ICI zone → ← ISI/ICI free →

Where g_i(n) can be expressed as,

$$g_i(n) = \begin{cases} \sum_{l=0}^{n} r\, r_{i,l}(n-l), & n = 0, \ldots\ldots, L-2 \\ \sum_{l=0}^{L-1} r r_{i,l}(n-l), & n = L-1, \ldots\ldots, M-1 \end{cases}$$

(2)

The samples which are affected by ISI/ICI, Stored feedback equalization is performed which gives,

$$\hat{\mathrm{g}}_{\mathrm{i}}(\mathrm{n})_{\mathrm{n}=0}^{\mathrm{L}-2} = [r_i(\mathrm{n})]_{\mathrm{n}=0}^{\mathrm{L}-2} - [\hat{\mathrm{I}}_{i-1}(n)]_{n=0}^{L-2} \qquad (3)$$

$[\hat{\mathrm{I}}_{i-1}(n)]_{n=0}^{L-2}$ Calculation has been done in (i-1)th block and saved in the buffer serving as a feedback signal and this operation is known as SFE. In a CP-free OFDM block ISI can be removed leaving a CP-gap and through feedback equalization. Due to multipath propagation, this CP "gap" can be viewed as different linear versions of an OFDM block.

In an OFDM system interference will occur between subcarrier which is called as ICI. Cyclic Prefix is again regenerated through signal estimation, to suppress ICI and this operation is called as CPR. SFE need to be done first before CPR operation. As shown in Fig:2 $\hat{\mathrm{g}}_{\mathrm{i}}(n)$ where (n= 0,….L-2) is the input to CPR. The nth symbol of path 1 can be estimated as

$$\acute{r}_{i,l}\,[(n)]_{n=0}^{L-1} = [\,\hat{\mathrm{g}}_{\mathrm{i}}(n) - [\mathrm{d'}_{\mathrm{i}}(\mathrm{n})]\,\frac{[\mathrm{h(l)}]_{\mathrm{l}=0}^{\mathrm{L}-1}}{\mathrm{h}(0)} \qquad (4)$$

Where, $\mathrm{d'}_{\mathrm{i}}(\mathrm{n})$ is intermediate term

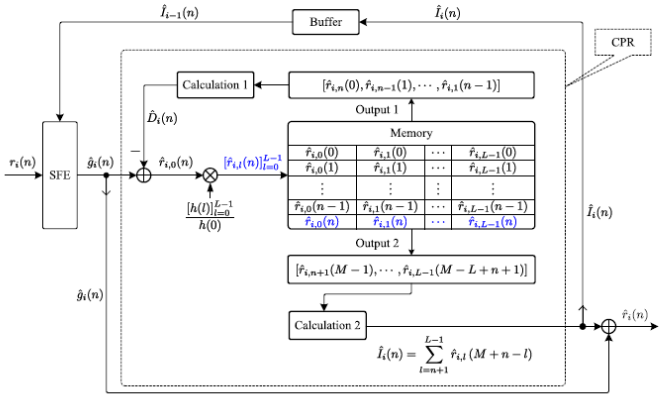

Fig: 2 Block Diagram of SMIC Algorithm

In the above figure 2 $\mathrm{d'}_{\mathrm{i}}(\mathrm{n})$ is denoted as calculation 1. Mathematically $\mathrm{d'}_{\mathrm{i}}(\mathrm{n})$ can be written as

$$\mathrm{d'}_{\mathrm{i}}(\mathrm{n}) = \begin{cases} 0, & n = 0 \\ \sum_{\mathrm{l}=1}^{\mathrm{n}} \acute{r}_{i,l}\,(n-l), & 1 \le n \le L-2 \end{cases} \qquad (5)$$

As shown in fig.2 $\hat{\mathrm{I}}_{i}(n)$ is denoted as calculation 2 and it is the estimation of CP signal. Mathematically $\hat{\mathrm{I}}_{i}(n)$ can be written as

$$\hat{\mathrm{I}}_{i}(n) = \sum_{l=n+1}^{L-1} \acute{r}_{i.l}(M+n-l), \quad 0 \le n \le L-2 \qquad (6)$$

CPR ALGORITHM

The Fig:2 explains the CPR in detail, an OFDM block contain 8 samples. CPR algorithm proceeds in eight steps.

1. First multiply the first sample by channel impulse response vector (CIRV); it can detect the first symbol from path l (l = 0, 1, 2), $\hat{g}_i(0)\,\frac{h}{h(0)} = [\acute{r}_{i,l}(n)]_{l=0}^{2}$. Subtracting the second sample from the first symbol of path 1, it obtains the second symbol in path 0.
2. Multiply $\acute{r}_{i,0}(1)$ acquired in step 1 by CIRV, it obtains the second symbols from paths 0, 1, 2. To obtain $\acute{r}_{i,0}(2)$, subtraction need to be done.
$$\acute{r}_{i,0}(2) = \hat{g}_i(2) - [\acute{r}_{i,2}(0) + \acute{r}_{i,1}(1)]$$
3. Multiplying $\acute{r}_{i,0}(2)$ by CIRV, second samples are obtained from path 0, 1, 2. To obtain $\acute{r}_{i,0}(3)$, subtraction need to be done.
$$\acute{r}_{i,0}(3) = \hat{g}_i(3) - [\acute{r}_{i,2}(1) + \acute{r}_{i,1}(2)]$$
4. According to sequential order, the samples are processed one by one. Multiplying $\acute{r}_{i,0}(n)$ with CIRV nth symbol is obtained from path l (l = 0, 1, 2), i.e., $\acute{r}_{i,0}(n)\,\frac{h}{h(0)} = [\acute{r}_{i,l}(n)]_{l=0}^{2}$. In this way it obtains all the symbols in an OFDM block.
5. CP gap is filled with the estimated signal. $[\,\acute{r}_{i,1}(7) + \acute{r}_{i,2}(6) + \acute{r}_{i,2}(7)]$, i.e., step 8(a) or

$$[\acute{r}_i(n)]_{l=0}^{7} = [\,\acute{r}_{i,1}(7) + \acute{r}_{i,2}(6) + \acute{r}_{i,2}(7), 0 \ldots\ldots 0]^{\mathrm{T}} \qquad (7)$$

← Estimated CP Signal →

The above equation (7) should be sent to memory unit i.e., Step 8(b) which will serve as a stored feedback signal to cancel the interference to the next block. For this reason the algorithm is named as SFE.

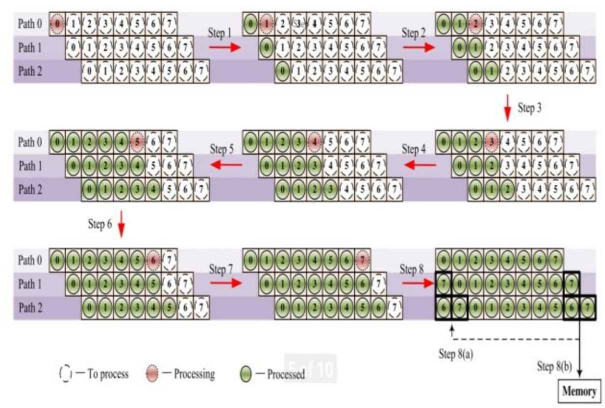

Fig: 3 Schematic Diagram of CPR

In step (8) the CPR algorithm is different from SCSE algorithm. SMIC-OFDM can offer a higher channel utilization ratio (CUR) than traditional CP-OFDM.

Signal detection may interrupt long feedback loop which is caused by delay, when the feedback signal cannot be acquired. At the final step of CPR, a SMIC store the tail of the current block which will interfere the next block. SFE mainly depends on memory unit. The delay spread in CPR is L-1 and block size is M where L-1<M.

As shown in Fig: 3, by using CPR algorithm circularly shifted blocks can be converted into linearly shifted blocks. Due to CPR there will be estimation errors. After completion of CPR algorithm a newly generated OFDM block, will consists of circularly shifted OFDM blocks and can be written as

$$\acute{r}_i = Hs_i + W_i + v_i \qquad (8)$$

Where, H is a circulant matrix

After SMIC operation, the output $\acute{r}_i$ will be sent to M-point FFT which obtains

$$\vec{q}_i = F\acute{r}_i = F[Hs_i + W_i + v_i]$$
$$= \wedge q_i + F(W_i + v_i) \qquad (9)$$

Where,
W_i represents noise and
v_i represents estimation errors.

After serial to parallel conversion, Decision Feedback Equalizer (DFE) is performed to remove random phases before decision device. In communication system, equalizers are used to reduce the inter symbol interference.

DECISION FEEDBACK EQUALIZER (DFE)

DFE is a filter which uses the feedback of detected symbol and produces the estimation of channel output. It can be used in combination of linear equalizer.

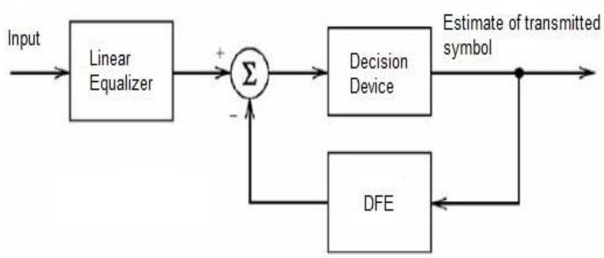

Fig: 4 Decision Feedback Equalizer

DFE is fed with detected symbols and produces an output which is typically subtracted from the output of linear equalizer. DFE is used for removing random phases before decision device.

Power is the major concern in wireless communication systems. So, the available power should be used effectively. PAPR occurs in multicarrier system because different subcarriers are out of phase with each other. At each instant sub-carrier are different with each other at different phase values. When all points reach maximum value simultaneously, will cause output envelope to shoot up suddenly which produces a peak in output envelope. The PAPR of system can be calculated as the ratio of maximum power of sample in OFDM transmit symbol to average power of that OFDM symbol. In simple way, PAPR is ratio of peak power to average power of the signal, which is expressed in dB. The PAPR of continuous time-based signal x(t) of OFDM system transmitted is represented as the ratio of maximum power to average power.

$$R = \frac{\max |x(t)|^2}{E|x(t)|^2}$$

III RESULTS AND DISCUSSION

The outputs of the existing and the proposed system simulated using MATLAB is presented here. The working of the system can be analysed from resulting graphs and can be easily understood. Here the graphs show comparison of Bit Error Rate (BER) and Symbol Error Rate (SER) of proposed system with existing system.

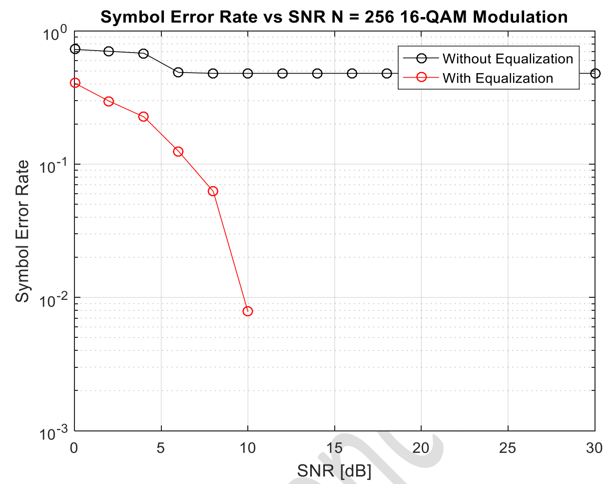

Fig: 5.1 Comparison of SER performance with and without equalizer

The analysis shows that SER performance of SMIC-OFDM system with and without equalizer as shown in fig 5.1 at the 6dB it is gradually decreasing i.e. with equalizer. Without equalizer the graph is like a straight line. So with using equalizer the SER performance of the SMIC-OFDM system performance is improved.

SER with equalizer	SER without equalizer	Type of noise
0.41379	0.73103	Additive White Gaussian
0.68966	1	Rician
0.7964	0.94510	Rayleigh

Table: 1 shows the Comparison of SER values with and without equalizer

From the above table, it can conclude that with using equalizer the SER performance is low than compared to without equalizer.

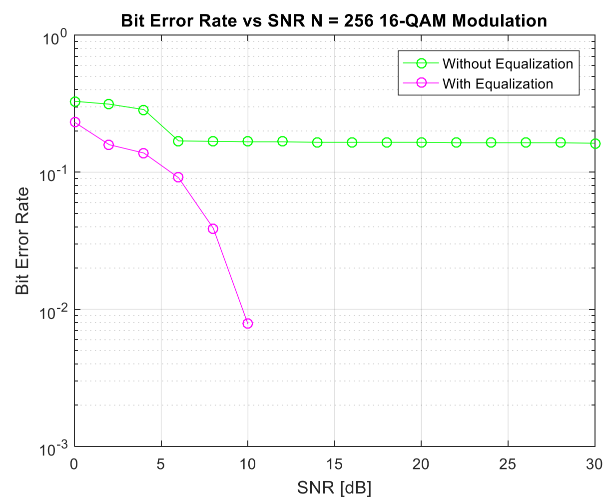

Fig: 5 Comparison of ER performance with and without equalizer

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The analysis shows that BER performance of SMIC-OFDM system with and without equalizer as shown in fig 5.2 at the 5dB it is gradually decreasing i.e. with equalizer. Without equalizer the graph is like a straight line. So with using equalizer the BER performance of the SMIC-OFDM system performance is improved. From the graph it can be conclude that with using equalizer the BER performance is low than compared to without equalizer.

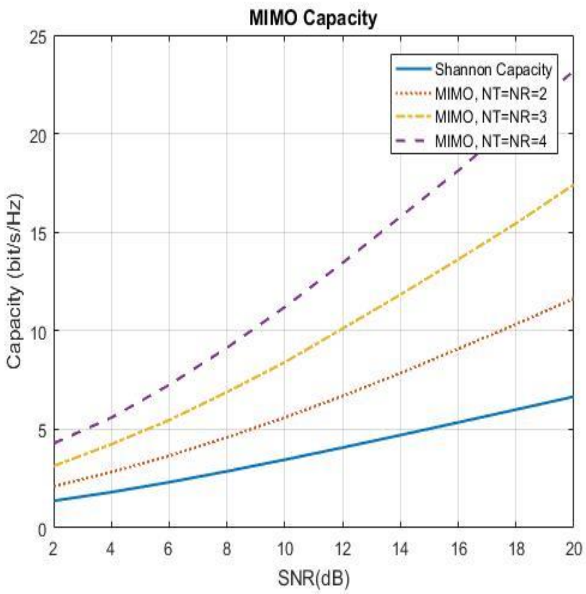

Fig: 5.3 MIMO channel capacity

The analysis shows that MIMO channel capacity performance of SMIC-OFDM system as shown in fig 5.3 with Shannon the capacity is low, for two transmitters and two receivers the capacity is low, as the number of transmitters and receivers are increasing the capacity is increasing. For four transmitters and four receivers the capacity is improved. With increase in SNR the channel capacity to accommodate no. of bits per symbol also increases.

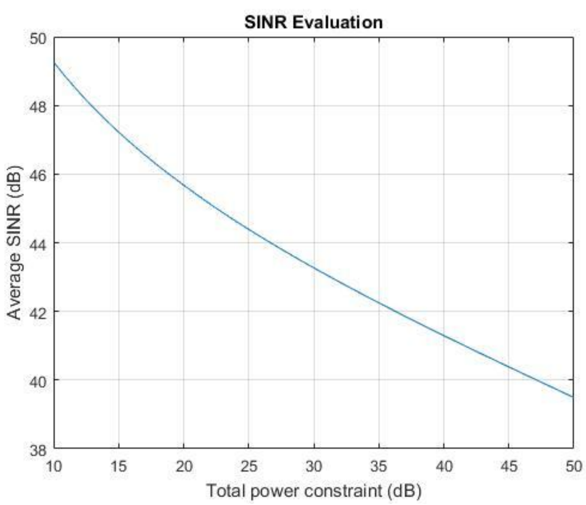

Fig: 5.4 Average SINR vs Total Power Constraint

The analysis shows that average signal to interference noise ratio vs total power constraint of SMIC-OFDM system as shown in fig 5.4 as power is increasing SNIR is decreasing i.e. in this interference can be reduced.

Average SINR	Total Power
49	10
47.5	15
45.9	20
44.2	25
43	30
42.1	35
41	40

Table: 2 Shows the average SINR and total power

From the above table it can conclude that as power is increasing SINR is decreasing.

From these results it can conclude that with using equalizer the SER and BER performance of SMIC-OFDM system performance is improved than compared to without equalizer. Average SINR and MIMO channel capacity is also discussed here.

IV CONCLUSION

In the existing work focuses that in an OFDM system cyclic prefix is added in the transmitter side and it is removed in the receiver. While removing the cyclic prefix there will be a loss of data. There is no equalizer is used.

In proposed work, SFE is used and it has lesser feedback loop. DFE is used for error correction and at the end the data will be an error free data. With SMIC interference can be reduced. SMIC-OFDM can achieve a higher spectral efficiency than traditional CP-based OFDM system, but due to estimation errors in CPR there will be loss in BER.MIMO channel capacity is improved and average signal to interference noise ratio is reduced. So, interference is reduced.

To further improve BER and SER performance of SMIC-OFDM system improved equalization methods can be applied like blind equalizer, Viterbi equalizer, fractionally spaces equalizer (FSE), etc.

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