

Side-Lobe Interference Minimization in MC-CDMA Based Cognitive Radio

Bhumika D. Kavaia and Vinay M. Thumar

Abstract Cognitive radio system is a promising technique to pull off spectrum utilization requirements. Key feature is high data rate wireless communication being offered to the unlicensed user on the basis of request. MC-CDMA is one of the promising multi-carrier transmission methods to achieve this in cognitive radio (CR) system. It is quite possible that transmission of primary and secondary users may occur in an adjacent spectrum, interference is caused by secondary users to the primary user (PU) band. Fourier-based transmission of such systems is having many rewards, but there this method generates side lobes which can cause interference in PU band. This paper focuses on minimizing side-lobe interference caused by secondary users to the PU band. Power allocation-based methods are verified to minimize the interference. Interference is minimized with the use of water-filling-based power allocation method as compared to uniform power allocation method. This objective is accomplishment and explained in this paper.

Keywords Cognitive radio · MC-CDMA · Power allocation · Side-lobe interference · Water-Filling

1 Introduction

The era of wireless communication is demanding for high data rate applications to the wide range of users. This leads to deficiency of spectrum availability. To achieve high data rate over traditional single carrier transmission causes ISI due to multipath and may increase receiver complexity. Above reason leads to need of mechanism which can increase spectrum efficiency. This has initiated the idea of cognitive radio (CR), where unlicensed users are allowed to use a portion of spectra when licensed users are disabled, in a way that this temporary allocation should not

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affect the primary transmission. Since like have been an increase among demand for greater information degree transmission, the structures are integrating the multi-carrier transmission techniques. The multi-carrier transmission approach employs the by Fourier transform mechanism. The entire bandwidth will remain cut up between numbers of tributary channels. As a result, a high information stream will be transformed among numbers of low rate channels, who are transmitted over distinct sub-channels. The splitting concerning high data rate channel of a range on lower information rate channels causes expand of symbol duration, whereas a decrease rate parallel sub-carriers reduce the relative amount of dispersion in period prompted via multipath delay spread. Various multi-carrier transmission systems are developed and used by many Telecom standards to fulfil requirements. MC-CDMA is one of the multi-carrier transmission techniques. MC-CDMA gives settlements of OFDM and CDMA. Earlier MC-CDMA was proposed by Linnartz in 1993 [1]. MC-CDMA has provided multi-carrier transmission with low complexity of receiver structure. In cognitive environment also MC-CDMA is providing suitability by fulfilling the criteria such as no hardware modification required to upgrade system, spectrum shaping and compatibility to adaptive modulation technique. It also provides advantage of CDMA such as diversity and spreading technique. MC-CDMA has variants which depend on spreading done in time domain or frequency domain. MC-CDMA uses frequency domain spreading, which has advantages of collecting energy in frequency domain at receiver side. Efficiency of this system also depends upon spreading code selection. Based upon the application in uplink or downlink, Walsh or PN codes are widely chosen for the system. In cognitive radio system, secondary user may get non-contiguous sub-carriers and thus the system transmission becomes non-contiguous. In this case, Walsh code lost its orthogonal property if number of sub-carriers are not in terms of 2^N , Where N indicates number of sub-carriers. The system performance gets poor in such environment. To overcome from this problem, Carrier Interferometry (CI) code is chosen. CI codes are introduced to mitigate the effect of losing orthogonal property in NC transmission. They are complex-valued code having any of the length. It also has capabilities to accommodate more number of users by providing extra phase shifting in code, no other modification required. In this work, CI code is chosen for NC-MC-CDMA system-based cognitive radio. Similar to NC-OFDM [2, 3] environment, NC-MC-CDMA also generates side lobes which may cause interference to nearer PU band [4, 5], which should be in limited form for any efficient CR system.

The paper is methodical as follows: Sect. 2 is about cognitive radio, Sect. 3 provides system model. Section 4 detailed the MC-CDMA system, Sect. 5 entitled power allocation and interference management. While Sect. 6 gives simulation results and Sect. 7 provides the conclusion.

2 Cognitive Radio

Cognitive radio is a smart Wi-Fi communication system so much is aware on its surrounding environment. It utilizes the methodology on understanding by building in conformity with learn beyond the environment yet inure its inner states according to statistical variations through two fundamental objectives, relatively reliable communication whenever yet any place needed and efficient utilization of the spectrum. The solution for enabling technology on dynamic spectrum gets right of entry to cognitive radio (CR) technology. CR provides the ability in accordance with portion the wireless channel including the unlicensed users of an opportunistic way. CRs are envisioned to stay in a position according to furnish the high bandwidth according to mobile users via heterogeneous wireless architectures or dynamic spectrum access techniques. The networked CRs also impose several challenges fit in imitation of the huge extent of reachable spectrum as well namely numerous QoS necessities about applications.

To share the spectrum with licensed customers except disturbing them, and associate the numerous quality of situation need of applications, every CR user into a CR Network have to determine the part concerning spectrum that is available—called spectrum sensing. To pick out the best accessible channel—referred to as spectrum decision. Coordinate get admission to this channel together with other users called spectrum distribution by means of following CR cycle shown in Fig. 1 [6].

3 System Model

Cognitive radio-based system model considering for this work is shown in Fig. 2. Single primary user and multiple secondary users are considered. All SUs transmissions are controlled by centralized control system. Channel condition between

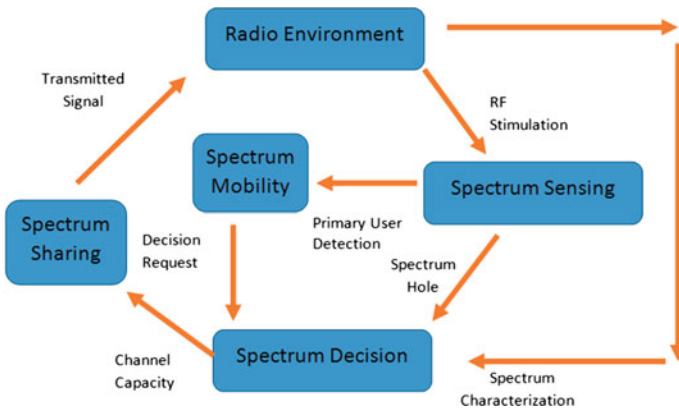
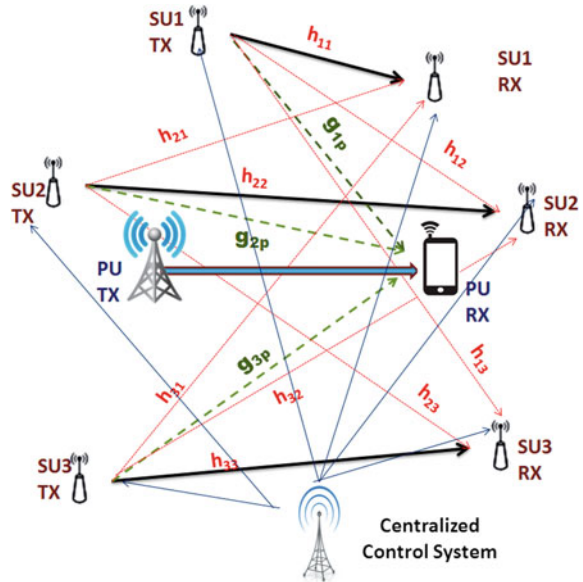


Fig. 1 Cognitive radio [6]

Fig. 2 System model



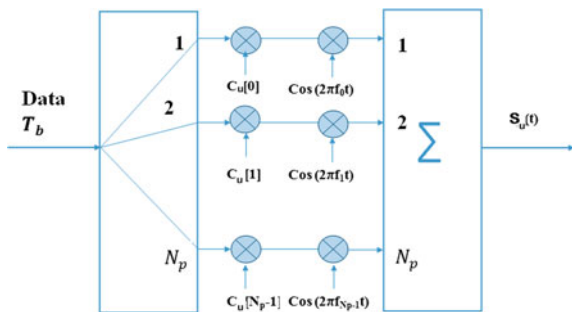
SU transmitter and SU receiver given by h_{kl} , intersecondary user interference considered by the channel gain of SU transmitter to near by SU receiver h_{kl} , Where l indicate path. Interference from SUs to PU gets affected via channel gain g_{kp} , where gain is from k th secondary user to p th PU band. Here, single PU with single band is considered.

4 Modelling of CI/NC-MC-CDMA

Implementation of NC-MC-CDMA system follows the NC-OFDM procedure. The difference is no serial to parallel conversion needed at input side and data bits are converted into number of copies via copier. Number of copier depends upon number of sub-carrier N_p of the system. Each copy is multiplied with spreading code and allocate to the sub-carrier. Thus spreading become in frequency domain and transmitting data rate will be same as input data bit [7]. Transmitter structure is as shown in Fig. 3. In MC-CDMA-based cognitive radio, few sub-carriers are used by licensed user and so that for secondary users transmission become non-contiguous transmission. In this case, sub-carrier under primary user band is considering as null sub-carriers.

CI codes are chosen for spreading data bits to preserve the orthogonal property in NC transmission and to achieve more efficient system response. Over a Walsh code whose code length is restricted to 2^N having bits +1 or -1, CI codes are complex orthogonal codes of any length of N . CI-based MC-CDMA provides the

Fig. 3 MC-CDMA transmitter structure [8]



capability of supporting $U > N$ users using phase shift $\frac{\pi}{N}$ without expansion of bandwidth. The spreading sequence for CI code is generated by Eq. 1 [9].

$$c^u(t) = \sum_{i=0}^{N_p-1} \beta_i^u * e^{j2\pi\Delta f i t} \quad (1)$$

where β_i^u is the u th user complex spreading sequence for $i = 0, 1, \dots, N_p - 1$.

$$\beta_i^u = \beta_0^u, \beta_1^u, \dots, \beta_{N_p-1}^u \quad (2)$$

Here, $\Delta f = 1/T_b$ where T_b is symbol duration.

For Hadamard code, β_i^u is $-1, +1$. For the case of CI codes, β_i^u are complex phases corresponding to Eq. 2 can be written as Eq. 3

$$\beta_i^u = 1, e^{j\Delta\theta u}, e^{j2\Delta\theta u}, e^{j3\Delta\theta u}, \dots, e^{j(N_p-1)\Delta\theta u} \quad (3)$$

When $u = 1, 2, \dots, N_p - 1$

$$\Delta\theta_u = \frac{2\pi}{N} u \quad (4)$$

And when $u = N_p, N_p + 1, \dots, 2N_p$, it is defined by

$$\Delta\theta_u = \frac{2\pi}{N} u + \frac{\pi}{n} \quad (5)$$

In this way from Eqs. 4 and 5, $2N$ users are supported on codes of length N with minimal performance degradation as the number of users increase from N to $2N$. The transmitted signal for the all users for CI/MC-CDMA in [10, 11]. Effect of CI code on simulation is also verified and shown in [12]. Here, $D^U(t)$ is input data bits, $u =$ Total number of users, $A =$ Amplitude [9].

5 Power Allocation and Interference Management

Frequency response of MC-CDMA-based cognitive radio system is shown in below Fig. 4. It is observed that because of the Fourier-based transmission of the secondary system side-lobe power may cause interference to nearby primary user [13–15]. This work intended to minimize the side-lobe interference caused by SUs to PU. Here, effect is observed on whole PU band. PU band may use CDMA-based transmission or FDMA-based transmission. Interference effect will be same on all PU users as here only SUs to PU effect is considered.

Let total available bandwidth of secondary user is B_{su} Hz which is decided by the coherence bandwidth. B is the sub-carrier bandwidth for secondary user. N_{su} are the total number of sub-carrier allocated to secondary user. So the number of sub-carriers is given by $N_{su} = \frac{B_{su}}{B}$. Uniform bandwidth allocation done on each sub-carrier for all u users. For the given power budget and allocated bandwidth system overall throughput should be maximum, with the condition that the interference caused by SU users to PU band should be under the threshold defined by spectrum regulatory authority. The optimization problem for sub-carrier power allocation and PU interference management is as follows:

Problem Definition:

$$\text{Obj} = \max C, \quad \forall u \quad (6)$$

Subject to,

$$I_m \leq I_{th} \quad (7)$$

$$p_{k,i} \geq 0 \quad (8)$$

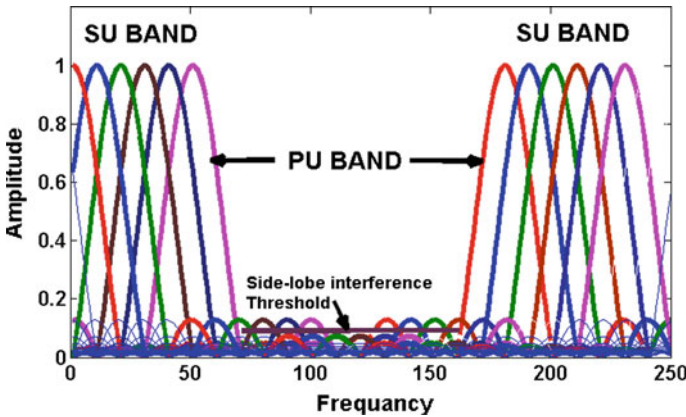


Fig. 4 Frequency response of NC-MC-CDMA

$$\sum_{k=1}^u \sum_{i=1}^{N_{su}} p_{k,i} \leq P_t \quad (9)$$

$$0 \leq B \leq \Delta f_{cu} \quad (10)$$

where,

$$C = \sum_{k=1}^u \sum_{i=1}^{N_{sc}} B \log_2 \left(1 + \frac{p_{k,i} * h_{kl,i}}{\sigma^2} \right) \quad (11)$$

$$I_m = \sum_{k=1}^u \sum_{i=1}^{N_{sc}} p_{sc} * g_{k,p} \int_{\text{PUBand}} \text{sinc}((f - f_{k,i}) * T_s)^2 \quad (12)$$

where $B = u$ th user sub-carrier bandwidth, $p_{u,i} = u$ th user power on i th sub-carrier, $h_{kl,i} = k$ th user transceiver channel gain on i th sub-carrier, $\sigma^2 = \text{AWGN variance}$.

Equation 6 gives the objective that system should achieve maximum overall throughput for all the users with the constraints that interference to the PU band should be below threshold given by authority as in Eq. 7. Power allocated to all the secondary users should satisfy the constraint given in Eqs. 8 and 9. Sub-carrier bandwidth should be lesser than coherence bandwidth as in Eq. 10. Overall capacity of the system is given as Eq. 11. Interference to the PU band by each secondary user is calculated by Eq. 12.

To fulfil the objective of obtaining maximum throughput with the constraint that side-lobe interference should be below the threshold interference, algorithms are developed using two different power allocation methods. Uniform power allocation-based on-off method is modified using the water-filling power allocation method to minimize the side-lobe interference. Algorithm is stated here shows that after allocating resources to the system, power allocation is done. Interference is calculated for allocated power and compared with threshold interference (decided by Telecom regulatory authority). If the interference is above the threshold level, highest interference causing sub-carrier is elected and power level to that sub-carrier is making null. Thus, on-off method is applied here to reduce the side-lobe interference level. Uniform power allocation does not give satisfied performance; hence, water-filling power allocation is applied to achieve the objective of this work. Algorithm is as shown below.

6 Simulation Results

In this section, calculation of side-lobe interference from SUs to PU and management of interference below threshold using different power allocation methods are carried out. Let system having total allocated bandwidth 6 MHz out of which 1 MHz

uses by PU and 5 MHz used by SU users. Here, we are considering only single PU in system but for the presence of more PU scenario is remain same. Here, we are considering total 64 sub-carrier allocated to both of them by centralized cognitive system. Sub-carrier allocated to the PU will be null sub-carrier for secondary user. Threshold interference arbitrary chosen for simulation is $I_{th} = 8e-11$ W and input power of single user is 2 W. Side-lobe interference calculation from SUs to PU is carried out by considering PU as a single band.

Algorithm 1 Modified Interference Management algorithm

procedure ALLOCATION OF RESOURCES

 Total Available Sub carrier Bandwidth = B

 Total Available Power for Each User = P_t
for each user $i \in u$ **do**

 let i^{th} user Bandwidth = B_{su} | $C \in \max C_t$

 let $N_{si} = \frac{2B_{su}}{B-1}$
for each Subcarrier $j \in$ **do** N_{si}

 let Channel gain $h_{i,j}, \forall N_{si}$
 $P_{ij} = \frac{P_t}{N_{si}}$
end for
end for
end procedure
procedure CALCULATION FOR INTERFERENCE TO PU

 While ($P_{ij} \geq 0$)

 Compute $I_{ij}, \forall N_{si}, \forall u$
 $I_{tot} = \sum_{i=1}^u I_{ij}$

 Calculate Throughput $, \forall N_{si}, \forall u$ | $C \in \max C_t$

 Use Water filling Algorithm for $\sum P_{ij} \leq P_t$

 Calculate Throughput $, \forall N_{si}, \forall u$ | $C \in \max C_t$

Compare Throughput with previous result

end procedure
procedure INTERFERENCE MINIMIZATION

for each user $i \in$ **do** u
for each Subcarrier $j \in$ N_{si} **do**

 Do Get max I_{ij}
 $h_{i,j} = 0$

 Compute $I_{ij}, \forall N_{si}, \forall u$
 $I_{tot} = \sum_{i=1}^u I_{ij}$

 While $I_{tot} > I_{th}$

 Calculate Throughput $, \forall N_{si}, \forall u$ | $C \in \max C_t$

using power allocation by uniform power allocation

 Calculate Throughput $, \forall N_{si}, \forall u$ | $C \in \max C_t$

using power allocation by water filling method

Compare Results

end for
end for
end procedure

Fig. 5 Interference from SU to PU

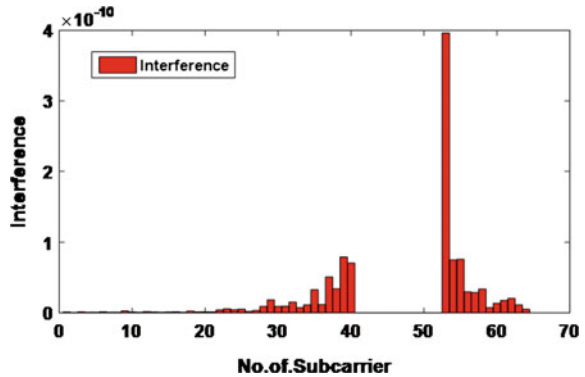


Fig. 6 Interference after minimization to PU band

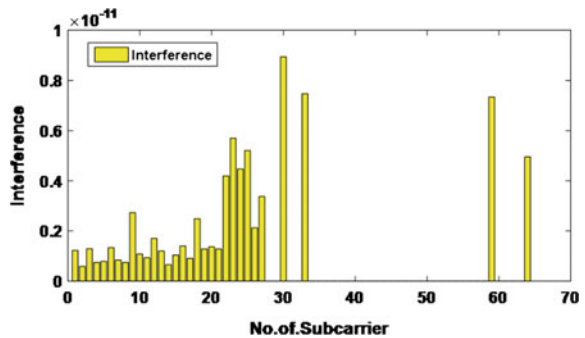


Figure 5 shows the interference caused by each sub-carrier of SU to PU band. We get total interference is $1.11e-9$ W to PU band which is above the threshold interference. We need to reduce this interference below threshold value. Algorithm based upon uniform power allocation is applied to minimize interference below the threshold value.

Figure 6 shows the interference caused by each sub-carrier after minimizing total interference. Result gets $7.8e-11$ W interference to PU which is below threshold. To minimize this algorithm has null the 21 sub-carrier of secondary user which causing maximum interference to PU band.

Throughput performance for single user before and after interference minimization is shown in Fig. 7, where throughput is degraded as number of sub-carriers to be null after minimizing the interference.

Another simulation carried out for such system using multi-users, as more than single user carried by MC-CDMA system interference causing to PU is also increase. For four users, each of having 2 W power on total 64 sub-carrier where PU having 1 MHz and SU 5 MHz and by keeping interference threshold $I_{th} = 1e-10$ W. Each user power equals distribution on 64 sub-carrier that is $2/64$ W. Before minimization total interference to PU is carried out $3.4e-9$ W to PU. Each sub-carrier interference is

Fig. 7 Throughput performance for single user

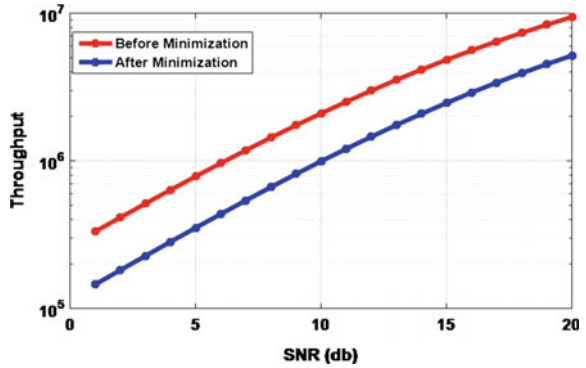


Fig. 8 Interference by four secondary users to PU band

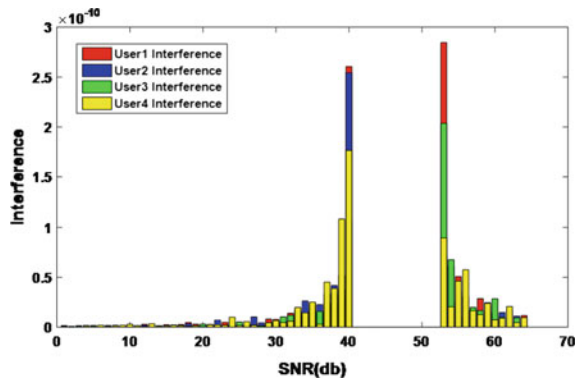
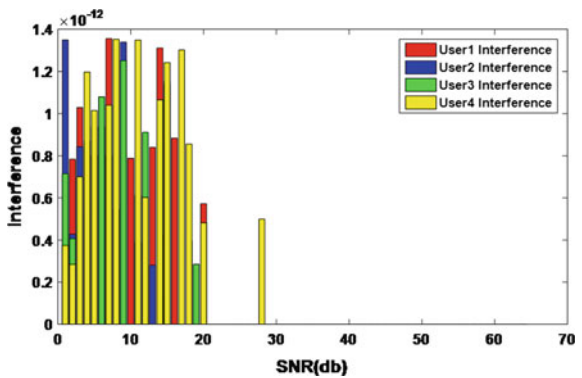


Fig. 9 Interference by four users after minimization



showing in Fig. 8. After applying algorithm, interference reduces to PU is 9.5×10^{-11} W which is obtained by null 160 SU sub-carrier which causing highest interference to PU shown in Fig. 9.

Throughput calculation for both scenarios is shown in Fig. 10.

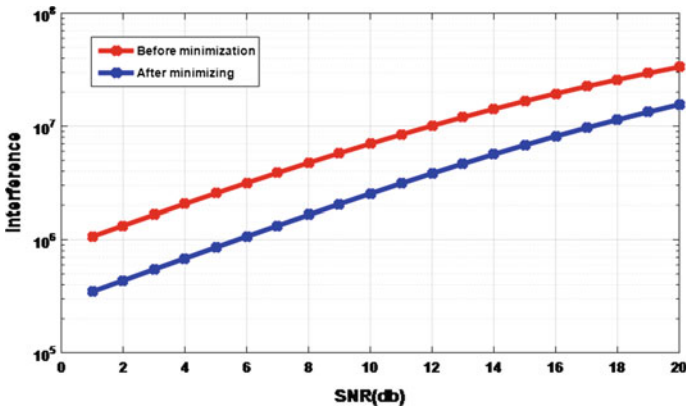


Fig. 10 Throughput performance of four users

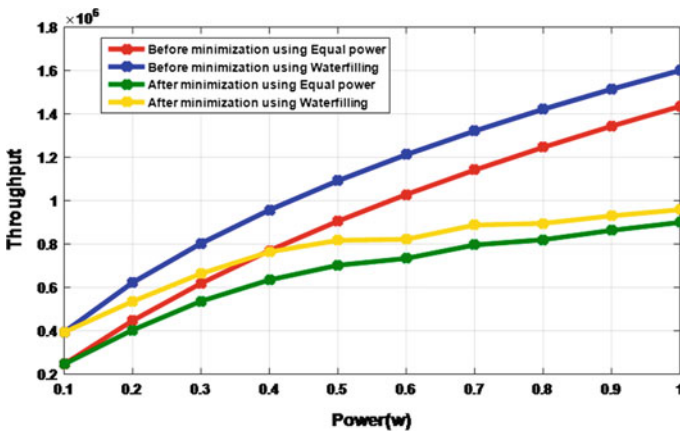


Fig. 11 Throughput versus power performance with modified algorithm

6.1 Interference Management and System Performance

Based upon algorithm using water-filling power allocation method as discussed in previous section interference management is performed. For the single user having input power range of 0.1–1 W and 64 sub-carrier system algorithm is applied to reduce the side-lobe interference causing from SU to PU. Here interference threshold is kept at $1e-11$ W. Here, system performance analyzed based upon throughput of the system. Throughput of the system before management and after management using developed algorithm is shown in Fig. 11.

Out of 64 sub-carrier, 20 sub-carriers became null to reduce interference level below threshold. After the management again power allocation done and throughput is calculated. In Fig. 11, if we compare result with previous algorithm

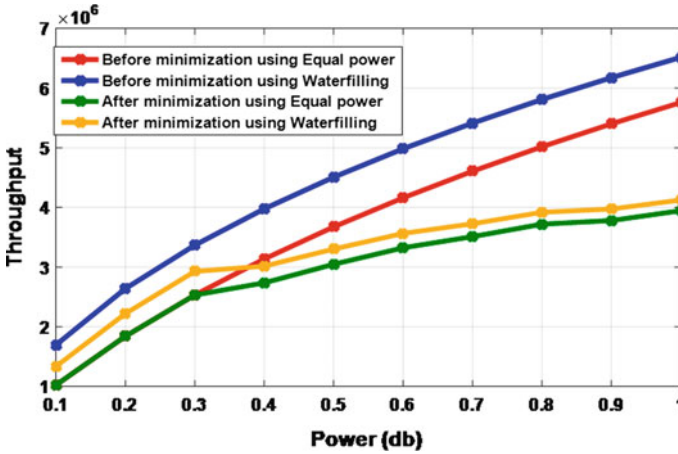


Fig. 12 Throughput versus power performance for multi-user MC-CDMA

here throughput is (shown in yellow) increased. It proves that the new mechanism is inferior compare to conventional on-off method. For the multi-user NC-MC-CDMA, above algorithm is also verified. For the four user and 64 sub-carrier, each user having input power range 0.1–1 W. Interference threshold is assumed $5e-10$ W.

Figure 12 shows the result for throughput of four-user system, here also it is verified that throughput of system is increased compare to conventional on-off method.

7 Conclusion

From the system model and interference calculation, it is shown that SU side lobe creates interference in PU band. The aim of this paper is to enhance the performance of SU transmission such that SU creates interference below threshold to the PU band. Interference calculation is carried out for Secondary users to PU band over a range of input power. When SU's interference to the PU band is above threshold, different power allocation-based algorithms can be applied to manage this interference below threshold. On-off method-based algorithm is applied with uniform power allocation; it is observed that it minimizes interference but at the same time throughput is degraded. To combat this limitation, on-off algorithm is used with water-filling-based power allocation and throughput is improved. Results are verified for single user as well as multiple users.

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