Analysis of Spectrum Band Sharing Between CDMA

And Other Systems

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Abstract

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Many mobile satellite systems have been proposed to employ Code Division Multiple Access (CDMA) technique at L/S band. These bands have been allocated to the mobile satellite services on a primary basis since 1992, in addition to the existing services. Therefore, the mobile satellite services will be subject to share spectrum with each other and with existing services.

This paper discusses spectrum overlapping for two cases: i)- between a CDMA channel and narrow-band signal channel; ii)- between CDMA channels sharing the same band.
Analyses have been performed to increase the overall spectral efficiency in the frequency band, taking into account various factors such as the relative position of overlapping and the amount of overlapping. Positions of optimum overlapping for spectral efficiency are discussed. This spectrum sharing is referred to as a CDMA overlay, and has a potential to enhance both the spectral utilization and the flexibility of that utilization.

From the results, the best position of the multiple narrow band signals, to allow sharing spectrum with CDMA signal without loosing significant capacity for both of them, is at the edge of the CDMA channel. Further improvement can be achieved for CDMA system, especially when narrow band signals have more power compared to the CDMA system, by implementing a notch filter at the specific location of the narrow-band signal.
For CDMA/CDMA spectrum sharing, the overall spectral efficiency may be increased significantly by carefully choosing the overlapping position.

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I. **Introduction**

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Recently, there has been considerable interest in applying direct sequence spread spectrum (*SS*) techniques to multiple access communications. This is partly due to its multiple access capability, robustness against fading and anti-interference capability. Since direct sequence (*DS*) spread spectrum waveforms have a wide bandwidth, whenever the bandwidth exceeds the coherence bandwidth of the channel the fading tends to be frequency selective, and a rake Receiver can be used to enhance the system performance [1]-[4].

Anti-interference capability in a *DS-CDMA* system is achieved by correlating the received signal with the predetermined spreading sequence thus allowing the inherent processing gain of the system to attenuate the interference [5]-[6]. Furthermore, an interference suppression filter can be utilized to reject the narrowband interference [7].

The radio frequency spectrum is a very limited resource already heavily utilized by terrestrial radio and satellite network's system in the *VHF/UHF and L/S* bands. Recently, many mobile satellite systems have been proposed to employ Code Division Multiple Access (*CDMA*) technique at *L/S* band. Those bands have been allocated to mobile satellite services on a primary basis since 1992, in addition to existing services. With the expected wireless revolution in telecommunication the available spectrum should be used efficiently and flexibly. Methods of sharing the frequency resource, not only amongst the satellite networks but also the existing terrestrial users of the bands, are the key to the successful implementation of the communication systems. Accurate knowledge of the state of occupation of the frequencies is especially important to control the interference.

One significant advantage of spread spectrum *CDMA* technique is its potential ability to coexist with other *CDMA* systems and narrow-band systems to improve the spectral efficiency. *CDMA* systems are relatively tolerant to narrow-band interference due to their inherent processing gain; spectrum spreading minimizes

the effect of the interference from CDMA systems to narrow-band system.

The interference suppression inherent to *CDMA* is not available to the other access methods. *FDMA* and *TDMA* channels should be separate and non-overlapping; the C/I ratio requirements give strong channel isolation, to avoid co-channel and adjacent channel interference.

The capacity of a *CDMA* system is interference limited due to the internal code interference (interference from other users sharing the same channel) and external interference. This implies that spectrum overlapping will result in the loss of capacity for the *CDMA* system compared with a non-sharing system. The overlapping techniques make use of multi-carrier code division multiple access (MC-CDMA) waveforms. In such a design, multiple narrow-band CDMA waveforms, each at a distinct carrier frequency, are combined together to form a composite wide-band CDMA signal. Among the advantages of such an approach is the ability to achieve the same types of system performance that a conventional, single carrier, wide-band CDMA signal would provide. Regarding the overlay, MC-CDMA transmission can be especially attractive, since frequency slots occupied by the narrowband waveform can be avoided altogether by simply not transmitting at the corresponding carrier frequencies.

The spectrum overlapping can be classified as follows:

i)- Overlapping between *CDMA* channels.

ii)-Overlapping between *CDMA* channel and a narrow band signal sharing the same band.

Also, the overlapping between *CDMA* channels can be categorized as follows:

1-Overlapping between *CDMA* channels is made by changing the frequency separation between the *CDMA* channels without increasing the channel bandwidth.

2-Overlapping between *CDMA* channels is made by fixing frequency separation between the *CDMA* channels and increasing the channel bandwidth (i.e., each channel is widened to occupy a larger portion of the band).

A survey of the organization of this paper is as follows:

The following section introduces a survey of the principle of the DS-CDMA technique, and section *III* presents the analysis of system performance of overlapping between the CDMA systems. In section *IV*, we present the analysis of system performance of overlapping between the CDMA system and narrow band system, and numerical results are presents in section *V*. Finally, in section *VI* we present the conclusion.

II. An Overview of The DS-CDMA Techniques
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In this section basic principals of *DS-CDMA* are briefly reviewed. *DS-CDMA* signals are separate, neither in frequency, nor in time. Every mobile unit is assigned a unique code, which has good orthogonal properties. Each cell uses the whole frequency bandwidth all the time (i.e., the frequency reuse ratio is equal 1). The *DS-CDMA* transmitter spreads the original data stream using a given spreading code in the time domain.

Spreading is obtained by multiplying the transmitted signal with a *PN* sequence code. The signal bandwidth is spread by the processing gain (PG). The internal interference, from the other users occupying the same *CDMA* channel, is reduced by the PG and by the choice of orthogonal code. The capability of suppressing multi-user interference is determined by the cross-correlation characteristic of the spreading codes. Also, a frequency selective fading channel is characterized by the superposition of several signals with different delays in the time domain. Therefore, the capability of distinguishing one component from other components in the composite received signal is determined by the auto-correlation characteristic of the spreading codes. *DS-CDMA* is a potential candidate for the next generation of mobile communication, mainly due to its interference reduction capabilities, which directly translates into higher capacity. Proper utilization of voice activity, frequency reuse, sectorization, soft hand over and rake receiver capability of *CDMA* makes it attractive for cellular systems. However, imperfect power control may result in significant reductions in estimated capacity.

More details about the technique can be found in [1]-[8].

III. Analysis System Performance of Overlapping Between the DS-CDMA Systems
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We are interested in exploring the optimum overlapping technique between the adjacent *MC-CDMA* channels or overlapping between different *CDMA* systems sharing the same spectrum for minimum adjacent channel interference, which improves spectrum efficiency.

The channel overlapping technique is applicable only to *CDMA* because a certain amount of interference can be tolerated, since it can operate on much lower C/I values (channel isolation is not required)[9,10]. The spectrum of *CDMA* is determined by the chip pulses of the PN sequence and has a sinc-shape. The power spectrum of each channel is concentrated at the middle of the band, results in power coming from the "tails" of the spectrum of the adjacent overlapping channel is small for small amount of overlap. For an optimum choice of the permissible channel overlap, the net effect is a reduction in total interference with considerable improvement of spectrum efficiency and increase in the capacity of the system.

3.1- Analysis of Overlapping by Widened Channels Bandwidth

In this technique, the channel overlapping technique results in an increase in the bandwidth of each channel which increases the processing gain, these result in a decrease in interference, and hence, an increase in capacity.

The adjacent *CDMA* channels are overlapped in frequency. Although the adjacent channel overlap permits adjacent channel interference, the larger bandwidth realized for each channel increases the processing gain and hence reduces the interference.

We assume the power control is perfect and the coded pulses have rectangular shapes.

In the case of non-overlap, orthogonal code and single cell; carrier to interference ratio is given by [4]:

$$(C/I)_n = \frac{P_n / K_n}{(K_n - 1).P_n / K_n} \qquad (1\text{-}1)$$

Where C is the carrier power, I is the interference power.

K_n is the number of users sharing the channel and P_n is the total power of one CDMA channel. The E_b / N_o is equal to:

$$E_b / N_o = PG_n.(C/I)_n \qquad (1\text{-}2)$$

Where PG_n is the processing gain without overlapping. By using Eq.(1-1) and Eq.(1-2) the number of users is equal to;

$$K_n = 1 + \frac{PG_n}{(E_b / N_o)_{th}} \qquad (1\text{-}3)$$

Where $(E_b / N_o)_{th}$ is the threshold value of the detector.

We assume both $(E_b / N_o)_{th}$ and PG_n are set to 6.8dB and 127 respectively. The bandwidth of the channel before overlapping is BW_n and BW_o is the bandwidth of the channel after overlapping. The amount of interference coming from the adjacent channel after overlapping is denoted by $(I_o)_{ext}$.

The relation between the processing gain of the CDMA channel after and before overlap is given by:

$$(PG_o / PG_n) = (BW_o / BW_n) \qquad (1\text{-}4)$$

Where, PG_o is the processing gain after increasing the channel bandwidth.

The total interference has two components; one from the internal interference $(I_o)_{int}$ from users sharing the CDMA channel, and the other from adjacent channel and is given by:

$$I_T = (I_o)_{int} + (I_o)_{ext} \qquad (1\text{-}5)$$

$$(I_o)_{int} = P_o - \frac{P_o}{K_o} \qquad (1\text{-}6)$$

Where K_o is the number of users in the *CDMA* channel after overlap, P_o is the power of the *CDMA* channel after overlap.

The total power of the channel is the net of the power of the desired channel (P_o) and the adjacent channel interference $(I_o)_{ext}$ and is given by:

$$P_T = (I_o)_{ext} + P_o \qquad (1\text{-}7)$$

The carrier to interference ratio for the *CDMA* channel after overlap is given by:

$$(C/I)_o = \frac{P_o}{K_o.P_T - P_o} \qquad (1\text{-}8)$$

We assume the threshold level of E_b / N_o of the Detector is the same in both cases then,

$$(E_b / N_o)_{th} = PG_o.(C/I)_o \qquad (1\text{-}9)$$

Substituting $(C/I)_o$ from Eq.(1-8) into Eq.(1-9), we obtain:

$$(E_b / N_o)_{th} = PG_n.(BW_o / BW_n).\frac{P_o}{K_o.P_T - P_o} \quad (1\text{-}10)$$

The factor BW_{on} represents the ratio BW_o / BW_n, the capacity K_o can be obtained by simplifying Eq.(1-10), we obtain:

$$K_o = (1 + BW_{on}\frac{PG_n}{(E_b/N_o)_{th}})\frac{P_o}{P_T} \qquad (1\text{-}11)$$

The improvement of the overlapping system can be obtain by dividing the capacity of the system in case of overlapping with respect to the Capacity of the system of non-overlapping, and is obtained from Eq.(1-3) and Eq.(1-11):

$$K_{on} = \frac{K_o}{K_n} \qquad (1\text{-}12)$$

All the values of this equation are known except P_2 and P_T which are given by the integration of the curve of desired channel after increasing the bandwidth of the channel before and after filtering respectively and this is done by the simulation.

3.2- Analysis of Overlapping by Changing Channel Separation Between CDMA Channels

The spectral shaping of the signal is achieved by a root-raised cosine filter at the transmitter.

The effect of filtering will be evaluated by assuming raised cosine filter with different *roll-off* factors.

The frequency characteristic of raised cosine filter are given by [2]:

$$H_R(f)=\begin{cases} T_{cp} & |f|\le f_1 \\ X & f_1 \prec |f| \prec f_2 \\ 0 & |f| \ge f_2 \end{cases} \qquad (1\text{-}13)$$

Where

$$X = T_{cp}\cos^2\left(\frac{p}{2\boldsymbol{b}\,R_{cp}}\left(|f|-\frac{R_{cp}(1-\boldsymbol{b})}{2}\right)\right)$$

$\boldsymbol{b}$ = Roll-off factor.

$f_1 = (1-\boldsymbol{b})R_{cp}/2$

$f_2 = (1+\boldsymbol{b})R_{cp}/2$

R_{cp} is the chip rate

3.3- A Simplified Model for the Block Diagram of CDMA System

The simulation block diagram of a CDMA system is shown in Fig. (1).

Assuming, the two *CDMA* systems are identical and have a perfect power control for both of them. Then the interference effect of *CDMA* system 2 to the other *CDMA* system 1 can be estimated as follows;

$$I_{sk} = \frac{Interference\ power\ of\ CDMA\ 2(I_{C2})}{Interference\ power\ of\ CDMA\ 1(I_{C1})} \qquad (1\text{-}14)$$

Where

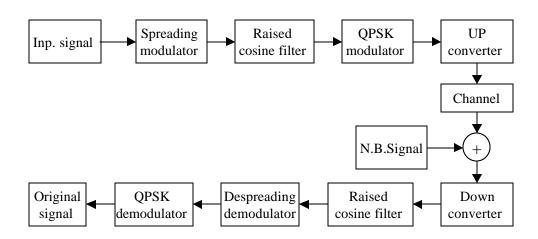$$I_{C2} = K.\int_{-W_s/2}^{W_s/2} P_{C1}.H_R^2(f-f_{sep})df \qquad (1\text{-}15)$$

Figure (1) Block diagram of CDMA system

$$I_{C1} = \int_{-W_s/2}^{W_s/2} P_{C1}.H_R^2(f)df \qquad (1\text{-}16)$$

$$I_{s1} = \frac{I_{sk}}{K} = \frac{\int_{-W_s/2}^{W_s/2} H_R^2(f-f_{sep})df}{\int_{-W_s/2}^{W_s/2} H_R^2(f)df} \qquad (1\text{-}17)$$

Where

I_{sk} is the loss of capacity due to overlapping

k is the number of users in CDMA channel

$W_s = R_{cp}(1+\boldsymbol{b})$

P_{c1} is the power of each CDMA user signal

f_{sep} is the frequency offset between carrier frequencies

I_{c1} is the internal code interference of a single *CDMA* signal.

The total frequency efficiency without any spectrum overlapping is given by:

$$eff_1 = \frac{Actual\ capacity\ of\ the\ channel}{Total\ frequency\ of\ the\ channel}$$

$$= \frac{2.K.R_b}{2.R_{cp}.(1+\boldsymbol{b})} \qquad (1\text{-}18)$$

With overlapping the total frequency efficiency is given by:

$$eff_2 = \frac{2.K.(1-I_{sk}).R_b}{f_{sep} + R_{cp}.(1+b)}$$ (1-19)

Where

R_b is the bit rate

Then the improvement in the spectral efficiency is given by:

$$eff_{12} = \frac{eff_2 - eff_1}{eff_1}$$ (1-20)

The overlapping of *CDMA/CDMA* system can achieve an improvement in the spectral efficiency and the amount of the spectral efficiency can be evaluated.

IV. Analysis of Sharing Between DS-CDMA and Narrowband Signal

One of the most attractive features of direct sequence code division multiple access (*DS-CDMA*) system is the ability to overlay the spread spectrum waveforms on the top of narrowband signal of communication systems. *DS-CDMA* signals, spread over a sufficiently wide bandwidth, have a very low power spectral density, so the additional degradation to the narrowband systems can be made small. Furthermore, to eliminate the interference from the *DS-SS* signals to a narrowband user, one can just stop transmitting at this frequency, which occupies the same spectrum as the narrowband user; in this case there is no interference from the *CDMA* to the existing narrowband system [11-13]. On the other hand, the *DS-CDMA* is inherently resistant to narrowband interference, because the despreading operation has the effect of spreading the narrowband interference over the wide bandwidth. However, the narrowband interference signal should be rejected before despreading especially when the power of interference is sufficiently large when compared with the power of the *DS-CDMA*.

From Figure (1), the narrowband signal experiences an attenuation by the square-root raised-cosine filter before despreading, the level of attenuation depends on the frequency offset from the center frequency of the *CDMA* and the bandwidth of the narrowband signal with respect the bandwidth of the *CDMA* signal.

Assuming the effect of the filter within the bandwidth of the narrowband signal is very small, the interference produced by the narrowband signal after despreading is given as follows;

$$I_N = \int_{-W_s/2}^{W_s/2} P_{Tn} . H_R^2 (f - f_{sep})df$$ (1-21)

Where

$$P_{Tn} = P_T . H_R (f_{sep})$$ (1-22)

The interference produced by the *CDMA* signal from other users after despreading is given as follows;

$$I_C = K . \int_{-W_s/2}^{W_s/2} P_C . H_R^2(f)df$$ (1-23)

The amount of interference accumulation of multiple narrowband signals sharing the bandwidth with respect to single *CDMA* signal is given by;

$$I_{TC} = \frac{\sum_{n=1}^{M} Interference\ power\ of\ NBS\ (I_{NBS}(n))}{Interference\ power\ of\ CDMA1\ (I_{c1})}$$ (1-24)

Where

$$I_{NBS}(n) = k . \int_{-W_s/2}^{W_s/2} P_T(n) . H_R^2(f - f_{sep}(n))df$$ (1-25)

Where

$I_{NBS}(n)$ is the nth narrowband interference

On the other side, the effect of the interference from CDMA system sharing the frequency band with narrowband signal will depend on the frequency separation between of them. The smaller the frequency separation, the larger the amount of interference signal from CDMA to narrowband signal.

It is very important to evaluate the bit error rate (*BER*) performance, in order to investigate the frequency-sharing problem of narrow band signal and *DS-CDMA* systems.

Bit Error Rate of Sharing System

The received signal at the receiver is multiplied by the *PN*-Sequence, then the narrowband interference signal is spread out and its power spectral density is reduced, the total average interference power is determined by the value of processing gain and interference power. In narrowband signals assuming an *AWGN* channel,

the *BER* of *CDMA* without *QPSK* modulations are used is given by [14]:

$$P_e = \frac{1}{2} erfc\left(\sqrt{\frac{E_b}{N_o + \frac{2}{3}.V.E_b.\frac{k-1}{PG}}}\right) \quad (1\text{-}26)$$

In the frequency sharing system, the *BER* of *DS-CDMA* with narrowband signals is given by;

$$P_e = \frac{1}{2} erfc\left(\sqrt{\frac{E_b}{N_o + \frac{2}{3}.V.E_b.\frac{k-1}{PG} + \frac{P_T}{P_c.PG}}}\right) \quad (1\text{-}27)$$

Where

P_T is the power of the narrowband interference signal.

PG is the processing gain

V is the voice activity factor

It can be observed from Eq.(1-27), that the performance of *CDMA* signal depends on the power of the narrow band interference and the bandwidth ratio of CDMA to narrow band signal. When the narrow band signal level is comparable to the CDMA signal. An active narrow band interference rejection technique can be employed at the CDMA receivers at the locations of the narrow-band waveforms would minimize interference to the CDMA network.

The *BER* of *DS-CDMA* with narrowband signals by using a notch filter is given by:

$$P_e = \frac{1}{2} erfc\left(\sqrt{\frac{E_b(1-e)}{N_o + \frac{2}{3}.V.E_b.\frac{k-1}{PG}}}\right) \quad (1\text{-}28)$$

Where e is the bandwidth ratio of the notch filter to *CDMA* signal.

It is observed that the rejection of the narrow band signals can significantly improve the bit error rate performance of the *CDMA* system and the total capacity of co-existence. However, the improvement of the performance of the *DS-CDMA* can result in some spectral distortion due to the notch filter, which destroys the auto-correlation and cross-correlation characteristic of spreading code of the signal passing through it.

The degree of destruction depends on the bandwidth of the notch filter and the performance of the band sharing depends on the ratio of the bandwidth of the notch filter to the bandwidth of the *DS-CDMA* signal.

In the frequency sharing system, the *BER* of narrowband signal with *DS-CDMA* signals is given by:

$$P_e = \frac{1}{2} erfc\left(\sqrt{\frac{1}{\frac{N_o}{E_b} + \frac{P_C}{P_T.PG}}}\right) \quad (1\text{-}29)$$

V. Results
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It is obviously from Fig. (2) that, the relative capacity increases when BW_{on} also increases. The capacity improvement reduces with increasing BW_{on} after the optimum value. The reason is that the amount of the reduction in the interference caused by the larger processing gain, due to increasing CDMA channel bandwidth, is less than the adjacent channel interference due to overlapping. For N=4 the optimum value of the capacity improvement (K_{on}) is 1.21 at BW_{on} =1.37 and the optimum value of the capacity improvement (K_{on}) is 1.18 at BW_{on} =1.33 for N=5. It is clear for N=5, where N is the order of the filter, the optimum value of the capacity improvement reduces because the slope of the roll-off factor filter increases and becomes more flat.

Fig.(3) shows that the optimum overlapping techniques depends on the roll-off factor of the raised cosine filter. For roll-off factor (b =1), the maximum efficiency improvements are 13.4%, at optimum overlapping between the adjacent *CDMA* channels (f_{sep}/W_s =0.71).

For b=0.8, maximum efficiency improvement is 11.8% at optimum overlapping (f_{sep}/W_s= 0.74). As b decreases the maximum efficiency improvement reduces.

There is no capacity improvement for all values of the roll-off factor of the raised cosine filter for (f_{sep}/W_s <0.48), because the amount of interference from the adjacent channel is

significant with respect to efficiency improvement.

From Fig. (4)**,** the overlapping between the adjacent *CDMA* channels causes a loss of the capacity of the *CDMA* channel, and the amount of loss depends on the roll-off factor of raised cosine filter, which reduces with increasing the roll-off factor at (f_{sep}/W_s >0.5). The loss of capacity is approximately the same for different roll-off factors at the optimum overlapping of each case and, equals 0.04.

Fig. (5), it can be seen that a greater number of narrow band signal channels may be achieved with greater roll-off factor of the raised-cosine filter with insignificant effect on the *CDMA* system, especially when the narrow band signal channels share the edge part of the *CDMA* spectrum. For instance, when the ratio between the bandwidth of *CDMA* signal to narrow band signal ($W_s/BW1$)=50; the internal code interference from single *CDMA* signal equals the effect of 13 narrow band signal users sharing the edge part of *CDMA* channel at $\boldsymbol{b}$ =1.0 and the number of narrow band signal users sharing the edge parts of *CDMA* channel reduce with decreasing the *roll-off* factor ($\boldsymbol{b}$=0.2) and the number of narrow band users equals 6.
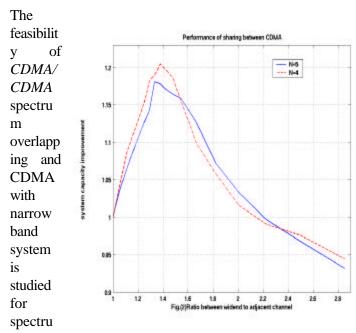
Also, It can be observed that the interference of *CDMA* to narrow band signal depends on the value of energy, which lies in the narrow band signal, and this value is significantly dependent of the frequency offset.

It can be observed from Figs. (6,7), that the performance of *CDMA* signal depends on the power ratio of the narrow band interference to the CDMA signal, and the bandwidth ratio of CDMA signal to the narrowband signal. For instance, when the power ratio equals -5dB the effect of narrow band signal on the performance of *CDMA* signal is more significant than power ratio equals 0dB. Furthermore, when the bandwidth ratio equals 4 the effect of narrow band signal on the performance of *CDMA* signal is more significant than bandwidth ratio equals 64 or 32.

From Fig. (8), when we employed a notch filter at the receiver. It is clear, that the rejection of the narrow band signals can be significantly improved the bit error rate performance of the *CDMA* system and the total capacity of co-

existence. As the power ratio of the total *DS-CDMA* to narrow band signal increases the *BER* of narrow band signal degrades, but when the power of narrow band signal is large enough compared to *DS-CDMA* signal, we can ignore the effect of *DS-CDMA* signal on the *BER* of narrow band signal.

VI. Conclusion

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The feasibility of *CDMA/CDMA* spectrum overlapping and CDMA with narrow band system is studied for spectrum sharing in the communication systems. The results show the feasibility of improving channel capacity and efficiency of the spectrum by the overlapping techniques.

Fig.(2)Ratio between widerd to adjacent channel

For the case of widened channel bandwidth of the CDMA channel, the overlapping is tested under different degrees of channel overlap and different order of the filters. The best result shows that at the optimum degree of channel overlap; channel capacity increases up to 21%.

For the case of fixed channel bandwidth, the optimum overlapping between *CDMA* systems depends on the filtering *Roll-off* factor and can be achieved an improvement of the spectrum efficiency up to 13.4%.
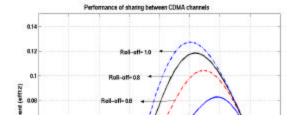
It can be observed that the number of narrowband signal users sharing with CDMA channel depends on the ratio between the bandwidth of *CDMA* signal to narrowband signal, and the offset of narrow band signal from the center frequency of *CDMA* channel. The
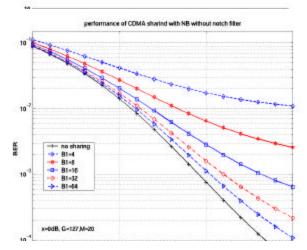
best location of narrowband signal to share spectrum with *CDMA* system is at the edge of the *CDMA* channel, where interference with each other is minimized. Also we can see that the frequency sharing system without notch filtering is interference limited and the *BER* of narrowband signal performance improves as its power increases, while the *BER* performance of the *DS-CDMA* signal degrades. Further improvement is possible in the frequency sharing system with notch filtering, especially when the power of narrowband signal is comparatively large with respect to the *CDMA* signal. The *BER* performance of *DS-CDMA* signal is significantly improved by rejecting Narrowband signals.
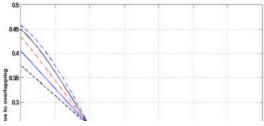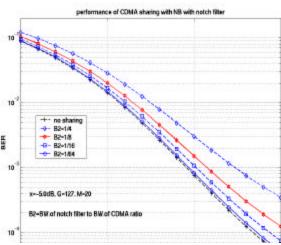
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Performance of sharing between CDMA channels

performance of CDMA sharing with NB without notch filter

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