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# Performance Evaluation of Hybrid - Multicarrier Access Schemes for Broadband Wireless Communication

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**Abstract:** The realization of wireless communication providing high speed, high capacity and high quality information exchange between two portable terminals that might be located anywhere in the world is still the communication challenge. For the development of future wireless communication systems, an extremely spectrum-efficient transmission technology is required. In this study authors propose a novel signal scheme called Hybrid CDMA-SFH which combines OFDM with CDMA and SFH to generate a system functionally superior to MC-CDMA systems. This study explores various merits and demerits of the proposed system and compares it to the other multicarrier access schemes. The CDMA component provides the inherent advantage of DS-CDMA systems incorporating a spreading signal based on PN code sequence, by providing user discrimination based on coding at the same carrier frequency and simultaneously. The OFDM component provides resistance to multipath effects making it unnecessary to use RAKE receivers for CDMA and thus avoid hardware complexity. The SFH component provides resistance to the "near-far" problem inherent in CDMA. Therefore, this system retains the greatest advantage of CDMA viz., multiple accesses without the disadvantages of "near-far" problems and complexity of RAKE receivers. Hence authors should look for OFDM because of its robustness to multipath and sophistication of synchronisation and because of the possibility of using coherent signal processing in spite of frequency hopping and at the same time the multiuser capability of CDMA systems. This is the novelty of our proposal. The simulated results elucidate that a significant amelioration in terms of utilities specifically spectral efficiency for all users can be achieved using this approach. Also the propounded scheme exhibits better performance in the Hybrid CDMA-SFH in terms of spectral efficiency as compared to the traditional system.

**Key words:** CDMA, Hybrid CDMA-SFH, MIMO-CDMA, RAKE

## INTRODUCTION

Multi-carrier system has been fuelled by large demand on frequency allocation, resulting in a crowded spectrum as well as large number of users requiring simultaneous access. Existing wireless systems may be utilized single frequency, single antenna and pulse for carrier transmission and reception. Problems of such system is that in case of failure the total system will become non operational. A distributed system in terms of multi-carrier, multi-antenna and coded pulse can provide a more suitable communication and sensor gives rise to multicarrier based hybrid CDMA-SFH technology is the ultimate solution.Recently, communication systems employing multiple antennas (MIMO technology) at the physical layer and code division multiple access (CDMA) as a multiple access technique at the MAC layer, which are known as MIMO-CDMA/MC-CDMA systems, has received remarkable research interest. In fact, the combination of the capacity enhancements arising from the utilization of spatial multiplexing in MIMO with the robustness of spread spectrum and Slow Frequency Hopped (SFH) communications is considered as a promising candidate for next generation wireless systems. CDMA protocols do not achieve their multiple access property by a division of the transmissions of different users in either time or frequency and it is already getting too crowded in these domains, but instead makes a division by assigning each user a different code. This code is used to transform a user's signal to a wideband signal (spread spectrum signal). If a receiver receives multiple wideband signals, it will use the code assigned to a particular user to transform the wideband signal received from that user back to the original signal. All other code words will appear as noise due to decorrelation. However, CDMA systems suffer from the "near-far" problem (Prasad, 1996). Therefore, an elaborate power control scheme is provided by each base

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Table 1: Types of multicarrier access schemes

| Types | Advantages | Disadvantages |
|---|---|---|
| OFDM | • Saving of large bandwidth, Spectral efficiency, Mitigation of ISI.<br>• Can be adapted to different transmission environments and available resources.<br>• Robust against multipath effects and narrowband interference.<br>• Capable of single frequency operation. | • Sensitive to frequency offset and phase noise.<br>• Synchronization problems.<br>• Large peak-to-average power ratios. |
| MIMO | • Increased coverage, capacity, data rate spectral efficiency and Reduced power consumption.<br>• Solve toughest problems facing any wireless technology today: speed and range.<br>• it does not increase bandwidth | • Cannot achieve zero ISI and hence cannot be utilized alone.<br>• Dependent on antenna configuration and scattering environment.<br>• Receiver complexity increase with increasing number of transmit antennas or /and transmission rate.<br>• Co-channel interference (CCI) which can also significantly decrease the capacity of wireless and personal communications systems. |
| MIMO-OFDM | • Improve the quality (BER) or potential of achieving extraordinary data rates by transferring the signals in time domain and space domain separately.<br>• Higher spectral efficiency without increasing the total transmission power or bandwidth of the communication system.<br>• Improved link reliability, beam forming, and adequate signal processing techniques at both ends of the system by using interference cancellation techniques.<br>• Avoids inter-symbol-interference and Co -Channel Interference (CCI).<br>• reduced equalizer complexity and improve frequency diversity due to delay spread.<br>• Simplifies the implementation of MIMO without loss of capacity. | • channel parameter estimation problem.<br>• less robust against jamming Effects<br>• Problems due to ''near far'' effect. |
| DS-CDMA | • Can address multiple users simultaneously and at same frequency.<br>• Resistivity to fading/multipath effect (quality) Interference, and Anti-jamming Effects. | • Complex Time Domain RAKE receivers.<br>• Synchronization within fraction of chip time becomes difficult. |
| SFH-CDMA | • Reduces ''near-far'' effect.<br>• Synchronization within fraction of hop time is easier.<br>• No need for contiguous bandwidths. | • Coherent demodulation difficult because of phase relationship during hops |
| MC-CDMA | • Higher number of users as full bandwidth utilized unlike in DS-CDMA<br>• Effectively combines all the signal energy in frequency domain, unlike CDMA<br>• Double the processing gain of DS-CDMA | • Peak-to-average ratio problem.<br>• Synchronization problems.<br>• Overcrowding of the spectrum as each bit is spread across the available bandwidth based on Walsh coding.<br>• Complex Frequency Domain RAKE receivers. |
| OFDM-SFH | • Anti multipath capability<br>• Multiple access due to FH requires very wide bandwidths depending upon the number of users. | Peak to average ratio problem.<br>Synchronisation problems |

station by rapidly sampling the Radio Signal Strength Indicator (RSSI) levels of each mobile and then sending a power change command over the forward link. The second problem in CDMA systems is that the signals travel by different paths to the receiver. It is, therefore, preferred to use a RAKE receiver to utilise maximum ratio combining techniques to take advantage of all the multipath delays, in order to get a strong signal. These RAKE receivers are extremely complex. In order to combat the "near-far" problem, DS-CDMA was combined with SFH systems. This hybrid technique consists of a direct sequence modulated signal whose centre frequency is made to hop periodically in a pseudorandom fashion. This ensures that, even within the same cell, no two mobiles are operating at the same frequency. There was, however, an industrial demand for very high bit rates, irrespective of the type of access scheme used. This was fuelled by multimedia considerations requiring bit rates as high as 155 Mbps. This gave rise to OFDM systems. In such systems very high data rates are converted to very low parallel data rates using a series-to parallel converter. This ensures flat fading for all the sub-carriers i.e. a wideband signal becomes a packet of narrowband signals. This will automatically combat multipath effects removing the need for equalisers and RAKE receivers. A variant of this approach was earlier introduced as Multicarrier - CDMA or MC-CDMA. This proposal envisages interfacing a DS-CDMA system with a system of orthogonal coding (not OFDM) using only Walsh coding (Prasad, 1996; Hara and Prasad, 1997). We shall briefly examine the advantages and disadvantages of the prevailing systems before proceeding to examine the new proposal. It is pointed out that the advantages/ disadvantages listed are not comprehensive, but only those relevant to this study. It can be seen in Table 1, that each multiple access approach has its advantages and disadvantages. It is especially to be noted that MC-CDMA achieves the same result as OFDM, but in a more complex manner, because it does not depend upon IFFT for modulation. In view of the novelty of the idea, as

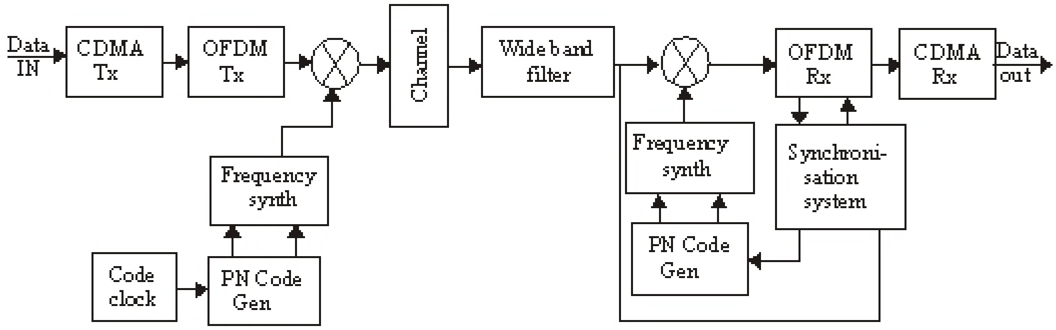


Fig. 1: Overall system schematic structure of hybrid CDMA-SFH system

compared to MC-CDMA, this system called Hybrid CDMA-SFH approach. This has essentially been developed for the 60 GHz frequency, but it is equally applicable at any other frequency if necessary bandwidth is available. This study proposes a comprehensive approach maximising the merits and minimising the demerits of the individual schemes.

## MATERIALS AND METHODS

**System model:** Recently the overall schematic structure of hybrid CDMA-SFH concept is fabricated at CEMK, W.B. The total system architecture is shown in Fig. 1.

The schematic is self-explanatory. However, there are a few salient points to be noted:

**Bandwidth and other considerations:** There is a multimedia requirement of high bit rates, typically 155 Mbps, which need wide bandwidths of around 100 MHz or higher. At 60 GHz, different channel conditions are not so severe because larger bandwidths are available. For the successful operation it is assume that there is no carrier offset for perfect OFDM synchronisation. The CDMA systems till now pertain to voice channels with a band spread factor of 128 for a data rate which is at the most 9600 bps. This is necessary due to the adverse transmission conditions and also due to the traffic at that frequency (around 850 MHz). Therefore, a band spread factor of 128 is unnecessary. More likely, a band spread factor of 10 or less will prove sufficient. This, however, has to be verified by extensive simulations. For the band spread factor of 10 the required bandwidth is set at1GHz for a 100 MHz data rate.In such a case the proposal shown in Fig. 2 is a better approach. In this case, band slots of subcarriers hoped within the bandwidth of the OFDM system (Mattias *et al.*, 1996; Jan-Jaap *et al.*, 1996). If the band spread factor is very less than 10,then this approach adopt the Fig. 3 for hop across multiples of the basic bandwidth. This approach is easier to implement. There is no need for such a design at such

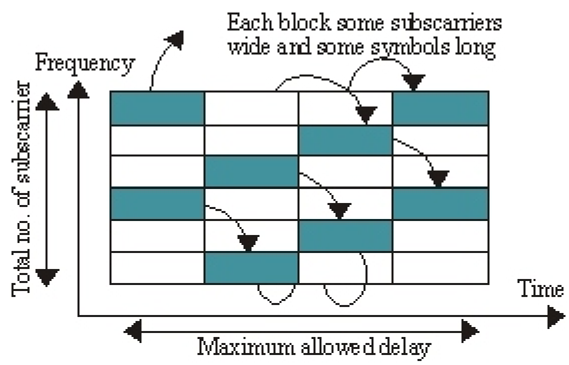


Fig. 2: Characteristics of the allocation design in a multi-user OFDM system

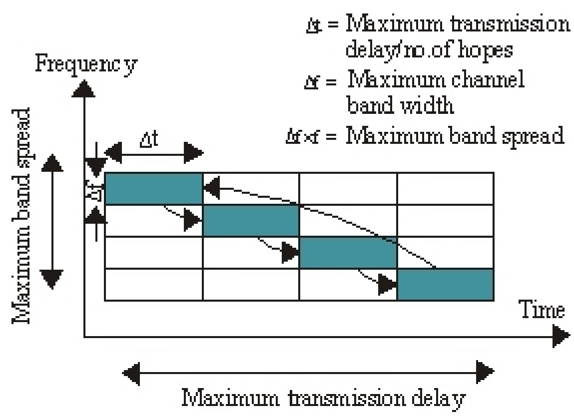


Fig. 3: Behaviour of the maximum band spread with maximum transmission delay when band spread factor is less than 10

frequencies. But we can expect a steep rise in the number of users when high data rates become realisable, especially in case of video-telephones. It is the CDMA aspect (code diversity) which really generate a lot of users. The frequency hopping has been introduced to obtain frequency diversity and also to reduce the "near-far" problem. This limits the number of users in order to avoid "collisions". The CDMA aspect makes up for this limitation by introducing a larger number of users due to code diversity. Interleaving and error correction coding may be dispensed with if the need so arises i.e. if the channel is not severe. In case, in the foreseeable future, the channel does pose problems, we can increase the spread factor of the CDMA transmission and/or introduce FEC and interleaving. The OFDM aspect is required, because it eliminates the need for RAKE receivers and allows us to use coherent modulation in spite of frequency hopping which makes coherent signal processing difficult. It also helps reduce the burden of synchronisation related to CDMA systems. In this connection, it is pointed out that MC-CDMA also uses OFDM techniques with RAKE receivers. But in this signal processing ,the development is based on without RAKE receivers. Hence, this method is named as Hybrid CDMA-SFH approach and not MC-CDMA.

**Error correction coding:** In the CDMA transmitter section, there are two levels of coding viz. Convolution encoding and Walsh encoding. The latter is an orthogonal coverage, since PN sequences by themselves are insufficient to ensure channel isolation. This orthogonal coverage should not be confused with the orthogonal sub-carrier in OFDM transmitter. The Walsh coding ensures orthogonality between users. The OFDM orthogonality ensures that the sub-carriers for each data frame are orthogonal. The convolution encoding ensures robustness of data as discussed above.

**Modulation:** Normally, in DS-CDMA systems, the matched filter in the receivers operates on the RF signal to achieve channel isolation based on the specific PN sequence for that channel. The signal is thereafter demodulated. In our case, the CDMA sequence after Walsh coding, does not get converted to RF via QPSK, DPSK or any other type of modulation, but instead is fed as an input to the OFDM transmitter. In the OFDM transmitter, it gets modulated as M-QAM or any other type of modulation.

**CDMA receiver:** In the CDMA receiver, the OFDM receiver gives it a sequence after M-QAM demodulation. Thereafter, in CDMA signal processing, there is a digital correlator which ensures channel isolation. The output of the correlator is then fed to a Viterbi decoder. The output from this decoder is the required data sequence. RAKE receivers are not required in this case at the matched filter level.

**Synchronisation:** Stringent synchronisation is still required as the PN sequences too need to be perfectly synchronised. However, in such cases, the burden of synchronisation is transferred to the OFDM system. The OFDM system has a more sophisticated synchronisation system (Jankiraman and Prasad, 1999; Magnus *et al.*, 1996) than the CDMA. As in this case, the OFDM system utilises the cyclic prefixes for synchronisation. Hence, the PN sequences emerging from the OFDM system and moving on to the CDMA system are synchronised more accurately than in case of a pure CDMA system. It is known that synchronisation is one of the limiting factors in CDMA systems for acquiring high data rates. It is expected that in our proposed system, such critical problems will be efectively reduced.

**Bit error probabilities:** The proposed system is basically an OFDM-FH system. This is because the transmission and reception is carried out by the OFDM-FH system. The CDMA system generates the data stream but in a more complicated manner. Hence, the same analysis applies to this system as for OFDM-FH systems, for determining bit error probabilities.

**Trade-off between OFDM and CDMA:** The OFDM-FH system by itself does not work for multimedia operations. This is because multimedia requires very high data rates, typically of the order of 155 Mbps. This requires large bandwidth of typically 100 MHz. By using FH among users, traffic reduces drastically, being limited by the bandwidth available. By adding CDMA in this situation further enhances the number of users since CDMA supports a large number of users working at the same frequency and bandwidth. Hopping is used to obtain frequency diversity with a view to reducing the "near-far" effect. Hence, there is a trade-off.

**CDMA signal processing:** It may argue that the present data rate of 1.2288 MHz in voice channels is inadequate for multimedia applications. However, in order to support a large number of users, use of CDMA technique is very vital. Hence, efforts must be made to increase data rates using better PLLs for synchronisation and high speed digital electronics. It is pointed out that in this proposal, the entire CDMA signal processing is carried out in the digital domain both for both transmitter and the receiver. Matched filtering is neither carried out at the RF level for the CDMA systems nor is there any operation of transmission or reception at the RF level for the same. This is a big advantage as signal processing is easier in the digital domain as compared to the other.

**Performance evaluation of Hybrid-Multicarrier Access Schemes:**

**Comparison of DSCDMA and DS- CDMA-SFH (DS-SFH) Systems:** It is assumed that there are K active users, each having a transmitter-receiver pair. Each user employs a channel Encoder. Let $b_k(t)$ denote the modulating sequence of the $K^{th}$ user, which randomly takes values from the Set {+1, -1} with equal probability. The coded bit duration is indicated by T and the transmitted power by $P_\tau$:

$$h_k(t) = \sum_{i=1}^{L} h_{ki}\,\delta(t - \tau_{ki})\exp(j\varnothing_{ki}) \quad (1)$$

For each path, the gain $h_{ki}$ is Rayleigh distributed, the delay $\tau_{ki}$ is uniformly distributed over (0, 2 ). The average power for each path and each user is $E[h^2_{ki}] = \sigma_0/2$. The receiver introduces AWGN n(t) with two sided power spectral density $N_0/2$.

**DS-CDMA:** The average SNR is given by the approximation (Evaggelos, 1985):

$$SNR = \gamma = \left[\left(\frac{2E_b}{N_0}\right)^{-1} + \frac{LK-1}{N} \times \frac{1}{3}\right]^{-\frac{1}{2}} \quad (2)$$

This is the SNR per bit. The constant 1/3 is due to the rectangular chip pulse. This equation is valid for binary Direct Sequence (DS) systems. In case of MRC with diversity of order M, given that the received signal is Rayleigh distributed, the bit error probability $P_b$ at the decoder input is given by (John, 1995).

$$P_b = \frac{1}{2^{(2M-1)}(M-1)!(1+\gamma)^M} \sum_{m=0}^{M-1} C_m (M-1+m)!\left(\frac{\gamma}{\gamma+1}\right)^m \quad (3)$$

Where,

$$C_m = \frac{1}{m!}\sum_{n=0}^{M-m-1}\binom{2M-1}{n} \quad (4)$$

At the output of the (n,k) block decoder, the probability of bit error is given by (John, 1995):

$$P_e = \sum_{j=t+1}^{n}\binom{n}{j} P_b^j (1-P_b)^{n-j} \quad (5)$$

where *t* denotes the error correction capability of the code.

**DS-CDMA-SFH:** The general derivation for this system is similar, except that the system uses Binary Frequency Shift Keying (BFSK) modulation followed by noncoherent demodulation, because, of the nature of slow frequency hopping. The considered system is asynchronous as this is the more realistic case. Even when synchronism can be achieved between individual user clocks, radio signals will not arrive synchronously to each user due to propagation delays. The probability of bit error for BFSK is given by (John, 1995):

$$P_b = \frac{1}{2^{(2M-1)}}\exp\left(-\frac{\gamma}{2}\right)\sum_{k=0}^{M-1} C_k \left(\frac{\gamma}{2}\right)^k \quad (6)$$

where,

$$C_k = \frac{1}{k!}\sum_{n=0}^{M-1-k}\binom{2M-1}{n} \quad (7)$$

However, if two users transmit simultaneously in the same frequency band, a collision or "hit" occurs. In this case, we assume the probability of error as 0.5. Hence, the overall probability of bit error for frequency hopped BFSK signal is:

$$P_b = P_b(1-P_{hit}) + \frac{1}{2}P_{hit} \quad (8)$$

where $P_{hit}$ is the probability of hit, if there are *q* possible hopping channels, there is a 1/q probability that a given interfering user will be present in the desired user's slot. Hence, for K-1 interfering users, the probability that at least one is present in the desired frequency slot is:

$$P_{hit} = 1 - \left\{1 - \frac{1}{q}\left(1 + \frac{1}{N_b}\right)\right\}^{k-1} \quad (9)$$

where $N_b$ is the number of bits/hop, for slow hopping it is equal to 1 hop/bit. At the output of the (n, k) block decoder; the probability of bit error is given by (John, 1995):

$$P = \sum_{j=t+1}^{n}\binom{n}{j} P_b^j (1-P_b)^{n-j} \quad (10)$$

Where, t denotes the error correction capability of the code.

## RESULTS AND DISCUSSION

This section provides the performance comparison of the DS-CDMA and DS-SFH systems taking diversity

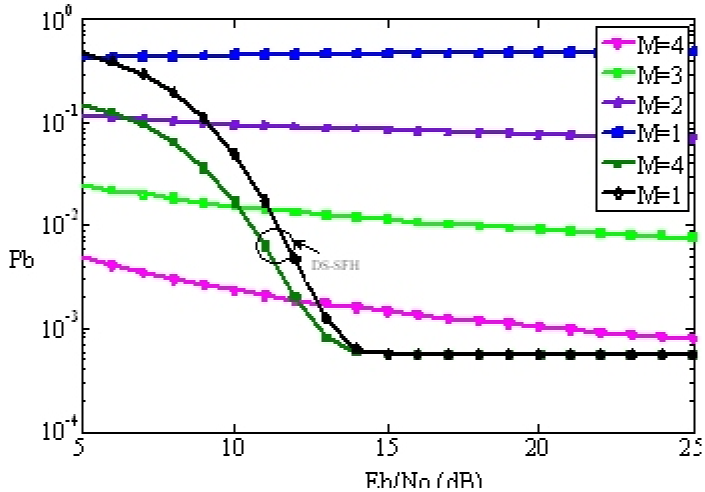


Fig. 4: DS-CDMA with BCH (15, 7) and DPSK and DS_SFH with BCH (15, 7) and BFSK

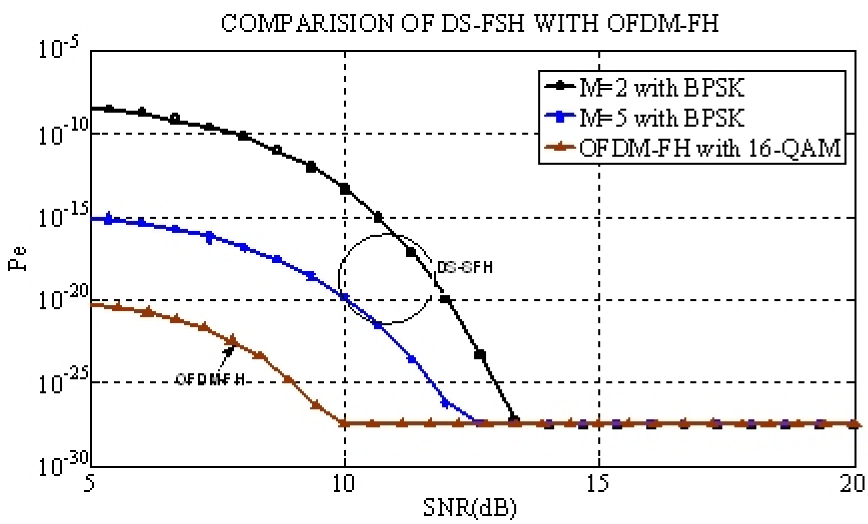


Fig. 5: DS-SFH with RS (32, 12) and OFDM with RS (32,12), 20% cyclic prefix and 10 users

values ranging from 1 to 4, which is depicted in Fig. 4. A very large number of frequency hopped channels for the DS-SFH system for q equals to1000 .In such a case, the limiting error will be due to other users. It can be seen that at high SNRs, the DS-SFH is superior. At a diversity of 4, the DS-CDMA performs well at SNRs below 10 dB. The asymptotic nature of the DS-SFH curve is due to multiple access interference as expected.

**OFDM-FH:** The probability of bit error for M- QAM is given by (Theodore, 1996):

$$P_b = 4\left(1 - \frac{1}{\sqrt{M}}\right)\frac{1}{2} erfc\left(\sqrt{\frac{E_b}{N_0}}\right) \tag{11}$$

In our case, M=16. We correct this, for probability of hit using (8) and then correct for error correction coding using (10).

Compares the superiority of DS-SFH which has already shown itself to be a superior system compared to DS-CDMA with OFDM - FH.From Fig. 5 it is seen that the OFDM system performs better due to the coherent nature of 16 QAM as compared to DS-SFH, operating with a diversity of 4. The OFDM can perform even better in presence of interference and frequency diversity caused due to interleaving and frequency hopping. This performance is compared taking Reed-Solomon (32, 12) code in both cases as compared to BCH (15, 7) in Fig. 4. For this case T is assumed to be 1000 with 10 users for both cases and also a cyclic prefix of 20% ($\eta_g$ = 0.8) for the OFDM system. For further reduction of the cyclic prefix the performance of the SNR improves, but

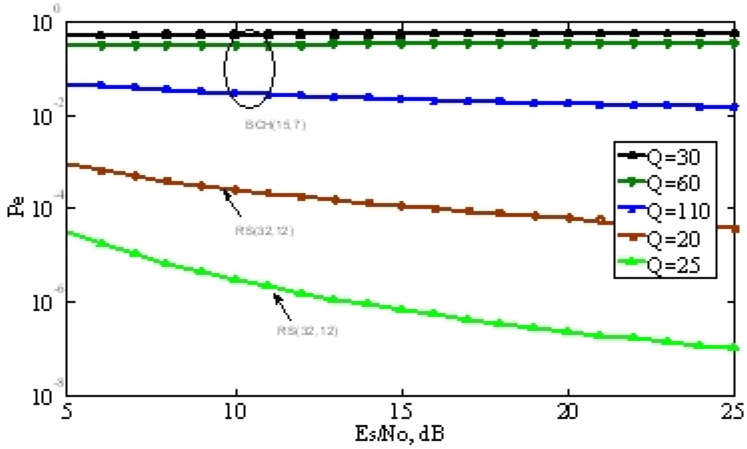


Fig. 6: Effect of coding and number of hops (Q) on OFDM –FH system and 10 users

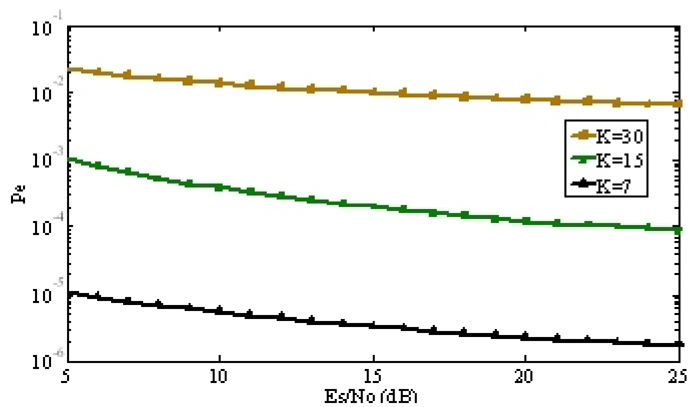


Fig. 7: OFDM-FH with RS (32, 12) and 20 hops

at the cost of poor synchronization (Jan-Jaap *et al.*, 1996; Jankiraman and Prasad, 1999). Hence, we can definitely conclude that OFDM - FH is a better choice. The bit error probability for the OFDM-FH system appears to be extremely low. The performance of OFDM-FH is explained using16 QAM as the coherent modulation technique and RS code. It is noted that the curve for bit error without RS coding and with 16 QAM, is inferior to the one with RS coding. The former is similar to the one derived by Proakis (John, 1995) for 16 QAM modulation. This result is due to the effect of Eq. (10) with RS coding. In reality, due to residual "near-far" effect, RS coding will help to improve the system performance, but the OFDM-FH result will not be so exceptional. Furthermore, in Fig. 5, both the curves tend to zero for SNRs in excess of 10 dB. This is, because, if we take a large $T$, Eq. (9) reduces to $P_{hit}$ = (K-1)/q. For large SNR, the $P_b$ (Eq. (6) and (8)) tends to ½×(K-1)/q. For large $q$ this value tends to zero i.e. multiple access interference limited. It now remains for us to identify as to what should be the typical value of q for such an OFDM -FH system, which is shown in Fig. 6. It is clear that Reed-Solomon coding performs better as compared to BCH coding. A q value of 20 hops appears to be an optimum value. This is, because, the chances of collisions and consequent errors appear to be less with a $T$ of 20. However, a larger spread of $T$ is preferred. Figure 7 indicates that for ideal case maximum number of user is 10. Users in excess of this number will cause collision and consequent poor bit error capability. However, this is where the advantage of our approach pays off. Then pass the burden of the additional users to the CDMA system. This means that OFDM-FH operates 10 users simultaneously, but in actuality there will be many more, being limited only by the capability of the respective CDMA systems.

## CONCLUSION

This researc discusses a novel concept of integrating CDMA with OFDM-FH with a view to reducing the main drawbacks of CDMA viz. "near-far" effect and complex RAKE receivers. This approach as given in this study, essentially applies to the downlink. It is, however, also applicable in the uplink provided synchronization problems are addressed in the OFDM systems. This is driven by a need to maintain orthogonality between mobile receivers. This is essentially an OFDM problem area and does not in any way restrict our suggested approach. This approach yields the greatest advantage of CDMA viz large number of users without the drawbacks of CDMA like power control, multipath effects etc. The suggested system makes this approach a promising solution for multimedia applications. It is recommended that efforts be made to increase the bit rates of CDMA systems for multimedia, but this proposed system is independent of data rate and can handle data rates as high as 155 Mbps due to OFDM. It is proposed to conduct further simulations using this approach, leading to a formal proposal for a fourth generation system for wideband multimedia communication.

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