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Capacity Improvement with DFC in QAM-CDMA

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Abstract: The use of Code Division for Multiple Access or CDMA is well established. We know that it has advantages in multipath environment and increase in capacity due to sectoring antenna and voice activity factor. Here a step by step comparison is made among Frequency Division Multiple Access, Time Division Multiple Access and Code Division Multiple Access when capacity or SNR is of main concern. A design of downlink and uplink CDMA along with Decision Feedback Cancellation Scheme and BCH coding is given to achieve lowest noise variance among competing CDMA design. To reduce channel outage due to excess Multiple Access Interference, a double six adjacent cells using two different frequencies in CDMA is proposed.

Keywords: CDMA, TDMA, FDMA, DFC, BCH Coding and capacity of Downlink and Uplink CDMA.

1.0 INTRODUCTION

The increasing demand for voice communications and Data Communication lead us to consider CDMA as the next generation mobile choice. Though the expected capacity increase by QUALCOMM CDMA (IS -95) is 15 to 20 time more than FDMA [1][2], we need to search for better demodulator for higher capacity. Qualcomm CDMA has many advantages such as automatic power control, universal channel reuse and soft hand off [3]. So the new technology should offer the same advantages and more [4].
The research done in last twenty five years have lead to better understanding of CDMA. Decorrelating detector [5], adaptive receiver [6], PIC and SIC detector [7] are the few linear detectors to name. The DFC detector [8][9] is very important as it offers lowest noise variance.

Here we discuss about a system of downlink and uplink synchronous CDMA with randomizer and BCH coding with DFC detector and find its SNR improvement for soft decoding and hard decoding. We also looked at the capacity improvement by sectoring antennas and using same frequency band in all the cells. This is possible by using PN code of long sequence like IS-95. Previously for Satellite communication it was established that CDMA capacity is same as TDMA or FDMA. But now we find that CDMA capacity is interference limited [1] and FDMA/TDMA are bandwidth and SNR limited. Here we make a comparison between CDMA and FDMA and show that noise variance is almost negligible if we use Decision Feedback Cancellation technique with adapted coefficients. So the recent finding is that in CDMA capacity is much more than previously predicted.

The next Section deals with single cell downlink system such as Satellite transmission and finds the capacity with DFC. Next we use adaptive detector and find it noise variance for full capacity for uplink when the code is shifted m sequence. The multiple cell scenario is checked next and the down link system design is done with BCH coding [10] and it performance is verified for hard decoding [11]. A new soft decoding technique is introduced next and performance is checked to nearly 7.78 db of gain for code length of 15 (BCH 15,7).

2.0 THE DOWNLINK SINGLE CELL QAM-CDMA CAPACITY

The network is downlink CDMA which is QAM-CDMA transmission or uplink QAM-CDMA/TDMA for single cell or multiple adjacent cells. In down link, signal is transmitted from base station to the mobile users and all the users have separate codes which is shifted m-sequence of length L (31 for example). There is a randomizer for each user bit and forward error correction code which Bose-Chaudhuri-Hocquenghem (BCH) code (15,7) for each user separately.

The channel capacity for a mobile system is defined as the maximum number of user that occupies a given frequency band. The capacity of CDMA is multiple access interference (MAI) limited. Let the number of user be N and the MAI is M, then the SNR from interference will be 1/(MN) provided the noise is low.

The received signal in single cell with twice capacity will be:

$$r = a\sum_{i=1}^{2L} b_i C_i + \text{Noise}$$

Where, a is the received signal strength, b_i and C_i are the transmitted bit and spreading sequence of i^{th} user. The demodulated signal with single stage DFC will be:

$$\hat{b}_1 = ab_1 - \frac{a}{L^2}\sum_{k\neq 1}^{2L}\sum_{i\neq k}^{2L} b_i C_i C_k{}^t C_k C_1^t + \frac{2NC_1^t}{L} - \frac{1}{L}\sum_{k=1}^{2L} NC_k^t C_k C_1^t$$

To compare we choose BPSK transmission which has SNR E_b/N_o. The Qualcomm CDMA in IS-95 has a SNR of $E_b/(N_o/32)$ if we use a Hadamard Code of length 32 for same number of users. Thus, the capacity is 32 times of FDMA or TDMA in single cell scenario. If we use shifted m-sequence of length 31 and single stage of DFC, we can reduce the noise variance to $N_o/(31^4/240)$. In general it will be $N_o/(L^4/8/(L-1))$, where L is length of chip sequence. Thus the capacity is enormous against noise and depends on interference which is statistically low. For shifted m-sequence, capacity is twice the normal capacity of IS-95 and we can transmit the signal at much lower signal power. We also can increase the bit rate and increase the capacity.

3.0 THE UPLINK CAPACITY IN SINGLE CELL SYSTEM

In the uplink we use CDMA/TDMA combination. Each user has all the capacity of SCDMA QAM transmission but for a small slot of time. We use power control of the mobile transmitter so that every user received power is same at base station. As the signal is TDMA there is no Near Far problem, except the pilot tone distribute the timing of each user every time a new user comes to the network. We use synchronizer bits for user synchronization. We also have bits to discern the multi-paths. To do that we send a signal intermittently, which is a PN sequence and in the mobile user we detect the multipath strengths using a correlator [12].

The relative fast variation of signal strength associated with Rayleigh Fading is of 20 dB of the range against a noise floor after demodulation is -43.6 dB down. So the signal can be easily recoverable.

4.0 MULTIPLE CELL DOWNLINK CAPACITY

Here we consider a case of six adjacent cell with a cell of interest. The received signal is given by if we consider two adjacent cells:

$$r = a_1\sum_{i=1}^{2L} b_i C_i + a_2\sum_{j=1}^{2L} b_j \bar{C}_j + \text{Noise}$$

Where the a1 and a2 are the received signal strengths from base station 1 and 2. We have to minimize multiple access interference keeping noise in DFC same as single cell case. Using a single DFC stage we get the user 1 of cell one as:

$$r = a_1 b_1 - \frac{a_1}{L^2}\sum_{k\neq 1}^{2L}\left(\sum_{i\neq k}^{2L} b_i C_i\right) C_k^t C_k C_1^t + \frac{a_2}{L}\sum_{j=1}^{2L} b_j \bar{C}_j\, C_1^t - \frac{a_2}{L^2}\sum_{k\neq 1}^{2L}\left(\sum_{j=1}^{2L} b_j \bar{C}_j\right) C_k^t C_k C_1^t + \frac{2NC_1^t}{L} - \frac{N}{L^2}\sum_{k=1}^{2L} C_k^t C_k C_1^t$$

For six adjacent cells, the third and fourth terms will six in number respectively. At the cell boundary a1=a2 and there are possibility of a1=a2=a3, but a4, a5 and a6 are negligible. From the equation MAI will be due to a2 and a3 which can be given by $\left(\frac{a2}{L}\sum_{j=1}^{2L} b_j \bar{C}_j\, C_1^t + \frac{a_3}{L}\sum_{j=1}^{2L} b_j \bar{\bar{C}}_j\, C_1^t\right)$ whch should be less than a1 approximately by factor of 2. So, a2 and a3 should less than a1/4. In case they are not, a different frequency is used. [4] explains how double six cells are arranged such that the effect of excessive MAI at cell edge can be solved. We can replace six adjacent cells by three sectoring antennas, where the under worst case, a2 and a3 will give the MAI, but that will same as before with a increase in capacity by 3. So the capacity will be 42 times of FDMA.

5.0 BCH DECODING AND PERFORMANCE EVALUATION

Normally, Qualcomm CDMA (IS-95) uses Convolutional code for forward error correcting of rate 1/3. We have found a way of decoding BCH code which is quick and also soft decoding is possible with a higher SNR for the receiver. The BCH code is given by (15,7). In [11] we have shown a syndrome decoding, where the syndrome is found by multiplying the received hard decoded (by sign at the output of a matched filter) signal by h(x). The bits between n and k+1 are used to decode it. The performance of the hard decoded BCH code is given by

$$\text{BER} = \sum_{j=dmin+1}^{n} \binom{n}{j} p^{j}(1-p)^{n-j}$$

Where, $p = Q(\sqrt{\frac{2RE_b}{N_o}})$ and R=k/n.

In the soft decoding, we receive the hard decoded signal (i(x)g(x)+noise) i(x)g(x) and its nearest other possible i(x)g(x). Let there be three such vectors we call them S1, S2 and S3. So the signal received is r=S + noise. We choose a pair at a time, and multiply r by (S1-S2) and add. So it will be either $S1*(S1-S2)^t$ or $S2*(S1-S2)^t$. The noise will be N*(S1-S2)'. So next S1 and S3 will be chosen and lastly S2 and S3 will be chosen to find the maximum distance. The SNR will be given by $N*(S1-S2)*(S1-S2)^t$. The signal will be $(S1*(S1-S2)^t)^2$.

The SNR achieved in the soft decoding is $10*\log10(31^4/40)+6$dB.

We consider a 10000 bps transmission. This is done by BPSK transmission. Now if we transmit Qualcomm CDMA with a chip rate 1/10000 per second, we get a bit rate 10000/32*32 users , so total 10000 bps. In our case we get total of 20000 bps. The SNR for BPSK $2E_b/N_o$, for Qualcomm CDMA it is $2E_b/(N_o/32)$ and in our case it is $2E_b/(N_o*240/31^4)$. With multiple cells, capacity increases to 21 times.

6.0 CONCLUSION

CDMA has become very popular over the past few decades not only in mobile and personal communications, but also in other applications like Satellite Communication, soft radio and ranging in radar application. In communications it frees operator from frequency planning, has anti jamming capacity and soft hand-off.

Here we analyze the user capacity of downlink and uplink in single cell or multi-cell QAM-CDMA transmission with shifted m sequence as spreading code. We find the capacity to be 42 times that of FDMA without considering the voice activity factor. Not only that we also reduce the noise level in demodulated signal to -40dB from noise floor for a chip length of 31 using decision feedback cancellation technique. So the signal transmission will take place at lower power. It has the capability to resolve multipath.

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