Analytical Results to Improve the Capacity of A Cellular System In Frequency Selective Rayleigh Fading Channel

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***Abstract* - One of the biggest draw back of wireless environment is the limited bandwidth. However, the users sharing this limited bandwidth have been increased considerably by using SDMA technique that can enhance the capacity of communication system. There are some techniques that can increase the capacity of the cellular system, these are- Spreading Technique, Error Control Coding Technique, Multipath Diversity Technique (i.e. Rake Receiver), Smart Antenna Technique. In this paper we have used all these technique and examined how the capacity of cellular system vary with varying the different parameters such as- the value of spreading factor, the number of Rake fingers, the number of interfering cells, value of directivity of Adaptive Antenna at base station. In the results we find that the capacity of a cellular system is varying with these parameters.**

***Index Terms* -- BER, Adaptive Antenna, DS-CDMA, Error Control Coding, Rake Receiver, Rayleigh Multipath channel, SDMA.**

INTRODUCTION

BER [1] is used to measure the end to end performance of wireless communication system which quantifies the reliability of communication system.

SDMA [2]-[5] with smart antennas at the base station can increase System capacity and support rate demanding services. Mobile communication systems are currently characterized by an ever-growing number of users, which however is Coupled with limited available resources, in particular in terms of usable frequency spectrum. The SDMA technique allows enhancing the capacity of a cellular system by exploiting spatial separation between users. In an SDMA system, the base station does not transmit the signal throughout the area of the cell, as in the case of conventional access techniques, but rather concentrates power in the direction of the desired mobile unit, and reduces power in the directions where other units are present. The same principle is applied for reception. The SDMA technique can be integrated with different multiple access techniques (FDMA, TDMA, CDMA).

A forward error correction (FEC) technique[6]-[9] known as convolutional coding with Viterbi decoding can improve the capacity of a channel by adding some carefully designed redundant information to the data being transmitted through the channel. The process of adding this redundant information is known as channel coding. Convolutional coding and block coding are the two major forms of channel coding. Convolutional codes operate on serial data, one or a few bits at a time.

Due to reflections from obstacles a radio channel can consist of many copies of originally transmitted signals having different amplitudes, phases, and delays. If the signal components arrive more than duration of one chip apart from each other, a Rake Receiver can be used to resolve and combine them. The Rake Receiver uses a multipath diversity principle. It is like a rake that rakes the energy from the multipath propagated signal components[10]-[15].

Section-1 gives the introduction of SDMA and Smart Antenna. The basic concept of Adaptive Antenna is given in section-2. Section-3 presents the Error Control Coding Technique. In section-4 we have given the basic concept of Rake receiver. In section-5 we have the Analytical Results. At the end the section-6 gives the conclusion.

1. INTRODUCTION OF SDMA

1.1 SDMA

In SDMA a number of users share the same available resources and are distinguished only in the spatial dimension. In traditional cellular systems the base station radiate the signal in all direction to cover the entire area of the cell, due to this we have both a waste of power and the transmission, in the directions where there are no mobile terminals to reach, of a signal which will be seen as interfering for co-channel cells, i.e.

those cells using the same group of radio channels. Analogously, in reception, the antenna picks up signals coming from all directions, including noise and interference. These considerations have lead to the development of the SDMA technique, which is based on deriving and exploiting information on the spatial position of mobile terminals. In particular, the radiation pattern of the base station, both in transmission and reception is adapted to each different user so as to obtain the highest gain in the direction of the mobile user. Thus SDMA is recognized as one of the most useful techniques for improving the capacity of cellular systems. This technique allows different users to be served on the same frequency channel at the same time thus improving the spectral efficiency.

1.2 Smart Antenna

A smart antenna is an antenna system that is able to direct the beam at each individual user, allowing the users to be separated in the spatial domain. It is not the antenna that is smart, but the antenna system. The impact of using smart antennas depend both on the level of intelligence of the antenna system and the type of mobile system in which it is deployed [4].

1.2.1 Levels of intelligence

Realizations of smart antennas can be divided into 3 levels of “intelligence”. These are:

- **Switched Lobe (SL)**

This is also called switched beam. It is the simplest technique, and comprises only a basic switching function between separate directive antennas or predefined beams of an array.

- **Phased Array (PA)**

By making the beamforming digitally, a continuously moveable beam is established, which is directed towards the strongest signal component. This is a generalization of the switched lobe concept and has an infinite number of possible beam directions. The optimizing criterion is to maximize the signal level.

- **Adaptive Array (AA)**

Similar to the phased array, the beamforming is done digitally, and a main lobe is generated in the direction of the strongest signal component. In addition side lobes are generated in the direction of multi path components and nulls in the direction of interferers. This technique will maximize the signal to interference and noise ratio (SINR).

1.2.2 Type of mobile system

In this paper we are using Universal Mobile Telecommunication System (UMTS) [15].

2. ADAPTIVE ANTENNA

Adaptive antenna provides a spot beam for each user and base station tracks each user in the cell as it moves. It can be seen that the probability of bit error is depend on the beam pattern of a receiver, and there is considerable improvement that is achieved using high gain adaptive antennas at the base station. In typical cellular installations, D ranges between 3dB to10 dB.

3. ERROR CONTROL CODING TECHNIQUE

3.1 Parameters of Convolutional coding

The output from the binary source could be applied directly to the modulator and transmitted as the channel wave form. Noise introduces the probability of error in the detected signal, this being given by bit error probability (BEP). One function of the channel encoder is to modify the binary stream in such a way that errors in the received signal can be detected and possibly corrected at the receiver without the need to request a retransmission of a message, it is referred to a forward error correction (FEC).

There are three parameters, which define the convolutional code. These are given as follows:

1. Code Rate (r)

Ratio of the number of input bits to the number of output bits is known as code rate. In this paper we use Code Rate $r = 1/2$, which means that there are two output bits for each input bit.

2. Constraint Length (C_L)

The number of shift required for a message bit to enter the shift register and finally come out. In this paper we use Constraint Length $C_L = 3$.

Constraint Length $C_L = m + 1$;

Where m is the number of shift register

3. Generator Polynomial

Generator Polynomial shows the wiring of the input sequence with the delay elements to form the output. In this thesis the Generator Polynomial is $[7,5]_8 = [111,101]_2$ e.g.The output from the $5_8 = 101_2$ arm use the X-or of the current input, previous input & the previous to previous input. The Block diagram of convolutional encoder is in Fig. 3

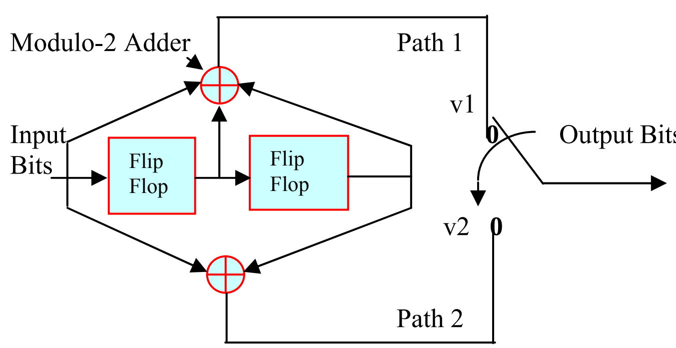

Fig. 1. Block Diagram of Convolutional Encoder

Hence the generator polynomial for path 1 is :

$$g^1(D) = 1 + D + D^2 \quad \text{.....(1)}$$

Here D denotes the unit delay variable.

The generator polynomial for path 2 is :

$$g^2(D) = 1 + D^2 \quad \text{.....(2)}$$

If message polynomial is $m(D)$, the output polynomial of path 1 is :

$$C^1(D) = g^1(D).m(D) \quad \text{.....(3)}$$

Similarly the output polynomial of path 2 is :

$$C^2(D) = g^2(D).m(D) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

3.2 Transfer function of convolutional code

Bit error rate performance with using convolutional coding and viterbi decoding can be defined by the Transfer function. To define the Transfer function we will define the state diagram of convolutional code.

3.2.1 State Diagram (Signal flow graph)

Since the output of the encoder is determined by the input and the current state of the encoder, a state diagram can be used to represent the encoding process. The state diagram is simply a graph of the possible states of the encoder and the possible transition from one state to another.

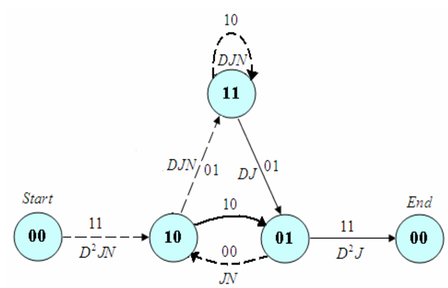

Fig. 2. State Diagram for convolutional encoder

Here doted lines indicate that the input bit is 1 and solid lines indicate that the input bit is 0.The corresponding output is given on the corresponding line.

Now the Transfer Function of a convolutional code is given as:

$$T(D;1;N) = \frac{D^5}{1-2DN} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

$$T(D;1;N) = D^5N + 2D^6N^2 + 4D^7N^3 + 8D^8N^4 + 16D^9N^5 + 32D^{10}N^6 + \ldots\ldots\ldots$$

Set $N = 1$ to get the distance transfer function, we get

$$T(D) = D^5 + 2D^6 + 4D^7 + 8D^8 + 16D^9 + 32D^{10} + \ldots\ldots\ldots \quad (6)$$

The exponent of D on a branch describes the hamming weight of encoder output corresponding to that branch. The exponent of J is always equal to 1, since the length of each branch is one. The exponent of N denotes the number of 1's in the information sequence for that path. (i.e, for input 0, exponent of N is 0 and for input 1, it is equal to1).

3.2.2 Free distance of a convolutional code

The performance of a convolutional code depends not only on the decoding algorithm used but also on the distance properties of the code. The most important signal measure of a convolutional code's ability to combat channel noise is the free distance denoted by d_{free}. The free distance of a convolutional code is defined as the minimum Hamming distance between any two code words in the code. A convolutional code with free distance d_{free} can correct t errors if and only if d_{free} is greater than $2t$ i.e. $2t < d_{free}$. The free distance can be obtained quite simply from the Transfer function of convolutional code.

From equation (6) we have the following conclusions:
There is one code sequence of weight 5. Therefore $d_{free} = 5$.

There are two code sequence of weight 6, There are four code sequence of weight 7,There are eight code sequence of weight8, ………………. etc.

3.3 Viterbi Decoding

The Viterbi decoding is the most general decoding for convolutional code. The Viterbi decoding is an efficient and recursive algorithm that performs the maximum likelihood (ML) decoding. A noisy channel causes bit errors at the receiver. The Viterbi decoder uses the redundancy, which is imposed by the convolutional encoder, to decode the bit stream and correct the errors. At first, we explain the various terms with respect to Viterbi decoding.

1. Trellis diagram

The trellis diagram is the diagram representing a transition of the state of shift registers in convolutional encoder by taking time axis to the horizontal axis.

2. Traceback depth

The traceback depth is the number of trellis states processed before the Viterbi decoder makes a decision on a bit.

3. Hard/soft decision

In hard decision, the receiver delivers a hard symbol equivalent to a binary ± 1 to the Viterbi decoder. In soft decision, the receiver delivers a soft symbol multileveled to represent the confidence in the bit being positive or negative to the Viterbi decoder.

3.4 Performance Using ViterbiDecoding

Bit error rate performance with using convolutional coding and viterbi decoding can be defined by the Transfer function.

Again:

$$T(D;J;N)\Big|_{J=1} = D^5N + 2D^6N^2 + 4D^7N^3 + 8D^8N^4 + 16D^9N^5 + 32D^{10}N^6 + \ldots\ldots\ldots$$

Now

$$\frac{d}{d_N}T(D;J;N)\Big|_{J=1} = D^5 + 4D^6N + 12D^7N^2 + 32D^8N^3 + 80D^9N^4 + \ldots..$$

$$\frac{d}{d_N}T(D;J;N)\Big|_{\substack{J=1\\N=1}} = D^5 + 4D^6N + 12D^7N^2 + 32D^8N^3 + 80D^9N^4 + \ldots..$$

Now the bit error rate is written as [9], [15] :

$$BER_c \le \frac{d}{d_N}T(D;J;N)\Big|_{J=1;N=1;D=2\sqrt{BEP_c(1-BEP_c)}} \quad \ldots\ldots\ldots(7)$$

4. RAKE RECEIVER

In asynchronous DS-CDMA [15]-[17] system for reverse link mobile to base station) that supports K active users the transmitting signals in DS-CDMA system given by [17]

$$S_k(t-\tau_k) = \sqrt{2P_k}\,b_k(t-\tau_k)a_k(t-\tau_k)Cos(\omega_c t + \theta_k) \quad \ldots(8)$$

Where $b_k(t)$ is binary data sequence, $a_k(t)$ is a pseudorandom sequence, P_k is the power of the transmitted signal, ω_c is the carrier angular frequency, τ_k is the time delay that accounts for the lack of synchronisation between the transmitters and θ_k is the phase angle of the k^th^ carrier. The k^th^ user's data signal is a sequence of unit amplitude rectangular pulse of duration Tb, taking values {-1,+1}.If Tc is the chip period and there are Nc chips per bit thus Nc = Tb / Tc is the spreading factor for user K. Let the desired user is K=0 and all other users contribute to MAI. If the channel $h_k(t)$ is multipath Rayleigh frequency selective fading channel. The delay difference between any two different paths is larger than the chip duration Tc. The complex low pass equivalent impulse response of the channel is given by

$$h_k(t) = \sum_{l_k=1}^{L_k} \alpha_{k,l_k} e^{j\phi_{k,l_k}} \delta(t - \tau_{k,l_k}) \quad \text{...............(9)}$$

Where ϕ_{k,l_k} is the phase of the multipath component, τ_{k,l_k} is the path delay, and L_k is the number of multipath components. α_{k,l_k} is magnitude of the l^{th} multipath with Rayleigh distribution. The received signal at the input of the receiver is given by

$$r(t) = \sum_{k=0}^{K-1} \sum_{l_k=1}^{L_k} \sqrt{2P_k}\alpha_{k,l_k} b_k(t - \tau_{k,l_k})$$
$$\times a_k(t) Cos(t - \tau_{k,l_k}) Cos(\omega_c t + \phi_{k,l_k}) + n(t) \quad \text{.......(10)}$$

Using Rake Receiver, with perfect (noiseless) estimates of the channel tap weights with Maximal Ratio Combiner in the system having M number of fingers, The Coded bit error probability(BEP_c) of Rake Receiver is given as [15]:

$$BEP_c = \left(\frac{1-\mu}{2}\right)^M \sum_{j=0}^{M-1} \binom{M-1+j}{j} \left(\frac{1+\mu}{2}\right)^j \quad \text{............(11)}$$

Where

$$\mu = \sqrt{\frac{1}{1 + \frac{N_0}{2rE_b} + \frac{2}{3D_a N_c}\left[\left(1 + \frac{M_c}{5}\right) LK - 1\right]}}$$

Where D_a is the directivity of base station antenna, r is the code rate, N_c is the spreading factor, M_c is the number of interfering cells, L is the number of multipath, K is the number of users.

5. RESULTS

5.1 . CAPACITY AS A FUNCTION OF NUMBER OF INTERFERING CELLS (Mc)-

In Fig.3, the number of multipath L =8, number of users K =3, spreading factor N_c =32, directivity of base station antenna D_a= 5dB, number of fingers M=3, number of interfering cells M_c =[1,4,6].Code rate r =1/2, Constraint length C_L =3. At BER value of 10^{-2} there are ≈7 users with 6 interfering cells, 9 users with 4 interfering cells and 13 users with 1 interfering cell. Thus the capacity of communication system with Rake Receiver will decreases with increasing the number of interfering cells.

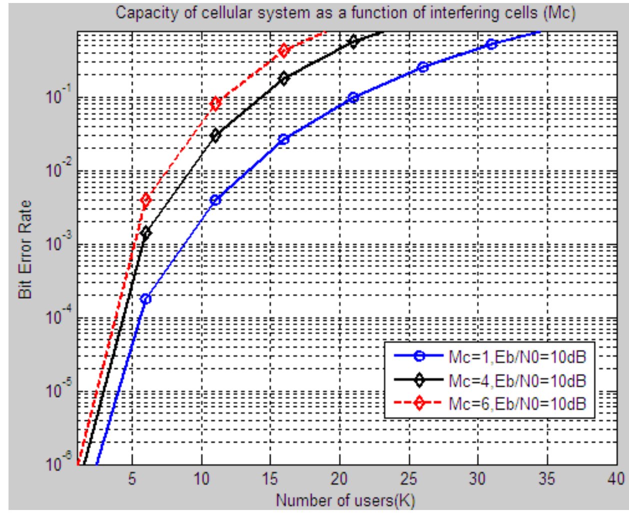

Fig.3. Capacity as a function of interfering cells (Mc)

5.2 . CAPACITY AS A FUNCTION OF SPREADING FACTOR (Nc) –

In fig.4, at BER value of 10^{-2} there are 9 users with N_c =32, ≈24 with N_c =64, 35 with N_c =128. Thus we see that the capacity of communication system is increased with increasing the value of Spreading Factor considerable.

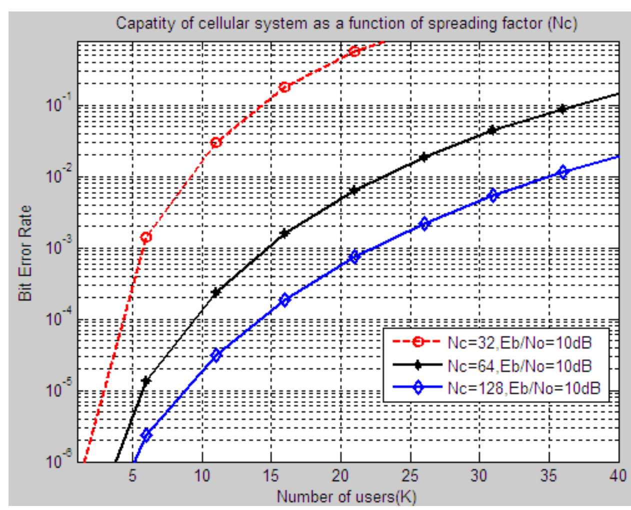

Fig.4. Capacity as a function of Spreading Factor (Nc)

5.3 . CAPACITY AS A FUNCTION OF RAKE FINGERS

In fig.5, at BER value of 10^{-2}, there are 6 users with using 2 Rake fingers, 9 users with 3 Rake fingers and 19 users with 5 Rake fingers. Thus capacity of communication system will increase with increasing the value of Rake finger.

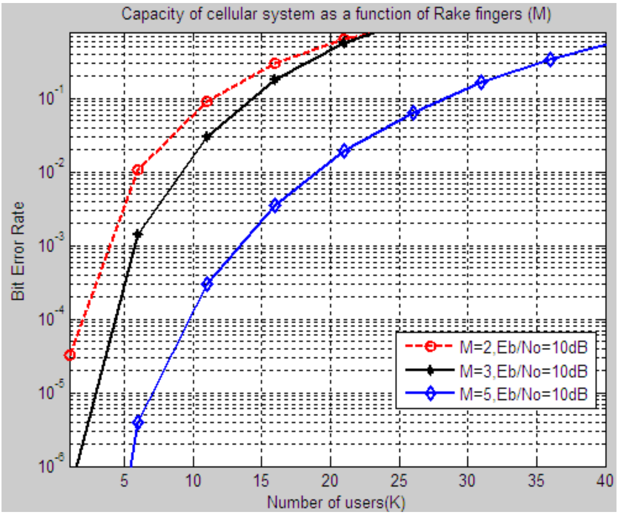

Fig.5. Capacity as a function of Rake Fingers (M)

5.4. CAPACITY AS A FUNCTION OF DIRECTIVITY OF BASE STATION ANTENNA (D_a) –

In fig.6, at BER value of 10^{-2} there are 7 users with directivity of base station antenna 4 dB, 11 users with directivity of base station antenna 6 dB and 17 users with directivity of base station antenna 8 dB. Thus the capacity of communication system with Rake receiver will increase with increasing the value of directivity of base station antenna.

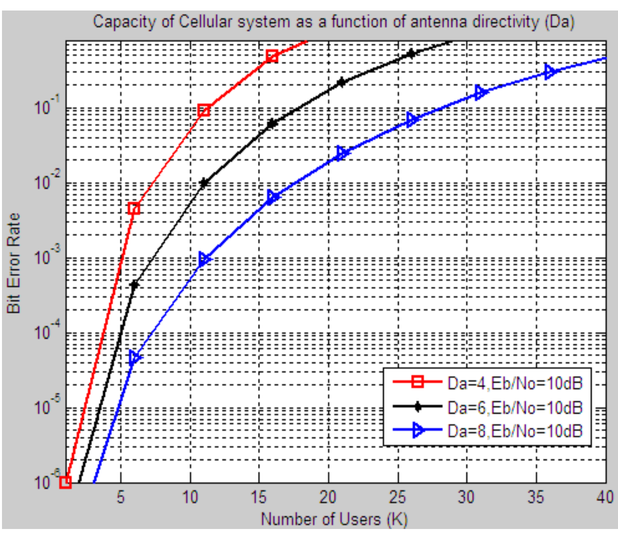

Fig.6. Capacity as a function of antenna directivity (D_a).

6. CONCLUSION

For the figures 3 capacity of cellular system will decrease by increasing the interfering cells (at BER 10^{-2} there are ≈7 users with 6 interfering cells and 13 users with 1). From Fig. 4, 5, 6, capacity of cellular system will increase by increasing, spreading factor (at BER 10^{-2} there are ≈9 users with N_c =32and 35 with N_c =128), Rake fingers (at BER 10^{-2} there are 6 users with M=2 and 19 users with M=5), directivity of antenna (at BER 10^{-2} there are 7 users with D_a =4dB and 17 users with D_a =8dB).

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