CHAPTER 3

SINR ESTIMATION FOR MC-CDMA SYSTEMS

3.1 INTRODUCTION

Multiple access is achieved through specific codes and the users are allowed to share the same bandwidth for their data transmission in all the CDMA based systems. The system is susceptible to multiple access interference (MAI) due to non-zero cross correlation among the user codes [120]. A tight and accurate closed loop power control scheme is essential to mitigate MAI. The reverse link channel information must be estimated at the base station to achieve perfect power control. The base station can either estimate the received signal strength or the SINR to obtain the reverse link channel information. Since MC-CDMA is an interference limited system SINR is more appropriate control parameter than the signal strength [64]. SINR is a true indicator of communication link quality for MC-CDMA systems [121-124] to implement effective power control. The accuracy of SINR estimation in a power control algorithm is significant in the sense it serves to enhance the system capacity with guaranteed QoS. Also, the time varying channel conditions in the mobile environment may degrade the system performance and can affect the capacity. A fast power control loop with a SINR estimator capable of predicting the channel conditions based on the fading statistics is essential [125] to compensate this problem [125, 126]. A SINR estimator suitable for MC-CDMA systems to satisfy the above requirement is proposed in this chapter. In the proposed approach the Kalman filter is utilized to predict the channel conditions according to the mobile speed.

3.2 SINR ESTIMATION

In SINR-based power control the transmitted power needs to be updated faster than the fading rate [25, 123]. Power control step size can be fixed, multilevel or
adaptive, according to the power update strategy. Actual step size is the quantization of the error which is the difference between the estimated and the threshold SINR ($\text{SINR}_d$). In the fixed step size the power control command (PCC) depends on the sign (positive or negative) of the error [22]. In the multilevel (variable) and adaptive step size power control algorithms [57] the PCC varies according the magnitude of error. Correct feedback information that enables to track the fading is vital in this procedure. The generated PCC bit may not be transmitted in the next immediate time slot on the forward link channel, as it depends on the synchronization between the forward and reverse link channels. Distance dependent propagation delay [124] may also exists that elapses to extract the PCC bit from the base station to the mobile, besides a negligible processing time at the mobile to gather the PCC bit from the received data-stream.

A good SINR estimator is one that is unbiased (or has a very small bias) and exhibits a negligible variance. In practice, however, the complexity of the estimator often becomes an important issue since good estimators, in general, require more complex operations. The basic challenge of the SINR estimation [126] is to find an efficient way to separate the signal component from the interference component. There are two categories of SINR estimators namely those requiring the knowledge of data bearing information (data aided estimators) and those solely relying on the observation of the received signals (non-data aided estimators). The data-aided estimators can either use the known transmitted data, such as training or pilot symbols if they are available, or use an estimate of the transmitted data from the receiver decisions. The non-data aided estimators do not require any training or pilot symbol. Various filtering algorithms are used to extract useful information from electromagnetic signals. Steele’s algorithm [65] uses the conventional FIR filters which can be implemented easily through signal processing techniques. The Kalman filter algorithm utilizes the Kalman filter which requires to solve complicated state equations. Kalman filter is preferred over other filters as this is the one which minimizes the variance of the estimation error, with high accuracy and speed of convergence. This recursive filter utilizes the past and present values of the received SINR to estimate the predicted SINR [127]. Kalman filter is used to predict the channel variations and adjust its coefficients according to the mobile speed. It is also
able to track the time varying channel conditions even at higher speed of the mobile users.

The fading coefficients of the filter, $f(n)$, are computed and are used to find the desired signal power. The average value of the total signal power is obtained at the input of the receiver. From these values the interference power is separated out to estimate the value of SINR.

### 3.3 ESTIMATION ALGORITHM

Reverse link transmission in MC-CDMA systems is considered to study the proposed algorithm, with transmitted base band signal, from $i^{th}$ mobile station (MS) to the $b^{th}$ base station (BS) assigned as $s_{ib}(n)$. As this signal is transmitted to its BS over a wideband radio channel whose impulse response is $h_{ib}(n)$, the received signal, $r_{ib}(n)$, at the $b^{th}$ BS is

\[ r_{ib}(n) = s_{ib}(n) * h_{ib}(n) \]  

(3.1)

While considering the desired communication between the $0^{th}$ MS and the $0^{th}$ BS, the received desired signal component from the $0^{th}$ MS is,

\[ r_{00}(n) = s_i(n) + js_Q(n) + I_i(n) + jI_Q(n) \]  

(3.2)

where $s_i(n)$ is the in-phase component of the desired signal
$s_Q(n)$ is the quadrature-phase component of the desired signal
$I_i(n)$ is the in-phase component of the interference and
$I_Q(n)$ is the quadrature-phase component of the interference

The intracell interference, which is the interference due to the signals received from the other $(M-1)$ mobile users in the $0^{th}$ BS is found by summing all such $r_{0i}(n)$ from $i=1$ to $M-1$ received signals. The interference from neighbouring cells, called intercellular interference, is found by summing the interference from $M$ users in each interfering cell. The total interference and noise, which is the summation of all the interferences and the receiver noise, tends to be Gaussian distributed according to the central limit theorem [127].
The total interference, $I(n)$, is represented by the in-phase interference component $I_I(n)$ and the quadrature-phase interference component $I_Q(n)$ as

$$I(n) = I_I(n) + jI_Q(n)$$  \hspace{1cm} (3.3)

The received signal at the $b^{th}$ base station which is the sum of the desired user's signal component and the total interference component can be represented as

$$r(n) = r_I(n) + jr_Q(n) = s_I(n) + js_Q(n) + I(n)$$  \hspace{1cm} (3.4)

The task of separating the desired signal from the interference and noise components, and measuring the signal power is difficult. A scheme for extracting the received signal power using Kalman filter is shown in Figure 3.1. The Kalman filter is applied in both in-phase ($I$) and quadrature-phase ($Q$) branches of the received signal at each subchannel. The in-phase and quadrature-phase components of the received signal, corrupted by interference noise are designated as $r_I$ and $r_Q$, respectively. The spreading sequence, the transmitted power, the pulse shaping filter, the delay of the received signal and the data sequence should be known initially at the receiver. These values can be estimated from the received signal statistics. The Kalman filter uses the knowledge of all this information along with the mobile speed to compute the fading coefficients.

The final estimate is taken as the mean of the two branch estimates. The Kalman filter prediction algorithm [128] is applied to the system, which is represented by the process and the state transition equations. The first order model [127] is given by

$$f(n + 1) = p(n + 1, n)f(n) + I(n)$$ \hspace{1cm} (3.5)

where

- $f(n)$ is the discrete time complex value of the fading coefficient (state process)
- $p(n + 1, n)$ is the state transition process
$I(n)$ is the assumed complex Gaussian noise, with zero mean and variance equal to $\sigma^2(n)$ and $n$ is the sample number at one sample per chip.

$p(n+1, n)$ and $\sigma^2(n)$ accounts for the Doppler spread of the received component. The discrete time received signal $r(n)$ is defined by

$$r(n) = s(n - \tau(n))f(n) + I(n)$$  \hspace{1cm} (3.6)

where

$s(n)$ is the transmitted signal
$\tau(n)$ is the delay of the received signal

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**Figure 3.1** Block diagram of Kalman filter SINR estimator
For satisfactory performance, the magnitude of the desired signal should be larger than the magnitude of the interference and noise. The received signal power at the output of Kalman filter is given by equation (3.6).

A novel method is proposed to improve the accuracy of the estimation of $\text{SINR}$. The average total power at the input of the receiver is calculated as

$$P_r = \frac{E \left[ |r(n)|^2 \right]}{2} \quad (3.7)$$

where $E[.]$ is the expected value.

The Kalman filter is used to estimate the fading coefficient $f(n)$. The desired signal power is calculated from

$$P_{\text{desired}} = \frac{E \left[ |s(n - \tau(n))f(n)|^2 \right]}{2} \quad (3.8)$$

This is a linear equation governing the channel coefficient. The interference and noise power is calculated by subtracting the signal power from the total power. Using equations (3.7) and (3.8), the estimated SINR is given by

$$\text{SINR} = \frac{E \left[ |s(n - \tau(n))f(n)|^2 \right]}{E \left[ |r(n)|^2 \right] - E \left[ |s(n - \tau(n))f(n)|^2 \right]} \quad (3.9)$$

The estimated SINR for each subchannel is used in the SINR based closed loop power control algorithm to adjust the transmitted power of the mobile user. The performance of the developed SINR estimator is analyzed through fixed step size and multilevel closed loop power control algorithms. The simulation results of the developed SINR estimator using Kalman filter are compared with that of the SINR estimator using Steele's algorithm.
3.4 SINR BASED CLOSED LOOP POWER CONTROL

The received power varies depending on the distance between the base station and the mobile, shadowing and multipath fading. Variations due to distance and shadowing are location dependent and hence are reciprocal on both the forward and the reverse links. Thus, the mobile determines these variations by measuring the average received power on the forward link and adjusts the mobile transmitted power accordingly. This is called open loop power control. This mechanism is not effective against multipath fading where fast power level fluctuations are not correlated [57]. The base station sends power control commands to the mobile to combat this problem demanding the mobile to either increase or decrease its power by a fixed amount. This is called closed loop power control. The SINR based closed loop power control may be inner or combination of inner and outer loop control.

The inner loop tracks the fast channel variations so that the SINR value is maintained close to the threshold SINR. The inner loop power control algorithm [57, 129] implemented at the base station to decide whether the mobile is to decrease or increase its power is shown in Figure 3.2. Fixed-step and the multi level power control schemes which can accommodate the effects of rapid fading are used to obtain the performance of the developed SINR estimator.

The base station will estimate the achieved SINR and compares it with the threshold SINR. If the estimated SINR is lower / higher than the threshold SINR, the base station sends an up/down command asking the mobile to increase/decrease its power. The transmission power at time \( (n+1) \) is obtained by adjusting the previous transmission power based on the step size and the power control command from the base station [67] as

\[
P(n+1) = P(n) + C \left( n + 1 \right) \Delta p
\]  

(3.10)

where

\[
\Delta p
\]

is a power adjustment step size

\[
C \left( n + 1 \right)
\]

is a power control command.
This process is executed at every power control period. The up command is sent as '1' while the down command is sent as '0' or vice versa depending on the standards used. The fixed step power control is performed at a higher rate than the multipath fading rate. It is suggested that the power control command updating rate is at least 10 times the maximum fading rate which corresponds to the $f_D T_p$ of 0.1.

Most of the available standards [22] support multiple step sizes. Although this multilevel approach may perform better than the fixed-step approach, it requires more bits to be used in the feedback channel for sending digitized values of power control command to each user. The received SINR still can not equal the $\text{SINR}_{th}$ due to the variations in the channel conditions or the interference level.
3.5 SIMULATION RESULTS AND DISCUSSION

The performance of the proposed SINR estimator for fixed step and multilevel closed loop power control algorithms is analysed through simulation using Matlab. The simulation parameters are shown in Table 3.1.

Table 3.1 Simulation parameters for SINR based closed loop power control

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of users</td>
<td>10 to 100</td>
</tr>
<tr>
<td>Carrier frequency (GHz)</td>
<td>5</td>
</tr>
<tr>
<td>Vehicle’s speed (Km/h)</td>
<td>5 to 100</td>
</tr>
<tr>
<td>Processing gain</td>
<td>64</td>
</tr>
<tr>
<td>Chip rate (Mcps)</td>
<td>3.84</td>
</tr>
<tr>
<td>Power control interval (ms)</td>
<td>0.43</td>
</tr>
<tr>
<td>Data rate (Kbps)</td>
<td>60</td>
</tr>
<tr>
<td>Power update step size (dBm)</td>
<td>± 0.5</td>
</tr>
</tbody>
</table>

A simplified representation of the received signal level against time is shown in Figure 3.3(a). The performance of the closed loop power control in a fading channel using fixed step and multi-level step algorithm are depicted in Figures 3.3(b) and 3.3(c) respectively. Consequently the transmitted power of the mobile station is adjusted according to the inverse of the fast fading characteristics as shown by the dashed line in Figure 3.3(d) to track the fast fading. The fading rate is proportional to the vehicle speed, while the depth of each fade is a random variable.

The BER performance as a function of SINR is investigated using the proposed Kalman filter algorithm and is compared with the Steele’s algorithm. A constant channel fading rate is characterized by a Doppler spread \((f_{DTP})\) of 0.1196 which corresponds to an average mobile speed of 60 Km/hr with a power control period of 0.43 ms. The low channel fading rates experienced at 5 Km/hr (pedestrians) corresponds to \(f_{DTP}\) of 0.01 and 30 Km/hr corresponds to \(f_{DTP}\) of 0.0598.
Figure 3.3  SINR based closed loop Power control in a fading channel
The effect of fading rates on the power control performance, fixed step algorithm and multi level step algorithm with quantization level of 4 are analysed. The BER performance of fixed step power control is depicted in Figure 3.4 using Steele’s algorithm and in Figure 3.5 using Kalman filter algorithm. The fixed step power control shows an effective performance at lower speed and degrades with increasing speeds.

Similar BER performance characteristics are obtained using multilevel step power control algorithm as evident from Figures 3.6 and 3.7. The performance is improved with decreasing values of Doppler spread \( f_{dp}T_d \). The multi level step algorithm has shown a better performance than the fixed step size algorithm for the given value of \( f_{dp}T_d \). The limited performance of fixed step algorithm to combat higher fading rates is due to the fact that it is very slow to follow the channel variations.

Compared with the Steele’s estimator, the Kalman filter based estimator gives a better performance as seen in Figures 3.8 and 3.9. This confirms that the performance of a SINR based power control is dependent on the performance of the SINR estimator used in the power control algorithm. The effect of SINR estimation error is less significant on the fixed-step algorithm than on the multi level step algorithm. Fixed step algorithm only needs to know whether the SINR is above or below the threshold level. Hence, the impact of SINR estimation error on the step size is reduced, resulting in a robust algorithm.

The performance curves of multi level power control deviate more significantly from the true value of SINR for increasing values of SINR. In the variable step size algorithm, the quantized step size is proportional to the difference between the estimated SINR and the \( \text{SINR}_{th} \). Any error on the estimated SINR will propagate to the step size. As a result, the step size may not be optimal and thus the power control performance degrades.
Figure 3.4 Effect of fading rates in fixed step algorithm - Steele's algorithm

Figure 3.5 Effect of fading rates in fixed step algorithm - Kalman filter algorithm
Figure 3.6 Effect of fading rates in multilevel algorithm—Steele's algorithm

Figure 3.7 Effect of fading rates in multilevel algorithm—Kalman filter algorithm
Figure 3.8 Effect of SINR estimator (fixed-step algorithm)

Figure 3.9 Effect of SINR estimator (multilevel-step algorithm)
2.2

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Steeles algorithm
Kalman filter algorithm

Figure 3.10  Standard deviation of error at different mobile speeds (Fixed step algorithm).

Figure 3.11  Standard deviation of error at different mobile speeds (Multi level algorithm).
The standard deviation of SINR estimation error is an important performance metric to analyse the channel tracking ability of the system. This is plotted against different mobile speeds using fixed step power control in Figure 3.10 and multilevel power control in Figure 3.11. The figures reveal that the standard deviation of estimation error is almost constant for the mobile speeds greater than 30 Km/hr using Kalman filter algorithm. The variation is more significant while using Steele's algorithm. This proves that the Kalman filter algorithm is able to track the channel variations irrespective of the mobile speed.

3.6 SUMMARY

A new adaptive algorithm for SINR estimation at the base station of MC-CDMA cellular systems has been developed and tested by simulation. The significant role of the proposed Kalman filter based SINR estimator in improving the performance of power control algorithms has been substantiated, particularly when the Doppler spread increases in a high velocity slow fading environment. This innovative approach can pave the way for the development of better power control strategies.