Chapter 2

Realization of QoS in handoffs by slope ratio method using Fuzzy logic

2.1 Introduction

Efficient handoff algorithms are a cost-effective way of enhancing the capacity and QoS of cellular systems. The received signal strength decreases as the mobile station recedes from base station (BS), and the chances of handoff increase. Any obstruction or Non Line of Sight (NLOS) condition in case of microcellular environment causes signal level to drop suddenly and results in dropped call if handoff does not take place immediately. The higher value of hysteresis effectively prevents unnecessary handoffs but causes undesired cell dragging. This undesired cell dragging causes interference or could lead to dropped calls in microcellular environment. The problems are further exacerbated by the corner effect phenomenon which causes the signal level to drop by 20-30 dB in 10-20m [26]. Thus, in order to maintain reliable communication in a microcellular system new and better handoff algorithms
must be developed. Handoff is an important feature in cellular mobile networks. A handoff algorithm with fixed parameters cannot perform well in different system environments. Specific characteristics of the communication system should be taken into account while designing handoff algorithms. The current trend of exponential growth in the use of personal communication services is causing the industry to examine ways to use the available bandwidth more efficiently.

We developed handoff technique on the basis of ratio of slopes of normal decaying signal to the actual signal. On the basis of nature of decaying signal, a threshold value is selected which decides whether a handoff is required or not. Reaching to this threshold value mobile station can make handoff to another nearby base station. This technique is novel, produces handoff by evaluating signal from the same BS. Thus, the handoff process is fast reduces the risk of dropped calls to a good extent. The method is best suited for the handoffs due to corner effect. The fuzzy based solution is supported by comparing its results with the results obtained in analytical solution.

2.2 Classification of handoffs

Handoff is the key operation in cellular mobile communication systems which is accomplished by the system and is imperceptible for the user. It is the mechanism through which the continuity of a call is maintained when mobile
moves from one cell area to another. Handoff is defined as the process of changing the current radio channel to a new radio channel which mainly takes place because of the movement of mobile unit and unfavorable radio conditions (deterioration of received signal quality) inside an individual cell or between a number of adjacent cells. Handoff includes two major steps, handoff initiation and execution. In initiation phase, the received signal quality is investigated according to radio propagation based methods. In execution phase, based on traffic control policies, a new radio channel will be assigned. It is necessary that while the handoff process should be imperceptible for the user, decision have to be well-timed and intact and execution must be fast and reliable.

As smaller cells (microcells) are deployed to meet the demands for increased capacity, the number of cell boundary crossings increases. Each handoff requires network resources to reroute the call to the new base station. High concentration of traffic is found in the city centers during rush hours, decreasing towards the outskirts. After the busy hours and towards the end of the day, this concentration changes as the users move from the town centers to their homes. Because of the mobility of users the handoffs and roaming are always occurring reducing the channel holding times in the cells where the calls are generated and increasing the traffic in the cell where the mobiles travel. When call traffic is heavy, the switching processor is loaded, and a lower number of handoffs would help the processor handle call processing more
adequately. If handoff does not occur quickly, the QoS may degenerate below an acceptable level. During the handoff there is brief service interruption and as the frequency of these interruptions increases, the perceived QoS is reduced. Handoff is needed in two situations where the cell site receives weak signals from the mobile unit.

- At the cell boundary, say-100dBm [27], which is the level for requesting a handoff in a noise-limited environment; and
- When the mobile unit is reaching the signal-strength holes (gaps) within the cell site.

The chances of dropping a call due to factors such as the non availability of channels increase with the number of handoff attempts. All of these issues place additional challenges on the cellular system. As the rate of handover increases, handoff algorithms need to be enhanced so that the perceived QoS does not degenerate and the cost to the cellular infrastructure does not skyrocket. Much effort is being expended to study existing handoff schemes, and to create new ones that meet these challenges. Figure 2.1 illustrates the handoff scenarios at cell boundary.
Delaying handoffs is advantageous in many cases and disadvantageous in many other cases. The received signal strength at the mobile station fluctuates up and down. If the mobile station is in a hole for less than 5 seconds, the delays in handoff call even circumvent the need for a handoff. In many cases, a two-handoff-level algorithm is used. The purpose of creating two request handoff levels is to provide more opportunity for a successful handoff. If the neighboring cells are busy, delayed handoff may take place.
2.3 Preliminaries

Mobile communication systems should use limited resources in an efficient and convenient manner. One way of achieving this is to use smaller cells at the expense of corresponding handoff and administration overhead. Many handoff algorithms are classified according to the metrics used to decide whether a handoff is necessary or not, where these metrics are monitored, and how these metrics are processed. Some of the metrics proposed are; signal strength [28], distance [29], signal to noise ratio [30], bit error rate [31], traffic load [32], word error indicator, quality indicator [33], and some combination of these [33, 34]. Metrics can be measured and processed on the network entity or on the mobile. There are several handoff decision algorithms that employ tools of artificial intelligence like fuzzy logic systems [35-38], neural networks [39], and pattern recognition algorithms [40-42] to process the collected metrics.

The Received Signal Strength (RSS) based handoff algorithm associates mobile host to the access point, which has the strongest perceived signal strength at the mobile host side. The signal received from an access point degrades as the distance between the mobile and the access point increases. However, this degradation is a random process due to uncertainties in the propagation environment. Around mid-point between two access points (BSs), the difference in the signal strengths received from the two access points oscillates and the mobile may handoff several times between these access
points. This is called the ping-pong effect. To remedy the ping-pong effect, a
threshold is introduced to the received signal strength based handoff algorithm
[43]. The mobile does not hand off as long as the received signal strength from
the currently serving access point does not drop below the predetermined
threshold level. This algorithm is called Absolute Signal Strength algorithm
[44]. Another technique is to introduce a hysteresis to the RSS algorithm. The
mobile does not handoff to another access point while the received signal
strength from the candidate access point is not better an amount of
predetermined hysteresis level than the received signal strength of the currently
serving access point. This algorithm is called Relative Signal Strength
algorithm [44, 45]. Introducing both hysteresis and threshold is called the
combined absolute and relative signal strength algorithm [46]. Either
introducing hysteresis or threshold reduces the ping-pong effect but introduces
a delay to the handoff, i.e., handoff is done later than it is expected. Effects of
delaying handoff are increased interference, lower grade of service, i.e., call
blocking and dropping rates. There are studies that have optimized signal-
strength based handoff algorithms by minimizing two conflicting design
criteria, the handoff delay and the mean number of handoffs between access
points [29, 34]. In the design of handoff algorithms, there is an inherent trade
off in timeliness and accuracy. The algorithms, which we described thus far,
were signal strength based algorithms. Another category is the distance-based
algorithms. Distance-based algorithms relate the mobile with the closest access point [29]. The relative distance measurements can be obtained by comparing propagation delay times. Velocity adaptive handoff algorithms consider mobiles with different velocities, i.e., the handoff needs of fast moving mobiles should be determined immediately. This can be achieved by adjusting the effective length of the averaging window in which received signal strengths from the access point are averaged [34]. In direction based algorithms, handoffs to the access points towards which the mobile is moving are encouraged, while handoffs to the access points from which the mobile is receding are discouraged [35]. In pre-selection handoff algorithm, a mobile hands off to the access point towards which the mobile is moving even though measured handoff decision metrics of that access point are not the best, considering that these metrics will improve as the mobile gets closer to the access point.

The microcells are cells with small radii and employed in highly populated areas such as city buildings and streets to meet high system capacity by frequency reuse. In Figure 2.2, we have shown two streets intersecting with three BSs employed on the streets. BS$_1$ and BS$_3$ have line-of-sight (LOS) with each other. The handoff between BS$_1$ and BS$_3$ is called LOS handoff; on the other hand the handoff between BS$_1$ and BS$_2$ is a non-LOS (NLOS) handoff since they don't have LOS [47-49]. In NLOS handoffs, when a MS lose LOS (by turning the corner) with current BS, a drop in RSS (20-30 dB) occurs [48,
This effect is called the corner effect and needs faster handoff algorithms since the RSS can drop quickly below the receiver threshold resulting in a call drop. Two types of handoffs, LOS and NLOS, have different characteristics where LOS handoffs try to minimize the number of unnecessary handoffs between BSs and NLOS must be as quickly as possible because of the corner effect.

In [49], a fast handoff algorithm for hard handoffs is proposed to remove fast fading fluctuations from the received signal resulting in an algorithm that reacts more quickly to corner effect. They propose a technique called local averaging, in which the averaging time interval is smaller than averaging time interval of common handoff algorithms and improve handoff performance. The authors proposed an improved version of the algorithm by adding a drop timer
and hysteresis to local averaging technique which decreases the unnecessary handoffs [50]. Then, they compare their proposal with a common averaging technique which uses an exponential window.

Fuzzy logic based techniques for handoff in cellular communication has been reported in [51-53]. The handoff criteria use threshold values to membership functions. The possible weakness in [51, 52] is due to the jump values inherent in some fuzzy sets and takes only (NLOS) transmission into consideration. The fuzzy sets chosen in this work have smooth membership function that increases or decreases gradually. A normal handoff scheme for channel carrying in mobile cellular networks has been reported by [54, 55]. In our new handoff decision algorithm [56], the handoff decision metrics are received signal strength from the current and candidate access points, ratio of the slopes of expected to actual signal strength from same BS, and the threshold value for implementing handoff. We use a fuzzy inference system to process these metrics.

2.4 Advantages of proposed technique over the existing methods

- The proposed method uses slope ratio of the actual received signal and the expected signal from same base station, thus based on the local information of actual decaying and expected decaying signals (decentralized system) the handoffs can be decided. The handoffs will be precisely decided by setting a
suitable threshold value. The existing methods compares signals received from neighboring BSs and the switching process for handoff (centralized controlled system) is higher.

- Most of the methods referred thus far use hysteresis and threshold values thus delaying handoffs which oftenly results in cell dragging and dropped calls in microcellular environment.
- The proposed technique is novel, uses decentralized approach for handoff process and achieves better performance than conventional hysteresis-based handoff methods.

2.5 Analytical Solution for handoff employing slope ratio method

The rapid decrease in signal strength is due to corner effect or any other NLOS condition in a cellular system. This may result in dropped call if handoff algorithm does not support. The decrease in received signal strength is always monitored by determining the ratio of slopes of expected signal and the actual signal. The slope of expected signal is obtained by the tangent of angle subtended by the decaying signal line and is determined by selecting any two points on the line. From the history of previous samples of the expected signal the new samples are determined by any extrapolation method. Figure 2.3 illustrates the method for obtaining slope ratios.
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Figure 2.3 Slopes of actual signal and expected signal

The slope of expected signal is given by

\[ \tan(\theta_1) = \frac{\Delta \text{RSS}}{\Delta S_1} \]  \hspace{1cm} (2.1)

The slope of actual signal is given by

\[ \tan(\theta_2) = \frac{\Delta \text{RSS}}{\Delta S_2} \]  \hspace{1cm} (2.2)

The ratio of slopes of expected signal and actual signal is given by

\[ S_R = \frac{\tan(\theta_1)}{\tan(\theta_2)} = \frac{\Delta S_2}{\Delta S_1} \]  \hspace{1cm} (2.3)

When \( \theta_1 = \theta_2 \)
\[ \Delta S_1 = \Delta S_2 \]
\[ \Rightarrow S_R = 1 \]
where RSS = Received signal strength

\[ S_R = \text{slope ratio} \]

\[ \Delta S_1 \text{ and } \Delta S_2 \text{ are small changes in distances of mobile station from base station with respect to normal and actual signals respectively.} \]

For different values of \( \theta_1 \) and \( \theta_2 \) various values of \( S_R \) are obtained. But for handoff to take place \( \theta_2 \) must always be greater than \( \theta_1 \). Thus we have only taken the values for \( \theta_2 > \theta_1 \) into consideration. The ratio from \( \theta_1 = 10^\circ \) to \( \theta_2 = 50^\circ \) has been considered with high probability region for handoff. To avoid the over crowding of data, the difference of two degrees in \( \theta_1 \) and \( \theta_2 \) are considered.

The various values of \( S_R = \tan \theta_1 / \tan \theta_2 \) are shown in Table 2.1. The threshold value for handoff is set as 0.6.
The tabulated values are plotted in Figure 2.4.

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2.6 Fuzzy logic solution for handoff

Fuzzy set theory allows a linguistic representation of the control and operational laws of a system. The main strength of fuzzy set theory is that it excels in dealing with imprecision. Fuzzy logic can be used to control a complex system [57, 58]. In classical set theory an element is either a member of a set or it is not. Classical set theory does not allow for partial membership. This kind of logic is called a crisp logic. Fuzzy set on the other hand realizes that there are a very few crisp sets in nature and so considers partial membership. Fuzzy set theory allows the gradual transition from full membership of a set to full non membership. The block diagram for a fuzzy logic system is shown in Figure 2.5. For handoff initiation three membership functions: Received Signal Strength (RSS), Slope ratio ($S_r$) and Threshold are used. Fuzzy sets contain elements that have a varying degree of membership in
a set. Therefore, it is different from an ordinary or crisp set, where elements will only be considered members of a class if they have full membership in the class. For example, if signal strength is considered in a crisp set, the signal can only be considered to be either strong or weak, not both simultaneously, whereas in a fuzzy set the signal can be classed as quite weak, not so strong, or medium, this indicates that an element in a fuzzy set can have membership in more than one set.

The membership values are obtained by mapping the values obtained for a particular parameter onto a membership function. This function is a curve or line that defines how each data or value is mapped onto a membership value. It is represented graphically in Figure 2.6a, where the three lines represent the range available for weak, medium, and strong. SS1, SS2, and SS3 represent the threshold for weak, medium and strong, respectively.
Then, by mapping the position of the received signal strength onto the graph of the membership function $\mu$, the signal will be allocated with a membership
value in each set ranging from 0 to 1 [59, 60]. Therefore, if a signal falls between SSI and SS2, it could be assigned a value of 0 in strong set and 0.6 in the medium set, and 0.4 in the weak set. This is shown in Fig 2.6a for the membership function related to signal strength. Figures 2.6 b and c refer to slope ratio and threshold respectively.

The fuzzified data is passed to the inference engine, where the fuzzified data is matched against a set of fuzzy rules using fuzzy techniques to produce output fuzzy sets. Fuzzy rules can be defined as a set of possible scenarios utilizing a series of IF-THEN rules, which decides whether handoff is necessary. Following this, a set of different handoff decisions can be obtained. The rules thus developed are as follows:

1. IF Received signal is Weak and Slope ratio is Low and Threshold is Low THEN Handoff is High

2. IF Received signal is Low and Slope ratio is Low and Threshold is Medium THEN Handoff is High

3. IF Received signal is Weak and Slope ratio is Low and Threshold is High THEN Handoff is High

4. IF Received signal is Weak and Slope ratio is Medium and Threshold is Low THEN Handoff is Medium

5. IF Received signal is Weak and Slope ratio is Medium and Threshold is Medium THEN Handoff is Medium
6 IF Received signal is Weak and Slope ratio is Medium and Threshold is High THEN Handoff is Medium
7 IF Received signal is Weak and Slope ratio is High and Threshold is Low THEN Handoff is Medium
8 IF Received signal is Weak and Slope ratio is High and Threshold is Medium THEN Handoff is Low
9 IF Received signal is Weak and Slope ratio is High and Threshold is High THEN Handoff is Low
10 IF Received signal is Medium and Slope ratio is Low and Threshold is Low THEN Handoff is High
11 IF Received signal is Medium and Slope ratio is Low and Threshold is Medium THEN Handoff is High
12 IF Received signal is Medium and Slope ratio is Low and Threshold is High THEN Handoff is High
13 IF Received signal is Medium and Slope ratio is Medium and Threshold is Low THEN Handoff is Medium
14 IF Received signal is Medium and Slope ratio is Medium and Threshold is Medium THEN Handoff is Low
15 IF Received signal is Medium and Slope ratio is Medium and Threshold is High THEN Handoff is Low
16 IF Received signal is Medium and Slope ratio is High and Threshold is Low THEN Handoff is Low
17 IF Received signal is Medium and Slope ratio is High and Threshold is Medium THEN Handoff is Low
18 IF Received signal is Medium and Slope ratio is High and Threshold is High THEN Handoff is Low
19 IF Received signal is Strong and Slope ratio is Low and Threshold is Low THEN Handoff is High
20 IF Received signal is Strong and Slope ratio is Low and Threshold is Medium THEN Handoff is High
21 IF Received signal is Strong and Slope ratio is Low and Threshold is High THEN Handoff is High
22 IF Received signal is Strong and Slope ratio is Medium and Threshold is Low THEN Handoff is Medium
23 IF Received signal is Strong and Slope ratio is Medium and Threshold is Medium THEN Handoff is Low
24 IF Received signal is Strong and Slope ratio is Medium and Threshold is High THEN Handoff is Low
25 IF Received signal is Strong and Slope ratio is High and Threshold is Low THEN Handoff is Low
26 IF Received signal is Strong and Slope ratio is High and Threshold is Medium THEN Handoff is Low

27 IF Received signal is Strong and Slope ratio is High and Threshold is High THEN Handoff is Low

Figure 2.7 Inference mechanism for calculation of Fuzzy handoff (QoS)
Chapter 2 Realization of QoS in handoffs by slope ratio method using fuzzy logic

The output fuzzy sets are then passed to the defuzzifier which computes a crisp output value. The fuzzy IF-THEN rules provide knowledge base to the system and results in proper handoff. The simulation data obtained from Mumdani inferences system is shown in Table 2.2. The tabulated data plotted is shown in Figure 2.8. These results are in coincidence with the results obtained by analytical solution.

<table>
<thead>
<tr>
<th>RSS</th>
<th>Slope ratio</th>
<th>Threshold</th>
<th>Handoff</th>
</tr>
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<tbody>
<tr>
<td>0.102</td>
<td>0.102</td>
<td>0.102</td>
<td>0.852</td>
</tr>
<tr>
<td>0.151</td>
<td>0.102</td>
<td>0.102</td>
<td>0.844</td>
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<tr>
<td>0.211</td>
<td>0.151</td>
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<tr>
<td>0.259</td>
<td>0.211</td>
<td>0.211</td>
<td>0.536</td>
</tr>
<tr>
<td>0.307</td>
<td>0.259</td>
<td>0.259</td>
<td>0.5</td>
</tr>
<tr>
<td>0.355</td>
<td>0.307</td>
<td>0.307</td>
<td>0.5</td>
</tr>
<tr>
<td>0.404</td>
<td>0.355</td>
<td>0.355</td>
<td>0.5</td>
</tr>
<tr>
<td>0.5</td>
<td>0.404</td>
<td>0.404</td>
<td>0.5</td>
</tr>
<tr>
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<td>0.5</td>
<td>0.5</td>
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<tr>
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<td>0.56</td>
<td>0.503</td>
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<tr>
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<td>0.608</td>
<td>0.608</td>
<td>0.52</td>
</tr>
<tr>
<td>0.705</td>
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<td>0.657</td>
<td>0.526</td>
</tr>
<tr>
<td>0.753</td>
<td>0.705</td>
<td>0.705</td>
<td>0.531</td>
</tr>
<tr>
<td>0.801</td>
<td>0.753</td>
<td>0.753</td>
<td>0.495</td>
</tr>
</tbody>
</table>
Chapter 2 Realization of QoS in handoffs by slope ratio method using fuzzy logic

\[
\begin{array}{cccc}
0.849 & 0.801 & 0.801 & 0.41 \\
0.898 & 0.849 & 0.849 & 0.29 \\
0.946 & 0.898 & 0.898 & 0.146 \\
0.982 & 0.982 & 0.982 & 0.13 \\
\end{array}
\]

Table 2.2 Membership values obtained from Mamdani inference system

Figure 2.8 Handoff with varying RSS, Slope ratio and Threshold

Figures 2.9 (a),b and (c) shows the three dimensional surface view of handoff versus slope ratio and RSS, handoff versus threshold and RSS and handoff versus slope ratio and threshold respectively.
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(a)

(b)
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Figure 2.9 a) handoff versus slope ratio and RSS b) Handoff versus Threshold and RSS c) Handoff versus Slope ratio and Threshold

2.7 Comparison of results

From Figure 2.4, it is evident that with the increase in slope ratio values, the curves become smoother indicating that handoff’s decrease. The higher value of slope ratio means decreasing denominator value in $(\tan \theta_1/\tan \theta_2)$ or in other wards $\theta_2$ approaches $\theta_1$ thereby the actual and normal signals approach coincidence. From Figure 2.8, the slope ratio and handoff factor act inversely proportional to each other. Thus higher value of slope ratio produces lower handoff’s and vice versa.