Chapter 5

Fuzzy logic based handoffs using path codification of mobile station

5.1 Introduction

Mobility management in cellular communication systems is needed to guarantee quality of service, and to offer advanced services based on the user location. The use of microcells to accommodate high density of calls results in the increased number of handoffs. High mobility of terminals determines a high effort to predict next movement in order to grant a correct transition to the next cell. Handoff processes are the transitions between two contiguous cells performed by a mobile station when traveling across a cellular system. Sensitivity to deviations from the real path followed by a mobile station is controlled by means of editing operations [111].

Mobile stations can measure seven different pilot signals power, since each cell of a cellular system is enclosed by six cells. During the movement of mobile station across the cell, a mobile station builds a string of fuzzy symbols. The strings obtained are matched with the strings contained in the hybrid
Chapter 5 Fuzzy logic based handoffs using path codification of mobile station

dictionary, obtaining a similarity measure calculated by a fuzzy automation [112-114]. The proposed method needs current string of symbols for handoff thus no match with the hybrid dictionary is required. This reduces the data basis and processing overhead for handoff purpose.

5.2 Advantages of the proposed method over existing method

- The existing similarity between the string of fuzzy symbols built by concatenation of observed symbols and the pattern strings contained in the dictionary is obtained for handoff. The dictionary needs to have huge data for most frequent paths followed by all the users of the cell. The proposed method does not need huge data base for codification.

- The system fails when the mobile station follows non regular movement as the path followed is not included in the user dictionary. The proposed method needs only the current path of mobile station for codification and no match with any predefined path is needed.

5.3 Preliminaries

Usually continuous service is achieved by supporting handoff from one cell to another. The handoff function is a most frequently encountered network
function and has direct impact on the perceived quality of service [115, 116]. It provides continuation of calls as the mobile station travels across cell boundaries. Handoff is the process of changing the channel associated with the current connection while a call is in process [117, 118]. It is often initiated either by crossing a cell boundary or by deterioration in quality of signal in the current channel. A direction based algorithm is proposed in [119] where all the base stations (BSs), in handoff decision are grouped in two groups. One set of BSs are those in which mobile station (MS) is approaching and the other set includes the BSs in which the MS moves away. Mobility management using fuzzy logic has been presented in [120]. Here the path is codified first and the similarity between the strings containing the path followed by the mobile station is matched with the possible paths contained in the hybrid dictionary. The mobility management system model fails when mobile station follows a non regular movement; the path followed is not included into its user dictionary. A new technique which is an alternative to the growth of the offered services and the effective use of bandwidth [121] has been developed. The codified paths of mobile station are recorded and the highest probability of existing codes in the string decides the expected motion and handoff of mobile station.
5.4 **Mobility management system model**

The mobility modeling in wireless networks for improving the performance of mobile communication system has been presented in [122-124]. Cellular systems deploy smaller cells in order to achieve high system capacity due to the limited spectrum. High mobility of terminals in microcells particularly at concerns determines a high effort to predict next movement in order to grant a correct and timely transition to the next phone cell.

We developed a fuzzy method in dealing with the problem of determining the propagation path of a mobile terminal in symbolic form [125]. The rate of occurrence of any symbol in the string of symbols gives the probability of handoff of mobile station. We present two newly developed models; one system model is based on time dependent path codification of mobile station which is decided by the signal strengths of various base stations of neighboring cells. Another is direction oriented system model based on the alignment of mobile move along these directions. The basic directions are obtained by connecting various base stations of neighboring cells to the base station of central cell. During movement across the cell a mobile station builds a string of fuzzy symbols. When the Received Signal Strength (RSS) becomes weak enough to handoff the control of one base station to another, the highest occurrence of symbol in the string of symbols decides the possibility of handoff.
i) Since each cell of a cellular system is enclosed by six neighboring cells, therefore, path codification of the time dependent movement of MS is recorded in accordance with the received signal strength from neighboring cells. So, a symbol (neighboring cells b, c, d, e, f and g of a) is built every time the MS measures signal power of neighboring cells during its movement and thus a string of symbols is obtained. The MS can be slow initially and may be fast during rest period of the call. Then the symbols pertaining to initial phase of mobile may be high which may lead to ambiguous situation for deciding about handoff on the basis of highest symbols in the code string. Thus the formation of codes is done at equal instants of time. When a set of codes in the string are equal then the decision of handoffs is made on the basis of highest degree of latest occurrence of symbols.

Figure 5.1 Path followed by mobile for the formation of symbols
The proposed model works efficiently for mobile units moving with uniform speeds. An example of the path followed by mobile station and the corresponding symbols across the cell is shown in Figure 5.1. The string of symbol is "g/f, g/f, g/f/b, g/f, g/f, d/e, b/c, c/d, c/d, c/d". The "g/f" determines the probability of occurrence of symbol between neighboring cells g and f. For simplicity of the neighborhood of cells the cell is divided in four zones. From the string of symbols it is obvious that the handoff will be to cell c.

ii) The other method of determining the occurrence of the symbols is direction oriented. The centers of six neighboring cells with the center of central cell give basic directions of the network, as shown in Figure 5.2.
Chapter 5 Fuzzy logic based handoffs using path codification of mobile station

The string of symbol followed by same mobile now becomes “g, b/f, g/d, b/f, g/d, c/e, c/e, c/d, c/b, c, c”. Here we again have the high probability for handoff to ‘c’ cell. This method is not necessarily time dependent.

5.5 Fuzzy logic handoff using path codification

Fuzzy logic being flexible in dealing with imprecise data is suited well for dealing with the problem of handoff with path codification technique. If any code in the string is high then handoff is given to cell with that code i.e.

\[
\text{IF } \sum_{i=1}^{L} (\text{Code}_i)_k = \max, \ i = b, \ldots, g \\
\text{THEN Handoff to cell with code}_i 
\]

If any two codes in the string are equal, then handoff is given to the cell with recent code occurrence i.e.

\[
\text{IF } \sum_{i=1}^{L} (\text{Code}_i)_k = \sum_{j=1}^{L} (\text{Code}_j)_k, \text{code}_i = \text{recent}, \ i = b, \ldots, g \\
\text{THEN Handoff to } i \text{ cell} \\
\text{Else to } j \text{ cell}
\]

where ‘L’ is the length of cell and i and j are any two codes in code string. The three variables, (code)_i , (code)_j, and recent code_i are fed into fuzzifier. The fuzzified data is passed to the inference engine. The inference engine matches the fuzzified data against a set of fuzzy rules to produce output fuzzy sets. The output fuzzy sets are then passed to defuzzifier which computes a crisp output.
value. The fuzzy IF-THEN rules provide knowledge base to the system for proper decision.

1. IF Code\textsubscript{i} is Low and Code\textsubscript{j} is Low and Recent code\textsubscript{i} is Low Then
   Handoff to i cell is Low and Handoff to j cell is High

2. IF Code\textsubscript{i} is Low and Code\textsubscript{j} is Low and Recent code\textsubscript{i} is Medium Then
   Handoff to i cell is High and Handoff to j cell is Low

3. IF Code\textsubscript{i} is Low and Code\textsubscript{j} is Low and Recent code\textsubscript{j} is High Then
   Handoff to i cell is High and Handoff to j cell is Low

4. IF Code\textsubscript{i} is Low and Code\textsubscript{j} is Medium and Recent code\textsubscript{i} is Low Then
   Handoff to i cell is Low and Handoff to j cell is High

5. IF Code\textsubscript{i} is Low and Code\textsubscript{j} is Medium and Recent code\textsubscript{i} is Medium Then
   Handoff to i cell is Low and Handoff to j cell is Medium

6. IF Code\textsubscript{i} is Low and Code\textsubscript{j} is Medium and Recent code\textsubscript{i} is High Then
   Handoff to i cell is Medium and Handoff to j cell is Medium

7. IF Code\textsubscript{i} is Low and Code\textsubscript{j} is High and Recent code\textsubscript{i} is Low Then
   Handoff to i cell is Low and Handoff to j cell is High

8. IF Code\textsubscript{i} is Low and Code\textsubscript{j} is High and Recent code\textsubscript{i} is Medium Then
   Handoff to i cell is Medium and Handoff to j cell is High

9. IF Code\textsubscript{i} is Low and Code\textsubscript{j} is High and Recent code is High Then
   Handoff to i cell is High and Handoff to j cell is High
Chapter 5 Fuzzy logic based handoffs using path codification of mobile station

10 IF Code\textsubscript{i} is Medium and Code\textsubscript{j} is Low and Recent code\textsubscript{i} is Low Then

Handoff to i cell is High and Handoff to j cell is Low

11 IF Code\textsubscript{i} is Medium and Code\textsubscript{j} is Low and Recent code\textsubscript{i} is Medium Then

Handoff to i cell is High and Handoff to j cell is Low

12 IF Code\textsubscript{i} is Medium and Code\textsubscript{j} is Low and Recent code\textsubscript{i} is High Then

Handoff to i cell is High and Handoff to j cell is Low

13 IF Code\textsubscript{i} is Medium and Code\textsubscript{j} is Low and Recent code\textsubscript{i} is Low Then

Handoff to i cell is Low and Handoff to j cell is High

14 IF Code\textsubscript{i} is Medium and Code\textsubscript{j} is Medium and Recent code\textsubscript{i} is Medium Then

Handoff to i cell is High and Handoff to j cell is Low

15 IF Code\textsubscript{i} is Medium and Code\textsubscript{j} is Medium and Recent code\textsubscript{i} is High Then

Handoff to i cell is High and Handoff to j cell is Low

16 IF Code\textsubscript{i} is Medium and Code\textsubscript{j} is High and Recent code\textsubscript{i} is Low Then

Handoff to i cell is Low and Handoff to j cell is High

17 IF Code\textsubscript{i} is Medium and Code\textsubscript{j} is High and Recent code\textsubscript{i} is Medium Then

Handoff to i cell is Medium and Handoff to j cell is Medium

18 IF Code\textsubscript{i} is Medium and Code\textsubscript{j} is High and Recent code\textsubscript{i} is High Then

Handoff to i cell is High and Handoff to j cell is Medium

19 IF Code\textsubscript{i} is High and Code\textsubscript{j} is Low and Recent code\textsubscript{i} is Low Then

Handoff to i cell is High and Handoff to j cell is Low
Chapter 5 Fuzzy logic based handoffs using path codification of mobile station

20 IF Code\textsubscript{i} is High and Code\textsubscript{j} is Low and Recent code\textsubscript{i} is Medium Then  
Handoff to i cell is High  and Handoff to j cell is Low

21 IF Code\textsubscript{i} is High and Code\textsubscript{j} is Low and Recent code\textsubscript{i} is High Then  
Handoff to i cell is High  and Handoff to j cell is High

22 IF Code\textsubscript{i} is High and Code\textsubscript{j} is Medium and Recent code\textsubscript{i} is Low Then  
Handoff to i cell is High  and Handoff to j cell is Medium

23 IF Code\textsubscript{i} is High and Code\textsubscript{j} is Medium and Recent code\textsubscript{i} is Medium Then  
Handoff to i cell is High  and Handoff to j cell is Low

24 IF Code\textsubscript{i} is High and Code\textsubscript{j} is Medium and Recent code\textsubscript{i} is High Then  
Handoff to i cell is High  and Handoff to j cell is Low

25 IF Code\textsubscript{i} is High and Code\textsubscript{j} is High and Recent code\textsubscript{i} is Low Then  
Handoff to i cell is Medium  and Handoff to j cell is High

26 IF Code\textsubscript{i} is High and Code\textsubscript{j} is High and Recent code\textsubscript{i} is Medium Then  
Handoff to i cell is High  and Handoff to j cell is Low

27 IF Code\textsubscript{i} is High and Code\textsubscript{j} is High and Recent code\textsubscript{i} is High Then  
Handoff to i cell is High  and Handoff to j cell is Low

The block diagram for fuzzy logic for handoff with different variables is similar to Figure 2.5 of chapter 2. The three variable membership functions used for calculating handoff of mobile are code\textsubscript{i}, code\textsubscript{j} and recent code\textsubscript{i}. All these membership functions have three states as Low, Medium and High and are fed into the fuzzifier. The output variable is the handoff function. The simulation
data obtained from Mamdani inference system is shown in Table 5.1. The tabulated data plotted is shown in Figure 5.3. Figure 5.4 and Figure 5.5 gives the three dimensional view of various membership functions. Figure 5.6 gives Inference mechanism for calculating handoff function.

<table>
<thead>
<tr>
<th>Code_{i}</th>
<th>Code_{j}</th>
<th>Recent code_{i}</th>
<th>Handoff_{i}</th>
<th>Handoff_{j}</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.053</td>
<td>0.0538</td>
<td>0.053</td>
<td>0.132</td>
<td>0.868</td>
</tr>
<tr>
<td>0.114</td>
<td>0.0538</td>
<td>0.053</td>
<td>0.184</td>
<td>0.816</td>
</tr>
<tr>
<td>0.205</td>
<td>0.0538</td>
<td>0.053</td>
<td>0.41</td>
<td>0.59</td>
</tr>
<tr>
<td>0.295</td>
<td>0.0538</td>
<td>0.053</td>
<td>0.59</td>
<td>0.41</td>
</tr>
<tr>
<td>0.356</td>
<td>0.0538</td>
<td>0.053</td>
<td>0.728</td>
<td>0.272</td>
</tr>
<tr>
<td>0.402</td>
<td>0.0538</td>
<td>0.053</td>
<td>0.863</td>
<td>0.137</td>
</tr>
<tr>
<td>0.508</td>
<td>0.0538</td>
<td>0.053</td>
<td>0.868</td>
<td>0.132</td>
</tr>
<tr>
<td>0.674</td>
<td>0.0538</td>
<td>0.053</td>
<td>0.852</td>
<td>0.148</td>
</tr>
<tr>
<td>0.72</td>
<td>0.0538</td>
<td>0.053</td>
<td>0.843</td>
<td>0.157</td>
</tr>
<tr>
<td>0.826</td>
<td>0.0538</td>
<td>0.053</td>
<td>0.852</td>
<td>0.148</td>
</tr>
<tr>
<td>0.871</td>
<td>0.0538</td>
<td>0.053</td>
<td>0.859</td>
<td>0.141</td>
</tr>
<tr>
<td>0.902</td>
<td>0.0538</td>
<td>0.053</td>
<td>0.863</td>
<td>0.137</td>
</tr>
<tr>
<td>0.947</td>
<td>0.0538</td>
<td>0.053</td>
<td>0.868</td>
<td>0.132</td>
</tr>
<tr>
<td>0.053</td>
<td>0.0538</td>
<td>0.053</td>
<td>0.132</td>
<td>0.868</td>
</tr>
<tr>
<td>0.053</td>
<td>0.115</td>
<td>0.053</td>
<td>0.139</td>
<td>0.861</td>
</tr>
<tr>
<td>0.053</td>
<td>0.208</td>
<td>0.053</td>
<td>0.154</td>
<td>0.846</td>
</tr>
<tr>
<td>0.053</td>
<td>0.3</td>
<td>0.053</td>
<td>0.153</td>
<td>0.847</td>
</tr>
</tbody>
</table>
Chapter 5 Fuzzy logic based handoffs using path codification of mobile station

| 0.053 | 0.362 | 0.053 | 0.142 | 0.858 |
| 0.053 | 0.408 | 0.053 | 0.136 | 0.864 |
| 0.053 | 0.5   | 0.053 | 0.132 | 0.868 |
| 0.053 | 0.669 | 0.053 | 0.147 | 0.853 |
| 0.053 | 0.7   | 0.053 | 0.153 | 0.846 |
| 0.053 | 0.808 | 0.053 | 0.152 | 0.848 |
| 0.053 | 0.869 | 0.053 | 0.141 | 0.859 |
| 0.053 | 0.9   | 0.053 | 0.137 | 0.863 |
| 0.053 | 0.946 | 0.053 | 0.132 | 0.868 |

| 0.205 | 0.205 | 0.053 | 0.412 | 0.588 |
| 0.205 | 0.205 | 0.0985| 0.412 | 0.588 |
| 0.205 | 0.205 | 0.174 | 0.412 | 0.572 |
| 0.205 | 0.205 | 0.25  | 0.5   | 0.5   |
| 0.205 | 0.205 | 0.28  | 0.559 | 0.456 |
| 0.205 | 0.205 | 0.326 | 0.584 | 0.413 |
| 0.205 | 0.205 | 0.371 | 0.584 | 0.382 |
| 0.205 | 0.205 | 0.402 | 0.584 | 0.364 |
| 0.205 | 0.205 | 0.598 | 0.584 | 0.364 |
| 0.205 | 0.205 | 0.659 | 0.572 | 0.364 |
| 0.205 | 0.205 | 0.705 | 0.563 | 0.364 |
| 0.205 | 0.205 | 0.811 | 0.576 | 0.364 |
| 0.205 | 0.205 | 0.871 | 0.618 | 0.364 |
| 0.205 | 0.205 | 0.902 | 0.636 | 0.364 |
Table 5.1 Membership values obtained from Mamdani inference system
Chapter 5 Fuzzy logic based handoffs using path codification of mobile station
Figure 5.3 Handoff with (a) varying code$_i$ (b) varying code$_j$ (c) and (d) varying recent codes
Figure 5.4 Handoff to i cell versus a) code, and code, b) code, and recent code, c) code, and recent code.
Chapter 5 Fuzzy logic based handoffs using path codification of mobile station

(d)

(e)
Chapter 5 Fuzzy logic based handoffs using path codification of mobile station

Figure 5.5 Handoff to j cell versus d) codei and codej, e) codei and recent codei, f) codej and recent codei.
Figure 5.6 Inference mechanism for calculating handoff function