Abstract—We propose new analytical Handoffs in a mobile cellular communications environment will become an increasingly important issue as cell sizes shrink to accommodate an ever growing service load demanded. When handoffs occur at the overlapping area of the cells in a cellular system, a mobile station (MS) must communicate with two different base stations (BS) for some period of time. In this case, an MS in the handoff area connects with two BS’s even though the MS does not move from the current cell to the other cell. Soft handoff region is surrounded by inner cell and outer cell boundaries. A soft handoff call occurs when a mobile station either crosses over the inner cell or outer cell boundary or makes a call inside the soft handoff region. The channel efficiency may increase to overcome this situation. Thus, analysis of handoff rate is a key to understanding and increasing channel efficiency. In this paper, a simple and straightforward mathematical function obtaining direction-based soft handoff rate in cellular systems is proposed.

Index Terms—Introduction, Cellular communication, Cell Model, Soft handoff algorithm.

I. INTRODUCTION

In CDMA cellular systems, a handoff process in which the mobile station (MS) can communicate with the target base station without interrupting the communication with the current base station is called soft handoff, i.e. it makes contact with the target base station before it breaks with the station it is operating on (“make before break”). Soft handoff is needed for seamless communications while a mobile station (MS) is moving between cells [6]. An MS requests a soft handoff to a neighbor base station (BS) whenever the received pilot strength from the neighbor BS exceeds the received handoff threshold, even though the MS may not actually be approaching the neighbor BS. Since two traffic channels have to assign to an MS during the soft handoff period, the utilization of traffic channels is wasted. In conventional cellular systems, a BS does not consider the moving direction of an MS when it assigns a channel to the MS. Therefore, all MSs in the handoff area have to be assigned two traffic channels. The handoff rate is one of the most important parameters for performance analysis of cellular systems. Many approaches have been proposed for handoff rate analysis [3, 4, 7]. The handoff rate can be estimated by a function of the size, the call density and speed of the MSs in the area [1, 4]. But, in the previous approaches, the moving direction of an MS was not considered [4]; the solutions were not straightforward and gave complicated solutions.

II. CELLULAR COMMUNICATION

A Cellular mobile communications system uses a large number of low-power wireless transmitters to create cells-the basic geographic service area of a wireless communications system. As the mobile user travel from cell to cell, their conversations are “handoff” between cells in order to maintain seamless service. Channels used in one cell can be reused in another cell some distance away. Cells can be added to accommodate growth, creating new cells in unserved areas or overlapping cells in the existing areas.

III. CELL MODEL

In CDMA systems, a cell boundary can be determined by the average power levels of pilot signals received. We assume a cell in a cellular network is a straightforward model for analysis of the handoff area. Fig. 1 shows how three concentric circles model the handoff area.

Fig.1. Cells in a CDMA Cellular System

[A] HANDOFF PROCESS IN THE COVENTIONAL CDMA CELLULAR SYSTEMS

The soft handoff area in CDMA cellular systems based on IS-95 is shown in Fig.2. The boundary of soft handoff area is determined by handoff thresholds such as T-ADD and T-DROP. The B1 drop is the boundary where the pilot...
strength from BSI is lower then T-DROP and B2add is the boundary where the pilot strength from BS2 is larger than T-ADD. In conventional cellular system, an MS in the soft handoff area holds two channels and maintains two communication links from BSI and BS2. If there is no traffic channel available in a cell due to the increased traffic load, a new call, or handoff call, has to be blocked until a channel becomes available. Thus, it is important to know the MS’ handoff rate. From fig. 2, when M1 and M2 are moving toward BS 2, two additional channels are needed for handoff in a conventional cellular system. For the purpose of analyzing this model, we will call the handoff process the “outgoing handoff”. If an MS passes over B1 boundary (Bldrop), then the MS has lost contact with BS 1, or “dropped out” of BSI contact. In fig.2, MS2 has dropped out but MS1 has not. Therefore, MS2 may need an additional channel and MS1 may not for handoff to occur. Let’s assume BSI is our model cell, and BS2 is any other target cell.

To calculate the outgoing handoff rate of the cell, we assume that the doughnut shape area from Os to Od in fig. 3 is the handoff area. This area model serves as our point of reference for our analysis of soft handoff rate. Within this area, analysis begins at the point where the MS initiates a call. (Like wise, analysis of any incoming signals from any other MS’ begins at the point in any other call area where the MS initiated the calls) Thus this cell model is universal in its application to all other target cells. The circle Os is a virtual circle whose circumference is determined by the signal limits of all other surrounding target base stations (B2-B7 of fig ). The circumference of the circle Od is determined by the limit of Bldrop signal. A cell boundary can be determined by the average power levels of pilot signals received at a MS from adjacent cell sites. The cell boundary is Ob and this boundary is also determined by the cell and surrounding six cells. We introduce the cell radius R which shows the distance from the base station to the cell boundary. We also introduce parameters “a” and “h” to describe the linear width of the handoff area in relation to R. Even though only one cell is analyzed for handoff rate, it gives us a straightforward understanding of a cell model that applies to all other cells.

R: The radius of cell.
Od: A circle where the pilot signal levels received from the current BS is T-DROP.
Ob: Cell boundary.
Os: The Virtual circle which is determined by pilot strength of surrounding six cell.
hR: Distance parameter from cell boundary to Od.
aR: Distance parameter from Os to ell boundary.

Fig.3. Proposed soft handoff area model

For obtaining soft handoff rate in a cellular system, a function which represents handoff area is needed. Soft handoff area in the original cell is

\[ H_a = R^2\pi - \{(1 - a) R \}^2 \pi = (2a - a^2) R^2 \pi, (1) \]

where \( a < 1 \) and \( R \) is the radius of the cell.

In this case, all calls in the handoff area need two channels in which one is from original cell and the other is from target cell for soft handoff. Therefore, the mean number of handoff calls for a cell in conventional cellular systems is \( E(\lambda) = \int_0^\infty \lambda e^{-\lambda x} dx = \frac{\lambda}{\lambda + 1} \) where \( \lambda \) is the call density per unit area.

[B] HANDOFF RATE IN THE DIRECTION AND SPEED-BASED CDMA CELLULAR SYSTEMS

- AN HANDOFF RATE IN CASE OF sR=aR

We have used the same assumption that the average incoming handoff rate to a cell is equal to the average outgoing handoff rate from a cell [8]. In the cell, we have to consider only the calls which may go beyond Od within its calling duration. For calculating the dropped out handoff rate which is going out from the cell within call duration time, we consider another small circle with its radius \( r = (s+h) R \) and a doughnut shape area with its width = \( (s+h) R \) For easy calculation modeling, we assume that the average moving distance of outgoing calls is \( s+R \) \( =aR \) and \( aR \) R.

We introduce circle Od which is kept apart \( (s+h)R \) from Od. Then, circle Od may overlap with Od as shown at fig.4. To calculate the outgoing handoff rate easily, we assume that an MS has opened its channel at the center of circle “r”. In this case, the circle “r” is moving from the point of call initiation to Od in a straight line azimuth. For example, MSI opens its channel at Od and closes its channel at Od in fig.4. MS2 opens its channel beyond Os, while moving the same distance as MSI, and closes its channel beyond Od. The MSI may not need a handoff channel and the MS2 may need a handoff channel. An outgoing call that occurred at A1 on the Od and then the MS continues to move to (but not beyond) Od on a straight line may have zero dropout probability. As a call occurs nearer the cell boundary, the probability that the MS will travel beyond Od increases.
As another example, a call opened at A2 may have some dropout probability and the dropout probability of the call can be shown as the angle A2 from a2 to a2’. For an easy calculation of angle A, we change the Ov and Od circles into parallel lines as fig. 5. We again consider that the call A3 has occurred, then the drop out probability of the call that can be obtained from angle a3-a3’ depends on its opening position in Fig.5. The dropout probability of the call is \( \frac{A}{180} \).

Let’s assume some calls occurred at the center of circle r from an MS which is moving from Ov to Ob on a straight line, and then the call’s dropout probability can be obtained by

\[
P = \frac{2 \cos^{-1} \left( x / (s + h) R \right)}{180},
\]

where \( x \) is the distance from the call opening position (A) to Od. The reason why we only consider the calls from Os to Ob depends on our one cell model.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{fig5.png}
\caption{The remodel of dropout handoff}
\end{figure}

The mean dropout handoff rate can be obtained by considering whole outgoing calls which open channels in the shadowed doughnut area from Os to Ob in fig.3. The mean dropout handoff rate is

\[
E(\lambda) = E(\lambda) \left( 2\pi p - 2\pi p \right) R^2 \pi p, SiR \geq aR
\]

\[= E(\lambda). (2\pi s^2) R^2, \text{ elsewhere.} \]

The proof of equation (3) is shown at appendix I. \( E(P) \) shows dropout probability of all calls on a straight line azimuth. For obtaining normalized handoff rate, i.e., to make the radius of the virtual circle’s”, the handoff rate multiply by

\[
E(\lambda) = E(P) \cdot \frac{1}{(s + h) R^2}, \quad (4)
\]

where \( (s + h) \) and \( R^2 \) at the denominator are the normalization factors.

The mean number of dropout handoff calls of the cell is obtained by multiplying the handoff area and the call density to the handoff rate.

Then, the mean number of the dropout handoff calls of the cell is \( E(\lambda) = E(P) Ha \)

\[
e = \frac{1}{4} \left( \frac{1}{360} (s + h)^2 R \right) \left( \frac{1}{180} \frac{h}{s + h} \right) + \frac{1}{720} \left( \frac{1}{50} \frac{h}{s + h} \right) R^2 \pi p, SR \geq aR
\]

\[= E(\lambda). (2\pi s^2) R^2, \text{ elsewhere.} \]

The mean number of dropout handoff calls of the cell by using function (4) is

\[
E(\lambda) = E(P) \cdot (2\pi a) R^2 \pi p, \quad SR \geq aR
\]

\[= E(\lambda). (2\pi s^2) R^2, \text{ elsewhere.} \]
IV. HANDOFF ALGORITHMS

The performance of handoff algorithms is quantitatively determined by the following metrics:
1. Number of handoffs: It indicates the total handoff count as the mobile terminal moves between several overlapping BSs/APs.
2. Ping-pong handoffs: The ping-pong handoffs over several overlapping BS/AP coverage areas unnecessarily utilize radio and network signaling resources.
3. Number of handoff attempts: It is the number of connection attempts between the mobile and a new base station before the establishment of a reliable link.
4. Blocking Probability (\( P \)): The denial of request is due to unavailability of channels. This denial of request is called as blocking and its probability is called as blocking probability.
5. Handoff probability (\( \lambda \)): The handoff is called as successful handoff if a mobile changes its connection from one BS to another BS. The probability of such successful handoff is called as handoff probability.
6. Dropping probability (\( \delta \)): Failure to get a successful handoff in the path forces the network to discontinue the call and is dropped.

The probability of such event is called as dropping probability.

V. FIGURES AND TABLES

For analysis of the handoff rate of a cell, we compare all previous functions numerically. Table.1 shows the dropout handoff rate depends on MS’ speed by functions (4) and (6). We assume basic parameter of the model is \( R = 1 \text{ km}, b=4.3 \) and \( a =0.2 \). We also assume that the mean call duration time is 2 minutes and call density \( p=1/\text{sec in a km}^2 \). As “\( s \)” increases from 0.1 to 1, i.e. the MS’s moving speed, the dropout handoff rate \( E(P) \) and the number of dropout call also increase.

Table 1. The number of the dropout handoff call depending on MS’ calls duration time.

<table>
<thead>
<tr>
<th>( s )</th>
<th>0.1</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
<th>0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>( E(p) )</td>
<td>0.0452</td>
<td>0.0726</td>
<td>0.0987</td>
<td>0.1241</td>
<td>0.1495</td>
</tr>
<tr>
<td>( E(\lambda) )</td>
<td>3.2365</td>
<td>9.8530</td>
<td>13.952</td>
<td>16.8425</td>
<td>20.2897</td>
</tr>
<tr>
<td>( P )</td>
<td>0.6</td>
<td>0.7</td>
<td>0.8</td>
<td>0.9</td>
<td>1</td>
</tr>
<tr>
<td>( E(p) )</td>
<td>0.1747</td>
<td>0.1998</td>
<td>0.2248</td>
<td>0.2498</td>
<td>0.2749</td>
</tr>
<tr>
<td>( E(\lambda) )</td>
<td>23.7097</td>
<td>27.1162</td>
<td>30.5091</td>
<td>33.8848</td>
<td>37.3085</td>
</tr>
</tbody>
</table>

Table 2. The dropout handoff rate depending on the change of boundary Od at constant speed. (MS speed being fixed, but signal strength of the model cell is increased by BS and signal strength of all other surrounding cells is decreased).

<table>
<thead>
<tr>
<th>( H )</th>
<th>0.1</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>( E(P) )</td>
<td>0.2093</td>
<td>0.1916</td>
<td>0.1747</td>
<td>0.1571</td>
</tr>
<tr>
<td>( P )</td>
<td>0.5</td>
<td>0.6</td>
<td>0.7</td>
<td>0.8</td>
</tr>
<tr>
<td>( E(P) )</td>
<td>0.1387</td>
<td>0.1187</td>
<td>0.0958</td>
<td>0.0670</td>
</tr>
</tbody>
</table>

Table 3. The number of the dropout handoff call depending on MS’ calls duration time.

\[ E(\lambda) = E(P) \times \text{area x pxl20} \] (a=0.2, R=1, p=1/sec in a km2)

Fig. 7 shows the comparison results between the conventional number of handoff calls and direction and speed-based number of handoff calls.

Table 4. The number of the dropout handoff call depending on the change of boundary Od at constant speed. (MS speed being fixed, but signal strength of the model cell is increased by BS and signal strength of all other surrounding cells is decreased).

<table>
<thead>
<tr>
<th>( H )</th>
<th>0.1</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>( E(P) )</td>
<td>0.2093</td>
<td>0.1916</td>
<td>0.1747</td>
<td>0.1571</td>
</tr>
<tr>
<td>( P )</td>
<td>0.5</td>
<td>0.6</td>
<td>0.7</td>
<td>0.8</td>
</tr>
<tr>
<td>( E(P) )</td>
<td>0.1387</td>
<td>0.1187</td>
<td>0.0958</td>
<td>0.0670</td>
</tr>
</tbody>
</table>

Fig. 8 The dropout handoff rate depending on the change of boundary Od about constant speed.

Fig. 7 Comparison between the conventional number of handoff calls and direction and speed-based number of handoff calls.
VI. CONCLUSION

In conventional cellular systems, a BS does not consider the moving direction and speed of an MS when it assigns a channel to the MS. Therefore, all MSs in the handoff area have to be assigned two traffic channels. If the moving directions of MSs and the moving speed in the handoff area are considered, it is possible to discriminate and ignore unnecessary soft handoff calls to help save traffic channels. We proposed a very simple and straightforward analytical cellular traffic model to estimate the soft handoff rate based on direction and speed based MSs. The handoff rate decreases as MS’ speed decreases. The main results of the study show how we can get handoff rates and number of calls on direction and speed based cellular systems very easily. The analysis results on the proposed calculation model show the theoretical performance of the direction and speed-based cellular handoff.

REFERENCES


Mr. Shelej Khera, H.O.D. & Assistant Professor in department of Electronics & Communication Engg. BAHAL (BHIWANI).