Impact of Platform Motion on Soft Handover in High Altitude Platform IMT-2000 System

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Abstract—In this paper, a platform motion model is proposed for simulations of high altitude platform station (HAPS) systems. Based on the model, the performance of the soft handover algorithm proposed for terrestrial UMTS is evaluated in a HAPS IMT-2000 system. The performance measures including quality of service and system overhead are discussed with different handover parameters. Through the comparison between the results in stationary and motional HAPS environments, the impact of platform motions on the soft handover in CDMA based HAPS systems is studied.

I. INTRODUCTION

In recent years, the development of the wireless communication systems using high altitude platform stations (HAPS) has been receiving more and more attentions due to many advantages of HAPS systems over conventional terrestrial and satellite systems [1]. The International Telecommunication Union (ITU) has accepted HAPS as an alternative means of delivering CDMA based IMT-2000 wireless services. With a multi-beam antenna projecting numerous spot beams within its coverage area, a stratospheric platform would play a role like a group of base stations in terrestrial cellular systems [2].

Handover is an important feature for all cellular systems in order to keep continuous communications of mobiles during the change of serving base stations (BS). In HAPS systems, handovers may occur not only due to terminal movements as in terrestrial systems, but also may due to cellular movements as in satellite systems. Although the stratosphere is a layer of relatively mild turbulence, the platform will inevitably encounter sudden wind gusts, resulting in vertical and horizontal motions of the platform around the destined position. Moreover, current stabilization mechanism cannot eliminate the swing of the antenna beams caused by the rolling and pitch of the platform. Alternatively speaking, even though mobile terminals are stationary, the handover may still exist because the cellular position may change.

In CDMA based cellular systems, soft handover is a widely used technique for its well-known benefits of fade margin improvement and higher uplink capacity. In order to ensure the quality-of-service (QoS) in CDMA based communication networks, many studies have been carried out on soft handover schemes for terrestrial systems [3], [4]. Up to now, however, little research has been devoted to those issues in a HAPS environment. While the performance of UMTS soft handover algorithm is evaluated for HAPS in [5], platform motion, the most important feature of the handover in HAPS systems is neglected by assuming a stationary platform. Due to the lack of a real stratospheric platform, almost no investigation of the soft handover has been addressed for an unstable HAPS system. In order to give a more practical analysis of handover issues in HAPS systems, in this paper, a platform motion model is proposed. Based on the model, the performance of the UMTS soft handover algorithm proposed for terrestrial IMT-2000 systems is evaluated. Through comparison between simulation results in both motional and stationary HAPS environments, the impact of platform motions on the soft handover in HAPS systems is explored.

II. PLATFORM MOTION MODEL

In a HAPS cellular system, a multi-beam antenna onboard projects a number of cells on the ground within the service area. Fig.1 illustrates a typical HAPS system scenario. Since a real stratospheric platform is not available yet, we can hardly give a precise description of the platform motion pattern. However, some form of stabilization mechanism must be...
equipped in HAPS to compensate random deflections of a beam point. Therefore, the beam point will keep swinging within a limited range around the destined direction, as depicted in Fig. 2, and a projected point on the ground will keep moving within a limited range around the destined position. The frequency of the swing is determined by both the power of the wind and the capability of the stabilization mechanism. Based on these features, we separate the two-dimensional moving of the projected point into two random reciprocative motions whose directions are perpendicular to each other. For simplicity, we assume that these two random motions are independent of each other and use a narrow band stationary Gaussian process with a zero mean to describe the angular deflection of the beam point \( \theta(t) \) in both directions, whose power spectral density is given by

\[
S_\theta(f) = \begin{cases} 
\frac{S_0}{f^2} & |f| < f_{ab} \\ 
0 & \text{otherwise} 
\end{cases}
\]

where \( f_{ab} \) is the frequency upper bound of the power spectrum and \( S_0 \) is given by

\[
S_0 = \frac{\sigma_\theta^2}{2f_{ab}},
\]

where \( \sigma_\theta^2 \) is the variance of \( \theta(t) \). By setting the values of \( f_{ab} \) and \( \sigma_\theta^2 \), various motional conditions of the platform can be obtained.

### III. SIMULATION MODELS

#### A. HAPS cellular system model

Our simulation system includes 19 cells located at the nadir. Wrap around method is used to eliminate the boundary effects [6]. To create the similar cellular structure to those in terrestrial systems, an antenna radiation pattern with a steep roll-off of 60 dB/decade is used as suggested in [5]. Fig. 3 shows its mask with a maximum main lobe gain \( G_{as} \) of 36.7 dB.

The location of newly generated calls is uniformly distributed in a cell. The cell from which a new call receives the strongest pilot signal will be assigned as the initial base station if free resource is available in that cell. Otherwise, the call is blocked.

Each mobile terminal is moving at a speed uniformly distributed between 1 and 50 km/h within the service area. The initial direction of a new user is generated by the uniform distribution \( U[0^\circ, 360^\circ] \). The time taken before a mobile user changes its traveling direction is exponentially distributed with mean \( T_{dir} \). In our simulation, \( T_{dir} \) is set to be 144 seconds for all terminals.

#### B. Traffic model

In the simulation, we consider only one class of 32 kbps voice service with a voice activity factor of 0.5. According to the analysis in [5], the maximum number of users that one cell can support is 30 for the forward link. Calls are generated by a Poisson process. The holding time of a call is assumed exponentially distributed with mean of 120 seconds. When the received \( E_b / I_0 \) of an ongoing call is below a specified threshold \( \gamma_{outage} \), we say that the call is in outage. If it keeps in outage for more than 5 seconds, the call is forced into termination (dropped from the network).

#### C. UMTS Soft Handover Algorithm

In order to analyze the impact of motional platforms on the performance of soft handover, the UMTS soft handover algorithm proposed for terrestrial IMT-2000 systems [7], [8] is used for our evaluation. In the soft handover procedure, a mobile constantly monitors the received \( E_b / I_0 \) of pilot signals from all BSs. Based on the measurements, a cell may be added to, removed from, or replaced in the active set of the mobile, as depicted in Fig. 4. The term active set is defined as the set of cells to which the mobile is simultaneously connected.

When the active set is not full, a new cell that the mobile are monitoring will be added to the active set if the received \( E_b / I_0 \) of its pilot signal is higher than the add threshold \( \gamma_{th, add} \) for the triggering time \( \Delta T \). Here, \( \gamma_{th, add} \) is defined as

\[
\gamma_{th, add} = \gamma_{best, as} - \delta_{add},
\]

where \( \gamma_{best, as} \) is the received \( E_b / I_0 \) from the strongest
Figure 4. The general concept of the UMTS soft handover algorithm [7].

measured cell in the active set and $\delta_{\text{add}}$ is the add margin. If the received $E_b/I_0$ from a cell in the active set keeps lower than the drop threshold $\gamma_{\text{th,drop}}$ for $\Delta T$, the cell is removed from the active set. Here, $\gamma_{\text{th,drop}}$ is defined as

$$\gamma_{\text{th,drop}} = \gamma_{\text{best,as}} - \delta_{\text{drop}},$$

where $\delta_{\text{drop}}$ is the drop margin. If the active set is full and the strongest received $E_b/I_0$ from a monitored cell keeps higher than the replacement threshold $\gamma_{\text{th,rep}}$ for $\Delta T$, the cell with the weakest received $E_b/I_0$ in the active set is replaced with the monitored cell. Here, $\gamma_{\text{th,rep}}$ is defined as

$$\gamma_{\text{th,rep}} = \gamma_{\text{worst,as}} + \delta_{\text{rep}},$$

where $\gamma_{\text{worst,as}}$ is the received $E_b/I_0$ from the weakest measured cell in the active set and $\delta_{\text{rep}}$ is the replacement margin.

The basic design parameters for the UMTS soft handover algorithm are the add and drop margins $\delta_{\text{add}}$ and $\delta_{\text{drop}}$, the triggering time $\Delta T$, and the size of the active set. According to the analysis in [9], the setting of add and drop margins has more significant impact on the overall network performance than do other parameters. Therefore, the evaluation below focuses on the performance of the algorithm with different $\delta_{\text{add}}$ and $\delta_{\text{drop}}$ and hence other handover parameters are set to be fixed values.

**D. Platform motion conditions**

As shown in (1) and (2), the frequency upper bound $f_{\text{ub}}$ and the variance $\sigma_{\theta}^2$ of the random angular deflection $\theta(t)$ are two essential parameters to represent the intensity of the beam swing. Considering a practical HAPS system, an effective station-keep mechanism should be adopted to keep the beam swing in a limited range, which is tolerable when the system traffic load is low. Here, any set of $f_{\text{ub}} \leq 0.02$Hz and $\sigma_{\theta} \leq 2^\circ$ can be chosen, since simulations show that few ongoing calls will be forced into termination at a low traffic load (e.g. $<14$Erlangs) under such parameters. It accords with the principle that the platform motion should not degrade the quality of services when the network resource is enough for handover requirements.

The simulation parameters are summarized in Table 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chip rate</td>
<td>3.84 Mcps</td>
</tr>
<tr>
<td>Data rate (speech)</td>
<td>32 kbps (voice activity factor = 0.5)</td>
</tr>
<tr>
<td>Outage threshold $\gamma_{\text{outage}}$</td>
<td>4 dB</td>
</tr>
<tr>
<td>Cell radius</td>
<td>1000 m</td>
</tr>
<tr>
<td>Mobile speed</td>
<td>[1, 50] (km/h)</td>
</tr>
<tr>
<td>Maximum number of users per cell</td>
<td></td>
</tr>
<tr>
<td>Simulation time slot</td>
<td>0.5 s</td>
</tr>
<tr>
<td>Pilot transmit power</td>
<td>33 dBm</td>
</tr>
<tr>
<td>Transmit power per traffic channel</td>
<td>30 dBm</td>
</tr>
<tr>
<td>Active set size</td>
<td>3</td>
</tr>
<tr>
<td>Time to trigger $\Delta T$</td>
<td>2.5 s</td>
</tr>
<tr>
<td>Replacing margin $\delta_{\text{rep}}$</td>
<td>0 dB</td>
</tr>
<tr>
<td>Max main lobe gain of the antenna beam $G_m$</td>
<td>36.7 dB</td>
</tr>
<tr>
<td>Frequency upper bound of the platform motion $f_{\text{ub}}$</td>
<td>0.01Hz</td>
</tr>
<tr>
<td>Std. deviation $\sigma_{\theta}$ of the angular deflection.</td>
<td>$1^\circ$</td>
</tr>
</tbody>
</table>

**IV. PERFORMANCE EVALUATION**

To identify reasonable values for the add and drop margins in the platform motion environment, three different settings of $\delta_{\text{add}}$ and $\delta_{\text{drop}}$ suggested in [5] and [9] are considered for the performance evaluation, which are 2 dB/4 dB, 2 dB/6 dB and 4 dB/6 dB. The evaluations both in a stationary system and in an unstable platform system are carried out to study the impact of the platform motion on the soft handover.

From Fig. 5, we see a significant deterioration on call dropping probability caused by the beam motion. Moreover, the performance with the same add/drop margins is significantly different between motional and stationary environments, where $\delta_{\text{add}}/\delta_{\text{drop}} = 4/6$ dB gives the highest and lowest dropping probabilities respectively.

Although there is a significant difference between the call dropping probability in these two conditions, the outage probability has no evident increase caused by the beam motion, as shown in Fig. 6. In both environments, $\delta_{\text{add}}/\delta_{\text{drop}} = 2/4$ dB gives the best quality of links and $\delta_{\text{add}}/\delta_{\text{drop}} = 4/6$ dB gives the worst outage rate.

In our simulation, as indicated above, the only cause of the drop of an ongoing call is that the call cannot obtain a new link to maintain its QoS during handover. Although the same traffic loads are offered in both environments, a handover is mainly caused by cellular movements under an unstable platform. During cellular movements, more terminals handover at
the same time (i.e. bursty handover) and thus more network resource are required for a successful handover. As a result, although the platform motion does not cause frequent outage of the ongoing call, the dropping probability increases significantly compared with that in a stationary environment.

Since more calls are dropped by the handover in a motional environment, new users have more possibility to access the network with the same traffic load. Therefore, Fig. 7 shows that the call blocking probability has a little improvement due to the beam motion. From the resource utilization point of view, the larger $\delta_{\text{add}}$ and $\delta_{\text{drop}}$ are, the more the network resource will be used by a mobile; hence $\delta_{\text{add}} / \delta_{\text{drop}} = 2/4$ dB gives the lowest call block probability in both cases and $\delta_{\text{add}} / \delta_{\text{drop}} = 4/6$ dB gives the highest one.

To investigate the operation overhead of the soft handover algorithm, two performance measures named the average number of handover operations and the average number of active links are evaluated. The former is the average number of handover operations (adding, dropping, or replacing a link) per call and the latter is the average number of cells in a mobile’s active set during its call. The results with a traffic load of 14 Erlangs are shown in Fig. 8 and Fig. 9, for a zero call dropping probability. As a result of the beam motion, we see an evident increase in the times of handover operations from Fig. 8, which will cause a handover operation every 38 seconds on average, while in the stationary environment the average time interval of handover operations is 90 seconds. Fig. 8 also shows that the average number of handover operations increase as $\delta_{\text{add}}$ increases or $\delta_{\text{drop}}$ decreases regardless of the stability of the platform. Although the motion of the platform increases the mobile’s handover operation times greatly, Fig. 9 shows that there is only slight difference in the average number of active links between motional and stationary environments. Even in a motional environment, as shown in the figure, it is not necessary to set the size of an active set larger than 2.

With respect to various performance requirement, to specify an optimum set of add/drop margins is generally a matter of trade-off. Here, a function for the QoS measure is given by

$$F_{\text{QoS}} = P_b + WP_d$$

as we mainly focus on the effect of call blocking probability $P_b$ and call dropping probability $P_d$. The forced termination of an ongoing call is less desirable than the denied access of a new call, and thus we give a larger weighting factor $W$ to the call dropping probability. Fig. 10 shows the QoS performance
for different add/drop margins when \( W = 50 \). As indicated above, more network resource is required to perform the handover caused by the beam motion and larger \( \delta_{\text{add}} \) and \( \delta_{\text{drop}} \) will result in higher resource utilization. Therefore, \( \delta_{\text{add}} / \delta_{\text{drop}} = 4/6 \) dB yields the worst QoS performance in a motional environment while it may be the best choice when the platform keeps stationary. In addition, we observe that the traffic loads that an unstable HAPS system can support are less than 85% of those in a stationary system in order to approach the same QoS performance.

V. CONCLUSIONS

In this paper, we have presented a motion model of the high altitude platform station. Through simulation, the performance of the UMTS soft handover algorithm for HAPS CDMA based IMT-2000 system has been evaluated. The evaluation is to explore the impact of the platform motion on the selection of the handover parameters. The system performance including call dropping probability, outage probability, blocking probability as well as handover overhead is analyzed for different sets of add/drop margins. Due to the movement of cells in a motional HAPS scenario, the results show that more network resource is required to support a burst of handovers than in a stationary environment. In addition, smaller add and drop margins result in less resource utilization during handover. In our evaluation, therefore, the best performance is achieved with add and drop margins of 2 dB and 4 dB, respectively. Although increasing margins will improve the stability of handovers in conventional terrestrial networks, such benefit may be diminished in a motional platform environment due to larger resource consumption. A trade-off between them needs to be investigated in the future work.

REFERENCES