An Adaptive Thresholds Capacity Reservation Scheme for High Altitude Platform CDMA Systems

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Abstract—In High Altitude Platform Station (HAPS) systems, one of the major challenges is to maintain the station-keeping in the face of stratospheric turbulences. Unstable antenna beam pointing will cause frequent handoffs in HAPS based cellular networks, which drastically increases the forced termination probability of handoff calls. In this paper, we propose an adaptive thresholds capacity reservation (ATCR) scheme for soft handoff in an unstable HAPS scenario. Through a prediction mechanism, a handoff call can dynamically adjust its handoff threshold according to potential traffic load in current cells. Based on a platform motion model, simulations show that the ATCR scheme reduces the blocking and the forced termination probabilities without degrading the quality of service.

I. INTRODUCTION

In recent years, the development of the wireless communication systems using high altitude platform stations (HAPS) has been receiving more and more attention 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 [2]. 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.

Soft handoff is an essential feature in CDMA cellular networks, for its well-known benefits of fade margin improvement and higher uplink capacity [3]. To achieve seamless connections between cells, a soft handoff call will hold two or more connections simultaneously and more network resource is required than during hard handoff. Therefore, one of the key issues in CDMA systems is to make a tradeoff between the capacity improvement and the provision of sufficient resource for soft handoff [4]-[6].

In HAPS based networks, handoff may be a crucial issue due to an unstable platform condition [7]. Caused by turbulence in the stratosphere, there will be roll, pitch and yaw of the platform inevitably. Since the cellular structure of HAPS systems is produced by projecting spot beams on the ground, handoff may occur not only due to terminal movements as in terrestrial systems, but also may due to cellular movements. Moreover, the cellular movements will cause the concurrence of a mass of handoff calls, which results in the forced termination of ongoing calls more probably. To reduce the forced termination probability, a preferred method is to reserve channels for handoff calls. However, in the unstable HAPS environment, the capacity only by reservation may be not enough for the handoff calls coming in bursts.

In this paper, we propose an adaptive capacity reservation scheme with adjustable thresholds for soft handoff in HAPS based CDMA systems. By setting a threshold of the pilot signal of a base station (BS), a mobile terminal (MT) can send a request for capacity reservation to its prospective cells. The BS can predict prospective handoff calls, using the information of received requests. A handoff call will set its drop threshold dynamically according to the potential traffic load in the cell to which its old link belongs. If the traffic load is becoming heavy, the call will drop its old link earlier than predetermination. Therefore, more resource will be available for incoming handoff calls and the forced termination probability will be reduced.

The rest of the paper is organized as follows. In Section II, we present a cellular system based on unstable HAPS platforms and illustrate the impact of the platform motion on the system performance. In Section III, an adaptive capacity reservation scheme is proposed. The performance of the scheme is evaluated through simulations in Section IV. Finally, we draw conclusions in Section V.

II. UNSTABLE HAPS CELLULAR NETWORKS

In a HAPS based cellular system, as illustrated in Fig. 1, a multi-beam antenna onboard projects a number of cells on the ground within the service area. Being subject to sudden wind gusts in the stratosphere, the platform keeps in vertical and horizontal motions around the destined position, which will cause the ceaseless swing of the beam pointing and hence the movement of cells. Mobile terminals on the ground, even at a very slow speed, will frequently handoff between BSs. Although there is no practical stratospheric platform yet, it can be assumed that the motion of the platform is random. In order to explore the impact of the motional platform on performance of the overall system, a stochastic motion model has been proposed in [7]. According to the analysis in [7], we observe...
that the platform motion will not only significantly increase the frequency of handoffs, but also result in the occurrence of handoffs in bursts, as shown in Fig. 2. It brings considerable traffic load to a cell at a short time and cause more handoff calls to be forced into termination. The problem is severer in CDMA systems, because the calls consume more network resource during soft handoff. In the HAPS based CDMA system, therefore, the resource used by soft handoff should be reduced, besides the capacity reservation.

III. ADAPTIVE THRESHOLD CAPACITY RESERVATION SCHEME

An adaptive channel reservation scheme is proposed in [5], based on a predetermined reservation threshold \( T_{\text{resv}} \), as shown in Fig. 3. \( T_{\text{resv}} \) is set to be less than the add threshold \( T_{\text{add}} \), which is used to trigger the request for adding a new link in soft handoff process. If a mobile detects the strength of a pilot signal from any neighboring BS above \( T_{\text{resv}} \), it will send a channel reservation request to that BS. When the pilot strength of the BS that has reserved a channel for the mobile is smaller than \( T_{\text{resv}} \), the mobile will send a request to cancel the reservation. The condition of a new call (originating in current cells) admission is given by

\[
P_{\text{new}}(t) + I_c(t) < I_{\text{total}} - P_t
\]

where \( P_{\text{new}}(t) \) is the assigned power for the new call, \( I_c(t) \) is the current interference, \( I_{\text{total}} \) is defined as the total interference margin and \( P_t \) is the power reserved for handoff calls. An incoming handoff call is admitted whenever there is idle resource.

Due to the stochastic property of the beam motions, the method of predicting prospective handoff calls above is very suitable for adaptive resource reservations in a HAPS based CDMA system. However, handoff calls generally occur in bursts caused by the movement of cells in the HAPS network. A neighboring cell will receive a great number of reservation requests during handoff. If we set the maximum reserved power \( P_{r_{\text{max}}} \) to be a large value, many new calls will be blocked and a considerable amount of system resource may be wasted. If \( P_{r_{\text{max}}} \) is small, the reservation itself cannot reduce the forced termination probability efficiently, which may be very large in the HAPS system. Therefore, we propose an adaptive thresholds capacity reservation (ATCR) scheme for the HAPS based CDMA systems.

For the resource utilization point of view, the less the add threshold \( T_{\text{add}} \) and the drop threshold \( T_{\text{drop}} \), the more network resource will be used. It conflicts with the urgent necessity for resource during the soft handoff. To relieve the pressure on network resource, with the fixed \( T_{\text{add}} \), we set \( T_{\text{drop}} \) to adaptively vary depending on the requests for capacity reservations in the current cell, which is given by

\[
T_{\text{drop}} = \begin{cases} 
\gamma_1 & (I_c(t) < I_{\text{total}} - P_t); \\
\gamma_2 & (I_c(t) \geq I_{\text{total}} - P_t);
\end{cases}
\]

where \( \gamma_1 \) is the predefined drop threshold in the current cell and \( \gamma_2 \) is the threshold for early drop of an old link. Therefore, \( \gamma_1 < \gamma_2 \). The update of the drop threshold is executed whenever a new link is added (i.e. during each adding or replacement process).

With adaptive adjustment of the drop threshold, the ATCR scheme can effectively reduce the forced termination probability of handoff calls. Since the handoff calls generally occur in bursts, the free resource in a cell is often not enough for prospective reservation requests. When a handoff call obtains a new link, it will inquire about the current traffic load and the capacity reserved in the cell to which its old link belongs. If the requested capacity is larger than the free resource, the call will set its drop threshold to be \( \gamma_2 \) and drop its old link earlier than the time predetermined by \( \gamma_1 \). Therefore, more network resource is available in heavy loaded cells and fewer handoff calls are forced into termination.
IV. PERFORMANCE EVALUATION

The performance of ATCR scheme is evaluated in a simulation system including 19 cells, as shown in Fig. 1. An antenna radiation pattern with a steep roll-off of 60 dB/decade is used to create the cellular structure [7]. The newly generated calls are uniformly distributed in a cell. The velocity of MTs has a uniform distribution between 1 and 40 km/h. Their moving direction is uniformly distributed among all directions. Wrap around method is used to eliminate the boundary effects [8]. In our evaluation, only one class of 32 kbps voice service is considered, with a voice activity factor of 0.5. Under the W-CDMA system parameters and the assumption of perfect forward link power control, each cell can support a maximum of 30 users [9]. Calls are generated by a Poisson process. The holding time of a call is assumed exponentially distributed with a mean of 90 seconds.

Referring to the UMTS soft handoff algorithm [7,10], the add and drop thresholds $T_{\text{add}}$ and $T_{\text{drop}}$ are give by

$$T_{\text{add}} = \gamma_{\text{best as}} - \delta_{\text{add}} \quad \text{and} \quad T_{\text{drop}} = \gamma_{\text{best as}} - \delta_{\text{drop}},$$

respectively, where $\gamma_{\text{best as}}$ is the strongest received pilot strength from a BS with which the MT hold a link. $\delta_{\text{add}}$ and $\delta_{\text{drop}}$ are add and drop margins, respectively.

The frequency upper bound $f_{ub}$ and the deviation $\sigma_\theta$ of the random angular deflection of the antenna beams are set to be 0.01 Hz and 1°, respectively. According to the analysis in [7], under such parameters, few ongoing calls are forced into termination caused by the beam motion at a low traffic load (e.g. < 14Erlangs in our simulation system).

The simulation parameters are summarized in Table 1.

![Figure 3. Reservation of capacity for soft handoff calls by the threshold mechanism of pilot strength [5].](image)

Since the ATCR allows a soft handoff call to quickly drop its old link with the cell where it predicts a burst of potential traffic, the cell will provide more resource for incoming calls, either new or handoff ones, compared with the other scheme. Moreover, Fig. 6 shows that this quick release approach does not degrade the link quality of ongoing calls. On the other hand, due to the handoffs in bursts, potential traffic load often exceeds the maximum capacity of a cell. Therefore, the reserved capacity has little effect on the overall system performance when $P_{r_{\text{max}}} > 2$.

V. CONCLUSIONS

In this paper, we have presented an unstable scenario of the high altitude platform station cellular system by using a platform motion model. The swing of the beam pointing brings handoffs in bursts and causes more calls to be forced into termination than in a stationary environment. In a HAPS based CDMA system, such issue is crucial due to larger resource consumption during soft handoff. To counteract the impact of the platform motion, an adaptive reservation scheme with adjustable drop threshold has been proposed. Owing to a prediction mechanism, a soft handoff call can set its drop threshold dynamically based on the prospective traffic load in the old cell. When the handoffs occur in bursts, the old link held by the call is released more quickly and more free resource is available for incoming handoff calls. The simulation results have shown that the ATCR scheme improves the system capacity by reducing the blocking and forced termination probabilities without degradation of the link quality.
REFERENCES


