DOWLINK SOFT HANDOVER GAIN IN UMTS NETWORKS
UNDER DIFFERENT POWER CONTROL CONDITIONS

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ABSTRACT

In this paper, the downlink soft handover gain is analysed in UMTS networks under three different power control situations: without power control, with perfect power control and with imperfect power control. The results show that although power control in the downlink direction is not as crucial as it in the uplink direction, it does have a significant influence on the downlink soft handover gain. The downlink soft handover gain will be overestimated without considering the power control and underestimated without considering the imperfection of the power control process.

I. INTRODUCTION

Soft handover is a technology used in CDMA mobile networks in order to improve the perceived quality of service (QoS) [1]. During the soft handover process, mobile terminals near cell boundaries communicate with more than one base station (BS) simultaneously. Compared to conventional hard handover, soft handover provides a smoother transition and enhanced communication quality.

So far, quite a lot research has been carried out on soft handover, but most of that has focused on the algorithms for soft handover and its impact in the uplink direction [2][3][4][5], or in the downlink direction without considering power control [6][7]. In [6], the effect of soft and softer handovers on CDMA systems capacity is evaluated based on the IS-95 system. The results show that there is a small percentage loss of capacity in the downlink direction when soft handover is employed in unsectorized cells. This small percentage of capacity loss does not affect the system capacity, as the forward-link capacity is higher than that of the uplink due to coherent demodulation. However, in WCDMA systems, coherent detection is also employed in the uplink, based on the use of pilot symbols, resulting in an overall increase of coverage and capacity on the uplink [8]. As a result, the downlink capacity can be the limiting factor of the system capacity in certain situations especially with those systems that support asymmetric Internet services. Therefore, the trade-off between the advantages and disadvantages of soft handover in the downlink direction needs to be further investigated. In [7], a comparison in terms of signal-to-interference ratio (SIR) between soft handover and hard handover is carried out. That paper verified that, compared with hard handover, soft handover has better performance in terms of SIR. However, both papers ([6] and [7]) ignored power control in the downlink direction.

It is well known that decreasing the inter-cell interference is the main reason for employing power control in the downlink direction of WCDMA UMTS systems. In fact, to the mobiles in soft handover status, near the edge of cells, the inter-cell interference is higher than the intra-cell interference. This is especially true when the orthogonality between different downlink channels is well preserved. Therefore, it is not difficult to come to a conclusion that there is some kind of relationship between the power control and the soft handover. In this paper, we verify this intuitional conclusion by analysing the downlink soft handover gain under three different power control conditions separately. The results show that although power control in the downlink direction is not as crucial as it in the uplink direction, it does have a significant influence on the downlink soft handover gain. The downlink soft handover gain will be overestimated without considering the power control and underestimated without considering the imperfection of the power control process.

II. SYSTEM MODEL

A. System Scenario and Radio Channel Model

Consider a UMTS system with ideal hexagonal topology as shown in Fig. 1.
To a mobile in cell 1, the intra-cell interference comes from its serving Base Station (BS) and the inter-cell interference comes from all the BSs around it. Here, we consider BSs in the first and second tiers around BS1. As the interference sources are fixed, the downlink interference received by a certain mobile inevitably depends on the mobile’s location. Assuming fast fading can be effectively combated by the receiver, the radio channel is modelled as the product of the -αth power of distance and a log-normal component representing shadowing losses. For a mobile at a distance r from BSi, the propagation attenuation is proportional to

\[ L(r, \zeta_i) = r^{-\alpha} \cdot 10^{\frac{\zeta_i}{10}} \]  

(1)

Where \( \alpha \) is the path loss exponent and \( \zeta_i \) (in dB) represents the attenuation due to shadowing from the i-th BS, with zero mean and a standard deviation of \( \sigma \), which is independent of the distance; it ranges from 5 to 12 with a typical value of 8 dB. Using the model in [9], the shadowing loss is correlated between BSs.

B. Soft Handover Algorithm

Fig. 2 shows the soft handover algorithm in the UTRAN. More detail can be found in [10].

**Fig. 2 UTRAN soft handover algorithm**

Where

- \( AS_{Th} \): Threshold for macro diversity (reporting range);
- \( AS_{Th} \_Hyst \): Hysteresis for the above threshold;
- \( AS_{Rep} \_Hyst \): Replacement Hysteresis;
- \( AT \): Time to trigger;

This differs from IS-95A and IS-95B because relative thresholds are used in WCDMA systems rather than absolute thresholds. The largest benefit of this algorithm is its easy parameterisation. In IS-95 systems, the absolute parameter has to be tuned to the interference level to maintain a proper proportion of mobiles in soft handover status. Therefore, with a relative threshold, the WCDMA soft handover algorithm is more adaptive to different load situations. In our analysis, the downlink soft handover gain is represented in terms of the downlink capacity gain due to implementing soft handover rather than hard handover within the system. As a function of the proportion of mobiles in soft handover status, the downlink soft handover gain is analysed under no power control, perfect power control and imperfect power control situations separately.

III. DOWNLINK SOFT HANDOVER GAIN

A. Without Power Control

As mentioned in the last section, relative thresholds are used in WCDMA soft handover algorithm. Therefore, the downlink soft handover gain is inevitably related to the system load level, which depends on the distribution and the mobility of users. To separate these effects from the effects caused by power control, we assume a uniform distribution of users, a uniform interference level during soft handover process and a single type of service supported throughout the whole system. Under this assumption, the total transmit power from each BS \( P_{o,\alpha} \) is the same.

To a mobile outside the soft handover zone (e.g. mobile 1 in Fig. 3, the intra-cell interference comes from its serving BS, BS1. Its level depends on the downlink orthogonality factor \( \alpha \) with 1 for perfect orthogonality and 0 for non-orthogonality.

**Fig. 3 soft handover in the downlink**

Ignoring the thermal noise, the received bit energy-to-interference power spectral density radio \( E_b/I_o \) of mobile 1 is

\[ E_b = \frac{W}{\nu R} \left( P_s \alpha^{\frac{1}{10}} \right) \]  

(2)

\[ I_o = \nu R (P_{o,\alpha} - P_s) \alpha^{\frac{1}{10}} + \sum_{i=2}^{M} \sum_{r=1}^{N} P_{o,\alpha} \alpha^{\frac{1}{10}} \]

Where \( W \) is the chip rate, \( R \) is the service bit rate, \( \nu \) is the activity factor, \( P_s \) is the downlink traffic channel transmit power for mobile 1, \( M \) is the number of BSs that are taken into account for the inter-cell interference, as mentioned in section A, \( M=19 \).

Without power control, each downlink traffic channel is allocated the same amount of power. Therefore, \( P_s = \frac{P_{o,\alpha} (1-\gamma)}{N(1-\alpha)} \)  

(3)

Where \( \gamma \) is the ratio of common control channel power to the total transmit power of BS, \( N \) is the number of
active users within each cell, \( x \) is the percentage proportion of users in soft handover status. Considering only two BSs involved soft handover process, the total number of downlink traffic channel for each cell is \( N(1-x) \). Substituting (3) to (2), we can obtain

\[
\frac{E_b}{I_b} = \left(1 - \gamma \right) \frac{1}{2^r} - 10 \frac{\log_{10} \gamma}{10}
\]

(4)

It is clear that without power control, \( E_b/I_b \) is a function of \( r \) and the downlink capacity \( N \) is related to the proportion of users in soft handover status.

To a mobile inside the soft handover zone as mobile 2 in Fig. 3, the desired signals from BSs \( BS_1 \) and \( BS_2 \) are combined together. The actual macrodiversity gain depends on the combining strategies. Here, we consider maximal ratio combining. The actual macrodiversity gain as a function of proportion of users in soft handover status.

\[
\frac{E_b}{I_b} = \left(1 - \gamma \right) \frac{1}{2^r} - 10 \frac{\log_{10} \gamma}{10}
\]

(5)

Where \( [E_b/I_b]_1 \) and \( [E_b/I_b]_2 \) can be obtained from (2) by replace \( r \) with \( r_1 \) and \( r_2 \).

Compared with the hard handover situation, which corresponds to \( x=0 \), the downlink capacity gain caused by soft handover can be obtained from (5). The curve 'no PC' in Fig. 4 shows the downlink soft handover gain as a function of proportion of users in soft handover status. To maximise the downlink capacity, there is an optimum proportion of soft handover.

B. With Perfect Power Control

Unlike that in the uplink, the motivation for having power control in the downlink is not for the near-far problem because in the downlink direction the scenario is one-to-many. For a single-cell system, power control is not needed because the intra-cell interference is independent of the mobile's location. However, the inter-cell interference is related to the mobile's location and the relationship is especially obvious to the mobiles near the cell boundaries. As a result, the allocation of the power to each downlink traffic channel is not even any more. The relationship between \( P_e \) and \( P_{\text{total}} \) becomes more complicated than (3).

Perfect downlink power control equalises the \( E_b/I_b \) of all mobiles at the target value at all times. Under the same system assumptions as section A, the transmit power from \( BS_1 \) for mobile 1 (which is outside the soft handover zone) can be derived from (2)

\[
P_e = \frac{\text{v} B}{W} \frac{E_b}{I_b} P_{\text{total}} \left[ 1 - a \frac{1}{1 - a} + \sum_{j=1}^{M} r_j 10^{-\frac{5}{6} r_j} \right]
\]

(6)

Where \( (E_b/I_b)_1 \) is the target value of \( E_b/I_b \), \( P_e \) relies on the location of the mobile and the load level of the system. During the soft handover process, balanced downlink power control is considered. As well as the inner closed loop power control, an adjustment loop is employed for balancing the downlink power among active set cells during macrodiversity [10][11]. This power control strategy avoids power drifting that leads to increased transmission power and stability problems. In the perfect situation, for mobile 2 (which is in soft handover status), \( P_{e2} = P_{e1} \). Substituting this equation into (5), the transmit power from \( BS_2 \) to mobile 2 can be obtained as

\[
P_{e1} = \frac{\text{v} B}{W} \frac{E_b}{I_b} P_{\text{total}}
\]

(7)

Where \( i, j \) represent the BSs in the first and second tiers around \( BS_1 \) and \( BS_2 \) separately.

C. With Imperfect Power Control

The analysis of downlink soft handover gain under imperfect power control situation is similar to the method used in section B. Letting \( P_e \) represents the error of power control, \( P_e \) can be rewritten as

\[
P_e = P_f + P_d \text{ [dB]}
\]

(10)

Where \( P_e \) is a random variable following a normal distribution. The standard deviation of \( P_e \) reflects the degree of the imperfection. Note that during the soft handover process, \( P_{e1} \) and \( P_{e2} \) are independent. Curve 'imperfect PC' (a) & (b) in Fig. 4 show the downlink soft handover gain as a function of \( x \) under different imperfection level of power control.

The alternative power control scheme is SSDT [10][11], which has an advantage of mitigating interference caused by multiple site transmission [12]. However, it loses the benefits of maximal ratio combining.
expected, soft handover can increase the downlink handover status under different power control conditions. The parameter values are taken from practical ranges of about $\alpha=4$, $\nu=0.5$, $\tau=20\%$, $\sigma=0.6$, $\sigma=4dB$, and $(E_b/N_0)=5dB$.

Consider first the situation without power control. As practical ranges of about $w_4$, the value of capacity when the proportion of users in soft handover conditions. The parameter values are taken from

downlink soft handover gain. However, when $x$ goes up to about 40%, rather than increase the downlink capacity, soft handover actually decreases the capacity. This is because of the disadvantage of having extra resource consumption outweighs the macrodiversity gain. The trade-off between the two opposing effects is quite obvious when power control is not employed.

With perfect power control, the downlink capacity starts to drop when $x$ goes up to only about 5% and there is hardly capacity gain caused by soft handover. The reason is that perfect power control already optimises the system by maintaining the $E_b/N_0$ of all mobiles at the target value at all times. The rise of the total interference caused by the extra downlink channel for soft handover has an influence on all the mobiles within the system. Therefore, without considering power control, the downlink soft handover gain will be overestimated.

The final two results show the downlink soft handover gain under the imperfect power control situation. The standard deviations of $P_e$ are 3dB and 5dB for (a) and (b) respectively. Compared with perfect power control, the downlink capacity gain caused by soft handover gain is higher. This is because the independency of the separate radio channels from the BSs in the active set can compensate for the fluctuation of the power due to the imperfection to a certain degree. The higher the standard deviation of $P_e$, the higher the downlink soft handover gain. For example, when $x=30\%$ (30 percentage of users are in soft handover status), compared to the perfect power control system, the downlink soft handover gain is about 13% higher in an imperfect power control system when the standard deviations of $P_e$ is 3dB.

**V. CONCLUSION**

Although power control in the downlink direction is not as crucial as it is in the uplink direction, it does have a significant influence on the downlink soft handover gain. The downlink soft handover gain will be overestimated without considering the power control and underestimated without considering the imperfection of the power control process. Choosing the proper proportion of active users in soft handover status according to different power control conditions can improve the downlink soft handover gain.

To avoid downlink capacity loss compared with hard handover, the proportion of active users in soft handover status should be maintained approximately under 40%, 5% and 20%, corresponding to no power control, perfect power control and imperfect power control with a standard deviation of 3dB.

References:

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[8] ETSI, Physical channels and mapping of transport channels onto physical channels (FDD). 3GPP TS 25.211 version 3.8.0


