Survey and Taxonomy of Soft Handoff in 3rd Generation CDMA based System

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Abstract

During handoff an ongoing call is transferred from one cell to another as a user moves through the coverage area of a cellular system. This paper presents an overview and critical analysis of published work over handoff performance both in uplink and downlink direction. Further it discusses with future and current trends in handoff research.

Keywords: Handoff, soft handoff, hard handoff, power control

1. Introduction

Handoff is a process of transferring a mobile station from one base station or channel to another. The channel change due to handoff occurs through a time slot for time division multiple access (TDMA), frequency band for frequency division multiple access (FDMA) and codeword for code division multiple access (CDMA) systems [8]. Handoff may be hard or soft. Hard handoff (HHO) is break-before-make, meaning that the connection to the old base station is broken before a connection to the candidate base station is made. Hard handoff occurs when handoff is made between disjointed radio systems, different frequency assignments, or different air interface characteristics or technologies [51]. Soft handoff (SHO) is make-before-break, meaning that the connection to the old BS is not broken until a connection to the new BS is made.

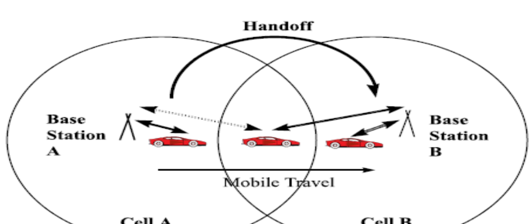

Figure 1: Handoff procedure in cellular system

In fact, more than one base station are normally connected simultaneously to the mobile station. Figure 1 shows a simple handoff scenario in which an MS travels from BS A to BS B.

Initially, the MS is connected to BS A. The overlap between the two cells is the handoff region in which the mobile may be connected to either BS A or BS B. At a certain time during the travel, the mobile is handed off from BS A to BS B. When the MS is close to BS B, it remains connected to BS B. The overall handoff procedure can be thought of as having two distinct phases. The initiation phase (in which the decision about handoff is made) and the execution phase (in which either a new channel is assigned to the MS or the call is forced to terminate). Handoff algorithms normally carry out the first phase. Handoff may be caused by factors related to radio link, network management, or service options [8].

Radio link related causes reflect the quality perceived by users. Some of the major variables affecting the service quality are received signal strength (RSS), signal-to-interference ratio (SIR) and system related constraints. Insufficient RSS and SIR reduce the service quality. Moreover, if certain system constraints are not met, service quality is adversely affected. Handoff is

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required in the following situations due to reduced RSS: (i) when the MS approaches the cell boundary (the RSS drops below a threshold) and (ii) when the MS is inside the signal strength holes in a cell (the signal is too weak to be detected easily). SIR drops, as co-channel interference (CCI) increases and handoff are required. Bit error rate (BER) can be used to estimate SIR.

2. Recent Developments

An enormous research work has been carried on soft handoff since the emergence of IS-95 systems. Previous work on soft handoff can be divided into three broad categories, investigation of soft handoff at link level, at system level and resource efficiency indicators. Work under all these three categories is summarized below.

Analysis of soft handoff algorithm has been done in many previous works [54,59,44,48,41,57,43,40,32,6,26,42,60,55,4,35]. In [54] analysis of soft handoff algorithm has been performed for two BS model considering absolute threshold for both T_{add} and T_{drop}. In [54,59] integral solutions for different performance parameters in infinite domain that involves certain approximation is considered. In [48] a closed-form analysis for performance evaluation of soft handoff is given. Authors have extended the model proposed in [54] for three BSs and have given a more generalized approach for performance analysis of soft handoff algorithm. To evaluate system performance incorporating soft handoff few models were constructed like [60] for combinatorial, [55, 4] for Markov chain and [40, 43] for stochastic reward net model.

During the handoff process each MS in the handoff area occupies at least two channels. It causes degradation in radio frequency (RF) capacity and an increase in call dropping probability in the downlink since handoff area takes about 30%-50% of the entire cell area in the urban CDMA cellular systems. Some techniques have been proposed to cope with these problems by adjusting soft handoff parameters to optimize performance [43,8,34], using adaptive channel reservation [6], eliminating pseudo-handoff calls [41], setting prioritized queues for handoff [20], channel borrowing scheme [33] etc. All these schemes concentrate on improving a particular aspect of the performance in the CDMA system. Some handoff calls unnecessarily occupy multiple channels with little contribution to the performance of handoffs in IS95/CDMA2000-based handoff schemes or systems. A new handoff scheme is proposed in [42] which reallocate these extra channels in the channel convertible set (CCS) to new handoff calls when there is no available free channel in the system. But this scheme adds extra hardware burden and computational complexity.

A soft handoff analysis model with user tracking is discussed in [3, 59]. The user tracking model present a unique analysis method which allows us to see the effects of handoff parameters as the MS is set in motion. But, the analysis is limited to individual MS basis and doing comparable analysis on multiple BSs and MSs becomes prohibitively complicated. In [55, 23], authors have incorporated channelized system models to describe soft handoff behavior. In [55] authors analyzed soft handoff based on a channelized CDMA model with a birth-death Markov process and shows the effects of soft handoff in terms of improving blocking and handoff refused probabilities. But, using a notion of channel to an inherently interference limited system is not easy to concile. In [5] soft handoff is modeled as a reward/cost stochastic optimization problem where the reward is a function of the received signal and the cost is a function of associated overheads. But this model has limitations in studying the effects of power control and resulting interference during soft handoff. In [35] an analytical expression using discrete-time framework is given for evaluating the soft handoff performance of a mobile unit traveling along an arbitrary straight-line trajectory in a CDMA cellular network.

Sensitivity of soft handoff percentage to variations in the propagation environment is analyzed in [18, 19]. Effects of handoff threshold setting on the mean number of active set updates and individual soft handoff statistics are analyzed in these papers. In [10] performance analysis of soft handoff when multimedia services are provided is given. A new analytical model of soft handoff when multimedia services are serviced in CDMA based intelligent transport system is proposed. Same authors in [9] have proposed a CDMA-based-radio-on-fiber road vehicle communication systems to support real-time streaming services in intelligent transportation system. Teletraffic performance analysis of CDMA cellular networks, while taking into account CDMA soft capacity and soft handoff is presented in [46].

For packet data services, allocation of processing gain and its effect on delay and throughput have been analyzed in [24,25,51] but without considering soft handoff. Effects of soft handoff on allocation of processing gain is considered in [29]. In [13] performance of multi-code CDMA based packet data transmission is studied in soft handoff and antenna array. It is found that soft handoff along with antenna array enhances capacity of cellular CDMA networks significantly. In [14] for packet data the combined effects of both soft handoff and space diversity on allocation of processing gain are studied. For packet transmission, transmission scheduling for integrated voice and data traffic is studied in [61] for CDMA downlink with an emphasis on the effect of soft handoff. Same researchers in [62] have studied soft handoff and its effects on connection reliability in cellular CDMA downlink transmissions. Few researchers have concentrated on circuit switched systems [26,7,30] and it is found that performing soft handoff may reduce the downlink capacity if resources are not properly allocated. The downlink soft handoff in [26,7,30] results in some contradictory effects on the system capacity and there is a significant capacity reduction when the geographical soft handoff area is not properly chosen. The reason is that a connection in soft handoff may require much more power resources than that in hard handoff. In [2] authors have presented new ways for designing IP-based wireless base station (IBSs) that can be used to accomplish soft handoff between distributed IBSs without modification to a mobile's radio system. The proposed data content resynchronization procedure is analyzed in [1] by the same researchers.

In [47,11,45] non-orthogonality factor is used to measure the amount of interference caused by the non-orthogonality among multiple fading components by assuming that the MS is only connected to a single BS. A more generalized approach for multiple BS's in the soft handoff set is presented in [37]. It is found in [37] that soft handoff does not always improve capacity and the capacity gain may result depending on the choice of the system parameters. Horizontal handoff manages the mobility within the same access network, while the vertical handoff manages mobility among different access networks. In [58] an analytical framework for vertical soft handoff in heterogeneous wireless network is proposed.

Effects of soft handoff on CDMA downlink capacity has been conducted by many researchers [31,56,12]. In [31,56] it was reported that soft handoff causes capacity loss, which gets larger as the soft handoff region gets wider. It is shown in [12] that under maximal ratio combining the maximum downlink capacity can be obtained without soft handoff. In [28] an analysis on CDMA downlink capacity with hard and soft handoff, when a handoff decision is based on filtered pilot signal strength, is provided. Soft handoff affects the generated interference, it is expected to have significant impact on spreading gain selection and successful transmission of packet data which is considered in [13].

In [16] performance analysis of call outage in CDMA communication network for hard handoff is presented while in [17] same authors have presented the same both for soft and hard handoff. Performance analysis of data services is studied in [50] for CDMA network in presence of soft handoff and beamforming. Same authors in [49] have presented outage analysis in cellular CDMA in presence of soft handoff and beamforming. Capacity improvement from soft handoff and the tradeoff between capacity improvements versus coverage expansion is provided in [21]. Same authors in [22] have proposed a theoretical framework for estimating reverse link cell coverage based on a duration outage criterion. Together with [22], the results presented in [21] can provide a useful methodology for designing cell coverage and capacity of CDMA cell networks. In [15] performance analysis of different handoff algorithms on the downlink direction of CDMA cellular system is presented. Authors in [27] have proposed a hierarchical cellular architecture for increasing cellular system capacity and flexibility.

Handoff area occupies about 30%-50% of the entire cell area in general CDMA cellular systems which in tern can result in channel shortage. Hence several call admission control (CAC) schemes [6,20,34,41,52,53,36,38,39] were presented to cope this problem such as adaptive channel reservation [6], parameter optimization [34], handoff queuing [20]. A new design of efficient call admission control in CDMA systems by using characteristics of the cellular configuration in soft handoff system is presented in [41]. In this work, a new view of cellular geometry in the CDMA system and a relative mobility algorithm for soft handoff are proposed. Based on relative mobility estimation, a new soft handoff scheme which increases system channel utilization and decreases handoff dropping probability is presented. Lindemamn *et al.* [38] introduced a call admission control scheme for real time traffic and developed Markov model for it. A scheme for periodically adjustment of threshold for maximal call degradation for the traffic conditions in the network is presented. In [39] analysis of preemption based call admission control scheme for voice and voice message service is presented. Bin Li *et al.* [36] proposed two schemes mainly as complete sharing and dynamic partition for bandwidth management in multi-service mobile cellular network. In [53] a two dimensional Markov model for integrated voice and data call admission control scheme for soft handoff threshold parameters is presented. Same authors in [52] have proposed an analytical model for new call and handoff call queuing based admission control along with reservation for handoff calls in a CDMA cellular network involving soft handoff region.

3. Future work

Future wireless communication systems will have

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higher data transmission rates, more advance services with higher capacity, flexible quality of service provisioning and user roaming among different networks. Cellular users are expected to access different services like Bluetooth, Wireless LAN, Ad Hoc, satellite networks, as per location, service availability etc. Thus internetworking among different kinds of wireless access networks and handoff among these networks would be of high importance. Work could be carried forward in this respect.

Now a day's variety of services is being provided by wireless service providers. Very few works has been carried out over the impact of soft handoff and user mobility on multi service cellular networks. Hence it could be one of the dimensions where future work can go on. In this work we have taken the base stations up to two tiers only. Work can be extended up to three tiers also to get a more accurate and better analysis. Separate analysis could be done for the MS which are fast moving where call dropping rate of handoff is usually much more. Further, in wireless mobile communication geographical constraints like shadowing of building, mountains, valley etc. play a vital role to the overall performance of the system. Hence these parameters could also be selected for analysis. It can also be analyzed the way in which different handoff algorithms and power control algorithms present in the system can be further optimized.

With Internet based services over mobile station, QoS is one of the vital issue of UMTS systems especially for real time services. In future more attention can be drawn on quality of service requirement in the system. One of the restrictions in this work has been that it did not consider the sectorization of the cell in CDMA systems. Future work can be extended by considering the cell sectorization in to consideration. Further, investigation of soft handoff effects on bursty traffic could be worth interesting.

4. Conclusion

With every year demand for mobile wireless communication is increasing, people want to get connected everywhere. In India this trend is much more where mobile users are increasing to its double in a short period of nine to ten months. Of course population plays an important part in this trend. But the RF resources available to us for communication are limited. Bandwidth is like geography that cannot be changed or modified. The only solution left to us for accommodating more and more users as per the demand is to have an advancement of the technology. Emergence of CDMA technology is a mile-stone in mobile cellular communication system. With this technology more number of users can be accommodated with the same bandwidth spectrum in contrast to earlier technologies FDMA or TDMA. But CDMA system suffers from interference. These are interference limited systems. Hence more work need to be done for encountering this effect. Further, these systems employ soft handoff which has its own advantages and disadvantages. It gives a smoother transmission, less ping-pong effects and macro-diversity gain to the system. However, there is extra resource consumption in employing soft handoff. Thus, optimization becomes crucial for better performance of SHO. Further, due the user demand of Internet based applications over MS, downlink became more critical than uplink in 3G systems.

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