An Overview of Handoff Techniques in Cellular Networks

Nasıf Ekiz, Tara Salih, Sibel Küçüköner, and Kemal Fidanboylu

Abstract—Continuation of an active call is one of the most important quality measurements in the cellular systems. Handoff process enables a cellular system to provide such a facility by transferring an active call from one cell to another. Different approaches are proposed and applied in order to achieve better handoff service. The principal parameters used to evaluate handoff techniques are: forced termination probability and call blocking probability. The mechanisms such as guard channels and queuing handoff calls decrease the forced termination probability while increasing the call blocking probability. In this paper we present an overview about the issues related to handoff initiation and decision and discuss about different types of handoff techniques available in the literature.

***Keywords*—**Handoff, Forced Termination Probability, Blocking probability, Handoff Initiation, Handoff Decision, Handoff Prioritization Schemes.

I. INTRODUCTION

CELLULAR systems deploy smaller cells in order to achieve high system capacity due to the limited spectrum. The frequency band is divided into smaller bands and those bands are reused in noninterfering cells [1-3]. Smaller cells cause an active mobile station (MS) to cross several cells during an ongoing conversation. This active call should be transferred from one cell to another one in order to achieve call continuation during boundary crossings. Handoff (or handover) process is transferring an active call from one cell to another. The transfer of current communication channel could be in terms of time slot, frequency band, or code word to a new base station (BS) [1-4]. If new BS has some unoccupied channels than it assigns one of them to the handed off call. If all of the channels are in use at the handoff time there are two possibilities: to drop the call or to delay it for a while. Different handoff techniques are proposed in literature and two of the most important metrics for evaluating a handoff technique are forced termination probability and call blocking probability. The forced termination probability is the probability of dropping an active call due to handoff failure and the call blocking probability is probability of blocking a new call request [2, 5-6]. The aim of a handoff procedure is to decrease forced termination probability while not increasing call blocking probability significantly.

Manuscript received June 20, 2005.
The authors are with the Computer Engineering Department at Fatih University, Istanbul, Turkey (phone: +90-212-8890810; fax: +90-212-8890906; e-mail: nekiz@fatih.edu.tr).

II. HANDOFF INITIATION

Handoff initiation is the process of deciding when to request a handoff. Handoff decision is based on received signal strengths (RSS) from current BS and neighboring BSs. In Fig. 1 we examine RSSs of current BS (BS1) and one neighboring BS (BS2). The RSS gets weaker as MS goes away from BS1 and gets stronger as it gets closer to the BS2 as a result of signal propagation. The received signal is averaged over time using an averaging window to remove momentary fadings due to geographical and environmental factors [1-2]. Below, we will examine the four main handoff initiation techniques mentioned in [2-3]: *relative signal strength*, *relative signal strength with threshold*, *relative signal strength with hysteresis*, and *relative signal strength with hysteresis and threshold*.

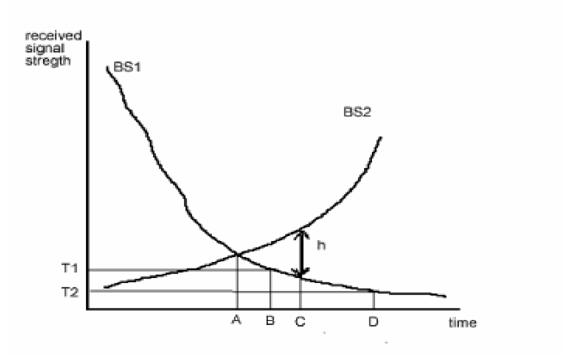

Fig.1 Movement of a MS in the handoff zone

A. Relative Signal Strength

In relative signal strength, the RSSs are measured over time and the BS with strongest signal is chosen to handoff. In Fig. 1 BS2's RSS exceeds RSS of BS1 at point A and handoff is requested. Due to signal fluctuations, several handoffs can be requested while BS1's RSS is still sufficient to serve MS. These unnecessary handoffs are known as *ping-pong* effect. As the number of handoffs increase, forced termination probability also increases. So, handoff techniques should avoid unnecessary handoffs.

B. Relative Signal Strength with Threshold

Relative signal strength with threshold introduces a threshold value (T1 in Fig. 1) to overcome the ping-pong effect. The handoff is initiated if BS1's RSS is lower than the threshold value and BS2's RSS is stronger than BS1's. The handoff request is issued at point B in Fig. 1.

International Journal of Information, Control and Computer Sciences
ISSN: 2517-9942
Vol:1, No:6, 2007

C. Relative Signal Strength with Hysteresis

This technique uses a hysteresis value (h in Fig.1) to initiate handoff. Handoff is requested when the BS2's RSS exceeds the BS1's RSS by the hysteresis value h (point C in Fig. 1).

D. Relative Signal Strength with Hysteresis and Threshold

The last technique combines both the threshold and hysteresis values concepts to come with a technique with minimum number of handoffs. The handoff is requested when the BS1's RSS is below the threshold (T1 in Fig. 1) and BS2's RSS is stronger than BS1's by the hysteresis value h (point C in Fig. 1). If we would choose a lower threshold than T1 (but higher than T2) than the handoff initiation would be somewhere at the right of point C.

All the techniques discussed above initiate handoff before point D where it is the "receiver threshold". Receiver threshold is the minimum acceptable RSS for call continuation (T2 in Fig. 1) [1]. If RSS drops below receiver threshold, the ongoing call is than dropped. The time interval between handoff request and receiver threshold enable cellular systems to delay the handoff request until the receiver threshold time is reached when the neighboring cell does not have any empty channels. This technique is known as queuing handoff calls and will be discussed in Section V.

In [7], a handoff algorithm using multi-level thresholds is proposed which assigns different threshold values to the users according to their speed. Since low speed users spend more time in handoff zone they are assigned a higher threshold to distribute high and low speed users evenly. High speed users are assigned lower thresholds. The performance results obtained by [7] shows that an 8-level threshold algorithm operates better than a single threshold algorithm in terms of forced termination and call blocking probabilities.

III. Handoff Decision

In the previous section we discussed when the handoff is requested. In this section we will examine the handoff decision protocols used in various cellular systems.

A. Network Controlled Handoff (NCHO)

NCHO is used in first generation cellular systems such as Advanced Mobile Phone System (AMPS) where the mobile telephone switching office (MTSO) is responsible for overall handoff decision [8]. In NCHO, the network handles the necessary RSS measurements and handoff decision.

B. Mobile Assisted Handoff (MAHO)

In NCHO the load of the network is high since network handles the all process itself. In order to reduce the load of the network, MS is responsible for doing RSS measurements and send them periodically to BS in MAHO. Based on the received measurements, the BS or the mobile switching center (MSC) decides when to handoff [3-4]. MAHO is used in Global System for Mobile Communications (GSM) [4].

C. Mobile Controlled Handoff (MCHO)

MCHO extends the role of the MS by giving overall control to it. The MS and BS, both, make the necessary measurements and the BS sends them to the MS [3]. Then, the MS decides when to handoff based on the information gained from the BS and itself. Digital European Cordless Telephone (DECT) is a sample cellular system using MCHO [4].

IV. Handoff Types

In this section we will mention about different types of handoffs. First, we will concentrate on channel usage. Then, we will investigate handoff in microcells and multilayered systems. Finally, we will explain handoff in homogeneous and heterogeneous systems.

A. Hard vs. Soft Handoff

The hard handoff term is used when the communication channel is released first and the new channel is acquired later from the neighboring cell. Thus, there is a service interruption when the handoff occurs reducing the quality of service. Hard handoff is used by the systems which use time division multiple access (TDMA) and frequency division multiple access (FDMA) such as GSM and General Packet Radio Service (GPRS) [9].

In contrast to hard handoff, a soft handoff can establish multiple connections with neighboring cells. Soft handoff is used by the code division multiple access (CDMA) systems where the cells use same frequency band using different code words. Each MS maintains an active set where BSs are added when the RSS exceeds a given threshold and removed when RSS drops below another threshold value for a given amount of time specified by a timer. When a presence or absence of a BS to the active set is encountered soft handoff occurs. The sample systems using soft handoff are Interim Standard 95 (IS-95) and Wideband CDMA (WCDMA) [2, 4, 9].

B. Microcellular vs. Multilayer Handoff

In this section we will first look at the handoff issues in microcellular environments. Later, we will investigate some systems that use microcells overlaid by macrocells in order to minimize number of handoffs.

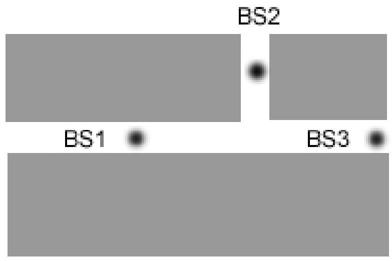

Fig. 2 A city segment with three BSs deployed on streets

1) Microcellular Handoff

The microcells are cells with small radii and employed in highly populated areas such as city buildings and streets to meet high system capacity by frequency reuse. In Fig. 2 we have two streets intersecting with three BSs employed on streets. BS1 and BS3 have line-of-sight (LOS) with each other. The handoff between BS1 and BS3 is called LOS handoff while the handoff between BS1 and BS2 is a non-

LOS (NLOS) handoff since they don't have LOS [2, 4, 9]. In NLOS handoffs, when a MS lose LOS (by turning the corner) with current BS, a drop in RSS (20-30 dB) occurs [4, 9]. This effect is called corner effect and needs faster handoff algorithms since the RSS can drop quickly below receiver threshold resulting in a call drop. Two types of handoffs, LOS and NLOS, have different characteristics where LOS handoffs try to minimize the number of unnecessary handoffs between BSs and NLOS must be as quickly as possible because of the corner effect.

In [9], a fast handoff algorithm for hard handoffs is proposed to remove fast fading fluctuations resulting in algorithm that reacts more quickly to corner effect. They propose a technique called local averaging, in which the averaging time interval is smaller than averaging time interval of common handoff algorithms and improve handoff performance.

A direction biased algorithm is proposed in [10] where all the BSs in handoff decision are grouped in two groups. One set of BSs are those in which MS is approaching and the other set includes the BSs in which the MS moves away. In handoff initiation an encouraging hysteresis (h_e) is used to first group where a discouraging hysteresis (h_d) is applied to the second one. The relation between these hysteresis values are $h_e \le h \le h_d$. A signal strength based direction estimation method is used for determining the mobile positions.

2) Multilayer Handoff

Some designs used a multilayer approach in order to decrease the number of handoffs and to increase system capacity. A number of microcells are overlaid by a macrocell and the users are assigned to each layer according to their speeds. Microcells and macrocells coverage area are respectively about 500 meters and 35 km for GSM900 in [11]. Since slow users are assigned to the microcells and fast users are assigned to the macrocells, the total number of handoff requests is decreased. Macrocells not only serve the fast users but also serve slow users when the microcells are congested. When a microcell allocates all of its channels, the new and handoff calls are overflowed to the macrocell layer. When the microcells load decreases it is possible to assign slow users back to the microcell. This type of handoff is called take-back. So far, we have four types of handoffs: microcell-to-microcell, microcell-to-macrocell, macrocell-to-macrocell, and macrocell-to-microcell [4].

In [6], a bonus-based algorithm is proposed where it is compared with classical and macro algorithms. In the classical algorithm, in the case of new call request a user is assigned to microcell or overflowed to macrocell if capacity of microcell is full. After the user speed estimation is done, the user is assigned to the appropriate layer using overflow and take-back. This scheme results in too many handoffs known as the ping-pong effect. Macro algorithm is similar to classical algorithm with one exception. When a user is assigned to the macrocell it is not permitted to take-back to microcell which decreases the number of handoffs. The bonus-based algorithm tries to prevent unnecessary handoffs to microcell when fast users temporarily slow down. For each fast user a time bonus is given and user can use this time bonus during temporary slow downs. If a user exceeds the timer then it is assigned as a slow user and is taken-back to the microcell layer.

Hu and Rappaport [12] also described and proposed a model for three-layer hierarchical network consisting of microcells, macrocells, and spot beams. Microcells and macrocells are terrestrial part of the network whereas spot beams correspond to satellite part. The users can be overflowed from low layers to the uppers but take-back is not allowed here.

C. Horizontal vs. Vertical Handoff

Handoff between homogenous networks where one type of network is considered is called horizontal handoff. On the other hand, handoff between different types of networks is also possible. A handoff in such a heterogeneous environment is named vertical handoff and it is out of scope of this paper [13]. All the issues described in this paper are related to horizontal handoff.

V. Prioritization Schemes

In non-prioritization schemes new calls and handoff calls are treated the same way. When a BS has an idle channel, it is assigned due to first-come first-serve basis regardless of whether the call is new or handoff. But, forced termination of an active call is less desirable by the cellular users in contrast to new call blocking [1, 5, 14]. In order to provide lower forced termination probability, prioritization schemes assigns more channels to the handoff calls. The two well-known prioritization schemes are: guard channels and queuing handoff calls [1, 3-5].

A. Guard Channels

The guard channel scheme reserves some fixed or adaptively changing number of channels for handoff calls only. The rest of the channels are used by new and handoff calls. So, the handoff calls are better served and forced termination probability is decreased. The cost of such a scheme is an increase in call blocking probability and total carried traffic.

In [14] the number of guard channels is determined dynamically by the use of neighboring BSs. Each BS determines the number of MSs in pre handover zone (PHZ) periodically and informs its neighbor BS related to that PHZ. PHZ is a small area located next to handoff zone and contains the possible users that will enter handoff zone soon. When the BS gets the number of MSs in PHZ it reserves that amount of guard channels for handoff calls. A new call is assigned a channel if no handoff calls are queued in the queue where handoff calls are kept and the total number of free channels is greater than the number of guard channels.

Zhang and Liu [15] proposed an adaptive algorithm which assigns the number of channels adaptively. When forced termination probability exceeds a predefined threshold the guard channel number is increased to decrease forced termination probability to below the threshold. The number of guard channels is decreased in the case where BS does not use reserved guard channels significantly.

B. Queuing Handoff Calls

Queuing handoff calls prioritization scheme queues the handoff calls when all of the channels are occupied in a BS. When a channel is released, it is assigned to one of the handoff calls in the queue. A new call request is assigned a channel if the queue is empty and if there is at least one free channel in the BS. Also, some systems queue new calls to decrease call blocking probability [16]. The time interval between handoff initiation and receiver threshold makes it possible to use queuing handoff calls. Queuing handoff calls can be used with/without the guard channel scheme.

In [3], a timer based handoff priority scheme is proposed. When a channel is released at BS, a timer is started. If a handoff request is done in that time interval it is assigned to it. Otherwise, when the timer expires, the channel can be assigned to new or handoff calls depending on the arrival order.

Tekinay and Jabbari [5] introduced a new prioritization scheme called Measurement Based Prioritization Scheme (MBSP). The handoff calls are added to the queue and priorities of the calls changes dynamically based on the power level they have. The calls with power level close to the receiver threshold have the highest priorities. This scheme provided better results from the first-in first-out (FIFO) queuing scheme where the handoff calls are served due to arrival time.

The Most Critical First (MCF) policy described in [14] determines the first handoff call that will be cut off and assigns the first released channel to that call. The first handoff call that will be cut off has the highest priority. The authors proposed a method to predict the first handoff call to be cut off by using simple radio measurements.

In [16] a queuing scheme using guard channels is described. Both new calls and handoff calls are queued. A number of guard channels are reserved for handoff calls. When the new calls are congested, a channel from the guard channels is used if it is available. This scheme decreases the call blocking probability while increasing forced termination probability slightly.

Salih and Fidanboylu [17], [18] described and modeled queuing techniques for two-tier cellular networks. In [17], a microcell/macrocell network using a FIFO queue in macrocell tier and in [18] a microcell/macrocell network using a FIFO queue in microcell tier is introduced and compared with each other. The results of both systems showed that forced termination probability for slow users is decreased when the FIFO queue is used in microcell and forced termination for fast users is decreased when the queue is in macrocell.

VI. Conclusion

In this paper, we introduced an overview on the concept of handoff and its evaluation parameters. We discussed the handoff initiation techniques based on the received signal strength and also the handoff decision protocols that are used. In addition, the handoff types based on channel usage, microcellular and multilayered systems and network characteristics are explained. Finally, we presented the handoff prioritization schemes to reduce the handoff call blocking probability, such as guard channels and queuing handoff calls.

References

[1] S. Tekinay and B. Jabbari, "Handover and Channel Assignment in Mobile Cellular Networks", *IEEE Communications Magazine,* vol. 29, November 1991, pp. 42-46.

[2] Gregory P. Pollioni, "Trends in Handover Design", *IEEE Communications Magazine*, vol. 34, March 1996, pp. 82-90

[3] P. Marichamy, S. Chakrabati and S. L. Maskara, "Overview of handoff schemes in cellular mobile networks and their comparative performance evaluation", *IEEE VTC'99,*vol. 3, 1999, pp. 1486-1490.

[4] Nishint D. Tripathi, Jeffrey H. Reed and Hugh F. VanLandinoham, "Handoff in Cellular Systems", *IEEE Personal Communications*, vol. 5, December 1998, pp. 26-37.

[5] S. Tekinay and B. Jabbari, "A Measurement-Based Prioritization Scheme for Handovers in Mobile Cellular Networks*", IEEE Journal on Selected Areas in Communications*, vol. 10, no. 8, Oct. 1992, pp. 1343-1350.

[6] A. Iera, A. Molinaro and S. Marano, "Handoff Management with Mobility Estimation in Hierarchical Systems", *IEEE Transactions on Vehicular Technology*, vol. 51, Sept. 2002, pp. 915-934.

[7] Y. Kim, K. Lee and Y. Chin, "Analysis of Multi-level Threshold Handoff Algorithm", *Global Telecommunications Conference (GLOBECOM'96)*, vol. 2, 1996, pp. 1141-1145.

[8] Andrew S. Tanenbaum, Computer Networks - Fourth Edition, Prentice Hall, 2003

[9] Alexe E. Leu and Brian L. Mark, "Modeling and Analysis of Fast Handoff Algorithms for Microcellular Networks", *Proceedings of the 10th IEEE MASCOTS'2002*, Oct. 2002, pp. 321-328.

[10] Mark D. Austin and Gordon L. Stüber, "Direction Biased Handoff Algorithms for Urban Microcells", *Proceedings of 44th IEEE Vehicular Technology Conference*, vol. 1, 1994, pp. 101-105.

[11] J. Naslund, C. Carneheim, C. Johansson, S.-O. Jonsson, M. Ljungberg, M. Madfors, J. Skold, "An Evolution of GSM", *IEEE 44th Vehicular Technology Conference*, vol. 1, 1998, pp. 348-352.

[12] Lon-Rong Hu and Stephen S. Rappaport, "Personal Communication Systems Using Multiple Hierarchical Cellular Overlays", *IEEE Jo*ı*rnal on Selected Areas in Communications,* vol. 13, no. 2, Feb. 1995, pp. 406-415.

[13] M. Stemm and Randy H. Katz, "Vertical handoffs in wireless overlay networks", *Mobile Networks and Applications,* vol. 3*,* 1999, pp. 335-350.

[14] P. Agrawal, Dinesh K. Anvekar and B. Narendran, "Channel Management Policies for Handovers in Cellular Networks", *Bell Labs Technical Journal*, vol. 1, Autumn, 1996, pp. 96-109.

[15] Y. Zhang and D. Liu, "An Adaptive Algorithm for Call Admission Control in Wireless Networks", *IEEE Global Telecommunications Conference (GLOBECOM'01),* vol. 6, 2001, pp. 3628-3632.

[16] S. Choi and K. Sohraby, "Analysis of a Mobile Cellular Systems with Hand-off Priority and Hysteresis Control", *IEEE INFOCOM 2000*, vol. 1, March 2000, pp. 217-224.

[17] T. Salih and K. Fidanboylu, "Performance Analysis and Modeling of Two-Tier Cellular Networks with Queuing Handoff Calls", *Proc. of the 8th IEEE Symposium on Computers and Communication (ISCC'03)*, vol. 1, 2003, pp. 143-148.

[18] T. Salih and K. Fidanboylu, "A Comparison of the Performance of Two-Tier Cellular Networks Based on Queuing Handoff Calls", *International Journal of Signal Processing,* vol. 1, 2004, No. 1-4, pp. 343-347.