Handoff in Mobile Cellular Communications

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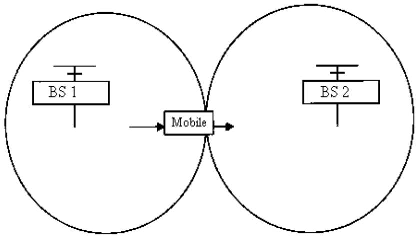
Abstract:

Mobile Computing is a generic term describing the application of small, portable, and wireless computing and communication devices. This includes devices like laptops with wireless LAN technology, mobile phones, wearable computers and Personal Digital Assistants (PDAs) with Bluetooth or IRDA interfaces, and USB flash drives. Mobile computing being able to use a computing device even when being mobile and therefore changing location. *Portability* is one aspect of mobile computing. One major issue that needs to be addressed then is a loss less handover from macro to macro cellular, terrestrial to satellite and vice versa.

Keywords: macro and micro cellular network, basestations, mobile devices , microcells

Introduction

When a mobile user travels from one area of coverage or cell to another cell within a call's duration the call should be transferred to the new cell's *base station*. Otherwise, the call will be dropped because the link with the current base station becomes too weak as the mobile recedes. Indeed, this ability for transference is a design matter in mobile cellular system design and is call *handoff*.

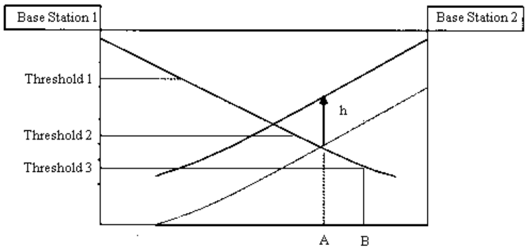


Two basic types of handoff are

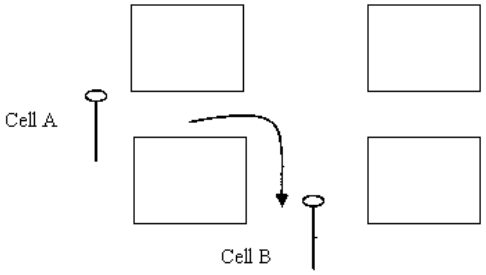
1. **Hard handoff**
2. **Soft handoff.**

With hard handoff, the link to the prior base station is terminated before or as the user is transferred to the new cell's base station. That is to say that the mobile is linked to no more than one base station at a given time. Initiation of the handoff may begin when the signal strength at the mobile received from base station 2 is greater than that of base station 1. The signal strength measures are really signal levels averaged over a chosen amount of time. This averaging is necessary because of the Rayleigh fading nature of the environment in which the cellular network resides. A major problem with this approach to handoff decision is that the received signals of both base stations often fluctuate. When the mobile is between the base stations, the effect is to cause the mobile to wildly switch links with either base station. The base stations bounce the link with the mobile back and forth. Hence the phenomenon is called ***ping- ponging***. Besides ping ponging this simple approach allows too many handoffs. It has been shown in early studies that much of the time the previous link was well adequate and that handoffs occurred unnecessarily. A better method is to use the averaged signal levels relative to a threshold and hysteresis margin for handoff decision. Furthermore, the condition should be imposed that the target base station's signal level should be greater than that of the current base station.

The handoff should take place at point A for the choice of Threshold 1 or Threshold 2. The handoff should take place at point B for Threshold 3. In has now been shown in practice that using the hysteresis margin greatly reduces the number of unneeded handoffs. However, there is a delay factor involved here. It will be shown later that one may set up optimum trade off values for the parameters threshold and hysteresis to obtain a tolerable delay.



Because of the increasing demand for wireless services, the available channels within the cells become insufficient to support the growing number of users. To increase the system capacity, techniques such as *cell splitting* and *sectoring* may be implemented. Using *microcells* also improves cellular system capacity, and it is an attractive alternative to the two former mentioned techniques. While the group of cells may maintain a particular area of coverage, the co-channel interference is reduced. Decreasing the co-channel interference increases the system capacity without *trunking* inefficiency degradation inherent to sectoring. However, innate to microcells is the increase in frequency of handoffs. So we seek efficient decision algorithms to achieve less unnecessary handoffs, yet more reliable handoffs with low blocking probability and low probability of lost calls. Mobiles moving around in microcells will face line of sight (LOS) handoffs and non line of sight (NLOS) handoffs. In the case of NLOS, completely reliable handoffs are difficult to achieve. A problem with microcells is the so called *corner effect*. When a mobile station moves around a corner such as at a street intersection, there can be a sudden drop in the received signal level. It loses its LOS component with the serving base station. Now if the mobile user does not link up with this new base station B fast enough, the call gets dropped. Furthermore, the mobile can cause interference to the new base station. The base station is unable to regulate the power of the mobile and users within this cell are blocked.



In the cellular design, one could carefully plan so that this can’t happen. That is lay out the cells in such a way that no corner effect will ever be encountered. This cannot always be practically done. Measures are taken in handoff design to help alleviate this problem. We may use a fast forward handoff as the old base station is dropped. Decentralizing the handoff decision, as in the case of the mobile assisted handoff, often achieves this fast forward handoff decision. With decentralizing, it is advantageous that the central switch does not have to make the handoff decisions for every mobile user. This amounts to a saving in system resources.

A problem with faster handoff is that we lose the benefits associated with signal averaging and hysteresis. As was mentioned before, this was helpful in mitigating unnecessary handoffs and ping ponging. However as is now clear, the time of handoff is critical in mircocellular systems and we may not tolerate the delay that comes with hysteresis windows. The handoff must be fast. Now recall that in order to initiate a handoff, the movement of the mobile station from one cell to another must be detected. A reliable method to make this detection and to accommodate the movement is to measure the received signal strengths to the base stations and from the user. In order to avoid excessive and inaccurate handoffs, an averaging of the received signal levels is performed as well as implementing a hysteresis margin. The total handoff delay is the sum of the signal averaging delay and the hysteresis delay. We seek to make this delay small. develops an analytic approach to select the signal averaging time and hysteresis delay in order to obtain an optimum tradeoff between those two parameters as well as a tradeoff between the total delay time and the number of allowable unnecessary handoffs. some important parameters are given mathematical expressions. It is shown that the probability of an unnecessary handoff is given as:

$$P_{u} = \left[\int_{-\infty}^{\infty} f(x)\cdot\left(\frac{1}{2}\cdot\operatorname{erf}\left(x-\frac{h-\Delta_{L}}{\sigma}\right)\right)dx\right]\left[\int_{-\infty}^{\infty} f(x)\cdot\left(\frac{1}{2}\cdot\operatorname{erf}\left(x-\frac{h+\Delta_{L}}{\sigma}\right)\right)dx\right]$$

where f(x) is considered as

$$\frac{1}{\sqrt{2\cdot\pi}}\cdot e^{-\frac{x^{2}}{2}}$$

D L is the difference between the two received signal levels due to the pathloss difference from the two base stations involved in the handoff. And, h is the hysteresis level.

For macrocells, the total delay time is:

$$\delta_{hM} := \frac{T}{2} + K_{rv}\cdot\frac{10^{\frac{h-\sigma}{K_{2}}-1}}{10^{\frac{h-\sigma}{K_{2}}+1}}$$

T denotes the signal averaging window .
K2 represents a path loss constant

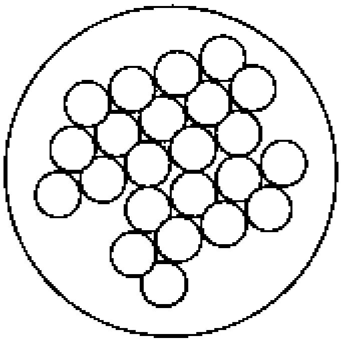
Krv represents the normalized distance from the mobile station to base station.

For microcells, the total delay time is:

$$\delta_{hu} := \frac{T}{2} + T\cdot\frac{h-\sigma}{4\cdot d_{cor}}$$

d_{cor} denotes the drop in signal level experienced at a street corner and is determined experimentally. The analysis shows that there exists compromises between the parameters of averaging time and hysteresis delay. It is evident that for microcells we may wish to choose short averaging time and a larger hysteresis. The converse is clear for macrocells. The main point here is that optimum parameter values may be selected for a tolerable delay in conjunction with some tolerable probability of unnecessary handoff.

By using alternate antenna heights working at different power levels, it is possible to have different size cells coexist within a single geographic framework. Thus may be implemented the so called *umbrella cell* consisting of two or more levels. That is a macrocell, which contains perhaps a grid of microcells.



Users in this system are assigned to a particular cellular level based on the mobile transmitter’s speed. The umbrella cell system is used to minimize the many handoffs incurred by high speed mobiles while providing capacity that is inherent to microcells for slow moving users. Handoffs from microcell to microcell can be avoided. Now the slow moving users are placed into the service of a microcell and retain service therein until an increase in mobile transmitter speed overtakes some deciding measure and is therefor urged into a macrocell. However, in the real cellular system, the speed is not really known. Fortunately, there are a couple of common ways to estimate the user speed. One way is to use the statistics of the dwell time. The dwell time is defined as the amount of time over which a call is maintained within a particular cell. Obviously, the dwell time is dependent upon the mobile station’s speed. Based on information of the dwell time, a rough estimate of the user speed may be obtained. Further, the estimate may be improved if the mobile’s past behavior is memorized and accounted for. Given n dwell times, mobile station speed may be estimated as follows. First assume that the mobile speed is uniform over an interval [a,b]. It is found that the maximum likelihood (ML) estimate is:

$$v_{estimate} := \frac{n}{k}$$

and the maximum squared error (MMSE) estimate is:

$$v_{estimate} := \frac{n+1}{k} + \frac{a^{n+1}\cdot e^{-k\cdot a} - b^{n+1}\cdot e^{-k\cdot b}}{\displaystyle\sum_{i=0}^{n} \frac{n!}{(n-i)!\cdot k!}\cdot\left(a^{n-i}\cdot e^{-k\cdot a} - b^{n-i}\cdot e^{-k\cdot b}\right)}$$

$$k := \prod_{i=1}^{n} c_i \cdot t_i$$

c_i depends on the type of handoff -- *i.e.* micro to micro, micro to macro etc.
four strategies are proposed to estimate speed so that an assignment can be made

for fast moving mobiles to the macro layer and slower users to the micro layer. The first two strategies are based only on the most recent dwell time t. The third and fourth acquire speed estimations based on the ML estimator and MMSE estimator respectively.

Strategy 1) All the users that are new are placed in a microcell. The idea is to simply move the user to a larger cell if the dwell time spent in that microcell is short in relation to a threshold parameter T.

Strategy 2) Like strategy 1, all new users are put into the service of a microcell. However here, users are updated regularly between cell levels base on continuous dwelling duration measurements.

Strategy 3) Make a record of all past cell dwell times spanning a call. Use ML estimators to approximate the speed. Make an appropriate level handoff decision based on those estimates.

Strategy 4) This is similar to strategy 3 except that MMSE is used to estimate mobile station speed. Results from models and real systems have shown that there is a marked reduction in handoffs for strategy 3 and 4 especially in low traffic situations.

Another method to estimate the mobile speed for optimum cell level placement is to take advantage of diversity reception. As will be seen for soft handoff in CDMA systems, it is good practice to use selection diversity to mitigate the effects of Rayleigh fading . Mobile velocity can be estimated from Doppler frequency. Recall that with selection diversity two or more antennas are used. A receiver will switch to the strongest received signal branch. To estimate the Doppler frequency, the rate of switching is measured. Based upon the autocorrelation of Rayleigh fading, the following relation exists between switching rate N_{BS} and Doppler frequency f_D.

$$f_D := \frac{N_{BS}}{1.3}$$

This is a good approximation and the Doppler measure here is used to estimate the speed.

i. CDMA uses ***soft handoff***. Soft handoff is beneficial because it reduces interference into other cells and improves performance by using *macro diversity*. Also, it has been shown that soft handoff can extend coverage area by as much as a factor of 2.5. [6] Recall hard handoff. There, a handoff was performed when the signal strength of an adjacent cell exceeded that of the current cell by some threshold. In CDMA, the adjacent cell frequencies are just the same as those of the current cell. Therefore, using this hard handoff technique would cause severe interference into neighbor cells and thus degrade capacity. In a CDMA system with soft handoff, each mobile user is connected to two or more base stations at a time. The base station with the highest relative strength seen from the mobile is given the control of the mobile user’s call. Also, because a user in soft handoff is connected to several adjacent base stations, probability of a lost call is reduced. Soft handoff fits nicely into the structure of CDMA. As was just mentioned, in the uplink the user signal may be received by several or more base stations. This is because of CDMA’s reuse factor of one. In the downlink, the signals from the base stations can be coherently combined as they are seen as multipath components. Here will be described the soft handoff procedure. But first, it is necessary to show the following definitions

ii. *Active set* is the set of base stations that are involved with the mobile station during the soft handoff.

iii. *Active set update* is when a change in the active set occurs. An update occurs when a candidate base station exceeds the add threshold, when an old base station has been below the drop threshold for too long, or the active list becomes too large.

iv. *Discard set* are the base stations that are currently members of the active set but will be dropped because they are no longer qualified as such.

v. *Candidate set* are those neighboring base stations to the current one.

Now the soft handoff procedure is as follows. Suppose that the mobile station is linked and communicating with base station 1. Every base station is sending a pilot signal, which among other things, gives a measure of the signal strength to mobile users. When the signal strength of base station 2 exceeds the add threshold, base station 1 is notified to place base station 2 onto the candidate list. Further, when the signal strength of base station 2 becomes greater than that of base station 1 by some specified level, Base station 2 is placed on the active list and it also is allowed control of the call. Here, diversity combining is implemented. Now upon the signal level of base station 1 going below the drop threshold, the drop timer is activated. If it happens now that the signal level of base station 1 goes back above the drop level, the drop timer will be reset. However, if the signal strength level goes below the drop threshold and the drop timer expires, base station1 is dropped from activity with the call.

Conclusion :

To summarize, soft handoff is advantageous over hard handoff because the mobile does not lose contact with the system during handoff execution. Ping ponging is eliminated and an extra measure of performance is obtained through diversity combining to mitigate fading. Furthermore, more control may be given to the mobile in handoff decisions. This autonomous handoff decision ability , selection diversity, and inherent improvement of reliable handoffs with fewer unnecessary decisions, make soft handoff an attractive choice meriting further study as it is being used in third generation CDMA.

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