Proceedings of the International Conference on Information and Automation, December 15-18, 2005, Colombo, Sri Lanka.

An Ideal Base Station Sequence for Pattern Recognition Based Handoff in Cellular Networks

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***Abstract*— The significance of having a correct criterion for evaluating handoff methods is that telecommunication providers can choose the right handoff algorithm in a cost effective way. In cellular or micro cellular environments in cities, users often move on predetermined paths. As the built environment is not changed often, this regularity can be exploited in a pattern recognition based handoff method. The most suitable sequence of assigned base stations or the Best Handoff Sequence (BHS) can provide the basis for pattern recognition based handoff methods. This paper describes in detail a computationally simple method to estimate BHS which can also be used as a benchmark for comparing different handoff algorithms. Further, it uses the recent work in Call Quality Signal Level ($CQSL$) evaluation to compare various well known handoff methods.**

I. Introduction

Transfer of an ongoing call from one cell to another as a user moves through the coverage area of a cellular system is the mechanism of the handoff. In wireless cellular systems the handoff process is expected to be successful, and imperceptible to users. It is also expected that the need for handoff be infrequent. In congested inner city type environments with small cell sizes, it has become a challenging task to meet these requirements.

Handoff in current wireless cellular systems is commonly achieved through hysteresis and threshold based methods. All such methods are centralised and managed by the base station controller assisted by the mobile station and the base station as in Fig. 1. Increased integration in electronic hardware makes it possible to include many complex features in mobile stations. Therefore, it is timely and useful to develop handoff algorithms that can be managed or processed by mobile terminals.

In cellular or micro cellular environments in cities, users move on predetermined paths such as roads and sidewalks. As the buildings and trees are not changed every day, received signal strengths at a point on such a path will not highly fluctuate. Considering sample points located on a straight line perpendicular to the road, it is estimated that received signal strengths belong to the same distribution [1]. This regularity is not exploited in current handoff methods. In order to use this regularity, the signal strengths need to be sampled along sample points in all predetermined paths such as roads.

The most suitable base station assignment at each sample point should be determined considering handoff costs and QoS parameters. The most suitable sequence of assigned base stations or the best handoff sequence can provide the basis for pattern recognition based handoff methods.

For example, consider the canonical case with 10 sample points involving only two base stations B1 and B2. When the user is moving from B1 to B2, the ideal or the best handoff sequence could be: $\{B_1, B_1, B_1, B_2, B_2, B_2, B_2, B_2, B_2, B_2\}$. The sequence entry at each sample indicates the serving base station at that point. When the cost function for the sequences is known, the ideal or best sequence that optimises the cost function can be found. Generally, a handoff sequence

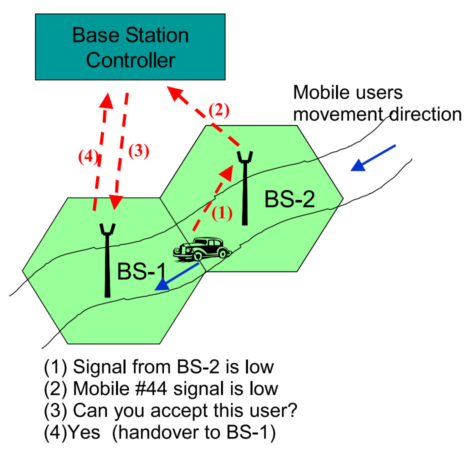

Fig. 1. What is handoff ? To transfer a radio link, to switch an ongoing call from one base station to another neighboring base station as a mobile user moves through the coverage area of a cellular system

is evaluated against the cost using the number of handoffs, which is justifiable, and the measure of quality or QoS it provides. However, the use of simple average signal strength as a measure of quality considered in [1]–[4] may not be the right choice. If the received signal strength falls below acceptable level, the connection is likely to discontinue, causing degradation of QoS. If there is a handoff sequence with a small number of assigned base stations having very high signal strengths and

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a large number of assigned base stations with signal strengths just below an acceptable level, the average signal strength can still indicate a high value of QoS. If it is considered as a part of the cost function, it can lead to a sub-optimal sequence as the best sequence. Unlike small canonical problems considered in most research studies, where the user moves from one base station to another, the exhaustive approach to find the best handoff sequence is not practicable in realistic scenarios with multiple paths and multiple base stations. Once the ideal or best sequence is known, various pattern recognition methods (for example template matching techniques used in [1]) can be used to find the pattern prior to each handoff. If the pattern recognition based method used is computationally simple, it can also have a low delay. Any pattern recognition method developed should be compared with other existing handoff algorithms for the handoff delay.

A realistic framework for evaluation and comparison of handoffs was presented recently in [5]. It uses a computationally simple benchmark for comparison of various handoff strategies using a new realistic signal quality measure. This paper illustrates in detail the algorithm to obtain the benchmark sequence and presents a comparison on commonly used handoff techniques and a fuzzy rule based handoff method using a modified form of the framework presented in [5].

II. Literature Review

Various network resources are needed for the handoff process. They include air signaling, network signaling, database lookup and network configuration [2], [6]. Air signalling is between the user and the base station while network signalling is between the base station and other network entity like mobile switching center. Handoff signaling uses radio bandwidth whether it is using control channels or traffic channels. Database accesses for registration and authentication contributes some handoff cost. Network reconfiguration costs are associated with providing user access to the new base station and terminating access to the old base station. Even though handoff costs are modeled in the literature as a constant cost per handoff due to the difficulty in quantifying the cost, all the above mentioned factors are dependent on the system design and configuration and therefore, influence the handoff cost.

Handoffs can happen between cells, within the cell (between channels) etc. It should be noted that we are also not concerned about soft handoff [7], where the old base station is released it's connection after a link with the new base station is established, as such, handoff is mainly used with CDMA type systems.

There are several handoff strategies proposed in literature [8]–[12]:

- The *Threshold* method [8] initiates handoff when average signal strength of current base station reduces certain given threshold value and signal strength of neighboring base station is greater than current base station. Proper selection of threshold value is very much needed here as it reduces the quality of communication link and result can be call dropping. This method is recommended by GSM Technical Specification GSM 08.08 [13]
- The *Hysteresis* method [11] initiates a handoff only if signal strength of the one of neighboring base stations is higher than certain given hysteresis margin than current base station. Advantage of this method is it prevent ping-pong effect, which is defined later, but still this initiates unnecessary handoffs though current serving base station signal strength is sufficiently strong enough.
- The *Threshold with Hysteresis* method [10] initiates a handoff when the signal strength of the current base station drops below a given threshold and the signal strength of a neighboring base station is higher by a given hysteresis margin to that of the current base station. This method is often used in practice with $+3$dB hysteresis.

It is interesting to observe that the *Threshold* method can be easily improved by restricting the handoffs to occur under the given rule, only in the case where the new base station can provide signal strength stronger than the minimum acceptable level. Otherwise, the handoff should not occur as it cannot lead to improvement in QoS. Consequently, the *Threshold with Hysteresis* method can also be extended to allow such a restriction.

There have been several recent extensions proposed to improve the hysteresis based strategies. In [14] three values were proposed for *Threshold with Hysteresis* and *hysteresis* method. When the current base station is busy (more handoff and new call requests than available resources) the hysteresis is lowered to 2 dB to encourage quicker handoff. When the new base station is busy, then the hysteresis is increased to 10 dB to discourage the handoff. If both base stations have the similar levels of activity, then a hysteresis at 6 dB is used. This approach has shown right direction, but this method needs to be generalised to include a more adaptive threshold and hysteresis method.

Fuzzy Handoff Algorithm (FHA) [3] is a complex scheme and uses a set of prototypes assigned to each cell to calculate the serving base station. The handoff method based on pattern recognition is the one proposed in [1]. It is practical for a canonical (Manhattan geometry) topology but involves large computation when applied to a general network.

It is possible that strong shadowing caused by large obstacles found in the line of sight with the serving base station or a highly mobile user in a boundary region between two base stations causes handoff from the serving base station to the neighboring base station only for a short period (generally for less than 10 s) until it gets back to the older serving base station. This effect, called the ping-pong effect, can add many unnecessary handoffs. Two commonly suggested methods to reduce this effect are:

- increase the hysteresis value
- introduce a high averaging length for the signal strength measure

However, neither of these methods are practical. A high hysteresis value may delay a necessary handoff at a boundary

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between two cells and a high averaging time may also slow the dynamics of handoff processes to the extent that calls could be lost. Therefore, finding an appropriate solution to this problem without causing delays for necessary handoff is a research question that has the attention of many researchers [15]–[17]. If the hysteresis can be varied, and the ping-pong case can be uniquely distinguished from the genuine boundary crossing case, a solution to this problem can be found.

Although the specification GSM 08.08 [13] considers only the *Threshold* method, the commercial providers seems to use a +3dB hysteresis value in addition (i.e., the *Threshold with Hysteresis* method) to minimise the ping-pong effect.

We consider a cellular mobile network with M base stations designated $B_1, B_2, ..., B_M$. Let a sample path be an arbitrary path in which a mobile user is travelling. Sample points are points on the sample path for which the signal strength values received from base stations are measured. Let S_{ij} be the signal strength at sample point i received from base station j. A handoff sequence is a sequence of base stations associated with the sequence of sample points. For a given handoff sequence, let B_i be the element of $\{B_1, B_2, ..., B_M\}$ assigned to the i^{th} sample point. For every sample path of N sample points there exist M^N possible handoff sequences. The number of handoffs in a handoff sequence equals to the number of changes in the base station sequence. For example, the handoff sequence $\{B_1, B_1, B_2, B_3, B_3, B_3\}$ has two handoffs.

For a given handoff sequence, let us define, for convenience, $S_i = S_{i,B_i}$. Let S_{min} be the minimum signal strength below which the signal quality is unacceptable for the user. Let $S_{max} > S_{min}$ be the signal strength beyond which the marginal benefit is considered negligible.

In [5] a new measure, Call Quality Signal Level (CQSL), has been defined where the penalty term was deducted from the average signal strength of sample points with signal strength greater than S_{min}. We denote these sample points as good sample points.

However, the above CQSL measure does not effectively distinguish between two sequences with the same average signal strength of good sample points, where one has a large number of good sample points with a relatively small signal strength, and another has only few good sample points but with a large signal strength. Because of it, we slightly modify the CQSL measure in this paper by deducting the penalty before getting the average as follows.

New $CQSL$ is described as follows:

$$CQSL(x) = \frac{1}{N}\left\{\sum_{i\in N_g(x)} A_i(x) - CN_b(x)\right\}, \quad (1)$$

where $\forall x \in N_g(x)$,

$$A_i(x) = \begin{cases} S_i(x) & \text{if } S_i(x) \le S_{max} \\ S_{max} & \text{otherwise} \end{cases},$$

N is the number of sample points, $N_g(x) = \{i|S_i(x) \ge S_{min}\}$, C is the cost (or the penalty) for an unacceptable sample point, $N_b(x) = (N - |N_g(x)|)$ is the number of samples with signal strength lower than S_{min}.

Similar to [5], we can obtain the lower bound as

$$CQSL(x) \ge \frac{\sum_{i\in N_g(x)} A_i(x)}{N} - \frac{S_{min}|N_b(x)|\ |N_g(x)|}{pN^2}, \quad (2)$$

where p is the maximum allowed proportion of sample points with signal quality below S_{min}, i.e., $N_b(x)/N \le p$.

We consider here the lower bound for $CQSL$ for comparison of different handoffs. In current practice, service providers do not associate 'p' the maximum bound of the proportion of "bad" sample points with QoS requirement, however, the framework proposed herein provides such a parameter to support differentiated services. As every handoff incurs cost, for comparison purposes we also define λ, the quality per handoff given by:

$$\lambda = \frac{\overline{CQSL}}{\overline{\gamma}}, \quad (3)$$

where

$$\overline{\gamma} = \frac{\sum_l [\gamma(x(l))]}{\eta}. \quad (4)$$

If a cost of single handoff is estimated as H_{cost} $US\$$, the signal quality per dollar is λ/H_{cost}. We will therefore use (3) to compare different handoff methods in section IV.

A pattern recognition method can detect a pattern of serving base stations that may appear before an eminent handoff. The first step in this process is to determine the best handoff sequence for a given sample path. For example, in a path of 100 sample points and 3 serving base stations, there are 3^{100} possible sample paths and one of them is the Best Handoff Sequence. Signal level quality and the number of handoffs for such sequences should be evaluated before selecting the Best Handoff Sequence. As this requires high computational complexity, a cluster based approach is proposed in [5] to find the ideal or the best handoff sequence. In the next section we describes in detail a computationally simple method to estimate Best Handoff Sequence (BHS) which can also be used as a benchmark for comparing different handoff algorithms.

III. The Best Handoff Sequence (BHS)

Our aim in this section is to obtain the best handoff sequence (BHS) which minimize the number of handoffs, and maintain the signal strengths $\ge S_{min}$ at all times [5]. Herein, we provide an off-line algorithm to find this sequence which will represent a benchmark value. A brute force method (exhaustive search) is impractical because of a large number of possible sample paths M^N involved. Due to this reason we use a heuristic method based on a cluster approach specified in [5] to find the optimal BHS by maximizing $CQSL$ and minimizing the number of handoffs (γ).

Consider a ($N \times M$) signal strength matrix, Φ, received from $M = 3$ base stations, with $N = 8$ sample points for a particular sample path as given in Fig. 2. Let G_{ij}, referred to as a cluster, be a set of signal strengths $\ge S_{min} = 15$ from base station j associated with a group of consecutive sample