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 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...
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 signalling 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 +3dB 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
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 $B_1, B_2, \ldots, B_M$. 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 $\{B_1, B_2, \ldots, B_M\}$ 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
$\{B_1, B_1, B_2, B_3, B_3, B_1\}$ 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
quality below $S_{min}$, i.e., $N_b(x)/N \leq p$.

We consider here the lower bound for CQSL for comparision
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 $\lambda$, the quality per
handoff given by:

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

where

$$\eta = \sum \gamma(x(l)) \quad (4)$$

If a cost of single handoff is estimated as $H_{cost} \text{ U.S}$, the
signal quality per dollar is $\lambda/H_{cost}$. 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 $\geq S_{min}$ 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 ($\gamma$).

Consider a $(N \times M)$ signal strength matrix, $\Phi$, 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 $\geq S_{min} = 15$ from
base station $j$ associated with a group of consecutive sample
points, $N_g(x) = (N - |N_g(x)|)$ is the number of samples with signal strength lower than $S_{min}$.

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

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

where $p$ is the maximum allowed proportion of sample points
with signal quality below $S_{min}$.

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

$$A_i(x) = \begin{cases} S_i(x) & \text{if } S_i(x) \leq S_{max} \\ S_{max} & \text{otherwise} \end{cases}, \quad (1)$$

$N$ is the number of sample points, $N_g(x) = \{i | S_i(x) \geq
S_{min}\}$, $C$ is the cost (or the penalty) for an unacceptable

where H defined as the weighted value quality by finding maximum average signal level W

\[ \Phi \]

of the element of the set is empty we need to proceed to Step 3.

\[ \gamma \]

at the same time minimises the number of handoffs \( \gamma(x) \) by choosing longest clusters. In the following we demonstrate the algorithm based on the example given in Fig. 2.

Set \( BHS = \{ \} \) and \( i = 1 \).

**Step 1:** Find the subset \( \Phi_i \) as a set of the base stations from which its signal strength in the \( i^{th} \) row of the matrix \( \Phi \) is \( \geq S_{min} = 15 \). So according to Fig. 2, \( \Phi_i = \{1, 2\} \). If \( \Phi_i \) is empty we need to proceed to Step 3.

**Step 2:** Find all the \( G_{ij} \) clusters which starts from each of the element of the set \( \Phi_i \). In our example, we can identify two clusters \( G_{i1}, G_{i2} \). The algorithm assigns the base station 2 associated with larger \( H_{ij} \) value as the serving base station for the first three sample points in the path. Therefore, we obtain \( BHS = \{B_2, B_2, B_2\} \). We proceed to Step 1 with \( i = 4 \).

**Step 3:** With \( i = 4 \), Step 1 produces an empty set which need to be addressed in this Step. Because \( \Phi_i \) is empty, we skip two rows (4th and 5th) until finding a row in a matrix \( \Phi \) which contains a signal strength > 15 (in our example this is the 6th row). We then proceed again from Step 1 by setting \( i = 6 \) to find the optimal base station for the 6th sample point and onwards. After repeating Step 1 and 2 we obtain \( \{B_1, B_1, B_1\} \) as an optimal handoff sequence for the 6th, 7th and 8th sample points in our example. For the skipped sample points 4th and 5th the algorithm then assigns the previous serving base station, \( b_{old} = B_2 \) (no handoff) or the new serving base station, \( b_{new} = B_1 \) (handoff) such that the average signal strength over all the skipped sample points is maximized. In our example \( b_{old} = B_2 \) is chosen because the average signal strength from \( B_2 \) is greater than the average signal strength from \( B_1 \) over the skipped sample points 4th and 5th. If after the skipping rows in matrix \( \Phi \) we cannot continue with Step 1, i.e., there is no new serving base station, we then simply continue with the old base station over all the skipped sample points. Repeat Steps 1, 2 and 3 until the last row of matrix \( \Phi \). In our example shown in Fig. 2 we obtain \( BHS = \{B_2, B_2, B_2, B_2, B_2, B_1, B_1, B_1\} \).

Recalling our aim of the \( BHS \) is to minimize the number of handoffs and maintain the signal strengths \( \geq S_{min} \) at all times, we observe that in the above numerical example, the number of handoffs \( \gamma(x) = 1 \).

It should be noted that the Best Handoff Sequence \( BHS \) contains indirectly the following features not considered by any other handoff method:

- when the strength of a serving base station is well above \( S_{min} \), further reduction in the number of handoffs can be achieved by adapting a flexible or variable hysteresis. Clustering all the signal strengths above the minimum acceptable level and then selecting the base station corresponding to the best cluster as the serving base station will help to achieve a nonlinear variable hysteresis.
- unnecessary handoffs are avoided in sample points where all base stations provide signal strengths below \( S_{min} \).

**IV. Simulation Results**

Figure 3 shows a realistic scenario in which both new and handoff calls appear over 24 hours period using the data base BALI-2 (Stanford University Mobile Activity Traces) [18]. BALI-2: Bay Area Location Information (real-time) dataset records the mobile users’ moving and calling activities in a day. We extract about 50,000 users from BALI-2 used for our experiments to analyse impact of handoff, in real system. This database was created using the real traffic data in San Francisco Bay area shown in Fig. 3(a). A more simple data set is created for our simulations to illustrate the use of \( BHS \) as a benchmark.

Here we compare the different handoff methods introduced in Section II using the quality measures of (2) and (3). We
consider three adjacent cells \((M = 3)\) with \(100\) m radius. The base stations are located in a plane with the following coordinates: \((100, 150), (250, 75)\) and \((250, 250)\) [meters]. We randomly generate \(\eta = 1000\) sample paths of mobile users, each with \(N = 100\) where each pair of consecutive points are one meter apart. This is a more realistic scheme than the canonical form used in most studies.

A log-normal propagation model [19] was assumed to generate signal strengths in each sample point along all the sample paths, i.e., \(S_{ij} = K_1 - K_2\log(r) + F\), where \(K_1 = 85; K_2 = 35\) are constants, \(r\) is the distance to the base station, and \(F\) is Gaussian distributed \((N(0, \sigma^2))\) representing the shadowing effect. We set \(\sigma = 5\) dB, shadowing correlation distance equals \(20\) m. Average received signal strength indicator (RSSI) values of the cell border is set at \(S_{\text{min}}\) to \(15\) dB as in [3], and \(S_{\text{max}} = 1.5S_{\text{min}}\). All the sample paths are straight lines that start from points in the square area \(\{(100, 100), (200, 100), (200, 200), (100, 200)\}\). Their directions are randomly chosen between \([0, 2\pi]\) uniformly. The parameter \(\alpha\) was varied in the best handoff sequence. Here we use \(p = 0.1\).

Figure 4 confirms that the mean number of handoffs for \(FHA\) increases with the increase of \(\sigma\) as reported in [3].

Figure 5(a) compares the number of handoffs of four handoff algorithms: Threshold, Hysteresis, Threshold with Hysteresis at 3dB, and \(FHA\), with \(BHS\). Figure 5(b) shows that the performance of \(BHS\) only slightly varies (12.65 to 12.7 dB) as \(\alpha\) is varied. The best performance is observed when \(\alpha = 1\), which justifies the use of cluster length rather than the weighted value \(H_{ij}\) in Step 2. It can be observed that the variation is not that significant. Minimum number of handoffs needed to guarantee \(p \leq 0.1\) can be found in Fig 5(a) by setting \(CQSL = 0\) for each handoff method. It is clear that \(FHA\) in the present form fails to reach this quality level with the low number of handoffs. Similar to the approach taken by [20] and [1], optimum parameter settings can be obtained from the “knee” of the curves. Clearly the benchmark \(BHS\) with \(S_{\text{min}} = 15\) dB and \(\alpha = 1\) provides the most efficient parameter setting or the highest \(\lambda\) value. When high numbers of handoffs can be afforded the Threshold method with \(T_{HO} = 14\) dB will be as efficient as the above two traditional handoff methods. Our simulations indicate \(FHA\) (similarity threshold at 21 dB) is less desirable in comparison to other methods.

Our results show that there is substantial room for improvement in existing handoff algorithms with respect to the signal level measures as well as the number of required handoffs. Previous studies have concentrated mostly on reducing the number of handoffs, neglecting quality of signal. It is therefore important to develop new handoff methods that would take into
account both signal strength quality and number of handoffs as proposed in this work. The performance of any new proposed algorithm can be compared with our benchmark solution. The effect of the selection of p on CQSL is also obvious from (2), as the CQSL measure increases with the increase of p. We can call p the probability of call failure due to unavailability of a suitable base station if N is sufficiently large.

V. CONCLUSION

In this paper, we have described a computationally simple benchmark solution for comparison between existing handoff algorithms. This ideal or best handoff sequence can be used as a reference for pattern recognition based handoff. This measure together with CQSL proposed in [5] or the slightly modified form proposed in this work can be used by telecommunications providers to choose the best handoff algorithm to optimise their handoff management functions.

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