INTERNATIONAL JOURNAL OF COMMUNICATION SYSTEMS
*Int. J. Commun. Syst.* 2011; **24**:363–383
Published online 20 June 2010 in Wiley Online Library (wileyonlinelibrary.com). DOI: 10.1002/dac.1159

# A call quality performance measure for handoff algorithms

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## SUMMARY

This paper proposes a new approach for performance evaluation and comparison between existing handoff algorithms taking into consideration signal levels, call dropping, and handoff cost. Using the new approach, existing handoff algorithms are then compared in terms of signal quality and number of handoffs required to achieve a desired overall signal quality. We also provide in this paper a method to estimate handoff cost and to optimize handoff sequences for retrial (where repeated call attempts are made after a call is lost) and non-retrial models based on the proposed approach. We observe that the Threshold with Hysteresis method performs better than other known methods including the one used in the GSM standard. Our results indicate that the Threshold with 4 dB Hysteresis method performs well for urban areas although with a high dropping probability, whereas the Threshold with 6 dB Hysteresis method suits for suburban areas with a low dropping probability. We find that handoff sequences obtained by existing handoff methods are less efficient than the optimal handoff sequence given in the paper by a margin of 29–45% for retrial model, and by 34–77% for non-retrial model. The paper also suggests some specific parameter values to improve the performance of currently used handoff methods based on our findings. 

Received 26 July 2009; Revised 29 November 2009; Accepted 1 May 2010

KEY WORDS: cellular networks; wireless; handoff; handover; optimal handoff; handoff cost; performance evaluation; optimal handoff; retrial model

## 1. INTRODUCTION

Handoff is a mechanism associated with the transfer of an ongoing call (voice, data, or multimedia) from one cell to another as user moves through a coverage area of a cellular system. In wireless cellular system processing handoff is a very important task. The handoff process is expected to be successful, infrequent and imperceptible to enable telecommunication providers meet required quality of service (QoS) of users. Use of reliable handoff mechanism is especially important for transportation systems as maintaining continuous sessions for vehicles traveling at high speeds or traveling in congested inner city-type environments is important for vehicle safety applications and electronic payment services (automated toll and parking fee collection). In congested inner city-type environments with smaller cell sizes, it has become a challenging task to meet above requirements. Therefore network system designers must specify optimal signal level to initiate

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Contract/grant sponsor: Publishing Arts Research Council; contract/grant number: 98-1846389

handoff. A comprehensive evaluation framework for handoff methods will ease the selection of the best handoff strategy by network designers.

Given the importance of the handoff operation in mobile networks, several handoff methods have been proposed in the literature and are summarized below:

The *Threshold* method [1] initiates a handoff when the average signal strength of the current base station is dropped below a given handoff threshold $T_{\mathrm{HO}}$, and the signal strength of a neighboring base station is greater than that of the current base station. However, the handoff threshold $T_{\mathrm{HO}}$, which is determined by the network operator, can be varied, according to the transmit power of the base station.

The *Hysteresis* method [2] initiates a handoff only if the signal strength of a neighboring base station is higher by a given hysteresis margin to that of the current base station. Advantage of this method is that it prevents a so-called ping-pong effect, in which handoffs occur back and forth between base stations, but still initiates unnecessary handoff when the current signal strength is sufficiently strong for communication.

The *Threshold with Hysteresis* method [3] combines the above two methods to initiate a handoff when the signal strength of the current base station drops below the handoff threshold $T_{\mathrm{HO}}$, and the signal strength of a neighboring base station is higher by a given hysteresis margin to that of the current serving base station. This method is often used in practice with $+3\,\mathrm{dB}$ hysteresis [4].

According to the GSM Technical Specification GSM 08.08 [5], the Threshold-based handoff method is recommended. However, service providers use $+3\,\mathrm{dB}$ hysteresis value together with Threshold method in attempt to minimize the ping-pong effect. This indicates that the choice of handoff strategy is currently made *ad hoc*, and therefore there is a need for a benchmark that enables designers choose the best one in a methodological way rather than in an *ad hoc* manner.

While all the above-mentioned methods are on-line handoff methods, the *Best Handoff Sequence* (BHS) method [6] is an off-line heuristic algorithm that obtains a near optimal handoff sequence. As a result, BHS can be used as a benchmark to assess relative performance among on-line handoff methods. A wireless environment gives rise to challenging design problems due to user movement and limited bandwidth on wireless links. Performance evaluation and comparison of different handoff algorithms are needed to determine the appropriate handoff algorithm with respect to call quality and number of handoffs. This received much attention [7–10] due to the cost associated with handoff. Various network resources and facilities are needed for the handoff process, including air signaling, network signaling, database lookup, and network configuration [11]. Air signaling is used between the user and the base station whereas network signaling is between the base station and other network entities like the mobile switching centers. Handoff signaling utilizes radio bandwidth whether it uses control channels or traffic channels. Database accesses for registration and authentication contributes to the handoff cost. The network reconfiguration is needed to provide new access users to the new base stations and terminate the user's access with the old base stations. Although in the literature handoff costs are modeled as a constant cost per handoff because of the difficulty in quantifying the cost, all the above-mentioned factors are dependent on the system design and configuration, and therefore influence handoff cost.

The remainder of this paper is organized as follows. In Section 2, we describe definitions and assumptions. In Section 3, we describe our handoff evaluation algorithm, Call Quality Signal Level (CQSL). In Section 4, we extend our evaluation algorithm as Extended Call Quality Signal Level (ECQSL), by considering all practical considerations: signal level, call dropping, and handoff cost. In Section 5, we apply this model for four alternatives. Then, in Section 6 we provide simulation results and discussion where we demonstrate the benefit of our handoff evaluation model. Section 7 concludes the paper.

## 2. DEFINITIONS AND ASSUMPTIONS

### 2.1. Definitions

For clarity we use here the same notation used in [6]. Consider a cellular mobile network with $M$ base stations designated $B_1, B_2, \ldots, B_M$. Define $\mathscr{B} = \{B_1, B_2, \ldots, B_M\}$. Let a sample path $l$



DOI: 10.1002/dac

be an arbitrary path in which a mobile or road-vehicle user is traveling. Consider a set of paths denoted $L$ for the purpose of evaluating handoff algorithms where $l \in L$. Sample points are points on the sample path for which the signal strength received from base stations are measured. Let $S_{ij}$ be the signal strength at sample point $i$ received from base station $B_j$. Define a handoff sequence $x$ or $x(l)$ for sample path $l$, as a sequence of base stations by assigning $b_i \in \mathscr{B}$ to the $i$th sample point, i.e. $x=\{b_1, b_2, \ldots, b_N\}$ where $N$ is the number of sample points. (Note that $b_i$ and $b_j$, $\forall i, j$ may designate the same base station.) For every sample path, define the set of all possible handoff sequences as $X=\{x_i | 0<i \leqslant M^N\}$. The number of handoffs $\gamma(x)$ in a handoff sequence $x$ equals to the number of changes in the base station sequence. For example, the handoff sequence $x=\{B_1, B_1, B_2, B_3, B_3, B_3\}$ has $\gamma(x)=2$. For a given handoff sequence $x \in X$, define $S_i(x)=S_{ij}$ such that $B_j=b_i$, $b_i \in x$. In other words, $S_i(x)$ is the signal strength received by sample point $i$ from the base station that is assigned to it, namely $b_i$. Let $S_{\min}$ be the minimum signal strength below which the signal quality is unacceptable to the user. Let $S_{\max}>S_{\min}$ be the signal strength beyond which the marginal benefit is considered negligible and $S_{\text{drop}}<S_{\min}$ is the dropping level signal below which the call is dropped, if that level is maintained for a certain period. We also refer to this signal range as 'drop level signal level'. Let $N_g(x)=\{i | S_i(x) \geqslant S_{\min}\}$, and $N_b(x)=(N-|N_g(x)|)$ is the number of samples with signal strength lower than $S_{\min}$. Let $\beta_x$ of handoff sequence $x$ be the set of all sample points with $S_{\text{drop}}<S_i(x)<S_{\min}$.

### 2.2. Assumptions

We assume a QoS requirement that does not allow delay due to queuing of calls in the handoff process. This means if handover is unsuccessful the call is dropped. Because power control can improve handoff performance for all the handoff schemes, here we only study a relative performance between handoff methods and do not consider power control in our framework. Further, similar to [12] we assume a homogeneous network where all cells are identical in size, user mobility and cell coverage. Each cell is assumed to have equal number of neighbors as in [13]. A log-normal propagation model is assumed and no power control is assumed to exist. Users move in any random direction with constant speed. A call is dropped after observing the drop level signal for a number of consecutive sample points. After a call is dropped there are two possible scenarios that could occur in a sample path:

- in the retrial mode, another call will be placed after some time that may be required to place the call
- in the non-retrial mode no such retrial attempt occurs.

Call retrials have a significant impact on the network performance utilizing bandwidth resources otherwise wasted. Therefore, we include a retrial model in our study. Figure 1 shows the previously proposed CQSL and a new suggestion described in Section 3.2 as 'ICQSL' (Improved Call Quality Signal Level). For both retrial and non-retrial models, CQSL and ICQSL measures can be further

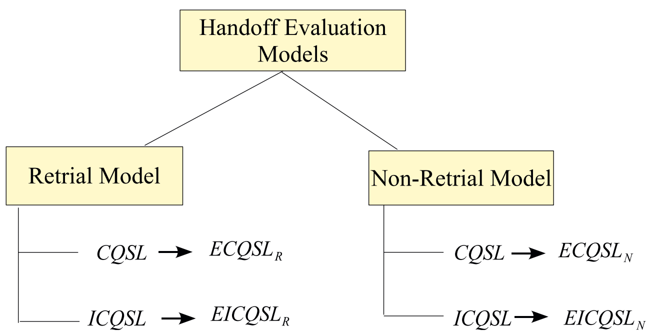


Figure 1. A taxonomy of handoff evaluation measures: CQSL, ICQSL, and ECQSL, under both retrial options where repeated call attempts are made and non-retrial call options.



DOI: 10.1002/dac

extended as shown in Section 3. Extensions to CQSL and ICQSL for retrial and non-retrial modes are given as $\mathrm{ECQSL}_R$, $\mathrm{ECQSL}_N$ and $\mathrm{EICQSL}_R$ and $\mathrm{EICQSL}_N$, respectively.

## 3. CALL QUALITY SIGNAL LEVEL

### *3.1. Previously proposed CQSL* [6]

The concept of Call Quality Signal Level (CQSL($x$)) proposed in [6] uses combination of the following signal quality measures:

- Average Received Signal Strength (ARSS($x$)) is defined by $(1/N)\sum_{i=1}^{N} S_i(x)$.
- Number of Acceptable Sample Points (NASP($x$)) represents the number of sample points of the handoff sequence with signal strength above $S_{\min}$. Here NASP($x$)$=|N_g(x)|$, where $|\Upsilon|$ denotes the number of elements (cardinality) in the set $\Upsilon$.

The CQSL($x$) associated with a handoff sequence $x$ of a path $l$ is the average signal strength of acceptable sample points minus the penalty assigned to unacceptable sample points on that path, i.e.:

$$\mathrm{CQSL}(x) = \frac{\sum_{i\in N_g(x)} A_i(x)}{|N_g(x)|} - CN_b(x), \tag{1}$$

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

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

and $C$ is the cost (or the penalty) for an unacceptable sample point. We assign $\sum_{i\in N_g(x)} A_i(x)/|N_g(x)|$ to zero when $|N_g(x)|=0$. Let $p$ be the maximum allowed proportion of sample points ($N$) with signal quality below $S_{\min}$, i.e. $N_b(x)/N \leqslant p$. The $p$-value may be agreed between the service provider and the user. Assuming $|N_g(x)| \neq 0$, the minimum value that CQSL($x$) can take is when (i) $N_b(x)/N = p$ and (ii) $\sum_{i\in N_g(x)} A_i(x)/|N_g(x)| = S_{\min}$ in (1). We choose $C$ such that the value of the proposed measure is greater or equal to zero. It is equivalent to setting a bound on $C$ as follows:

$$C \leqslant \frac{\sum_{i\in N_g(x)} A_i(x)/|N_g(x)|}{N_b(x)} = \frac{S_{\min}}{pN}. \tag{2}$$

Here, we choose the cost to be linear with $N_b(x)$. Using (1) and (2), we can obtain

$$\mathrm{CQSL}(x) \geqslant \frac{\sum_{i\in N_g(x)} A_i(x)}{|N_g(x)|} - \frac{S_{\min} N_b(x)}{pN}. \tag{3}$$

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. In the next section the CQSL is improved by considering these problems.

### *3.2. Improved call quality signal level*

We modify the CQSL measure (refer to as Improved CQSL or ICQSL) by deducting the penalty before getting the average as follows:

$$\mathrm{ICQSL}(x) = \frac{1}{N}\left\{ \sum_{i\in N_g(x)} A_i(x) - CN_b(x) \right\}. \tag{4}$$



DOI: 10.1002/dac

As previously we choose $C$ such that the minimum possible value is equal to zero. The parameter $C$ in (4) can be bounded as follows:

$$C \leqslant \frac{\sum_{i \in N_g(x)} A_i(x)}{N_b(x)} = \frac{S_{\min}|N_g(x)|}{pN}, \tag{5}$$

where $S_{\min}|N_g(x)| \leqslant \sum_{i \in N_g(x)} A_i(x) \leqslant S_{\max}|N_g(x)|$ and $N_b(x)/N \leqslant p$.

Using (4) and (5), we can obtain the lower bound as

$$\mathrm{ICQSL}(x) \geqslant \frac{\sum_{i \in N_g(x)} A_i(x)}{N} - \frac{S_{\min} N_b(x)|N_g(x)|}{pN^2}. \tag{6}$$

In both options, we choose the cost to be linear with $N_b(x)$. However, we could differentiate between a drop level ($S_i \geqslant S_{\text{drop}}$) sample points and an unacceptable ($S_i \leqslant S_{\min}$), but still non-drop level ($S_{\min} \geqslant S_i \geqslant S_{\text{drop}}$) sample points. We may set a cost for drop level sample point dynamically to reflect the fact that consecutive drop level sample points are worse than a single drop level sample point. Such an extension will represent the scenario more realistically as described in Section 4.

## 4. EXTENDED CALL QUALITY SIGNAL LEVEL

In this section we propose improvements to the CQSL and ICQSL presented in Section 3. The reduction in call quality leads to the call drop, and therefore it is integrated as a penalty in CQSL and ICQSL. Here we assume both retrial and non-retrial models and for retrial model we assume that a handoff sequence may contain multiple droppings, i.e. a dropped call is immediately replaced by another call when the dropping occurs. We propose in this section three extensions to the CQSL and ICQSL which are presented in Section 3:

- Differentiation of the penalties based on different levels of signal quality associated with $N_b(x)$,
- Introduction of higher penalties for consecutive sample points with signal strengths below a drop level,
- Inclusion of the handoff cost.

In order to take into account the different levels of quality impairment caused by unacceptable signal strengths, we define the cost (penalty) as a function of signal strengths as follows:

$$C(S_i(x)) = \begin{cases} C_1 & \text{if } 0 \leqslant S_i(x) \leqslant S_{\text{drop}}, \\ \dfrac{C_1}{2}(J) & \text{if } S_{\text{drop}} \leqslant S_i(x) \leqslant S_{\min}, \\ 0 & \text{if } S_i(x) \geqslant S_{\min}, \end{cases} \tag{7}$$

where $C_1$ is a predefined parameter and $J = [1 + \cos\pi((S_i(x) - S_{\text{drop}})/(S_{\min} - S_{\text{drop}}))]$. The above function is illustrated in Figure 2.

### 4.1. No penalty region

The first term in (4), $\sum_{i \in N_g(x)} A_i(x)$, corresponds to sample points with acceptable signal strengths, and therefore there is no cost (penalty) involved. These sample points belong to the no penalty region as shown in Figure 2.

### 4.2. Low penalty region

The second term in (4), $\mathrm{CN}_b(x)$, corresponds to sample points with unacceptable signal strengths. We characterize these sample points into two groups. The first group consists of sample points with signal strengths between $S_{\text{drop}} < S_i(x) < S_{\min}$ (low penalty region). For any



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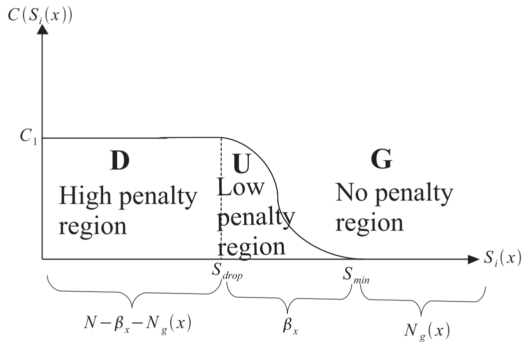


Figure 2. Penalty function $C(S_i(x))$ with signal strength $S_i(x)$, considering the different levels of quality caused by unacceptable signal strength.

handoff sequence $x$ the total cost associated with its sample points in the low penalty region is $(C_1/2)[1+\cos\pi((S_i - S_{\text{drop}})/(S_{\min} - S_{\text{drop}}))]$, where $\beta(x) = \{i \mid S_{\min} > S_i(x) > S_{\text{drop}}\}$.

### 4.3. *High penalty region*

The second group is a set of sample points with signal strengths below a call dropping level ($0 \leqslant S_i(x) \leqslant S_{\text{drop}}$), which correspond to the high penalty region in Figure 2. In any handoff sequence $x$, a call is dropped as explained in Figure 3, if the signal strength is below the call dropping level ($S_{\text{drop}}$), for $d$ consecutive sample points (dropping points). In practice these $d$ consecutive sample points can be varied with user speed, therefore we assume that users move with constant speed. The cost assigned for each of the sample points among these $d$ dropping points is defined as follows:

$$C_r = \begin{cases} a^{r-1} C_1 & \text{if } 2 \leqslant r \leqslant d-1, \\ a^{d-1} C_1 & \text{if } d \leqslant r \leqslant N, \end{cases} \tag{8}$$

where $a$ is a scaling factor and the $r$ is the number of consecutive dropping points ($2 \leqslant r \leqslant N$) in a sample path and its associated cost (or penalty) $C_r$. For example, as shown in Figure 4, where sample path has three sets of two consecutive sample points and one set of three consecutive sample points associating with signal strength less than $S_{\text{drop}}$ and the costs are from (8) using $d=3$, $a=1$ values. Therefore the total cost associated for this sample path is $4C_1 + 4C_2 + C_3$. The parameter $a$ is chosen such that the cost associated with the $i$ dropping point weighted by the probability that there are $i$ consecutive dropping sample points is equal to the probability weighted cost of the $(i+1)$th dropping point. The probability of having $i$ consecutive dropping sample points in an arbitrary handoff sequence $x$ is given by

$$p(i) = (N-i+1)\delta^i (1-\delta)^{N-i}, \tag{9}$$

where $\delta$ is the probability of receiving a signal strength below $S_{\text{drop}}$. Knowing $p(i), \forall\ 1 \leqslant i \leqslant d$ the value of parameter $a$ is given by assuming,

$$a = \frac{p(d-1)}{p(d)} + \text{const} = \left(\frac{N-d+2}{N-d+1}\right)\frac{(1-\delta)}{\delta} + \text{const}.$$

In practice $N \gg d$, and therefore we obtain $a = ((1-\delta)/\delta) + \text{const}$, which will be used as a scaling factor in our cost function. Considering that $a \geqslant 1$, and obvious choice of $a \Rightarrow 1$ when $\delta \Rightarrow 1$, therefore we can set const $=1$. Now we can write, $a = ((1-\delta)/\delta) + 1$. In practice, different systems may have different drop rates, caused by either coverage problems because of irregular terrain configurations or inadequate channel availability [14]. Therefore, here we consider weighting factor, $a$, to be constant for a given terrain configuration. According to Figure 5, we choose weighting factor, $a$, once we know the dropping probability.



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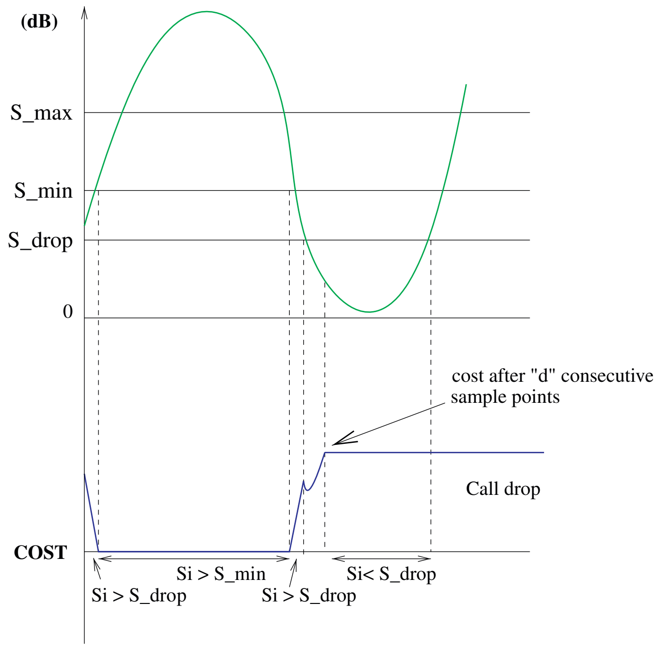


Figure 3. Call is dropped, if the signal strength is below the call dropping level ($S_{\text{drop}}$), for $d$ consecutive sample points.

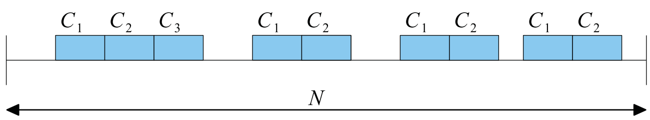


Figure 4. Example for number of consecutive sample points associated with signal strength less than $S_{\text{drop}}$ and the costs are from (8) using $d=3$, $a=1$ values.

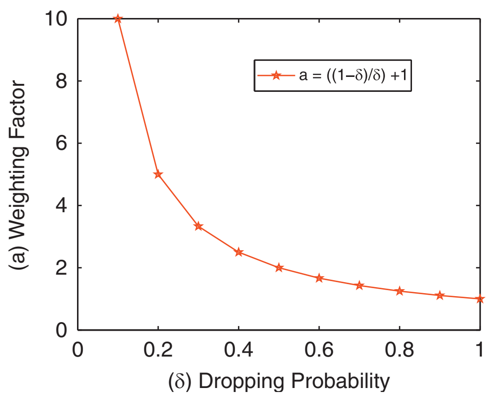


Figure 5. Weight factor, $a$, versus dropping probability, $\delta$. Different systems would have different drop rates, caused by either coverage problems or inadequate channel availability.

### *4.4. Handoff cost*

Another important issue is the cost for handoff. Therefore, finally, we include the handoff cost, $C_h$, as a linear function of the number of handoffs $\gamma_x$. In the following two sections we suggest the adaptation of the above three penalties to retrial and non-retrial models. Let $K$ denote the sample point at which the first call drop happen. Note that, for retrial and non-retrial models $N_g(x)$ can be varied as in Table I. In Sections 5.3 and 5.4 we propose how these extensions apply to CQSL and ICQSL for retrial model and Sections 5.5 and 5.6 for non-retrial model.



DOI: 10.1002/dac

Table I. $N_g(x)$ values used in retrial and non-retrial models.

| Model | $N_g(x)$ |
|---|---|
| Retrial model | $i=1,\ldots,N$ |
| Non-retrial model | $i=1,\ldots,K$ |

## 5. ECQSL FOR FOUR CASES: RETRIAL and NON-RETRIAL

In this section we explain derivations of $\mathrm{ECQSL}_R$, and improved version, $\mathrm{EICQSL}_R$, for retrial and non-retrial models.

### 5.1. Connection between $C_1$ and $C_h$

Considering that the maximum cost of having $(d-1)$ consecutive drops followed by an unacceptable but non-drop level signals level should be less than the cost of having $d$ consecutive drops leading to the call drop, we derive:

$$\begin{aligned} \max \mathrm{cost}(DD\ldots U) &\leqslant \min \mathrm{cost}(DD\ldots D)\\ C_1+\mathrm{cost}(DD)+(d-1)C_h &\leqslant \mathrm{cost}(DD)+a^{d-1}C_1\\ \text{Therefore, } C_1+(d-1)C_h &\leqslant a^{d-1}C_1\\ C_h &\leqslant \frac{(a^{d-1}-1)C_1}{(d-1)}. \end{aligned} \tag{10}$$

### 5.2. Gamma function for retrial model

In the literature [15] various retrial models were proposed considering user retrial patterns. For example, it takes only few seconds to redial a number that was not successfully connected in the previous attempt. In this model we assume that call discontinuation (drop) does not mean the end of consideration of the sample path for the proposed extended quality measure $\mathrm{ECQSL}_R$ including the handoff cost for handoff sequence $x$. A sample path may have multiple call drops. We will still consider good components between those call drops for the $\mathrm{ECQSL}_R$ and $\mathrm{EICQSL}_R$.

As the retrial behavior of users may vary, it is not straightforward to estimate the call waiting time after a call is dropped. In this work we employ gamma distribution to model the call waiting time just after call drop from existing call as described in Figure 6.

$$X_i \sim \mathrm{Gamma}(\omega_i,\zeta), \tag{11}$$

where $i=1,2,\ldots,N$, mean is $N_g\zeta$ and variance is $\omega\zeta^2$. We select $\omega=2$ and $\zeta=1$ based on the assumption that a user can retry and connect the call within few seconds after call drop. The measures $\mathrm{ECQSL}_R$ and $\mathrm{EICQSL}_R$ will be able to differentiate between the various lengths of 'call drop regions' in the sample path.

### 5.3. Measure for the retrial model, $\mathrm{ECQSL}_R$

The extended expression of (1) for CQSL using this cost function is given by

$$\begin{aligned} \mathrm{ECQSL}_R(x) = {} & \frac{\sum_{i\in N_g(x)} A_i(x)}{|N_g(x)|} - \frac{C_1}{2}\left[\sum_{i\in\beta_x}\left(1+\cos\pi\left(\frac{S_i(x)-S_{\mathrm{drop}}}{S_{\min}-S_{\mathrm{drop}}}\right)\right)\right]\\ & -\sum_{r=1}^{d_{\max}} h_r \sum_{j=1}^{r} C_r - C_h\gamma_x, \end{aligned} \tag{12}$$

where $\beta(x)=\{i\,|\,S_{\min}>S_i(x)>S_{\mathrm{drop}}\}$, $d_{\max}$ is the largest number of consecutive dropping points in a sample path, and $h_r$ is the number of $r$ consecutive dropping points in the same sample path. The



DOI: 10.1002/dac

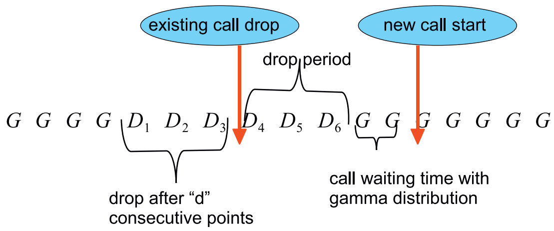


Figure 6. Call waiting time to connect next call just after call drop from previous existing call, with retrial model where repeated call attempts.

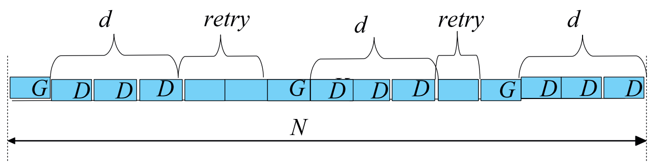


Figure 7. Retrial model where repeated call attempts are made. Here $G$—good sample points where $S_i > S_{\min}$ and $D$—dropping sample points where $S_i < S_{\text{drop}}$, with $d = 3$.

constant $C_1$ in (12) is chosen such that the lower bound of $\text{ECQSL}_R(x)$ is never less than zero. In order to find the lower bound of $\text{ECQSL}_R(x)$ we consider each individual term in (12). The first term in (12) corresponds to good sample points with signal strengths $S_i(x) > S_{\min}$, therefore we have

$$S_{\min} \leqslant \frac{\sum_{i \in N_g(x)} A_i(x)}{|N_g(x)|}. \tag{13}$$

Maximum penalty for retrial case occurs when the retrial is used for maximum number of times or $N/(d+1)$ as in the following sequence with $d=3$, as shown in Figure 7. We assume that a retrial can only occur with a good level signal (G). Therefore, we can obtain: $N_g = \lceil N/d+1 \rceil$ and $\gamma = \lceil N/d+1 \rceil d$, and derive:

$$\text{Max penalty } = \underbrace{C_h \left\lceil \frac{N}{d+1} \right\rceil d}_{\text{handoff}} + \underbrace{\left( \frac{a^d - 1}{a-1} \right) C_1 \left\lceil \frac{N}{d+1} \right\rceil}_{\text{dropping}}. \tag{14}$$

The next three terms are interdependent as bad sample points are distinguished between those sample points with $S_{\text{drop}} \leqslant S_i(x) < S_{\min}$, and those sample points where there are consecutive points with $S_i(x) < S_{\text{drop}}$. The lowest of these three negative terms in (12) is the maximum cost which corresponds to a case when all the bad sample points fall within the high penalty region, and is given by

$$\left\lceil \frac{N_b(x)}{d} \right\rceil (a^0 C_1 + a^1 C_1 + a^2 C_1 + \cdots + a^{d-2} C_1 + a^{d-1} C_1) = \left\lceil \frac{N_b(x)}{d} \right\rceil C_1 \left( \frac{a^d - 1}{a-1} \right).$$

We assume that handoff should have a lower penalty than the dropping. Thus

$$-C_h \left\lceil \frac{N}{d+1} \right\rceil d - \left( \frac{a^d - 1}{a-1} \right) C_1 \left\lceil \frac{N}{d+1} \right\rceil \leqslant -\frac{C_1}{2} \left[ \sum_{i \in \beta_x} \left( 1 + \cos \pi \left( \frac{S_i(x) - S_{\text{drop}}}{S_{\min} - S_{\text{drop}}} \right) \right) \right]$$
$$- \sum_{r=1}^{d_{\max}} h_r \sum_{j=1}^{r} C_r - C_h \gamma_x. \tag{15}$$

 

From (12), (13), and (15), we obtain

$$S_{\min}-\left\lceil\frac{N}{d+1}\right\rceil C_1\left(\frac{a^d-1}{a-1}\right)-C_h\left\lceil\frac{N}{d+1}\right\rceil d\leqslant \mathrm{ECQSL}_R(x).$$

The $C_1$ constant is then determined by setting the lower bound value to zero. Therefore, we can compute $C_1$ for $\mathrm{ECQSL}_R$ as,

$$C_1=\frac{S_{\min}}{\left\lceil\frac{N}{d+1}\right\rceil\left[\left(\frac{a^d-1}{a-1}\right)+\frac{(a^{d-1}-1)}{(d-1)}d\right]},$$

and, handoff cost $C_h$, for $\mathrm{ECQSL}_R$ as

$$C_{h1}=C_h=\frac{S_{\min}(a^{d-1}-1)}{\left\lceil\frac{N}{d+1}\right\rceil(d-1)\left[\left(\frac{a^d-1}{a-1}\right)+\frac{(a^{d-1}-1)}{(d-1)}d\right]}. \tag{16}$$

*5.4. Measure for the retrial model, $EICQSL_R$*

The extended expression for ICQSL, (4), using retrial model, cost function is given by

$$\mathrm{EICQSL}_R(x)=\frac{1}{N}\left\{\sum_{i\in N_g(x)}A_i(x)-\frac{C_1}{2}\left[\sum_{i\in\beta_x}\left(1+\cos\pi\left(\frac{S_i(x)-S_{\mathrm{drop}}}{S_{\min}-S_{\mathrm{drop}}}\right)\right)\right]\right.$$
$$\left.-\sum_{r=1}^{d_{\max}}h_r\sum_{j=1}^{r}C_r-C_h\gamma_x\right\}. \tag{17}$$

Similar to Section 5.3 the constant $C_1$ in (17) is chosen such that the lower bound of $\mathrm{EICQSL}_R(x)$ is never less than zero. The first term in (30) corresponds to good sample points with signal strengths $S_i(x)>S_{\min}$, therefore we have

$$|N_g(x)|S_{\min}\leqslant\sum_{i\in N_g(x)}A_i(x). \tag{18}$$

From (15), (17), and (18) we obtain

$$\frac{1}{N}\left[|N_g(x)|S_{\min}-\left\lceil\frac{N}{d+1}\right\rceil C_1\left(\frac{a^d-1}{a-1}\right)-C_h\left\lceil\frac{N}{d+1}\right\rceil d\right]<\mathrm{EICQSL}_R(x).$$

Similar to the argument mentioned in Section 5.3, we consider that lower bound is equal to zero. Therefore, we can compute $C_1$ and $C_h$ for $\mathrm{EICQSL}_R$ as,

$$C_1=\frac{|N_g(x)|S_{\min}}{\left\lceil\frac{N}{d+1}\right\rceil\left[\left(\frac{a^d-1}{a-1}\right)+\frac{(a^{d-1}-1)}{(d-1)}d\right]},$$

and

$$C_{h2}=C_h=\frac{|N_g(x)|S_{\min}(a^{d-1}-1)}{\left\lceil\frac{N}{d+1}\right\rceil(d-1)\left[\left(\frac{a^d-1}{a-1}\right)+\frac{(a^{d-1}-1)}{(d-1)}d\right]}. \tag{19}$$

In the following section we propose how extensions proposed in this section apply to CQSL and ICQSL for non-retrial model which has only one attempt.



DOI: 10.1002/dac

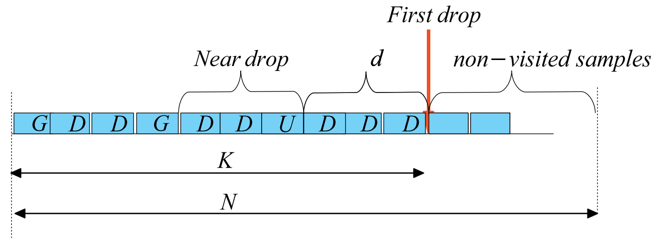


Figure 8. First call drop at the $K$th sample point, under non-retrial model.

### 5.5. *Measure for the non-retrial model, ECQSL$_N$*

In this model, we assume that call discontinuation (drop) means the end of consideration of the sample path for the proposed ECQSL$_N$ estimation. We are only interested in a sample path until the first call drop. We will not consider good components between call drops. The ECQSL$_N$ will not be able to differentiate between the various lengths of 'call drop regions' in the sample path.

$$\mathrm{ECQSL}_N(x) = \frac{\sum_{i \in N_g(x)} A_i(x)}{|N_g(x)|} - \frac{C_1}{2}\left[\sum_{i \in \beta_x}\left(1+\cos\pi\left(\frac{S_i(x)-S_{\mathrm{drop}}}{S_{\min}-S_{\mathrm{drop}}}\right)\right)\right] - \sum_{r=1}^{d_{\max}} h_r \sum_{j=1}^{d-1} C_r - C_k(N-K) - C_h\gamma_x, \tag{20}$$

where $1<K<N$ and $C_k$ is a constant cost associated with the first call drop at the $K$th sample point, therefore can give opportunity for longest calling. Note that $K=0$ is not valid due to the assumption $|N_g(x)| \geqslant 1$. Here $N_g=1$ and $\gamma=(K-1)$. The minimum of these three negative terms in (20) is the maximum cost which corresponds to a case when all the bad sample points fall within the high penalty region as shown in Figure 8, and is given by

$$\underbrace{\text{Max penalty}}_{\text{non-retrial}} = \underbrace{C_h(K-1)}_{\text{handoff}} + \underbrace{\left(\frac{a^d-1}{a-1}\right)C_1}_{\text{drop}} + \underbrace{\left(\frac{a^{d-1}-1}{a-1}+1\right)C_1\left\lceil\frac{K-d-1}{d}\right\rceil}_{\text{near-drop}} + \underbrace{C_k\left\lceil\frac{N-K}{d}\right\rceil}_{\text{non-visited samples}}. \tag{21}$$

The penalty associated with (20) should be less than the maximum penalty calculated in (21). Therefore,

$$-C_h(K-1) - \left(\frac{a^{d-1}-1}{a-1}+1\right)C_1\left\lceil\frac{K-d-1}{d}\right\rceil - \left(\frac{a^d-1}{a-1}\right)C_1 - C_k\left\lceil\frac{N-K}{d}\right\rceil \leqslant -\frac{C_1}{2}\left[\sum_{i\in\beta_x}\left(1+\cos\pi\left(\frac{S_i(x)-S_{\mathrm{drop}}}{S_{\min}-S_{\mathrm{drop}}}\right)\right)\right] - \sum_{r=1}^{d_{\max}} h_r \sum_{j=1}^{d-1} C_r - C_k(N-K) - C_h\gamma_x. \tag{22}$$

By substituting (13) and (22) in (20) we obtain

$$S_{\min} - C_h(K-1) - \left(\frac{a^{d-1}-1}{a-1}+1\right)C_1\left\lceil\frac{K-d-1}{d}\right\rceil - \left(\frac{a^d-1}{a-1}\right)C_1 - C_k\left\lceil\frac{N-K}{d}\right\rceil \leqslant \mathrm{ECQSL}_N(x).$$



DOI: 10.1002/dac

The $C_1$ constant is then determined by setting the above minimum cost value to zero, and is given by

$$C_1 = \frac{S_{\min} - C_h(K-1) - C_k\left\lceil \dfrac{N-K}{d} \right\rceil}{\left(\dfrac{a^{d-1}-1}{a-1}+1\right)\left\lceil \dfrac{K-d-1}{d} \right\rceil + \left(\dfrac{a^d-1}{a-1}\right)}. \tag{23}$$

So far we have used (10) and (22) for determining three parameters $C_1$, $C_h$, and $C_k$. We need a third equation to determine the parameters for the non-retrial case. (Now we compare cost of near drop with cost of non-visited samples using the group of samples with the same number of samples.) Here we assume that cost of non-visited samples is greater than cost of near drop sample points and is given by

$$C_k \geqslant \left(\frac{a^{d-1}-1}{a-1}+1\right) C_1. \tag{24}$$

From (10), (23), and (24) $C_1$ for $\mathrm{ECQSL}_N$ can be obtained

$$C_1 = \frac{S_{\min}}{\alpha_1+\alpha_2+\alpha_3+\alpha_4}, \tag{25}$$

where

$$\alpha_1 = \left(\frac{a^{d-1}-1}{d-1}\right)(K-1),$$

$$\alpha_2 = \left(\frac{a^{d-1}-1}{a-1}+1\right)\left\lceil \frac{K-d-1}{d} \right\rceil,$$

$$\alpha_3 = \left(\frac{a^d-1}{a-1}\right),$$

and

$$\alpha_4 = \left(\frac{a^{d-1}-1}{a-1}+1\right)\left\lceil \frac{N-K}{d} \right\rceil.$$

Therefore, handoff cost, $C_h$, for $\mathrm{ECQSL}_N$ can be obtained as

$$C_{h3} = C_h = \frac{S_{\min}(a^{d-1}-1)}{(d-1)[\alpha_1+\alpha_2+\alpha_3+\alpha_4]}. \tag{26}$$

We can obtain the signal quality measure for the non-retrial case by substituting (24), (25), and (26) in (20).

### *5.6. Measure for the non-retrial model, $EICQSL_N$*

The extended expression for ICQSL, (4), using non-retrial model, cost function is given by

$$\mathrm{EICQSL}_N(x) = \frac{1}{N}\left\{ \sum_{i\in N_g(x)} A_i(x) - \frac{C_1}{2}\left[\sum_{i\in\beta_x}\left(1+\cos\pi\left(\frac{S_i(x)-S_{\mathrm{drop}}}{S_{\min}-S_{\mathrm{drop}}}\right)\right)\right] - \sum_{r=1}^{d_{\max}} h_r \sum_{j=1}^{d-1} C_r - C_k(N-K) - C_h\gamma_x \right\}. \tag{27}$$



DOI: 10.1002/dac

From (18), (21), and (27) we obtain

$$\mathrm{EICQSL}_N(x) > \frac{1}{N}\Bigg[S_{\min}|N_g(x)| - C_h(K-1) - \left(\frac{a^{d-1}-1}{a-1}+1\right)C_1\left\lceil\frac{K-d-1}{d}\right\rceil - \left(\frac{a^d-1}{a-1}\right)C_1 - C_k\left\lceil\frac{N-K}{d}\right\rceil\Bigg].$$

Finally, $C_1$ and $C_h$ for $\mathrm{EICQSL}_N$ can be obtained as

$$C_1 = \frac{S_{\min}|N_g(x)|}{\alpha_1+\alpha_2+\alpha_3+\alpha_4}, \tag{28}$$

$$C_{h4} = C_h = \frac{S_{\min}|N_g(x)|(a^{d-1}-1)}{(d-1)[\alpha_1+\alpha_2+\alpha_3+\alpha_4]}. \tag{29}$$

### 5.7. *Optimal value for ECQSL*

*5.7.1. Exhaustive search.* The optimal handoff sequence can be defined as one which provides the best performance among all available handoff sequences. To find the optimal handoff sequence, we use the following objective function:

$$\max_{i\in 1,\ldots,N}\ \max_{(n,m)\in C}\left\{\sum_{k=1}^{i} S_{kn} + \sum_{k=i+1}^{N} S_{km}\right\}. \tag{30}$$

For retrial and non-retrial models we obtain:

$$\mathrm{ECQSL}_R(x) = \frac{\sum_{i\in N_g(x)} A_i(x)}{|N_g(x)|} - \frac{C_1}{2}\left[\sum_{i\in\beta_x}\left(1+\cos\pi\left(\frac{S_i(x)-S_{\mathrm{drop}}}{S_{\min}-S_{\mathrm{drop}}}\right)\right)\right] - \sum_{r=1}^{d_{\max}} h_r \sum_{j=1}^{r} C_r - C_{h1}\gamma_x,$$

$$\mathrm{EICQSL}_R(x) = \frac{1}{N}\Bigg\{\sum_{i\in N_g(x)} A_i(x) - \frac{C_1}{2}\left[\sum_{i\in\beta_x}\left(1+\cos\pi\left(\frac{S_i(x)-S_{\mathrm{drop}}}{S_{\min}-S_{\mathrm{drop}}}\right)\right)\right] - \sum_{r=1}^{d_{\max}} h_r \sum_{j=1}^{r} C_r - C_{h2}\gamma_x\Bigg\},$$

$$\mathrm{ECQSL}_N(x) = \frac{\sum_{i\in N_g(x)} A_i(x)}{|N_g(x)|} - \frac{C_1}{2}\left[\sum_{i\in\beta_x}\left(1+\cos\pi\left(\frac{S_i(x)-S_{\mathrm{drop}}}{S_{\min}-S_{\mathrm{drop}}}\right)\right)\right] - \sum_{r=1}^{d_{\max}} h_r \sum_{j=1}^{d-1} C_r - C_k(N-K) - C_{h3}\gamma_x,$$

$$\mathrm{EICQSL}_N(x) = \frac{1}{N}\Bigg\{\sum_{i\in N_g(x)} A_i(x) - \frac{C_1}{2}\left[\sum_{i\in\beta_x}\left(1+\cos\pi\left(\frac{S_i(x)-S_{\mathrm{drop}}}{S_{\min}-S_{\mathrm{drop}}}\right)\right)\right] - \sum_{r=1}^{d_{\max}} h_r \sum_{j=1}^{d-1} C_r - C_k(N-K) - C_{h4}\gamma_x\Bigg\},$$

where $C=\{(n,m)|n\in\{1,\ldots,M\}, m\in\{1,\ldots,M\}, n\neq m\}$. By using (30) we can exhaustively search optimal handoff sequence for only one handoff. In contrast to an exhaustive method, in our method, we only search through the following set of handoff sequences $=\{x_i|0<i\leqslant M(Nd)\}$, $d\in\{1,\ldots,L\}$,



DOI: 10.1002/dac

Table II. Handoff cost for ECQSL and EICQSL for retrial and non-retrial models.

| | |
|---|---|
| *Retrial model* | |
| ECQSL | $C_{h1}=\dfrac{S_{\min}(a^{d-1}-1)}{\left\lceil \frac{N}{d+1}\right\rceil (d-1)\left[\left(\frac{a^d-1}{a-1}\right)+\frac{(a^{d-1}-1)}{(d-1)}d\right]}$ |
| EICQSL | $C_{h2}=\dfrac{\lvert N_g(x)\rvert S_{\min}(a^{d-1}-1)}{\left\lceil \frac{N}{d+1}\right\rceil (d-1)\left[\left(\frac{a^d-1}{a-1}\right)+\frac{(a^{d-1}-1)}{(d-1)}d\right]}$ |
| *Non-retrial model* | |
| ECQSL | $C_{h3}=\dfrac{S_{\min}(a^{d-1}-1)}{(d-1)\left[\left(\frac{a^{d-1}-1}{d-1}\right)(K-1)+\left(\frac{a^{d-1}-1}{a-1}+1\right)\left\lceil\frac{K-d-1}{d}\right\rceil+\left(\frac{a^d-1}{a-1}\right)+\left(\frac{a^{d-1}-1}{a-1}+1\right)\left\lceil\frac{N-K}{d}\right\rceil\right]}$ |
| EICQSL | $C_{h4}=\dfrac{S_{\min}\lvert N_g(x)\rvert(a^{d-1}-1)}{(d-1)\left[\left(\frac{a^{d-1}-1}{d-1}\right)(K-1)+\left(\frac{a^{d-1}-1}{a-1}+1\right)\left\lceil\frac{K-d-1}{d}\right\rceil+\left(\frac{a^d-1}{a-1}\right)+\left(\frac{a^{d-1}-1}{a-1}+1\right)\left\lceil\frac{N-K}{d}\right\rceil\right]}$ |

where $L$ is the maximum number of handoffs and $L \ll (N-1)$. The complexity of our method is $O(MN^d)$ in comparison to the complexity $O(M^N)$ using exhaustive search. The following procedure is used to obtain optimal handoff sequences carried out in obtaining the results presented in the following section (in Figure 15) (Table II).

*Variables for algorithm*: Here, set of all possible handoff sequences $X=\{x_i \mid 0<i\leqslant M^N\}$ where $x_i$ is the $i$th handoff sequence, $i=0,1,2,\ldots,M^N$. We define $k$ is optimal number of handoff (that defines the subset in the search space).

## 6. SIMULATION RESULTS AND DISCUSSION

In this work we compare the different handoff methods introduced in Section 1 using different quality measures. We randomly generate $\eta=1000$ sample paths, each with a number of sample points $N=100$ where each pair of consecutive points are 1 m apart. For a more realistic view, we add shadowing to the simulation following a log-normal propagation model, as described in [16]. This was assumed to generate signal strengths in each sample point along all the sample paths, i.e. $S_{ij}=K_1-K_2\log(\tau)+F$, where $K_1=85$; $K_2=35$ are constants, $\tau$ is the distance to the base station, and $F$ is a Gaussian-distributed random variable ($N(0,\sigma^2)$) representing the shadowing effect. We set $\sigma=5$ dB, shadowing correlation distance equals 20 m, $S_{\min}=15$ dB as in [17], and $S_{\max}=1.5S_{\min}$. All the sample paths are straight lines that start from points in the square area $\{(100,100),(200,100),(200,200),(100,200)\}$ and distributed uniformly in the region [18]. Their directions are randomly uniformly distributed over $[0,2\pi]$ as in [18]. In our simulations, we assume that a call will be dropped after $d=3$ consecutive dropping sample points. Assuming that the user is traveling at a constant speed, it is possible to calculate the speed corresponding to $d=3$. In practice, often a time period (for GSM call dropping timer is 6 s) with dropping signal strength level is considered as a service failure or call dropping. When the user speed increases, it is possible to increase $d$ hence leading to lower call dropping. Simulation parameters are summarized in Table III.

**Algorithm 1** : Search for optimal values

```
for x ∈ {x_1, ..., x_1000} do
   best = 0
   next = exhaustive (X, ECQSL, k)
   while next > best and k < L do
      best = next
      k = k + 1
      next = exhaustive (X, ECQSL, k)
   end while
end for
```



DOI: 10.1002/dac

Table III. Parameters used in simulation.

| | |
|---|---|
| Cell radius ($\tau$) | 100 m [19] |
| Number of base stations ($M$) | 3 [17] |
| Number of sample paths ($\eta$) | 1000 [17, 19] |
| Spatial sampling interval | 1 m [20] |
| Standard deviation of shadow fading ($\sigma$) | 5 dB [21] |
| Correlation distance of shadow fading | 20 m [20] |
| Sample points ($N$) | 100 |
| Threshold ($T$) | Variable |
| Minimum acceptable signal strength ($S_{\text{min}}$) | 15 dB [17] |
| Dropping signal strength ($S_{\text{drop}}$) | 14.5 dB |
| Maximum signal strength ($S_{\text{max}}$) | $1.5S_{\text{min}}$ dB |
| Path-loss constant ($K_1$) | 85 |
| Path-loss exponent ($K_2$) | 35 [17] |
| Consecutive sample points ($d$) | 3 |

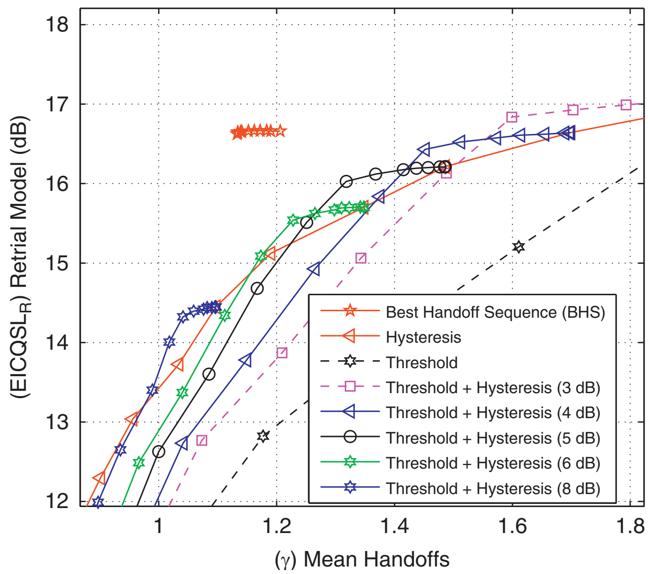


Figure 9. EICQSL versus mean handoffs ($\overline{\gamma}$) values for retrial model, when $\delta = 0.9$.

Performance was evaluated for different handoff methods as shown in Figures 9–13 for retrial model, where repeated call attempts are made for retrial model, where repeated call attempts are made assuming $\delta = 0.9$. The values in these figures are obtained by varying the threshold in the Threshold method, as well as the hysteresis threshold in both the Hysteresis and the Threshold with Hysteresis methods, respectively, from 1 to 30 dB, to see the most efficient threshold value. BHS provides a minimum number of handoffs while maximizing the call quality. This can be observed in Figures 9–13. In our work we use benchmark, BHS, to evaluate online handoff methods that provide maximum quality with low cost; hence, it provides an ideal target that enables comparison between handoff schemes. It is indicated that the Threshold method with 5 or 6 dB performs well as we need to minimize the number of handoffs as well as to maximize the signal quality. It can be observed that, from Figures 11 and 12 that with non-retrial case, there is less quality difference between existing handoff methods. We observed that there is low call drop with Threshold method with 5 or 6 dB hysteresis in retrial model, as demonstrated in Figure 13. Using the parameter values from Table III, and varying the system dropping probability $\delta$ from 0.1 to 0.9 with the Threshold with 6 dB Hysteresis method, we find that the total quality of the call decreases with increasing $\delta$, as shown in Figure 14. This is caused by the call quality decrease with increasing call dropping probability. For this reason, we compare existing handoff methods by varying $\delta$, within



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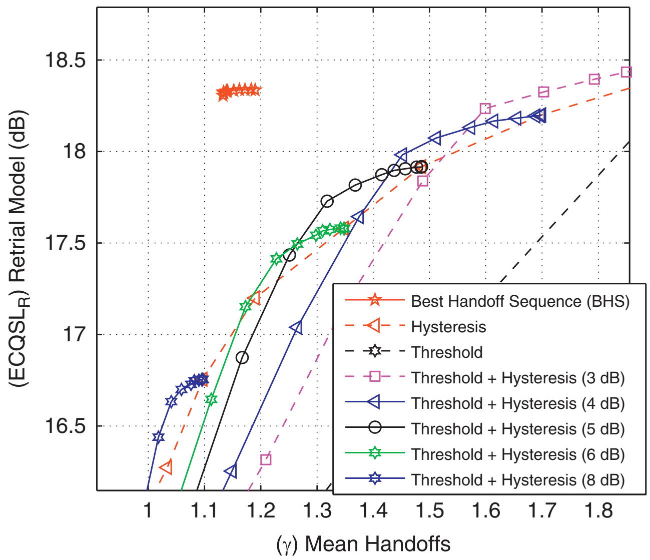


Figure 10. ECQSL versus mean handoffs ($\overline{\gamma}$) values for retrial model, when $\delta = 0.9$.

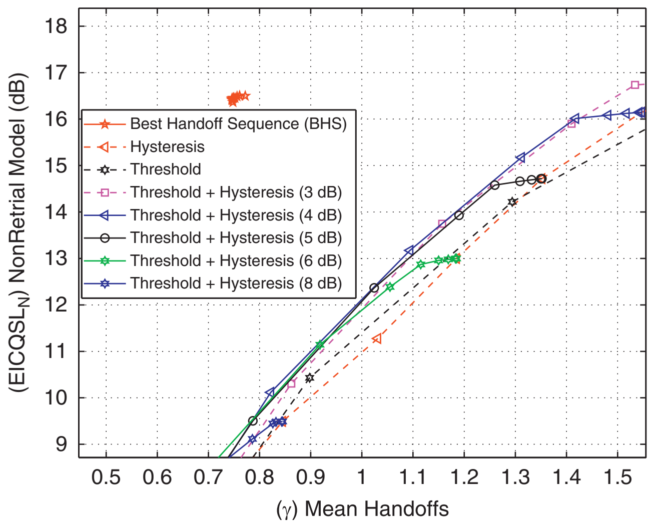


Figure 11. EICQSL versus mean handoffs ($\overline{\gamma}$) values for non-retrial model, when $\delta = 0.9$.

the interval $0 < \delta < 1$ and observe that the handoff method with the best performance varies when $\delta$ is increased as shown in Table IV. The simulation results indicate that the threshold method with 4 dB hysteresis performs well for urban areas with high dropping probability, whereas the threshold method with 6 dB hysteresis performs well for suburban areas with low dropping probability. Suitable handoff methods for given terrain configuration is suggested. The results in Figure 15 are generated using Algorithm 1 (procedure) proposed in Section 5.7. The values associated with each point along the curves in the graph are the average number of handoff per user.

For example, the values (0.87, 0.80) connected with each point along the curves in Figure 15 are the average number of handoff per user. Here, 0.87 is average number of handoff per user for Retrial Optimal ECQSL$_R$ and 0.80 for ECQSL$_N$. We observe that the quality (ECQSL$_R$ and ECQSL$_N$) does not improve as the maximum allowable number of handoff per user increases. (The optimal curve expected to be flat with increasing search space as in Figure 15.) This peaks on point one due to one average number of handoff.

 
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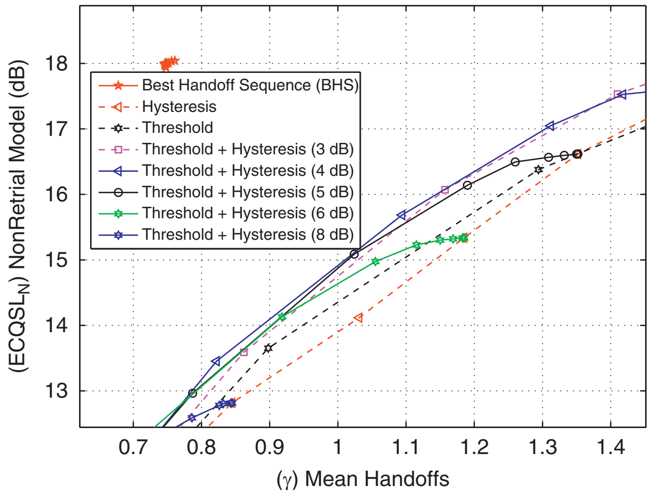


Figure 12. ECQSL versus mean handoffs ($\overline{\gamma}$) values for non-retrial model, when $\delta = 0.9$.

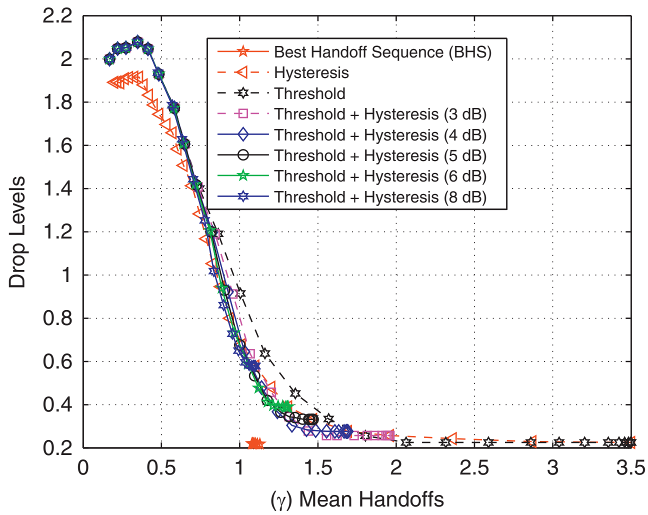


Figure 13. Drop levels versus mean handoffs ($\overline{\gamma}$) for retrial model.

Due to repeated call attempts are made after a call is lost in retrial method, value of EICQSL$_R$ is higher than EICQSL$_N$. Similar results are obtained using EICQSL$_R$ and EICQSL$_N$. We also observe that the handoff distributions of various handoff methods are different when 1000 users are considered, as shown in Figure 16. We also observed that the handoff distributions of various handoff methods are different when 1000 users are considered, as shown in Figure 16. We conducted simulations involving 1000 users moving within the boundary of three adjacent cells and observed that, in most cases studied, users require no more than one handoff. The number of users corresponding to each individual number of handoffs is shown in this figure. Accordingly, the summation of all the values represented by the bars in the $y$-axis is equal to 1000 in all the four graphs.

## 7. CONCLUSION

In this paper, we have proposed a new measure for performance evaluation and comparison between existing handoff algorithms, taking into consideration signal level, call dropping, and handoff cost for cellular networks, for both the retrial (where repeated call attempts are made) and non-retrial



DOI: 10.1002/dac

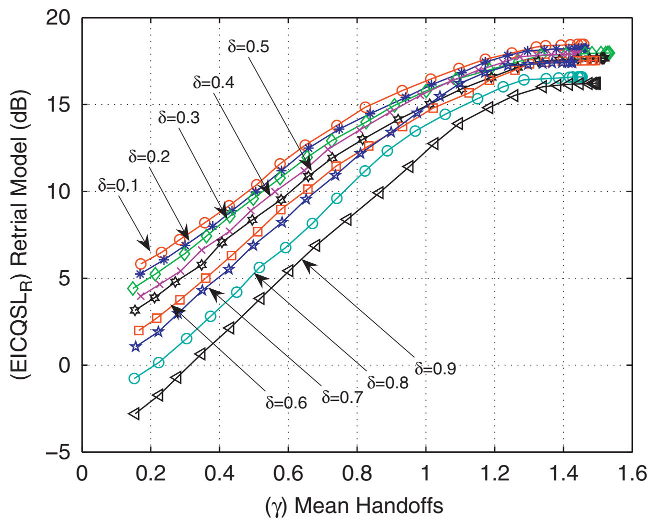


Figure 14. EICQSL$_R$ for retrial model when $\delta$ varies.

Table IV. Recommended handoff methods for different system dropping probabilities.

| Dropping probability ($\delta$) | Retrial model | | Non-retrial model | |
|---|---|---|---|---|
| | ECQSL$_R$ | EICQSL$_R$ | ECQSL$_N$ | EICQSL$_N$ |
| 0.1 | Hysteresis | Hysteresis | T+H 6 dB | T+H 6 dB |
| 0.2 | Hysteresis | Hysteresis | T+H 6 dB | T+H 6 dB |
| 0.3 | Hysteresis | Hysteresis | T+H 6 dB | T+H 6 dB |
| 0.4 | Hyst or T+H 6 dB | Hyst or T+H 6 dB | T+H 5 dB | T+H 5 dB |
| 0.5 | T+H 6 dB | T+H 6 dB | T+H 4 dB | T+H 4 dB |
| 0.6 | T+H 5 or 6 dB | T+H 5 or 6 dB | T+H 5 dB | T+H 5 dB |
| 0.7 | T+H 5 or 6 dB | T+H 5 or 6 dB | T+H 4 or 5 dB | T+H 4 or 5 dB |
| 0.8 | T+H 5 or 6 dB | T+H 5 or 6 dB | T+H 4 dB | T+H 4 dB |
| 0.9 | T+H 5 or 6 dB | T+H 5 or 6 dB | T+H 4 dB | T+H 4 dB |

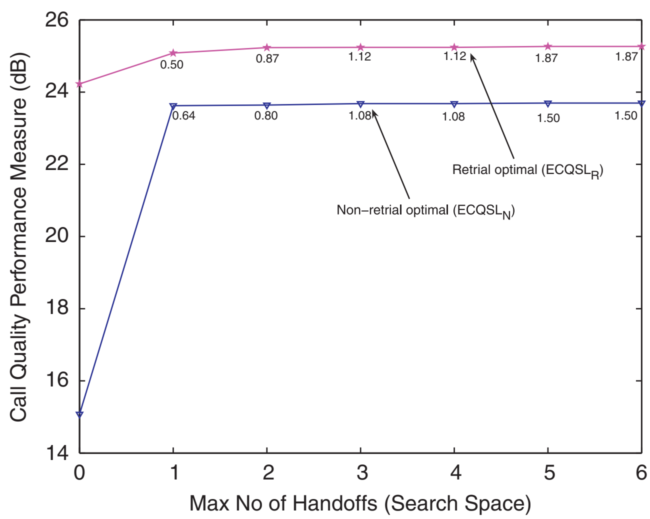


Figure 15. Optimal curves for retrial and non-retrial for ECQSL. This figure is generated using Algorithm 1 proposed in Section 5.7.



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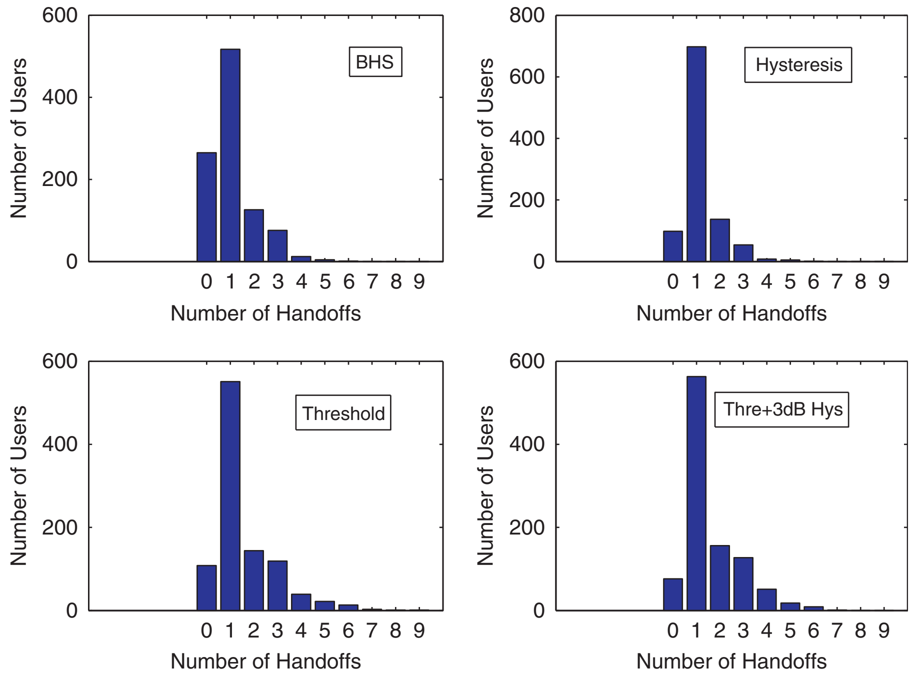


Figure 16. User distribution of various handoff evaluation methods considering 1000 users.

call options. The increase in quality of the calls is quantified using the proposed quality measure. Moreover, this measure can be used by network operators to set suitable values for the hysteresis margin, and the handoff threshold to obtain optimal quality while reducing the number of handoffs and call dropping. The results indicate that, for urban areas with high dropping probability, the Threshold with 4 dB Hysteresis performs well, whereas for suburban areas with low dropping probability, the Threshold with 6 dB Hysteresis performs well. We have found that the existing handoff methods are less efficient than the optimal handoff sequence for retrial model by 29–45% and for non-retrial model by 34–77%. We have also proposed a method to estimate handoff cost and optimal values for retrial and non-retrial models. The paper also provides recommendations for specific parameter values to improve performance of currently used handoff methods. Designers can now optimize quality of the call based on efficient handoff algorithm and using other recommended parameter values.

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DOI: 10.1002/dac

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DOI: 10.1002/dac

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DOI: 10.1002/dac