An Efficient Handoff Scheme Using a Minimum Residual Time First Scheme

Bilal Owaidat, Rola Kassem and Hamza Issa

***Abstract*—When a mobile station (MS) with an ongoing call is about to leave a cell, the base station (BS) of that cell hands off the call to the BS of the new cell. Since a BS typically serves a large number of MSs, it is likely that many handoff requests arrive at a short period of time at the BS, where they are queued for handling according to some queueing discipline. Current handoff schemes use a FCFS discipline, whose problem is that it does not pay attention to the remaining time in the cell of the leaving MS.**

In this paper we propose a scheme to remedy the above problem. The Shortest Job First-like Handoff Scheme (SJFLHS) still queues the MSs requiring handoff, but serves always the MS with the least remaining time in the cell. To this end the BS keeps monitoring the remaining times of MSs requiring handoff. The cost of this overhead is insignificant compared to the resulting performance improvement, which is shown here through extensive simulations.

***Keywords*—cellular network, handoff, priority, shortest job first queue**

I. Introduction

In the fourth generation wireless networks, multiple base stations cooperate to serve mobile stations requests. When a MS with an ongoing call arrives at a BS, it will connect only if there exist a free channel, otherwise its call will be blocked. Once connected, this BS is called the serving base station (SBS) of the MS. A BS has a circular coverage area with a radius ranging from a few hundred meters to a few kilometers in radius. When a MS reaches the boundaries of the SBS coverage area, it should disconnect from this SBS and connect to a new BS, which is called the target base station (TBS). Therefore, the corresponding channel in the SBS is released, and on the other hand a channel is reserved in the TBS. This process is known as handoff. The channel frequencies could be reused in cells that are separated in distance so that there is no mutual interference between them. In a practical environment, there is some handoff time delay before that a MS connects to a TBS. This delay is composed of handoff preparation and handoff execution. The handoff time delay is constrained by a timeout period that when exceeded, the handoff fails and the call is forced-terminated. There are two types of handoff schemes: hard handoffs and soft handoffs [1],[2]. In hard handoff, the channel in the SBS is released and then a channel in the TBS is reserved. Thus the connection to the SBS is ended before or as the connection to the TBS is being created. Determining an accurate trigger time for hard handoffs is a difficult task. Soft handoffs solve this problem by connecting the MS to the TBS before breaking with the SBS. The MS holds the radio resources of the SBS and TBS simultaneously during a soft handoff period.

A call is either complete or incomplete. A complete call is a one that is served without any handoff failure. An incomplete call is either a blocked call (a new call that is blocked) or a forced-terminated call (an ongoing call that failed to handoff). Note that a call could succeed multiple handoffs before it is forced terminated. There are two major metrics that define the performance of cellular systems: the probability that an ongoing call is dropped (because of its forced-termination) and the probability that a new call is blocked (because of unavailability of a free channel). When a MS is moving with high velocity, the number of handoff attempts dramatically increases. From a user's point of view, it is more annoying to drop an ongoing call than to block a new call. Therefore, handoff calls are given a higher priority to get a channel over new calls. This prioritization rule have a significant impact on those two major metrics; it decreases the handoff failure probability at the expense of an increase in the call blocking probability. The most popular strategies for prioritizing handoff calls are the guarded channel strategy and the handoff queueing strategy [3]. In the guarded channel strategy, a fixed number of channels is reserved exclusively for handoff calls. New calls are not allowed to use these guarded channels for service, however a handoff call can use any channel [4]. If only the dropping probability of handoff calls is considered, the guarded channels algorithm gives good results, however it will increase the blocking probability of new calls dramatically. The guarded channel strategy has some drawbacks, when all the channels (reserved and non reserved) are busy then the handoff will fail and the call is forced-terminated. On the other hand, in the handoff queueing strategy, if there is no available channel for the handoff request, this request is queued until a channel gets free. Queueing is possible due to the overlap region between neighbor cells where the MS can reach both the SBS and the TBS. The MSs remaining time in the overlapping area specifies the maximum allowed queueing time. In [5], the Predictive Received Signal Strength (PRSS) studied whether to start a handoff by comparing some quantitative decision values to select a target network. However, this algorithm could not be applied because the MS should know how strong is the PRSS of its neighbors in order to decide an early handoff. Two handoff algorithms were developed in [6] based on the PRSS and the current RSS, but they didn't avoid the ping-pong effect. Other vertical handoff decision algorithms were

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proposed based on fuzzy logic to give the best solution for handoff decision [7],[8]. The problem with these algorithms is that they all need to establish some proper rules that require a large memory to store rules in databases. The following studies [9],[10],[11] improved handoff decisions by analyzing the signal power received by stations, but without taking the MSs velocities into considerations. Other studies considered the mobility of MSs to decrease handoff failure probabilities [12],[13]. Many other feasible solutions were developed to enhance handoffs by monitoring the MSs positions [14]. Using the global positioning system (GPS) is a way to get the locations of MSs; however, when used in extreme weather conditions, it could suffer from serious interfering problems [15]. A mechanism to determine the location of devices without using the GPS was developed in [16]. In [17], the handoff mechanism ASAP considered both the SNR value and the mobility of MSs using geometric analysis. A fast handoff scheme for voip was considered in [18], it is based on selective scanning and caching to predict the next cell. None of the previously proposed schemes is efficiently able to serve handoff requests when MSs are moving with high velocity. The present scheme treats each MS individually, it gives a higher priority for channel reservation to the MS with the *minimum* remaining time in the cell τ. It sorts the MSs handoff requests according to their remaining times, and handoffs the one that has the lowest τ first. In other words, this scheme implements a shortest job first (SJF)-like queue. The rest of this paper is organized as follows: in section 2 we provide some background about handoff strategies, then the system model is introduced in section 3, the simulation model is introduced in section 4, in section 5 the simulation results are given and finally conclusions are presented in Section 6.

II. BACKGROUND

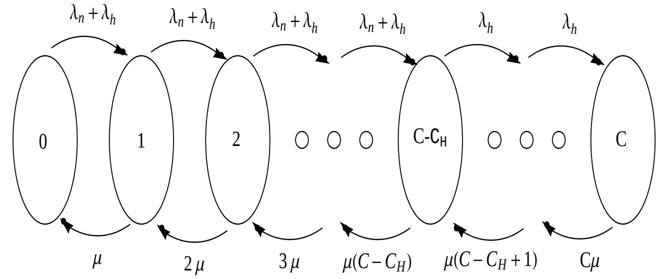
A cell is represented by a circular region with center coordinates (x, y) and radius R. The center of the first cell is located at the point $(0, 0)$. Each cell intersects with its neighbors with a small area called the overlap region, that is the area where a MS can receive signal from both cells. When a MS is moving across the boundaries of a serving cell to a neighboring cell, it will pass through the overlap region where it can start the handoff procedure to transfer its call from the SBS to the TBS.

We assume that the new calls and handoff calls arrive according to a Poisson distribution with parameters λ_n and λ_h respectively. Each station has C channels that can serve C calls in parallel. The time that the MS spends in the system is referred to as the call holding time T and is assumed to be exponentially distributed with parameter μ. Therefore μ is the ongoing calls termination rate and $\frac{1}{\mu}$ is the average time a call spends in the system. We should also note that when an ongoing call is ended or handed off to a TBS, it is discarded from the records of the SBS.

A. Guarded channels strategy

In the guarded channel strategy, a MS requests a handoff once it enters the coverage area of the new cell, that is when

Fig. 1. State transition diagram for the guarded channel strategy.



it enters the overlap region where it can reach both the SBS and TBS. The number of channels reserved for handoffs is C_H. Let E_n be the state that there are n ongoing calls in a cell and P_n be the steady state probability for a cell to be in state E_n. These probabilities are determined by using the Markovian birth-death process shown in the state diagram in Figure 1 and are found to be:

$$P_n = \begin{cases} \frac{(\lambda_n+\lambda_h)^n}{n!\mu^n} P_0, & n < C - C_H. \\ \frac{(\lambda_n+\lambda_h)^{C-C_H} \lambda_h^{n-(C-C_H)}}{n!\mu^n} P_0, & C - C_H \leq n \leq C. \end{cases}$$

Where P_0 is found from the equation $P_0 + P_1 + \cdots + P_n = 1$

$$P_0 = \left(\sum_{n=0}^{C-C_H} \frac{(\lambda_n + \lambda_h)^n}{n!\mu^n} + \sum_{n=C-C_H+1}^{C} \frac{(\lambda_n + \lambda_h)^{C-C_H} \lambda_h^{n-(C-C_H)}}{n!\mu^n} \right)^{-1}$$

Let P_{fh} represent the handoff failure probability and P_B represent the call blocking probability because no channels are available. A call is blocked if all the non-guarded channels were busy when this call was initiated, therefore:

$$P_B = \sum_{n=C-C_H}^{C} P_n$$

A handoff fails when all the channels (guarded and non-guarded) are busy, therefore:

$$P_{fh} = P_C$$

B. Handoff queuing strategy

In the handoff queueing strategy, there are no guarded channels. Here, if the number of busy channels is less than C then the TBS accepts every incoming call. But, when the C channels are all busy, then the TBS will only accept handoff calls. These handoff calls wait for their turn in a queue until a channel gets free and then they are treated equally on a FCFS basis. Let the time that a mobile station spends in the overlap area to be exponentially distributed with rate η, thus η is the departure rate for calls that leave the overlap region. The mobile station's association time with a cell is exponentially distributed with rate v, also v is the departure rate for calls

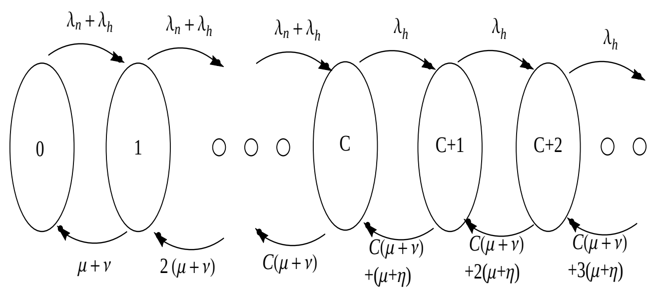


Fig. 2. State transition diagram for the queuing strategy.

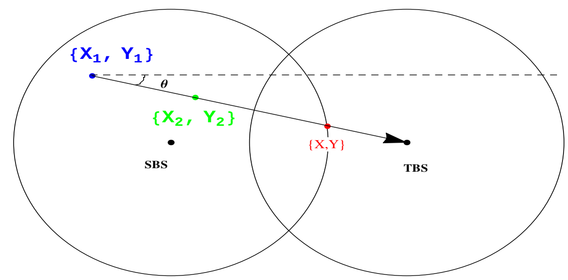


Fig. 3. A MS leaving its SBS and moving toward a TBS.

that leave the cell. Figure 2 shows the state diagram for the queuing strategy.

Here the steady state probability is:

$$P_n = \begin{cases} P_0 \frac{(\lambda_n+\lambda_h)^n}{n!(\mu+v)^n}, & n < C. \\ P_0 \frac{(\lambda_n+\lambda_h)^c \lambda_h^{n-c}}{(c-1)!(\mu+v)^{c-1} \prod_{j=0}^{n-c} [c(\mu+v)+j(\mu+\eta)]}, & n \geq C. \end{cases}$$

Where

$$P_0 = \left(\sum_{n=0}^{c-1} \frac{(\lambda_n + \lambda_h)^n}{n!(\mu + v)^n} + \sum_{n=c}^{\infty} \frac{(\lambda_n + \lambda_h)^c \lambda_h^{n-c}}{(c-1)!(\mu + v)^{c-1} \prod_{j=0}^{n-c} [c(\mu + v) + j(\mu + \eta)]} \right)^{-1}$$

The call blocking probability is

$$P_B = \sum_{n=c}^{\infty} P_n$$

and, according to [19], the handoff failure probability is

$$P_{fh} = \sum_{j=0}^{\infty} \frac{\eta\,(j+1)\,P_{c+j}}{c\,(\mu + v) + (j+1)\,(\mu + \eta)}$$

III. System Model

In the present study, we use a model that combines both strategies (guarded channels and handoff queuing). In this model, a MS starts a new call anywhere in a cell and then it travels towards a neighbor cell. We assume that the velocity (speed and direction) of each MS remains constant while in a cell. But two different MSs may travel with two different velocities. When a MS leaves its SBS and connects to a TBS, it will travel with a new velocity towards the neighbor cell of the TBS. The velocity magnitude of the MS changes from cell to cell and is uniformly distributed on the interval $[V_{\min}, V_{\max}]$. The time spent in a cell and the time spent in the overlap region is not the same for all MSs. We specify a threshold time τ_h; a MS can reserve a channel when its τ becomes less than this threshold ($\tau < \tau_h$). Note that this channel will start serving the call when the MS enters the overlap region. If no channel is available at the TBS, the MS keeps trying to succeed the handoff as long as it is still in the overlap region. If the MS leaves the overlap region before succeeding to handoff its call, then the call is forced-terminated. Therefore τ and τ_h are two major factors that affect the call forced termination probability. If two MSs (MS1 and MS2) have $\tau_{MS1} < \tau_{MS2} < \tau_h$, then MS1 is more likely to leave the cell before MS2. In previous studies, the MSs are treated equally, and are served in a FCFS discipline. This discipline could serve MS2 before MS1 if it requested the handoff first, and this could lead to the forced-termination of the call of MS1 if there are no more free channels at the TBS. To solve this problem, the MSs should not be treated equally. In SJFLHS, we make sure that the MSs are served in ascending order of their τ, i.e. when two MSs request a handoff, the one with the lowest τ gets the channel first. This is similar to the Shortest Job First (SJF) queueing discipline [20].

Let N be the number of MSs that starts their calls in a cell during a time T. The position of every MS is updated every $\Delta t << T$. If MS1 is a mobile station located at coordinates (X_1, Y_1), the new position of MS1 depends on its velocity vector $\overrightarrow{V}_{MS1}$, which is constant both in magnitude and angle θ (taken with respect to X-axis) as shown in Figure 3. Note that the magnitude $\left|\overrightarrow{V}_{MS}\right|$ for a MS is uniformly distributed over the interval $[V_{\min}, V_{\max}]$.

The value of θ is found to be:

$$\theta = \tan^{-1}\left(\frac{X_{TBS} - X_1}{Y_{TBS} - Y_1}\right)$$

Where X_{TBS} and Y_{TBS} are the coordinates of the center of the TBS. The new coordinates (X_2, Y_2) of MS1 are :

$$\begin{aligned} X_2 &= X_1 + \Delta t * V \cos\theta \\ Y_2 &= Y_1 + \Delta t * V \sin\theta \end{aligned}$$

MS1 is moving on the straight line $Y = Y_1 + (X - X_1)\tan\theta$, it will leave the SBS's coverage area when it reaches the point of intersection (X, Y) of this straight line with the coverage area of the SBS, which is a circle of radius R. The remaining time τ_{MS1} for MS1 in the SBS is :

$$\tau_{MS1} = \frac{\sqrt{(Y - Y_{MS1})^2 + (X - X_{MS1})^2}}{\left|\overrightarrow{V}_{MS1}\right|}$$

When a MS have $\tau < \tau_h$, it will ask its SBS to handoff its call. The SBS sorts the MSs every Δt seconds in ascending order of their τ, then it request from the TBS a channel for the

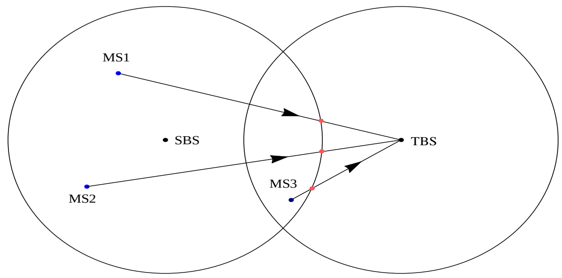


Fig. 4. Handoff requests with different priorities.

MS that has the lowest τ. For example, referring to Figure 4, if $\tau_1 < \tau_2 < \tau_3 < \tau_h$, then MS3 is moving slowly and should be handed off last. On the other hand, MS1 is moving faster than MS2 and MS3 and should reserve a channel first.

IV. Simulation

When a new call arrives at an SBS, it will check whether there is a free (non-guarded and not reserved by a MS) channel to serve this call, if no channel is free then the call is blocked. When a MS with an ongoing call have $\tau < \tau_h$, it will attempt to reserve a channel (guarded or not guarded) at the TBS. If the TBS has an available channel, it will reserve it for this MS and will allocate it as soon as this MS enters the overlap region. However, if the TBS has no free channels, this MS should wait for its turn in a queue that is periodically sorted in ascending order of τ. If a MS finishes its call while waiting in the queue, then the corresponding reserved channel is released. If a handoff call leaves the SBS while waiting in the queue then the call is forced terminated and the corresponding reserved TBS channel is also released. The following algorithm shows how SJFLHS treats new calls and handoffs.

```
New Call
If (there is a free non guarded channel)
    Allocate the channel
Else Block call (New call blocking)


Reservation
If (there is a free channel (guarded or
non guarded) at the TBS)
    Reserve this channel
Else Ignore the request


Cancellation
If(A call associated with a reserved
channel has finished)
    Free this reserved channel


Handoff
If (MS has reserved a channel)
    Allocate the reserved channel to the
MS
Else If there is an available channel
    Allocate the available channel to the
MS
Else Block the Call (Forced Termination)
```

TABLE I. Values used in simulation

Parameter	Value	Description
R	3000 m	Radius of a Cell
S	50	Number of Cells
N	100	Number of MSs in a cell
C	32	Number of channels in a cell
GC	2	Number of guarded channels in a cell
$V_{\min}$	1 m/s	Minimum speed of a MS
$V_{\max}$	30 m/s	Maximum speed of a MS
λ	1/10 Calls/sec	Call Arrival rate
μ	1/180 Calls/sec	Call Service rate
τ_h	10 sec	Threshold time

We have simulated the above model using a C++ program. Let N be the number of calls that starts in a cell during a time T. First, we specify the number of MSs in each cell. Then we specify the call arrival and ending times, and also the initial position and the velocity vector for each MS. Next we update the position and τ for each MS every Δt seconds. Finally, the SBS sorts the calls in ascending order of their τ, and then it will handoff the MS with smallest τ first. That is, the most critical calls are always handed off first. This should reduce the handoff failure probability at the expense of an increase in call blocking probability.

The parameters used in the simulation are shown in Table I, unless otherwise specified. We show the effect of various parameters on the call blocking probability P_B and handoff failure probability P_{fh}

A. *Impact of new calls arrival rate on P_B and P_{fh}*

Figure 5 (a) and (b) show P_B and P_{fh} for FCFC and SJFLHS against new calls arrival rate λ. We notice that the increase in λ has lead to more blocked calls. Also P_B in SJFLHS is slightly higher than the FCFS strategy, and this is because the former strategy succeeds the handoffs better than the latter, therefore there are less channels for new calls. On the other hand, P_{fh} has decreased when λ has increased, and that is because an increase in λ will result in more blocked calls and therefore handoffs will have more channels for their service. Also, it is clear that P_{fh} in SJFLHS is significantly lower than that of the other strategy.

B. *Impact of calls service rate on on P_B and P_{fh}*

Figure 6 (a) and (b) shows P_B and P_{fh} against the service rate μ. Both probabilities have decreased when μ has increased. The ongoing calls will get served much better when the service rate is high, therefore the new calls and the handoffs will have more channels to compete for. This of course will lead to a decrease in blocking probabilities. Again SJFLHS gives lower P_{fh} than FCFS technique.

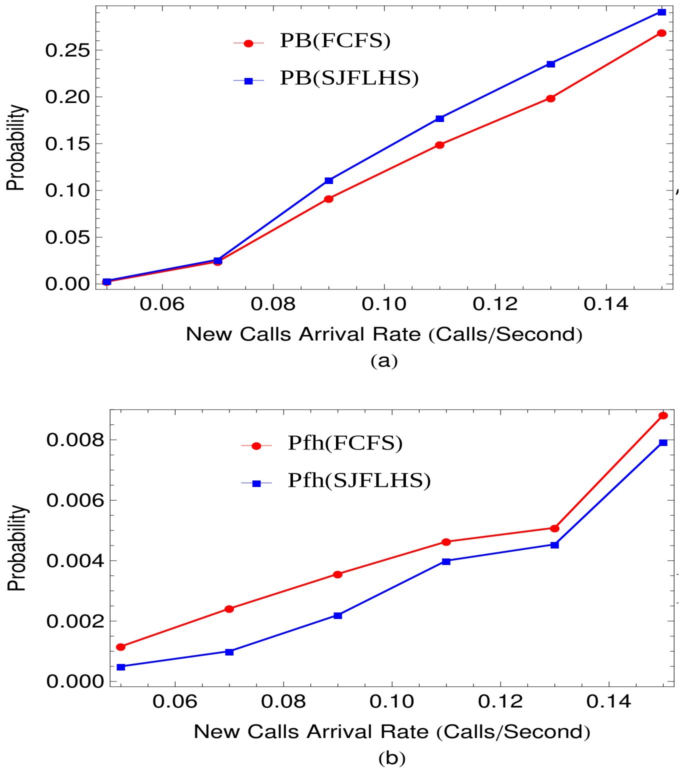


Fig. 5. Call Blocking And Handoff Failure Probabilities vs. Calls Arrival Rate.

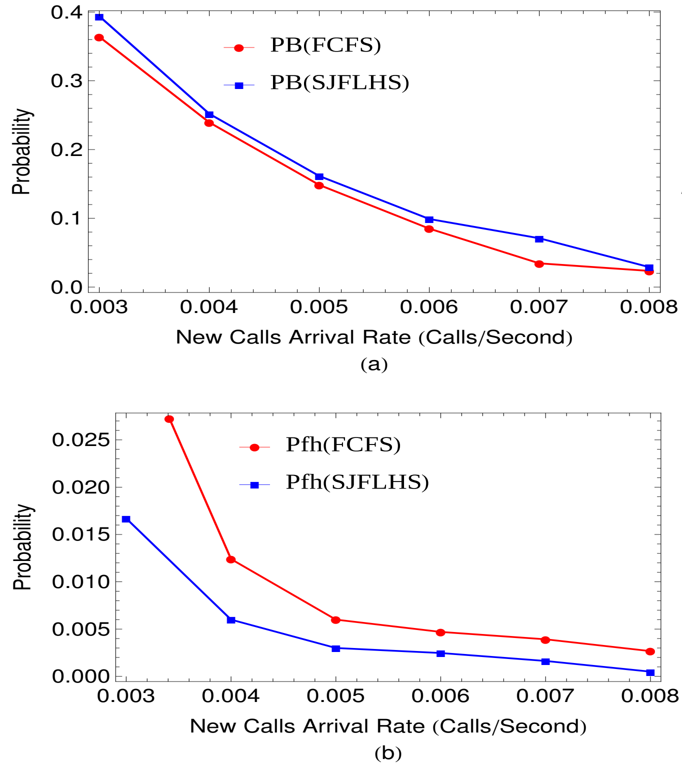


Fig. 6. Call Blocking And Handoff Failure Probabilities vs. Calls Service Rate.

C. Impact of guarded channels on P_B and P_{fh}

In Figure 7 (a) and (b), we show the impact of guarded channels on both techniques. When the number of guarded channels has increased, P_B has increased while P_{fh} has decreased. P_{fh} in SJFLHS is lower than P_{fh} in the FCFS strategy, of course at the expense of an increase in P_B.

D. Impact of time threshold on P_B and P_{fh}

Figure 8 (a) and (b) show P_B and P_{fh} for different threshold times. When threshold τ_h has increased, P_{fh} has decreased because the MS will have more time to reserve a channel which means they have more advantage to succeed their handoffs. On the other hand, P_B has increased because less remaining channels are available for new calls. Also, in SJFLHS, P_{fh} is lower than the FCFS strategy, while P_B is higher.

E. Impact of MS velocity on P_B and P_{fh}

In this part, we assume that the MS's maximum velocity $V_{\max}$ which is shown in Table I does not change and the MS's minimum velocity $V_{\min}$ will increase from 1 meter/second up to $V_{\max}$. When a MS is moving with a high velocity, it will leave the coverage area of a cell much faster than if it is moving with a low velocity. Therefore the MS will request more handoffs for its call, this will increase the total number of handoffs in the system as shown in Figure 9. The increase in handoffs will also result in more handoff failures. In Figure 10, we show the impact of velocities on P_B and P_{fh}. When the velocity of MSs increased, P_{fh} has also increased while P_B has decreased because more handoff failures mean more channels for new calls. Also, in SJFLHS, P_{fh} is lower than the FCFS strategy, of course at the expense of a small increase in P_B.

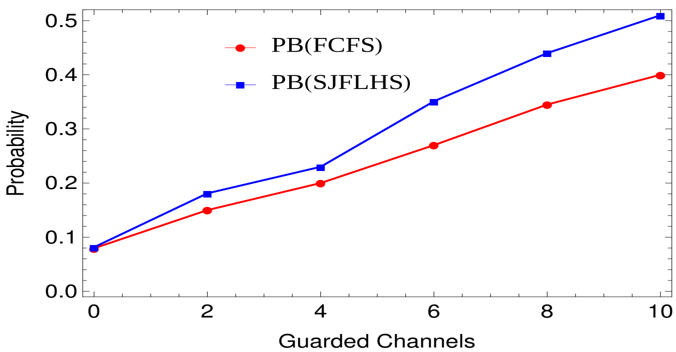
F. SJFLHS vs ASAP

In Figure 11, we compare our scheme to a recently developed scheme ASAP. It is clear that SJFLHS has significantly decreased the handoff failure probability P_{fh} in comparison to ASAP, however it has also increased significantly the call blocking probability P_B.

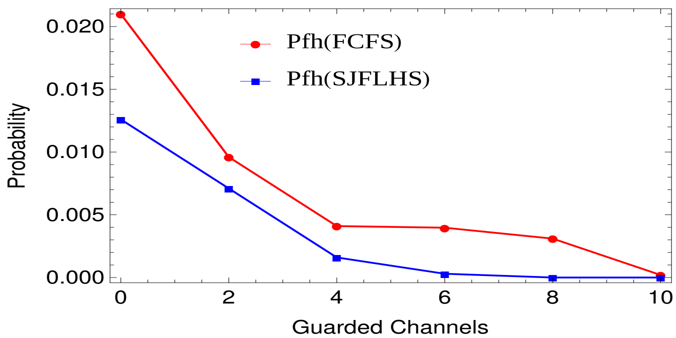
V. Conclusions

In this paper, we have presented a novel cellular handoff scheme particularly suitable for MSs moving with high velocity. The idea of the scheme is not to handle MSs queued for handoff on a FCFS basis, but rather to select for service the MS with remaining time in the cell less than all others in the queue, a scheme akin to the shortest job first (SJF) discipline. This scheme decreases the likelihood that a MS leaves the cell before its handoff request is handled, a common problem with FCFS schemes.

The simulation program used to validate the proposed scheme is written in the C language, which requires more

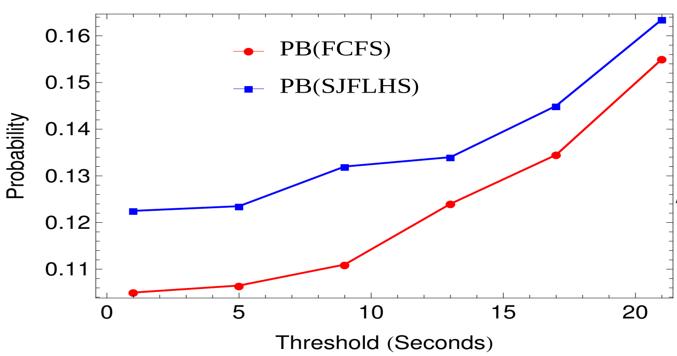


(a)

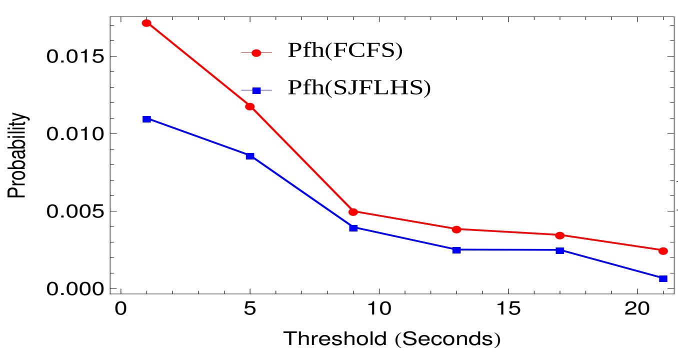


(b)

Fig. 7. Call Blocking And Handoff Failure Probabilities vs. Calls Guarded Channels.



(a)



(b)

Fig. 8. Call Blocking And Handoff Failure Probabilities vs. Threshold.

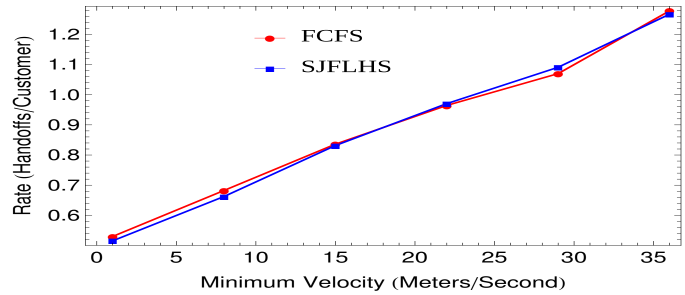
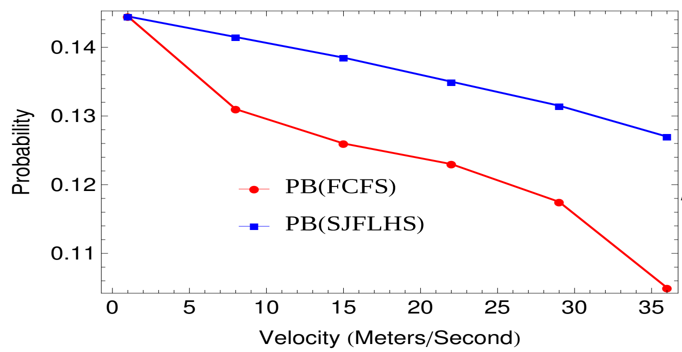
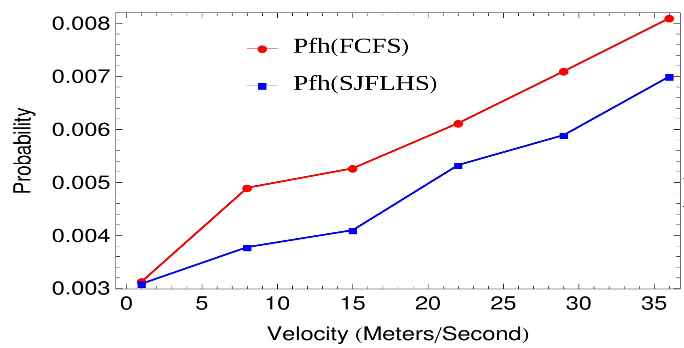


Fig. 9. Handoff Rate vs. Velocity.



(a)



(b)

Fig. 10. Call Blocking And Handoff Failure Probabilities vs. Velocity.

effort, but yet provides more control, than very high level simulation languages and platforms. The simulation results show that the proposed scheme decreases noticeably the handoff failure probability, compared to FCFS based schemes. The overhead due to always placing the request with the least remaining time at the head of queue is $O(n)$, a practically desired property. The simulation also shows that the decrease in the probability failure rate comes at the expense of an increase in the call blocking probability, clearly because a channel taken for a handoff call is basically taken from a new call. However, as is well known in cellular technology, to block a new call is more preferable than to terminate an ongoing one.

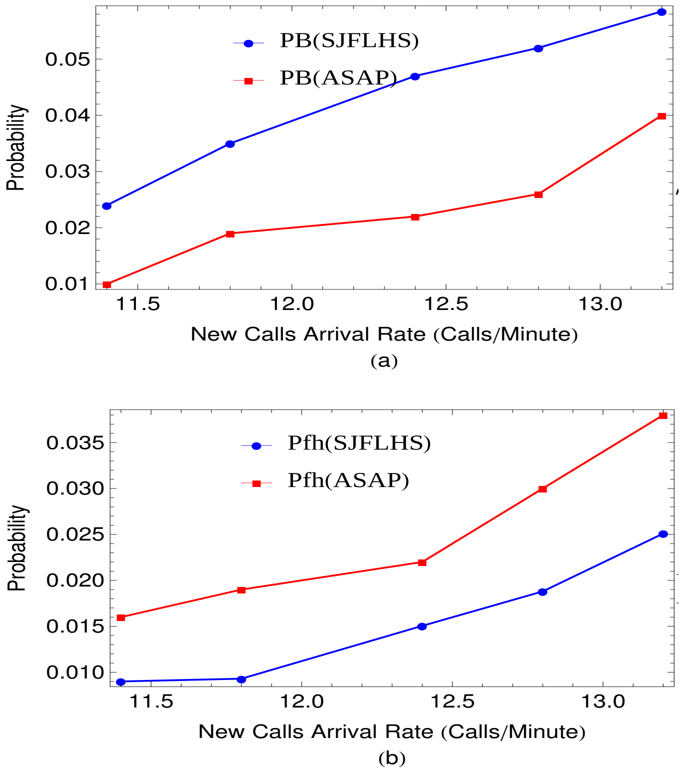


Fig. 11. A comparison of call blocking probabilities bewteen SJFLHS and ASAP.

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