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Minimizing Unnecessary Handovers in a Heterogeneous Network Environment

***Abstract**. In this paper, we have provided a model to minimize the unnecessary handovers from a cellular network to a WLAN. Exploiting traveling distance prediction method, the proposed handover necessity estimation mechanism uses distance threshold parameters to avoid unnecessary handovers. Our analysis and simulation results suggest that the proposed mechanism can keep the probabilities of handover failure and unnecessary handover close to the predetermined designed values.*

***Streszczenie.** Przedstawiono model umożliwiający minimalizowanie niepotrzebnych przełączeń typu handover między siecią komórkowa a siecią bezprzewodową WLAN. (**Minimalizacja niepożądanych przełączeń w niejednorodnym środowisku sieciowym**)*

Keywords: Vertical handover, handover failure probability, unnecessary handover probability.
Słowa kluczowe: przełączenie typu handover, sieci komórkowe, sieci bezprzewodowe..

Introduction

Vertical handovers, which transfer a live call/session from one access technology network to another, are likely to play an important role in B3G scenario for supporting always best connectivity. However, minimizing unnecessary handovers is as important as handover triggering condition estimation and optimization of handover execution. If the unnecessary handovers are not checked, the phenomenon will have adverse effect on the system performance. Not only overhead involved in unnecessary handovers would consume network resources, but it would also increase the probability of handover failure. This problem is particularly important in the context of wireless local area network (WLAN), which has a small coverage region.

Reducing unnecessary handovers in intra-technology (horizontal) handovers has widely been studied [1], [2], however, Yan et al. [3] have made first serious effort for the same in inter-technology (vertical) handover. They made an interesting contribution to the study of handover decision method based on the prediction of traveling distance within an IEEE 802.11 WLAN region. Based on the computation of certain distance (threshold) parameters, they developed a rule to initiate handover while limiting the probability of handover failure and unnecessary handover to pre-decided values.

However, there are some mathematical imperfections in [3] which lead to incorrect estimation of threshold parameters. In this work, we not only fix those imperfections, but we also obtain new expressions for those (distance-based) threshold parameters. Monte-Carlo simulation results are presented for both proposed and existing schemes. The simulation results for our proposed scheme are in good conformance with analysis. The system works as follows:

An unnecessary handover occurs when the total time of an MT with-in a WLAN coverage cell is smaller than the total handover latency for moving in and moving out. Whereas, a handover failure occurs when the total time in WLAN coverage cell is even less than the handover latency for moving into WLAN network. By predicting the travelling distance in a WLAN cell the MT can avoid handovers that could lead to handover failure or are unnecessary. Based on probabilistic model a system is designed that could keep probability of unnecessary handover and probability of handover failure within acceptable limits. We find the probability distribution of traversal length of an MT crossing through a WLAN cell. A distance threshold value for a given speed and a given probability of unnecessary handover is obtained using probability distribution of traversal length. An MT executes handover to a WLAN network only if the traversal length is greater than this threshold value. In an identical fashion another threshold value, corresponding to probability of handover failure is obtained and in order to keep handover failure within bounds the handover to WLAN is triggered only if the traversal distance in the WLAN cell is greater than this threshold value.

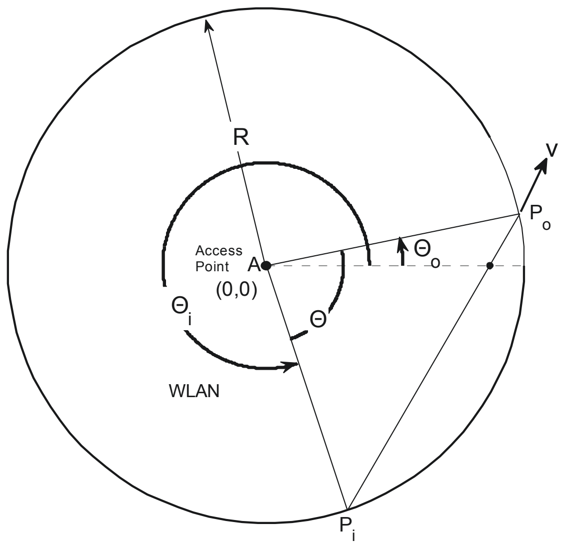

Fig.1. An MT traversing a WLAN cell

Geometrical and Analytical Model

1) PDF of traveling distance: Evaluation

Let Θ be the interior absolute difference between the angle of arrival Θ_i and the angle of departure Θ_o of the mobile terminal (MT) in a circular WLAN cell with radius R. Within the small coverage area of WLAN, we assume that MT traverses linear motion with constant velocity. We also assume that Θ_i and Θ_o are uniformly distributed. Since the upper and lower semicircles are identical, for the purpose of calculation, it would be sufficient to consider the range $[0, \pi]$; refer to [4, page 967]. Secondly, for any given value of Θ_i and Θ_o in $[0, 2\pi]$, the random variable $\Theta = \min\left\{\tilde{\Theta}, 2\pi - \tilde{\Theta}\right\}$, can only have values in the range $[0, \pi]$, where $\tilde{\Theta} = |\Theta_i - \Theta_o|$. Based on these considerations, we obtain the pdf of Θ as follows:[1]

(1) $$f_\Theta(\theta) = \frac{2}{\pi}\left(1 - \frac{\theta}{\pi}\right), 0 \le \theta \le \pi$$

Using cosine law, we compute the travelling distance

(2) $$D = m\overline{P_i P_o} = \sqrt{2R^2(1-\cos\Theta)},$$

where we have assumed that the value of D is known to MT. The value of D can be obtained by using any of the existing traveling distance prediction methods like those of [3], [5]. Next, based on (1) and (2), the expression for the pdf of distance D covered by MT is obtained as

(3)

$$f_D(d) = \frac{4}{\pi\sqrt{4R^2 - d^2}}\left(1 - \frac{1}{\pi}\arccos\left(1 - \frac{d^2}{2R^2}\right)\right), \quad 0 \le d \le 2R$$

2) PDF of traveling distance: A linear approximation

Since no closed-form integral exists for (3), it is difficult to use it to compute probabilities of handover failure and unnecessary handover in a straightforward manner. Note that the expression (3) is a monotonically decreasing function of d; we want to linearize it. First we find the limits at $(d = 0)$ and $(d = 2R)$, which gives $\lim_{d\to 0} f_D(d) \to \frac{2}{\pi R}$ and $\lim_{d\to 2R} f_D(d) \to \frac{4}{\pi^2 R}$. Joining these points, $\left(0, \frac{2}{\pi R}\right)$ and $\left(2R, \frac{4}{\pi^2 R}\right)$, with a straight line, we get $\frac{1}{\pi R^2}\left(\frac{2}{\pi} - 1\right)d + \frac{2}{\pi R}$. For $d \in (0, 2R]$, the area under the curve is $\frac{4+2\pi}{\pi^2}$. Dividing the linear expression with the area, we get a linear approximation for the pdf of travelling distance as follows:

(4)

$$\tilde{\tilde{f}}_D(d) = \frac{\pi}{(\pi+2)R}\left(1 - \left(\frac{\pi-2}{2\pi R}\right)d\right), 0 \le d \le 2R$$

We can use the above linear approximation for (3), which not only satisfies $\int \tilde{\tilde{f}}_D(x)\,\mathrm{d}x = 1$, but also approximates expression (3) very well, as demonstrated in Fig. 2, for four different values of R. Using (4), we obtain the cdf expression

(5)

$$\Pr[D \le d] \approx \int_0^d \tilde{\tilde{f}}_D(x)\,dx = \begin{cases} -c_1 d^2 + c_2 d^2, & d \le 2R \\ 1, & d > 2R \end{cases}$$

Where

(6) $$c_1 = \frac{\pi - 2}{4(\pi+2)R^2} \text{ and } c_2 = \frac{\pi-2}{4(\pi+2)R}$$

3) Probability of handover failure

A handover failure occurs if the travelling time inside the WLAN cell is shorter than the handover latency τ_i from the cellular network to the WLAN, i.e., the traveling distance D is smaller than $v\tau_i$, where v is the velocity of MT. In [3], a distance threshold parameter L was introduced to make handover decision: whenever the estimated travelling distance D is greater than L, the handover will be initiated. In this context, the probability of handover failure, P_f, is given by

(7a) $$\mathrm{P}_f = \begin{cases} \Pr[L < D \le v\tau_i], & 0 < L \le v\tau_i \\ 0, & \text{otherwise} \end{cases}$$

(7b)

$$\Pr[L < D \le v\tau_i] = -c_1 v^2 \tau_i^2 + c_2 v \tau_i + c_1 L^2 - c_2 L^2$$

where c_1 and c_2 are as specified in (6). As suggested in [3], an equation can be obtained to calculate the value of L by MT, for a given (fixed) P_f, to decide handover. From (7), we obtain

(8)

$$L = \max\left\{0, \frac{c_2 - \sqrt{c_2^2 - 4c_1\left(c_2 v\tau_i - c_1 v^2 \tau_i^2 - P_f\right)}}{2c_1}\right\}$$

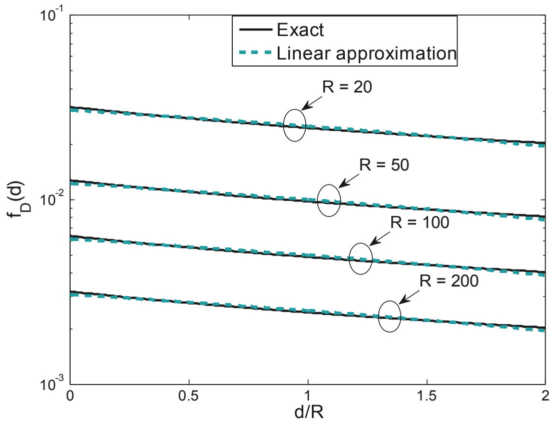

Fig.2. Comparing pdf of travelling distance (3) with its linear approximation (4)

4) Probability of unnecessary handover

If the MT's traveling time (D/v) inside the WLAN is smaller than the sum of the handover time into (τ_i) and out of (τ_o) the WLAN cell, the handover to the WLAN cell becomes unnecessary [3]. The probability of unnecessary handover, P_u, can be obtained easily by replacing τ_i with $(\tau_i + \tau_o)$ in expression (7). Denoting $\tau_T = \tau_i + \tau_o$, we obtain

(9a) $$P_u = \begin{cases} \Pr[C < D \le v\tau_T], & 0 < C \le v\tau_T \\ 0, & \text{otherwise} \end{cases}$$

[1] In [3], the following expression was obtained for the pdf of Θ

$$f_\Theta(\theta) = \frac{1}{\pi}\left(1 - \frac{\theta}{2\pi}\right), 0 \le \theta \le 2\pi,$$

which is incorrect because Θ can never be greater than π.

(9b)

$$\Pr[C < D \le v\tau_T] = -c_1 v^2 \tau_T{}^2 + c_2 v\tau_T + c_1 C^2 - c_2 C^2$$

where C is the distance threshold parameter corresponding to unnecessary handover, c_1 and c_2 are as specified in (6), and $C \ge L$. For a particular value of P_u, the parameter C can be obtained as

(10)

$$C = \max\left\{0, \frac{c_2 - \sqrt{c_2{}^2 - 4c_1\left(c_2 v\tau_T - c_1 v^2 \tau_T{}^2 - P_u\right)}}{2c_1}\right\}$$

5) Comparison and simulation results

We compare our derived threshold expressions, (8) and (10), with those of [3]. In [3], Yan et al. obtained the following expressions for L and C:

(11) $$L = 2R\sin\left(\arcsin\left(\frac{v\tau_i}{2R}\right) - \frac{\pi}{2}P_f\right),$$

(12) $$C = 2R\sin\left(\arcsin\left(\frac{v\tau_T}{2R}\right) - \frac{\pi}{2}P_u\right),$$

Note that the values of L and C in (11) and (12) cannot be considered correct because the interior angle Θ was mistakenly assumed to satisfy $\Theta \in (0, 2\pi]$.

Now we compare values of L obtained from (8) and (11) in Fig. 3(a) for R = 50m, τ_i= 1sec and the probability of handover failure is nearly 2%, as mentioned in [6], i.e., P_f = 0.02. Note that both expressions of L can be seen to exhibit similar trend but the proposed one (8) suggests a larger value of L for the given P_f and does not yield negative values at low velocity. Similarly, in Fig. 3(b), we compare values of C obtained from (10) and (12) for τ_i = τ_o= 1sec and P_u = 0.04. Again, both expressions of C can be seen to exhibit similar trend but the proposed one (10) suggests a larger value of C for the given P_u and does not yield negative values at low velocity.

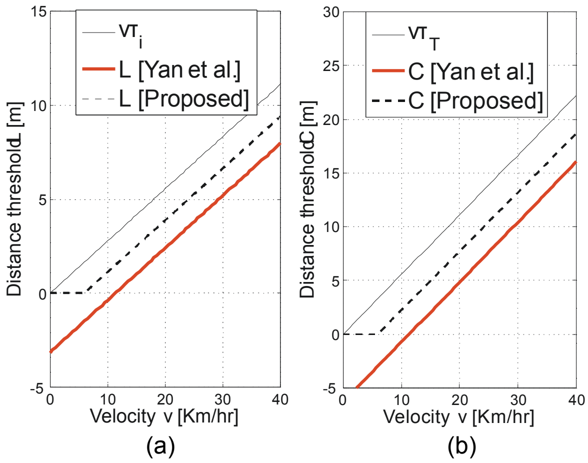

Fig.3. Comparison of threshold values (a) L (8) and (11), and (b) C (10) and (12)

In Fig. 4-5, we present Monte-Carlo simulation results for our proposed handover necessity estimation model as well as for that in [3][2]. By varying the velocity of the MT from 1 m/s to 10 m/s, we check the performance of our model for two designed values for each of probability of handover failure (P_f) and probability of unnecessary handover (P_u). To avoid negative values of thresholds at low velocities, we modified the expressions of [3] for L and C as follows:

(13)

$$L = \max\left\{0, 2R\sin\left(\arcsin\left(\frac{v\tau_i}{2R}\right) - \frac{\pi}{2}P_f\right)\right\},$$

(14)

$$C = \max\left\{0, 2R\sin\left(\arcsin\left(\frac{v\tau_T}{2R}\right) - \frac{\pi}{2}P_u\right)\right\},$$

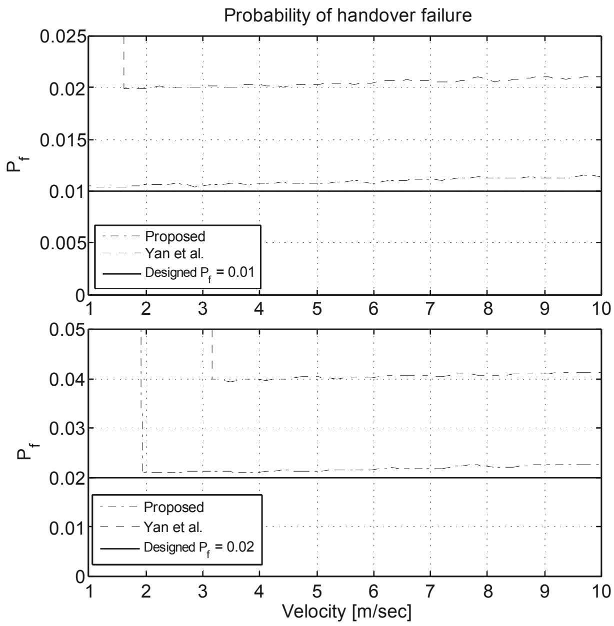

Fig.4. Comparing probability of handover failure

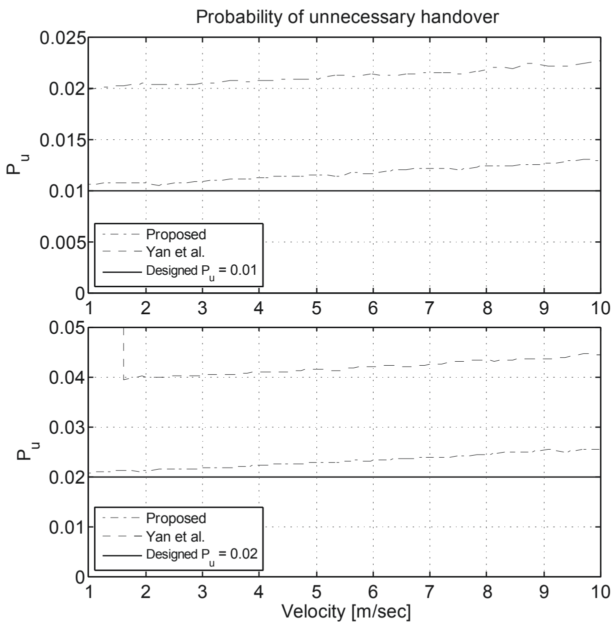

Fig.5. Comparing probability of unnecessary handovers

First of all we note that both P_f and P_u grow gradually with increase in velocity. Secondly, the values of P_f and P_u obtained from the handover necessity estimation model of [3] deviate from the desired values by a large margin. On

[2] Note that no Monte-Carlo simulation results were reported in [3].

the other hand, the values obtained from our proposed handover necessity estimation model stay close to desired values. Keeping the fact that the distance thresholds (L and C), obtained from our method, are larger than those of [3], it is easy to understand why our model outperformed that of [3].

Finally in Fig 6-7, we demonstrate the average number of handovers executed out of 20,000 random entries into a WLAN cell. For simulation we used two different values for both P_f and P_u. The trend is identical in all cases i.e. with increasing velocity the threshold values increase, resulting in reduced number of handovers into the WLAN cell. However, it can be observed that our proposed model avoids unnecessary handovers more expeditiously as in all the simulation results the number of handovers using our proposed model is less than that for model of [3].

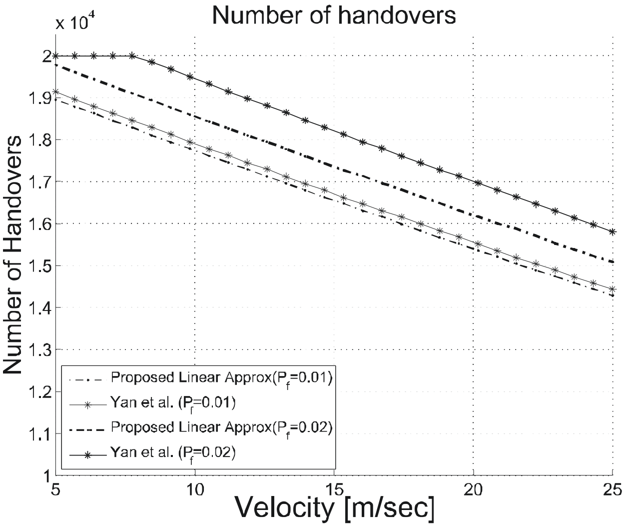

Fig.6. Comparing number of handovers for

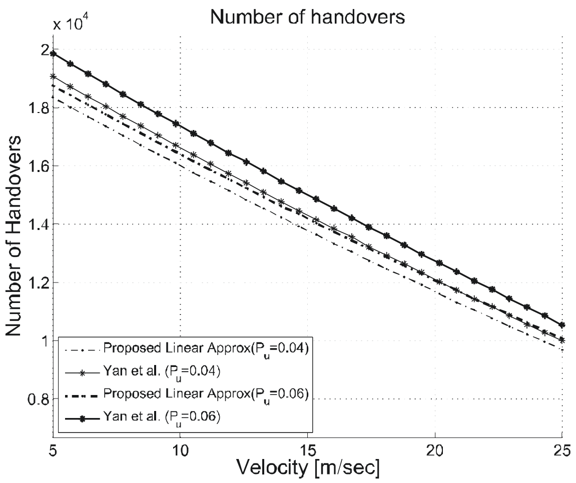

Fig.7. Comparing probability of unnecessary handovers

6) Conclusion

In this work we have used a method for handover necessity estimation. Based on a geometrical model we derived the probability distribution of traversal length and provided a linear approximation of the pdf, whose closed form integral can be obtained. Two threshold values, corresponding to handover failure and unnecessary handover, are obtained using this linear approximation of pdf of traversal length. These threshold values are used to keep the probability of handover failure and probability of unnecessary handover within pre-designed limits. We have proved the validity of our proposed model using Monte-Carlo simulations. Comparison with an existing model shows that our model performs much better by keeping the probabilities of handover failure and unnecessary handover much closer to the designed values. We have also shown that how many of unnecessary handovers are actually avoided by using our proposed model. With increase in velocity the threshold values increase, blocking higher number of unnecessary handovers.

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