A Traveling Distance Prediction Based Method to Minimize Unnecessary Handovers from Cellular Networks to WLANs

Xiaohuan Yan, *Student Member, IEEE,* Nallasamy Mani, *Member, IEEE,*
and Y. Ahmet Şekercioğlu, *Member, IEEE*

***Abstract*— We propose a handover decision method based on the prediction of traveling distance within an IEEE 802.11 wireless local area network (WLAN) cell. The method uses two thresholds which are calculated by the mobile terminal (MT) as it enters the WLAN cell. The predicted traveling distance is compared against these thresholds to make a handover decision in order to minimize the probability of handover failures or unnecessary handovers from a cellular network to a WLAN. Our analysis shows that the proposed method successfully keeps the number of failed or unnecessary handovers low.**

***Index Terms*— Handover failure probability, received signal strength, unnecessary handover probability, vertical handover decision.**

I. INTRODUCTION

DUAL mode handsets equipped with cellular and wireless local area network (WLAN) interfaces are becoming more popular due to the complementary advantages of wide coverage of cellular networks, and high speed access and reduced usage cost of WLANs [1]. However, in order to fully exploit the advantages offered by either of the access technologies, intelligent and efficient vertical handover decision methods are always desirable to guarantee the Quality of Service (QoS) while maximizing the use of the available WLAN connectivity.

In the existing technical literature, many related studies on vertical handover decisions have been reported. In [2] and [3], a context-aware cross-layer architecture for handover decisions in heterogeneous networks is presented. A cross-layer management protocol proposed in [4] uses the speed of the mobile terminal (MT) and handover signaling delay information to calculate a value for the received signal strength (RSS) threshold for handover initiation. An algorithm for calculating a boundary area based on the speed of the MT and the WLAN cell size is proposed in [5]. In this algorithm, a handover from a WLAN to a 3G network is triggered when the MT enters the boundary area of the WLAN and handover procedures are completed before the MT leaves the WLAN. In the mobility architecture using this algorithm, and also in most of the other handover decision methods such as in [6], handovers from the cellular network to the WLAN are initiated once the MT enters the WLAN coverage area.

Mohanty's method presented in [5] is especially interesting in that it operates efficiently for handovers from WLAN to 3G. However, it is not effective enough for handovers from 3G to WLAN. The main reason for this is that in situations where the MT travels through an area close to the coverage boundary of the WLAN at speeds above a certain threshold, handovers to the WLAN become unnecessary. It is always better to avoid these handovers as much as possible since they lead to network resource wastage [7]. Furthermore, if the handover process has not been completed before the MT leaves the WLAN coverage area, connection breakdown inevitably occurs. In the method presented in [5] for handovers from the cellular network to the WLAN, the MT remains connected to both networks while staying in a boundary cell of the WLAN in order to avoid connection breakdown and also the ping-pong effect. However, this approach does not take into consideration the network resource wastage caused by unnecessary handovers. As yet, no study on handover necessity estimation or on efficient methods for minimizing unnecessary handovers has been presented.

In this letter, we present our handover decision method, which is based on the prediction of traveling distance in order to minimize the probability of handover failures and unnecessary handovers from cellular networks to WLANs. Through performance analysis, we show that our proposed method is successful in minimizing both.

II. TRAVELING DISTANCE PREDICTION BASED HANDOVER DECISION METHOD

Our method was designed for MTs with dual cellular and WLAN interfaces. Its objective is to minimize the probability of unnecessary handovers to the WLAN to improve the overall network utilization and user experience.

A. Traveling Distance Prediction Based on RSS Change Rate

The handover decision method relies on an algorithm which attempts to predict the traveling distance in a WLAN cell coverage area by using the change rate of RSS [8]. The relationship between RSS (in mW), and the distance between the access point (AP) and the MT at any point P (Fig. 1) inside the WLAN coverage area can be obtained by using the path loss model [9, Eq. 1]

$$RSS_P = E_t l_{OP}^{-\beta} 10^{\xi/10} \tag{1}$$

where E_t (in mW) is the transmit power of the AP, β is the path loss exponent (a value between 2 and 4 chosen depending on the transmission environment), and ξ is a Gaussian distributed random variable with a mean of zero and a standard deviation up to 12 dB [10]. l_{OP} represents the distance between P and the AP. In order to estimate the MT's traveling distance by using RSS measurements, let P_i

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The authors are with the Department of Electrical and Computer Systems Engineering, Monash University, Melbourne, Victoria 3800, Australia (e-mail: {xiaohuan.yan, nallasamy.mani, ahmet.sekercioglu}@eng.monash.edu.au).

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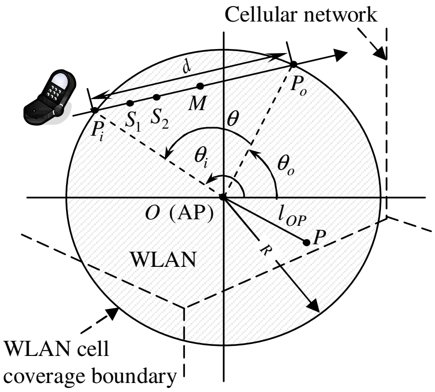

Fig. 1. Prediction of traveling distance in a WLAN cell.

and P_o be the entry and exit points of the MT to and from the WLAN cell, M be the middle point of the traveling trajectory. By using (1), when the MT enters the WLAN cell coverage area (i.e., the RSS level detected by the MT reaches a predetermined threshold), the distance l_{OP_i} (an approximation of the cell radius R) can be calculated by

$$R \cong l_{OP_i} = \left(\frac{E_t 10^{\xi/10}}{RSS_{P_i}} \right)^{1/\beta} \tag{2}$$

Using the RSS calculation given by (1), and RSS change rate definition in [8], we obtain

$$\begin{aligned} \mathit{\Delta RSS} &= \left| \frac{RSS_M - RSS_{P_i}}{t_M - t_{P_i}} \right| \\ &= \left| \frac{[(R^2 - d^2/4)^{-\beta/2} - R^{-\beta}] E_t 10^{\xi/10}}{d/2v} \right| \end{aligned} \tag{3}$$

where RSS_M and RSS_{P_i} are the RSS at points M and P_i, t_M and t_{P_i} are the times the MT passes through points M and P_i, d is the traveling distance inside the WLAN, R is the radius of the WLAN cell, and v is the velocity of the MT.

To get $\mathit{\Delta RSS}$, the MT takes two consecutive RSS samples (points S_1 and S_2 in Fig. 1) when it enters the WLAN coverage. If RSS_{S_2} is smaller than RSS_{S_1}, which means the MT has already passed the middle point M of the trajectory and will not stay long enough in the WLAN coverage area to initiate a handover, so it does not attempt to hand over to the WLAN. Otherwise, it calculates $\mathit{\Delta RSS}$ as

$$\mathit{\Delta RSS} = \left| \frac{RSS_{S_2} - RSS_{S_1}}{t_{S_2} - t_{S_1}} \right| \tag{4}$$

where RSS_{S_1} and RSS_{S_2} are the RSS at points S_1 and S_2, and the MT takes the samples at times t_1 and t_2. Then, the MT estimates the traveling speed (v) by using the VEPSD algorithm given in [11] (we selected the VEPSD algorithm since it has a reported estimation error lower than the other methods). Afterwards, the MT obtains an estimate of the traveling distance (d) by using (3).

In this algorithm, we assume the MT is traveling at a constant velocity, and consecutive RSS measurements can be obtained by the MT in quite a short time after it enters the WLAN coverage area.

B. Distance Threshold Estimation for Minimizing Handover Failures

A handover failure occurs if the traveling 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 $v\tau_i$.

Assume that the MT starts receiving a sufficiently strong signal (i.e., it "enters" the WLAN cell) at point P_i and the signal strength drops below the usable level at point P_o. P_i and P_o can be any arbitrarily chosen points on the circle enclosing the WLAN coverage area, with equal probability (Fig. 1). Then the angles θ_i and θ_o are both uniformly distributed in $[0, 2\pi]$, where $\theta = \theta_i - \theta_o$.

We derive the probability density function (pdf) of θ using [5, Eq. 10] as follows

$$f_\theta(\theta) = \frac{1}{\pi}(1 - \frac{\theta}{2\pi}) \, , \quad 0 \le \theta \le 2\pi \tag{5}$$

by replacing l with θ, d with 2π (as in our method θ ranges from 0 to 2π, while in [5, Eq. 10] l ranges from 0 to d), and set $x = 0$ (as there is no boundary area in our algorithm).

From the geometric configuration in Fig. 1 we get

$$d^2 = 2R^2(1 - \cos\theta) \tag{6}$$

Based on (5) and (6), by using the theorem stated in [12, Eq. 5.6], the pdf of d is expressed as

$$f_D(d) = \frac{2}{\pi\sqrt{4R^2 - d^2}} \, , \quad 0 \le d \le 2R \tag{7}$$

The cumulative density function (cdf) of d can be derived by integrating (7)

$$P(d \le D) = \begin{cases} \frac{2}{\pi} \sin^{-1}\!\left(\frac{D}{2R}\right) , & 0 \le D \le 2R, \\ 1, & 2R < D. \end{cases} \tag{8}$$

Let us introduce a distance threshold parameter L which will be used to make handover decisions: whenever the estimated traveling distance d is greater than L, the MT will initiate the handover procedure. Then, the probability of a handover failure is given by

$$P_f = \begin{cases} \frac{2}{\pi} \left[\sin^{-1}\!\left(\frac{v\tau_i}{2R}\right) - \sin^{-1}\!\left(\frac{L}{2R}\right) \right] , & 0 \le L \le v\tau_i, \\ 0, & v\tau_i < L. \end{cases} \tag{9}$$

By using (9), we derive an equation which can be used by the MT to calculate the value of L for a given (fixed) probability of handover failures P_f as

$$L = 2R \sin\!\left(\sin^{-1}\!\left(\frac{v\tau_i}{2R}\right) - \frac{\pi}{2} P_f \right) \tag{10}$$

To calculate L, MT's speed v and handover latency τ_i need to be estimated. In our method, VEPSD algorithm [11] and the technique described in [4] are used to estimate v and τ_i respectively.

C. Distance Threshold Estimation for Minimizing Unnecessary Handovers

If the MT's traveling time inside the WLAN cell is smaller than the sum of the handover time into (τ_i) and out of (τ_o) the WLAN cell (i.e., the traveling distance d is smaller than $v(\tau_i + \tau_o)$), the handover to the WLAN cell becomes unnecessary.

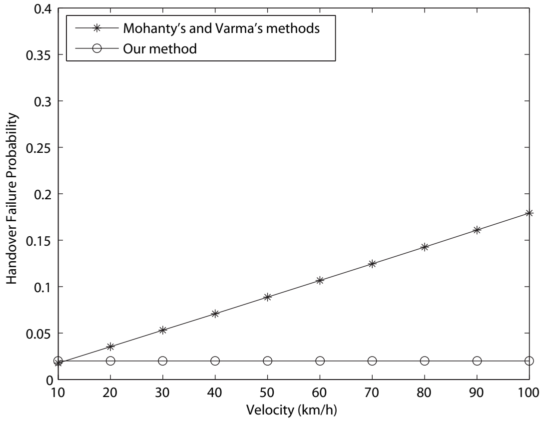

Fig. 2. Probability of handover failures of Mohanty's [5], Varma's [6] and our methods.

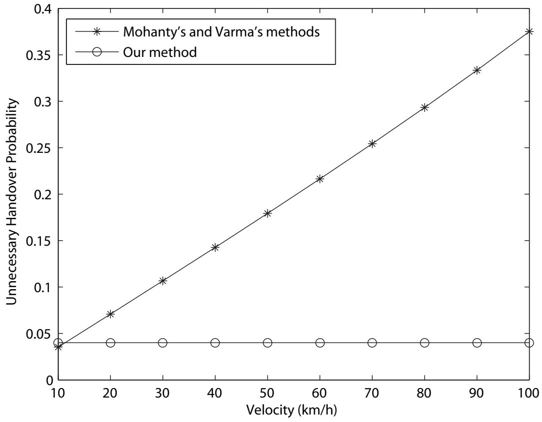

Fig. 3. Probability of unnecessary handovers of Mohanty's [5], Varma's [6] and our methods.

Similar to the arguments used in the previous section, we introduce another parameter C ($L < C < v(\tau_i + \tau_o)$), which can be used to minimize the probability of unnecessary handovers. Then the probability of an unnecessary handover is calculated as

$$P_u = \begin{cases} \frac{2}{\pi}\left[\sin^{-1}\left(\frac{v(\tau_i+\tau_o)}{2R}\right) - \sin^{-1}\left(\frac{C}{2R}\right)\right], & \\ & 0 \le C \le v(\tau_i+\tau_o), \\ 0, & v(\tau_i+\tau_o) < C. \end{cases} \tag{11}$$

Thus

$$C = 2R\sin\left(\sin^{-1}\left(\frac{v(\tau_i+\tau_o)}{2R}\right) - \frac{\pi P_u}{2}\right) \tag{12}$$

Equation (12) is derived from (11) for a particular value of P_u when $0 < P_u < 1$.

Parameters L and C depend on values of constants P_f and P_u which are selected by system designers. They also depend on estimates of d, v, R, τ_i and τ_o. The parameter C can be further adjusted dynamically to encourage or discourage handovers to WLAN by considering other performance criteria such as network load.

III. PERFORMANCE ANALYSIS AND DISCUSSION

To analyze the probability of handover failures and unnecessary handovers for different handover decision methods, we assume that the target P_f and P_u are 0.02 [5] and 0.04, respectively, the coverage radius of the WLAN cell, R, is 50 m [13], and the handover latencies from the cellular network to the WLAN and from the WLAN to the cellular network, τ_i = τ_o, are both 1 s as in [4]. The handover failure probability for Mohanty's [5] and Varma's [6] methods is given by

$$P_f = \begin{cases} 1, & v\tau_i > 2R, \\ \frac{2}{\pi}\sin^{-1}\left(\frac{v\tau_i}{2R}\right), & 0 \le v\tau_i \le 2R. \end{cases} \tag{13}$$

The unnecessary handover probability for these two methods is given by

$$P_u = \begin{cases} 1, & v(\tau_i+\tau_o) > 2R, \\ \frac{2}{\pi}\sin^{-1}\left(\frac{\tau_i+\tau_o}{2R}\right), & 0 \le v(\tau_i+\tau_o) \le 2R. \end{cases} \tag{14}$$

The probability of handover failures and unnecessary handovers for Varma's, Mohanty's and our methods are shown in Figs. 2 and 3, respectively. Since our system is designed to keep the probability of handover failures or unnecessary handovers below preset levels, even though the speed of the MT increases, the probabilities remain the same. As illustrated by the figures, for higher speeds, our method yields lower probability of handover failures and unnecessary handovers than the other two methods. Otherwise, only for velocities less than 10 km/h, Mohanty's and Varma's methods yield marginally better results.

A possible improvement to the scheme is to periodically sample the RSS, recalculate and refine the estimations for v to improve the performance, and eliminate the assumption that the MT's speed remains fixed inside the WLAN cell. However, this work is beyond the scope of the current letter.

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