A Calculation of WLAN Dwell Time Model for Wireless Network Selection

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***Abstract*—In an integrated wireless and mobile network, selecting a desired a network is an important issue. Parameters such as system load, service characteristics and user mobility are the main criteria in network selection strategy. In this paper, we devise a mobility estimation method for a Mobile Node (MN) during initial network selection and Vertical Handover (VHO). The method relies on a new prediction dwelling time and the Call Holding Time (CHT) of a user. By comparing the predicted dwelling time with the CHT, a MN is able to make decision which network is suitable to be used in order to minimize the VHO. The proposed theoretical model has been validated by the Monte-Carlo experiments. The simulation results demonstrate the validity of the proposed method.**

***Index Terms*—Wireless; Network Selection; Dwelling Time.**

I. INTRODUCTION

The next generation wireless systems is seen to be heterogeneous, which can provide ubiquitous services for users through multiple Radio Access Technologies (RATs). In this environment, a MN is equipped with heterogeneous interfaces, which is called the multimode terminal. Since the Heterogeneous Wireless Network (HWN) are overlapped with each other, a network selection scheme which is part of the Common Radio Resource Management (CRRM) is required in order to decide which network to access. When a MN generates a new call and the MN location is in the overlapped coverage, it can select the network connections based on the network selection strategies. A moving MN, from a non-overlapped to the overlapped area can also change its connection among different types of access technologies which is called VHO.

In the existing technical literature, many related studies on CRRM have been reported [1]. The work by Hasib et.al. in [2] and [3] proposed a CRRM algorithm that include user mobility and service characteristics. Shi Zheng et. al. [4] proposed a CRRM scheme that consider user mobility, types of services and load balance parameters which produce better results in terms of blocking probability and throughput as compared to [2]. Both of the researches, classify user mobility as either vehicular or non-vehicular based on a preset speed threshold (*Vth*). If the MNs speed is less than the speed threshold, it is higher probability that the user will be allocated to WLAN resources. However, the speed alone may not accurate to consider the duration of resources usage. For example, there are cases where the user is traveling more than the threshold speed but able to complete the task prior moving out from the overlapped coverage. In addition, there are users who travel less than the speed threshold but may use longer time of resources. This may cause resource wastage and unnecessary VHO for both scenarios. The latest work in network selection by [5] also includes the user's mobility by dividing the coverage area into inner zones and outer zones, but their approach is impractical because no users' direction are considered.

The importance of VHO probability has been highlighted in [6], but no derivation of the VHO probability is proposed in their work. The works by [7] and [8] take into consideration the traveling time and handover latency for making VHO decision from cellular to WLAN. The traveling time is calculated based on the variation of MNs' direction only. However, our derivation of traveling time is based not only the variation of direction, but also the variation of the radius since the location of MN is inside WLAN.

In this work, we will focus on how to derive an analytical model of a MN moving out from the WLAN coverage area. The proposed method use a geometrical model for predicting the dwell time within WLAN and the call holding time. Velocity, cell size, mobility direction, the transmitted power, signal propagation and interference are the main parameters that determine the dwell time. In the following, we will neglect the influences by radio related propagations.

II. SYSTEM MODEL DESCRIPTION

We consider a Heterogeneous Wireless Network (HWN) which consist of a tightly coupled cellular and WLAN system. For the purpose of simplicity, we focus on one cellular network covered by one WLAN system as shown in Figure 1.

The HWN is divided into hotspot (overlapped area) and out-of-hotspot (non-overlapped) areas. In the hotspot area, a user can either connect to cellular or WLAN depending on network selection parameters assigned by the network operator. Users in the overlapped region may have different mobility. As such, to avoid frequent VHO, the probability of moving out from WLAN area has to be calculated and take into consideration in the initial network selection. In addition, the moving out probability from WLAN region could also be used when users from non-overlapped area enter to the hotspot area, where the system can decide whether to change the connection from cellular to WLAN or remain with cellular connection.

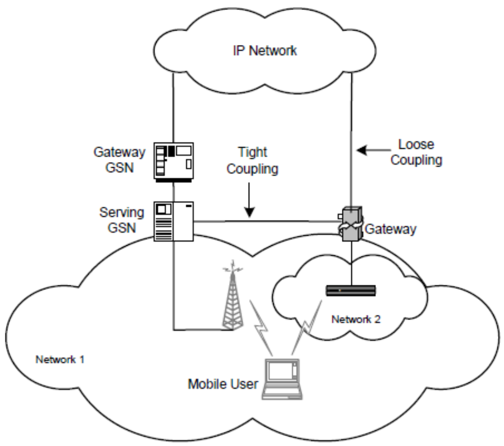

Figure 1: Interworking of Heterogeneous Wireless Networks

The procedure for initial network selection is illustrated in Figure 2. This paper focus on the mobility prediction where it will calculate the probability of a MN can complete its task while remaining in the overlapped area.

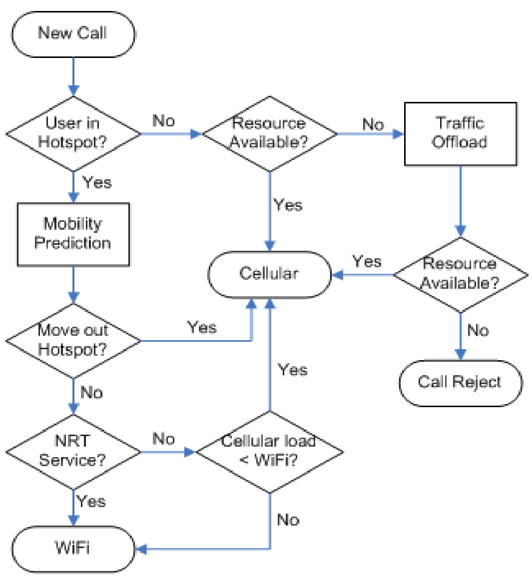

Figure 2: Flow Chart for Initial Network Selection

III. Estimating Dwell Time for Initial Network Selection

As shown in Figure 3, let the access point located at point O having coverage radius of a. Point P *is* the current location of MN which are uniformly distributed in the circle, and r is the MN distance from the access point. Q is the direction of the MN which is depending on the θ. All the MN in the overlapped region is assumed to follow fluid mobility model where the direction of movement unchanged during the duration of moving.

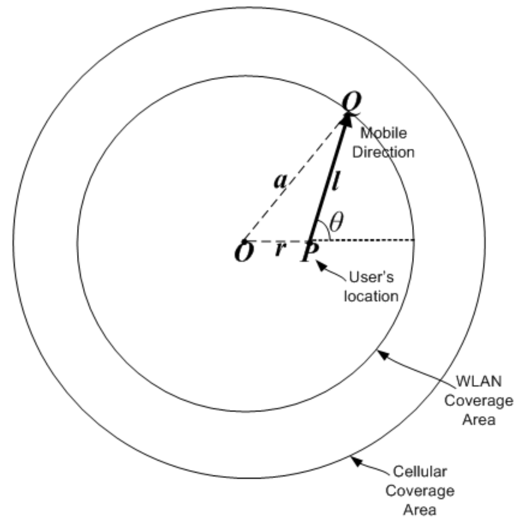

Figure 3: Dwell Time Model for Initial Network Selection

Since we assume users are uniformly distributed in the cell with radius a, the probability density function (PDF) of the user with Cartesian coordinates (x, y) is given by:

$$f(x, y) = \frac{1}{\pi a^2}, x^2 + y^2 \leq a^2 \tag{1}$$

By applying the transformation of Polar coordinates, it follows that:

$$f(r, \theta) = \frac{r}{\pi a^2}, 0 \leq r \leq a \text{ and } 0 \leq \theta \leq 2\pi \tag{2}$$

where $x = r\cos(\theta)$, $y = r\sin(\theta)$ and r defines the distance between the user and the centre of cell. Therefore, the marginal PDF of r can be derived from (2) by integrating out θ as:

$$f_r(r) = \frac{2r}{a^2} \tag{3}$$

A practical angle mobility model [9], has proved that the mobile direction θ of users follows uniform distribution in [0, 2π]. As shown in Figure 3, due to the symmetry of the cell, we can limit the value of θ in $0 \leq \theta \leq \pi$. Herein, we assume that the location of users and mobile direction are independent, which is practical assumption in most cases. Thus the joint PDF of user distance r and mobile direction θ are given by:

$$f_{r,\theta}(r, \theta) = \frac{2r}{a^2}\,\frac{1}{\pi} = \frac{2r}{\pi a^2} \tag{4}$$

To obtain the distribution of l, it is necessary to determine its relationship with r and θ, applying the law of cosines yields:

$$a^2 = r^2 + l^2 + 2rl\cos\theta \tag{5}$$

Thus θ can be written as:

$$\theta = \arccos(\tfrac{a^2-r^2-l^2}{2rl}) \triangleq h(r,l), a-r \le l \le a+r \qquad (6)$$

It can be proved that $h\ (r,\ l)$ is a monotonically increasing function of l. Therefore, by making change of variable (6) and applying Jacobian transform [10] into (4), the joint distribution of r and l is given by:

$$\begin{aligned} f_{l,r}\,(l,r) &= \frac{2r}{\pi a^2}\left|\det\begin{pmatrix} 1 & 0 \\ \frac{\partial h(r,l)}{\partial r} & \frac{\partial h(r,l)}{\partial l} \end{pmatrix}\right| \\ &= \frac{2r}{\pi a^2}\left|\frac{\partial h(r,l)}{\partial l}\right| \end{aligned} \qquad (7)$$

where:

$$\frac{\partial h(r,l)}{\partial l} = \frac{\frac{a^2-r^2+l^2}{2rl^2}}{\sqrt{1-\left(\frac{a^2-r^2+\ l^2}{2rl^2}\right)^2}} \qquad (8)$$

Substituting (8) into (7) yields:

$$\begin{aligned} f_{l,r}\,(l,r) &= \frac{2r}{\pi a^2}\frac{\frac{a^2-r^2+l^2}{2rl^2}}{\sqrt{1-\left(\frac{a^2-r^2+\ l^2}{2rl^2}\right)^2}} \\ &= \frac{1}{\pi a^2}\frac{\frac{a^2-r^2+l^2}{2rl^2}}{l^2\sqrt{1-\left(\frac{a^2-r^2+\ l^2}{2rl^2}\right)^2}} \end{aligned} \qquad (9)$$

Thus the marginal PDF of l can be derived by integrating out r from (9) along with the integral region given in (6), such that:

$$f_l\,(l) = \int_{|a-l|}^{a} f(l,r)dr,\ 0 \le l \le 2a \qquad (10)$$

Therefore, with (9), (10) can be rewritten as:

$$\begin{aligned} f_l(l) &= \frac{1}{\pi a^2}\int_{|a-l|}^{a}\frac{a^2-r^2+l^2}{l^2\sqrt{1-\left(\frac{a^2-r^2+\ l^2}{2rl^2}\right)^2}}\,dr \\ &= \frac{1}{\pi l a^2}\int_{|a-l|}^{a}\frac{2r(a^2-r^2+l^2)}{\sqrt{(2rl)^2-(a^2-r^2-\ l^2)^2}}\,dr \\ &= \frac{1}{\pi l a^2}\int_{|a-l|}^{a}\frac{a^2-r^2+l^2}{\sqrt{-(a^2-l^2)^2-r^4+2(a^2+l^2)r^2}}\,dr^2 \end{aligned} \qquad (11)$$

By making change of variable as $z = r2$, we have:

$$f_l(l) = \frac{1}{\pi l a^2}\int_{(a-l)^2}^{a^2}\frac{2r(a^2-r^2+l^2)}{\sqrt{4a^2l^2-(a^2+l^2-\ z)^2}}\,dr^2 \qquad (12)$$

Then through making change of variable as $t = a^2 + l^2 - z$, it follows that:

$$\begin{aligned} f_l(l) &= \frac{1}{\pi l a^2}\int_{l^2}^{2al}\frac{t}{\sqrt{4a^2l^2-t^2}}\,dt \\ &= \frac{1}{2\pi l a^2}\int_{l^2}^{2al}\frac{t}{\sqrt{4a^2l^2-t^2}}\,dt^2 \\ &= \frac{1}{2\pi l a^2}\int_{l^2}^{2al}\frac{t}{\sqrt{4a^2l^2-t^2}}\,dt^2 \\ &= -\frac{1}{2\pi l a^2}\sqrt{4a^2l^2-\ t^2}\,\Big|_{l^2}^{2al} \\ &= \frac{1}{\pi a^2}\sqrt{4a^2-\ l^2} \end{aligned} \qquad (13)$$

Thus the PDF of traversal time $T = l/v$ for a user with an average velocity of v can be expressed as:

$$f_T(t) = \ vf(vt) \qquad (14)$$

$$f_T(t) = \frac{v}{\pi a}\sqrt{4a^2-\ (vt)^2} \qquad (15)$$

If the call holding time τ is greater than the dwell time T then the MN will select connection to cellular in order to avoid frequent VHO. So, the probability of moving out from the WLAN coverage region can be obtained as follows:

$$\begin{aligned} P_{out} &= P(T \le \tau) \\ &= \int_0^{\tau} f(t)dt \\ &= \begin{cases} 1, & \tau \ge \frac{2a}{v} \\ \frac{2\,arcsin\left(\frac{\tau v}{2a}\right)}{\pi} + \frac{\tau v\sqrt{1-\frac{\tau^2v^2}{4a^2}}}{\pi}, & 0 \le \tau \le \frac{2a}{v} \end{cases} \end{aligned} \qquad (16)$$

Consequently, the probability of MN remain in the overlapped region while completing its task is derived as:

$$P_{in} = 1 - \ P_{out} \qquad (17)$$

IV. Numerical Results and Model Validation

In order to validate the accuracy of theoretical analysis in section III, analytical and simulation results are presented. For verification purposes, we set the cell radius to 250m and 150m, call holding time is 60s and the velocity ranging from 1m/s to10m/s. Numerical results are generated using equation (16).

Figure 4 shows the comparison of analytical and simulation results of MN probability of moving out from the WLAN region plotted against v, the average velocity of users in the overlapped area. It is seen that all the results of the theoretical analysis are very close to the simulation results, thus confirming the accuracy of the analytical modeling. The results show that the probability of moving out increases with the increment of the velocity. Clearly, as *v* increases, the proportion of high-speed users in the hotspot area are also increases, which lead to an increase in the probability of moving out from the WLAN area. Comparing the results with different values of radius *a*, it is observed that, at each value of *v*, shorter radius always have higher probability of moving out from WLAN. This is due to the fact that there are more users with shorter dwelling time as compared to the resource usage duration.

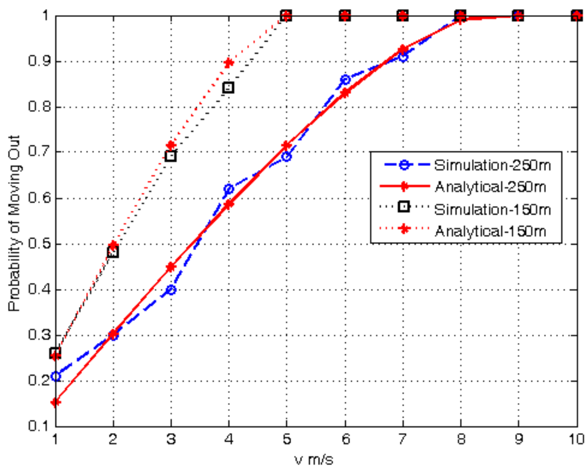

Figure 4: Probability of Moving Out against Velocity

V. Conclusions and Future Works

In this paper, we introduced some insights in the interrelation between the user's usage behavior and the traveling distance. Based on the call holding time and geometric model, a probability of moving out from WLAN coverage area are calculated and presented. The simulation results demonstrate the validity of theoretical analysis for dwelling time. The hypothesis is, if the user can complete its call prior moving out from the WLAN coverage area, he will be connected to WLAN and thus reduce the cellular resource usage. On the other hand, if the call is longer than the dwelling time, cellular resources will be assigned to the user in order to avoid the VHO. The obtained results can be used to evaluate the hypothesis above in the future work in terms of throughput, new call and VHO blocking probability.

Acknowledgment

This research is supported by Malaysia Ministry of Higher Education under Fundamental Research Grant Scheme (FRGS) grant number 203/PKOMP/6711423.

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