A Location-Aware Vertical Handoff Algorithm for Hybrid Networks

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***Abstract*— One of the main objectives of wireless networking is to provide mobile users with a robust connection to different networks so that they can move freely between heterogeneous networks while running their computing applications with no interruption. Horizontal handoff, or generally speaking handoff, is a process which maintains a mobile user's active connection as it moves within a wireless network, whereas vertical handoff (VHO) refers to handover between different types of networks or different network layers. Optimizing VHO process is an important issue, required to reduce network signalling and mobile device power consumption as well as to improve network quality of service (QoS) and grade of service (GoS). In this paper, a VHO algorithm in multitier (overlay) networks is proposed. This algorithm uses pattern recognition to estimate user's position, and decides on the handoff based on this information. For the pattern recognition algorithm structure, the probabilistic neural network (PNN) which has considerable simplicity and efficiency over existing pattern classifiers is used. Further optimization is proposed to improve the performance of the PNN algorithm. Performance analysis and comparisons with the existing VHO algorithm are provided and demonstrate a significant improvement with the proposed algorithm. Furthermore, incorporating the proposed algorithm, a structure is proposed for VHO from the medium access control (MAC) layer point of view.**

***Index Terms*— Vertical handoff, Handoff, Mobile positioning, Overlay networks, 4G wireless networks, Heterogeneous networks.**

I. Introduction

In this section, we describe the handoff and vertical handoff (VHO) problems with their associated challenges, related work pertinent to this subject along with the paper's contribution.

A. Handoff and its Associated Problems

Handoff process is an important resource management module in most wireless networks. A new handoff process considered for the next generation of wireless networks is VHO. While the handoff process defines the transfer of an active mobile connection between cells within a single layer (also referred to as horizontal handoff), VHO defines this process between different layers [1]–[5]. Throughout this paper the term handoff is used mostly instead of horizontal handoff for writing simplification but it is important to mention that the two terms are analogous. Layered cell structure idea suggests using different cellular networks with different sizes and possibly different technologies, such that the user can still preserve its connection while moving out of the coverage of a lower layer, because it is still in the coverage of an upper layer. Another benefit of such networks is the capability of adapting network parameters to user's specifications, such as speed and demanded service. Using different types of networks (heterogeneous networks), their coordination, integration and VHO procedures is a significant challenge for beyond 3G and 4G wireless networks [6], [7].

Research on handoff is mainly categorized in two parts. In the first, handoff is addressed from the upper network layers point of view, which focus on data transfer and performance of network protocols, such as internet protocol (IP) and transmission control protocol (TCP) [8]–[10]. Works in the second category are done from the physical layer point of view, and mostly deal with radio propagation characteristics and handoff decision process. One significant characteristic of wireless systems is the signal variations caused by the movement of the mobile station (MS). The variations can cause some unnecessary handoffs on cell boundaries, a phenomenon referred to as ping-pong effect [2]. Such effect increases network traffic load which indirectly leads to an increase in the handoff blocking probability (HBP). The ping-pong effect also causes power loss at the transmitters and receivers. Crossover point is another metric used to compare different VHO algorithms, and is defined as the distance between the point where a handoff is made and the cell boundary. An ideal algorithm makes handoff on cells and layers boundaries. However, if the crossover distance is large, it can cause an increase in channel interference and a degradation in the

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link Quality of Service (QoS). An idea for improving the precision of the handoff algorithm and the crossover point consists in exploiting the user position information. Different localization methods can be applied for subscriber-positioning in wireless networks. Localization methods can be classified in self-, remote- and indirect-positioning, according to the place where the measurements and evaluations take place [2]. In self-positioning systems, the handset itself performs the measurements and the necessary evaluations to finally estimate its own position. In remote-positioning systems, the fixed part of the network takes the measurements and estimates the terminal's position. Finally, in indirect-positioning systems the MS takes the measurements and transmits them to the base station (BS) for evaluation.

B. Related Work and Contribution

In [11], a policy-based VHO is proposed where different metrics are taken into consideration for the process of decision making in VHO such as user preferences and direction of the MS. Despite the distinctive feature of this work, the cost function does not consider signal variations and cellular boundaries, hence there is a high probability of ping-pong in the related algorithm. In [12], a VHO designed with fuzzy logic is proposed, which uses global positioning system (GPS) to obtain location information. In [13], a handoff scheme for multimedia networks has been proposed, however the work has been done just for flat networks and not for overlay networks. In [14], a VHO has been proposed considering channel distribution. This algorithm does not have a strategy for reducing the ping-pong effect and HBP. In [15], a location estimation technique based on pattern recognition is proposed to define optimum points for handoff. This algorithm is not designed for overlay networks and considers location estimation within cellular boundaries, which needs heavy calculations for advance selection of desired handoff locations. Another weak point in the latter algorithm is exploiting minimum distance criteria for pattern classification, and as it will be seen later detection error probability of this method is too high. In [16], the authors have proposed a received signal strength (RSS) classifier for path identification with application to handoff decision in multi-service networks. Their scenario only considers a restricted system consisting of two layers with only two cells. As a result, studying the effect of different network parameters on the pattern classification is not possible. In [18], a location estimation technique based on pattern recognition is proposed with probabilistic neural network (PNN) to be used with handoff algorithm similar to what is done in [15]. The algorithm considers only the traditional cellular structure with one layer and a simple scenario using only four BSs, and its handoff decision strategy is also different. Finally, [20] proposed an intelligent handoff algorithm using grey prediction and fuzzy decision. The grey prediction is used to predict the future RSS which is applied to a fuzzy decision system for handoff decision. This algorithm is designed for conventional single layer networks and needs significant computing resources.

In this paper, we propose an algorithm that improves the ping-pong effect and the crossover point. First, user location

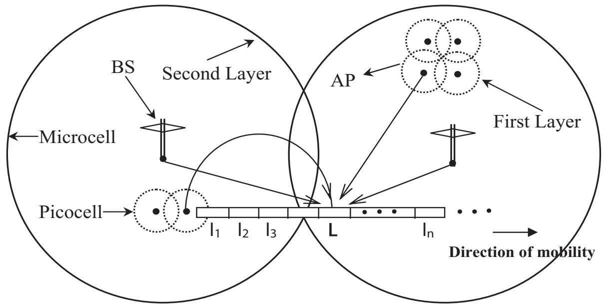

Fig. 1. The idea of using pattern recognition for vertical handoff.

is estimated with a pattern recognition technique, and then location information is used in the VHO algorithm to deduce the right time and the right place at which the VHO should take place. The positioning technique proposed in this work is based on pattern recognition and we consider an indirect-positioning method. This technique is the most cost-effective technique and can be easily integrated into any wireless network process module [17]. Pattern recognition-based positioning can be a practical solution for underground and confined environments where using GPS is not possible. Our algorithm uses different RSS samples of BSs to construct the pattern classes. Since shadow fading is constant for a given path between a BS and a given point, pattern recognition techniques can be applied to mobile positioning algorithms. Due to the fact that the shadow fading is constant, the averaged signal samples of MSs, which travel along the same path will be similar and the averaged signal samples can be stored in nearby BS database. These samples are used later for positioning purposes using pattern recognition. Because of outstanding features of intelligent techniques, we use PNN as our pattern classifier similar to the work in [18]. Another contribution of this paper is the optimization process done for the pattern recognition part, which along with the proposed VHO algorithm shows significant performance improvement.

The aforementioned process is categorized in the physical layer part of the network. As for the upper network layer point of view, we propose a structure for VHO between universal mobile telecommunication systems (UMTS) and wireless local area networks (WLAN), incorporating the location information in the signalling. The proposed algorithm can be generalized for any wireless system and is not necessarily restricted to UMTS and WLAN. As a matter of fact, this paper extends the approach in [19] which deals with physical layer based VHO. Moreover, we include the typical VHO structure proposal between UMTS and WLAN which discusses the corresponding procedures in network layers.

In the next section, the proposed idea for VHO in overlay networks is presented. In section III, further details on the PNN classifier are discussed. In section IV, the simulation environment and parameters are explained, and in section V performance analysis and simulation results are provided.

II. The Proposed Method

In this section, the proposed method for VHO is discussed from physical layer and upper layers point of view.

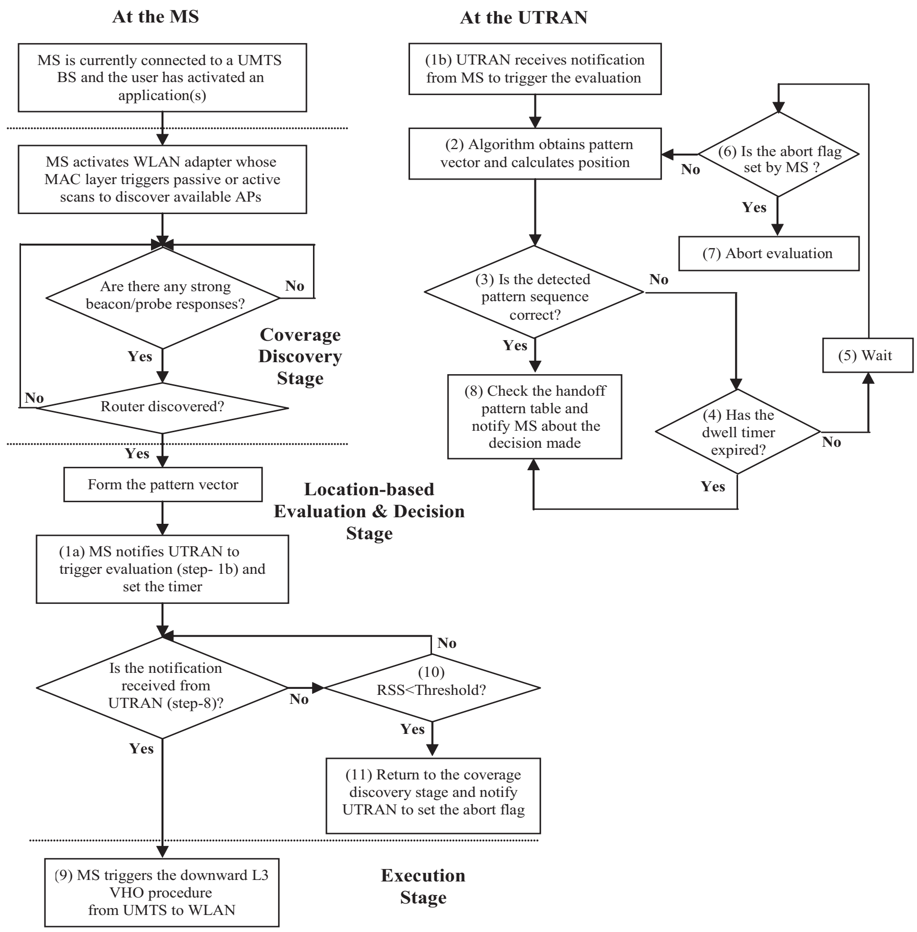

Fig. 2. The proposed algorithm for vertical handoff from UMTS to WLAN.

A. From Physical Layer Point of View

Fig. 1 illustrates the idea of using pattern classes for VHO in overlay networks. Let's assume that a given path (e.g., a road, a passage, a corridor or a mine gallery) within a wireless network coverage is divided into smaller blocks. Each block is called a pattern class, L, and is the representative of a small location area. As the MS travels along the specified path, it collects RSS samples for different cells in different layers with a specific sampling rate. During a training phase, a MS travels along a particular path and collects averaged signal samples from nearby BSs. Let $\xi^{ik} = [\xi_0^{ik}, \xi_1^{ik}, ..., \xi_{N_{\max}-1}^{ik}]^T$ denote the averaged samples of ith BS in kth layer, B_{ik}. The total number of samples recorded from each BS is $N_{\max}$ and N_w is the block's length. Hence, the number of classes is given by:

$$C = \left\lfloor \frac{N_{\max}}{N_w} \right\rfloor, \tag{1}$$

where $\lfloor . \rfloor$ denotes the upper integer rounding operator. For each block, signal samples of different cells in different layers are arranged in vectors called pattern vectors, which are then used to train the PNN. Each pattern vector is identical to its block and is unique for that block in the area. After collecting all signal samples and forming the pattern vectors, the algorithm can run in online mode as MSs move along the path. When a complete pattern vector is formed, it will be classified within one of the existing pattern vectors. Knowing the pattern class number, we can decide on the handoff time so that to avoid unnecessary handoffs caused by uncertainty. But before that, we should somehow make sure about the correctness of the classification. For this purpose, we compare previously detected patterns with the current pattern number. If the difference is within a tolerable factor, T_M, the classified pattern is considered as correct and consequent decisions can be made:

$$\left\| \hat{l}_n - \hat{l}_{n-1} \right\| \leq \Delta l T_M, \tag{2}$$

where Δl is the distance between adjacent pattern vectors and $\hat{l}_n$ represents the n-th pattern vector.

B. From Upper Network Layers Point of View

The conventional method for discovering coverage and making the decision to trigger an upward or downward VHO, is primarily based on radio frequency (RF) measurements [3]. The basic approach consists of a MS currently connected to an upper layer and scanning for coverage by a lower layer. Upon discovering WLAN coverage through beacons sent by access points (APs) and receiving a router advertisement from the associated router, a downward VHO is activated. During

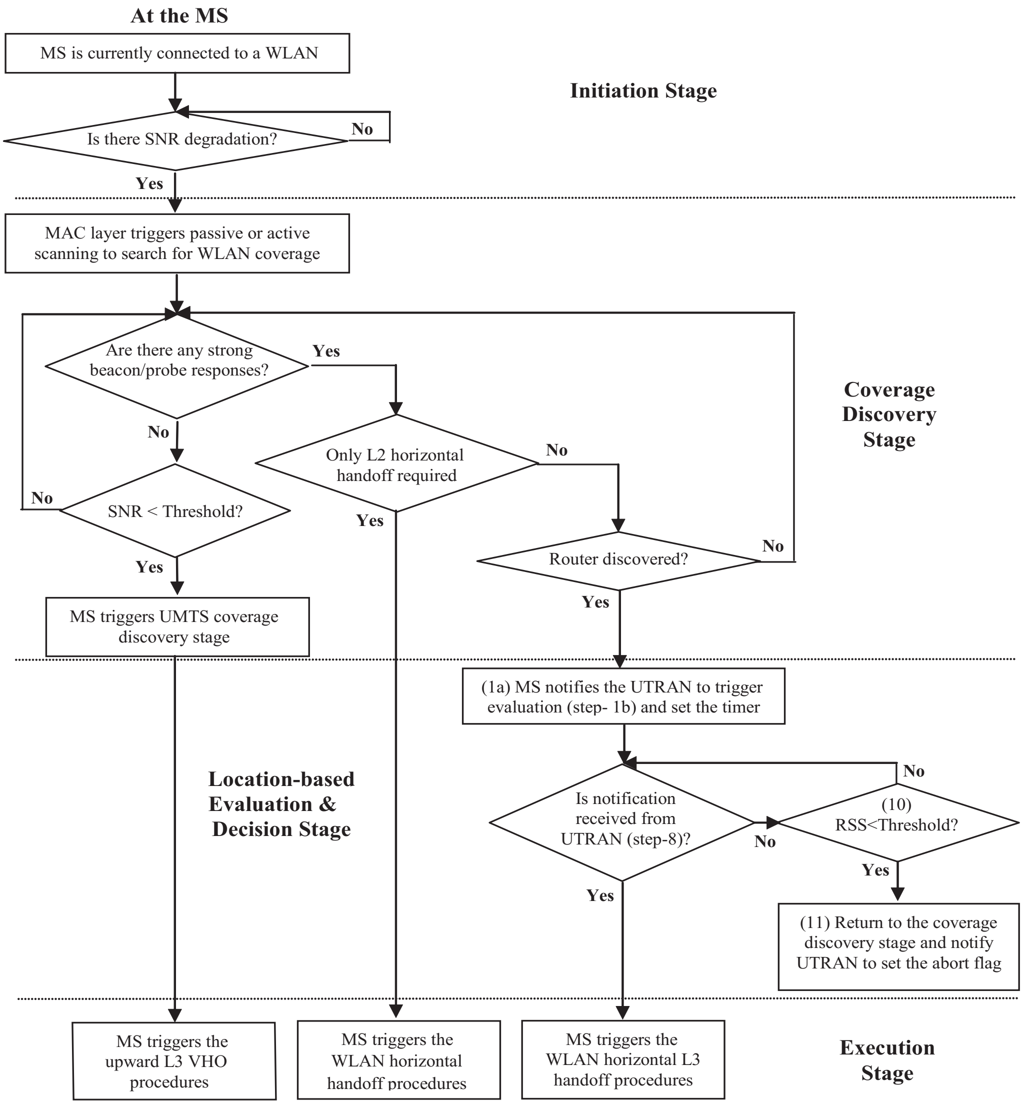

Fig. 3. The proposed algorithm for vertical handoff from WLAN to UMTS.

the MS's entrance into a WLAN cell, it remains connected to the current AP until a degradation in the signal-to-noise ratio (SNR) is sensed. The medium access control (MAC) layer is responsible for locating other APs. If another AP within the same hotspot is found, a layer 2 (L2) handoff (a handoff indicating that the packet header is processed up to data link layer) takes place without notifying the home network. However, if the AP belongs to another hotspot, then a Layer 3 (L3) handoff (a handoff indicating that the packet header is processed up to network layer) is needed. A horizontal L3 handoff to a visited WLAN network includes notifying the MS's home UMTS network, of the MS new location. On the other hand, if the discovery stage fails to locate other APs with strong beacons, an upward handoff is activated when the SNR value falls below a specific threshold. Upon such activation, the UMTS adapter uses RF measurements to discover and evaluate UMTS cells, and then triggers the L3 handoff once the discovery stage completes successfully. According to the relevant literature, there exist several schemes for evaluation of RF measurements to determine the best time to activate a handoff in homogeneous and heterogeneous networks [2].

Fig. 2 shows our proposed VHO algorithm from UMTS to WLAN. This algorithm is a general algorithm including upper layers point of view and is proposed to improve the performance of conventional algorithms. In Fig. 3, a similar algorithm for VHO but from WLAN to UMTS is proposed. These algorithms are a combination of the conventional algorithm in [21] and the above presented proposal for physical layer.

As illustrated in Fig. 2, the MS scans for coverage permanently using its WLAN network adaptor. If a strong signal is detected, the MS forms the pattern vector and notifies UMTS terrestrial radio access network (UTRAN) in step (1a), and then transfers the pattern vector to UTRAN. In step (1b), while UTRAN is notified, it estimates the location of the user (2), with the proposed algorithm, and checks for the correctness of

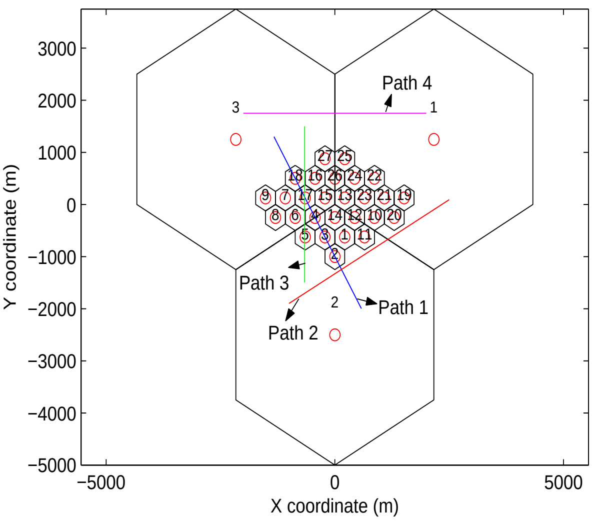

Fig. 4. The hierarchical cell layout in two-dimensional space.

the pattern sequence (3). If the detected sequence is correct, decisions will be made in step (8) and the MS is notified (9) to do a VHO of type L3 to WLAN. If there is no need for handoff, MS continues scanning for WLAN coverage as usual, and if RSS becomes less than a threshold, step (11), UTRAN will be notified to ignore the calculations. From UTRAN's point of view, in step (3), if the location estimation is not approved, a dwell timer will be used for handoff optimization and reduction of signal power fluctuations. The process is as follows: a constant value is set for this timer (1a), and when the algorithm enters UTRAN mode, the timer starts its count down. In step (4), the value of the timer is checked, if it reaches zero a handoff is established, otherwise the algorithm waits for few seconds. This interruption is considered for the purpose of reducing unnecessary calculations in UTRAN. After this interruption, step (11) at the MS side will be checked; if the abort flag was set, UTRAN mode calculations will be terminated, otherwise the algorithm returns back to UTRAN loop in step (2), and calculations and evaluations restart.

As for the Fig. 3, most parts of the algorithm are similar to downward VHO, the only difference is the utilization of the SNR for the detection of signal power degradation in WLAN cells.

III. Simulation Environment

In this section we discuss the structures and parameters considered for the PNN pattern classifier, radio propagation environment and VHO algorithm.

A. Pattern Classifier Structure

Minimum distance algorithm for pattern recognition does not provide enough accuracy. In order to achieve higher accuracy and lower execution time, neural networks are chosen for pattern classification. Neural networks have already been applied to various pattern recognition problems. Generally speaking, they can be regarded as techniques for nonlinear function approximation; pattern recognition can be regarded as a special case of function approximation where the function values form a discrete set. The output y_n of the n-th neuron in PNN structure is given by [18]:

$$y_n = e^{-\frac{\|X-W_n\|^2}{\sigma^2_{\text{PNN}}}}. \tag{3}$$

This activation function is a Normal function where $X = [x_1, x_2, ..., x_{N_P}]^T$ is the input vector to be classified or given to the network for training. In (3), $W_n = [w_{n,1}, w_{n,2}, ..., w_{n,N_P}]^T$ is the weight vector for n-th neuron in the network and σ^2_{PNN} is the smoothing parameter of the PNN. This parameter is in fact the bias value of the network. As it gets larger, the Normal function's slope gets smoother and several neuron's may respond to an input vector. In this case, the network acts like it is taking a weighted average between target vectors whose design input vectors are closest to the new input vector. On the other hand, if the value is small, only the neuron with the weight vector nearest to the input vector will respond and the network will function as a minimum distance algorithm. It is worth to mention that the main reason for choosing PNN for this algorithm among all other neural networks, is their high ability of classification, their very low computational complexity and their highest convergence time for this application. These features make PNN favorable to be implemented even at the mobile set processor unit for minimum delay real-time processing.

B. General Model Specifications

For our simulations, we consider a multi-layer cellular environment as shown in Fig. 4. It consists of two layers. The upper layer which is referred to as macrocell, has 3 cells and can be a network like UMTS. The lower layer, called microcell, has 27 cells and can be WLAN. Furthermore, it is assumed that the speed of the MS is known. Spatial sampling is used, which means that signals are sampled at constant distances. Four paths are considered as different scenarios. The user travels along each path and its position segment is estimated. This information can later be applied to the VHO algorithm to decide about the time and place of inter-layer or inter-cellular handoff. For simulations, we used *MATLAB* software and a set of functions called *RUNE* [22]. The time model in our simulator is a discrete-time step model. The model for the received signal (in dB) is given by:

$$P(d) = P_t + \alpha - 10\beta log(d) + f_i(d) + S(d), \tag{4}$$

where P_t is the effective transmit power, d is the distance to the transmitter, α is the path loss constant and β is the path loss exponent. In (4), $f_i(d)$ is the log-normal shadow fading factor and $S(d)$ denotes the Rayleigh fading parameter.

For each point in space, samples of shadow fading are the same and depend upon the following correlation function:

$$R_{ff}(\Delta) = E\{f(d+\Delta)f(d)\} = \sigma_s^2 e^{-\frac{|\Delta|}{d_0}}, \tag{5}$$

where σ_s is the standard deviation of shadow fading and d_0 is the correlation distance. Samples of this fading have a normal

TABLE I
MAIN PARAMETERS USED IN THE SIMULATIONS

Parameter	Microcell	Macrocell
Cell radius (m)	250	2500
Number of clusters	1	9
Attenuation at 1 meter distance, α (dB)	-40	-31
Thermal noise floor, N_0 (dBm)	-118	-118
Distance attenuation coefficient, β (dB)	3.3	4
Standard deviation of shadow fading, σ_s (dB)	7	6
Correlation distance, d_0 (m)	20	20
Sampling distance (m)	0.8	0.8

distribution. To model these samples in one-dimensional space, we use the following recursive function:

$$f_i(n) = x_i(n) + e^{-\frac{V.T}{d_0}} f_i(n-1), \tag{6}$$

where V is the average user velocity, T is the sampling period, d_0 is the correlation distance and x_i is a Gaussian random variable with zero mean and standard deviation given by:

$$\sigma = \sqrt{1 - e^{\frac{-2.V.T}{d_0}}}\, \sigma_s. \tag{7}$$

In a practical system, there is often a correlation between the lognormal shadow fading for the links between one MS and the BSs, modelled by assigning one random fading component related to each link, G_{ij}, and one fading component related to the MS, G_M. These are then added according to the expression [22]:

$$G = \sqrt{\rho}\, G_M + \sqrt{1-\rho}\, G_{ij}, \tag{8}$$

where ρ defines the effect of each component. In order to compensate the effect of Rayleigh fading, an averaging window is considered according to:

$$\overline{P}(n) = \frac{1}{n_w} \sum_{i=n-n_w-1}^{n} P(i), \tag{9}$$

where n_w is the averaging window size.

Table I indicates the parameters used in the simulations.

C. VHO Algorithm Specifications

Although PNN classifier has better performance than minimum distance classifiers, it can further be improved. We propose three methods for this purpose. The first technique sorts input data (training or test data) in an ascending or descending order before they are fed to the PNN network. In this way, random effects in the propagation will be compensated to some extent. The second technique consists of multiplying the test data by a magnitude factor (MF) before classification because training data sets, which are in fact averaged signal samples, have a small variation in scale and this magnitude factor will compensate this variation. The third technique uses the same averaging window size for training data or test data. The value we have chosen for the neural network bias is 10, so that the network takes into consideration the effect of all nearby neurons. The averaging window size is 10 in all simulation

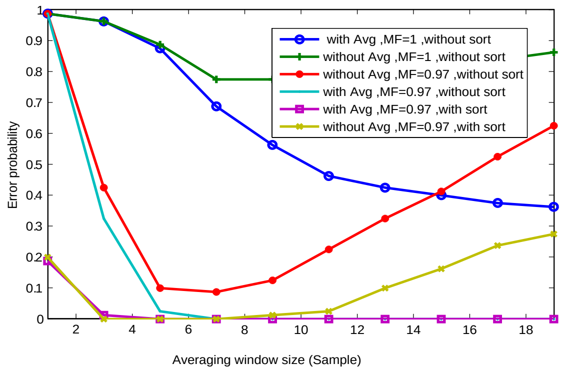

Fig. 5. DEP diagram for three proposed optimizations.

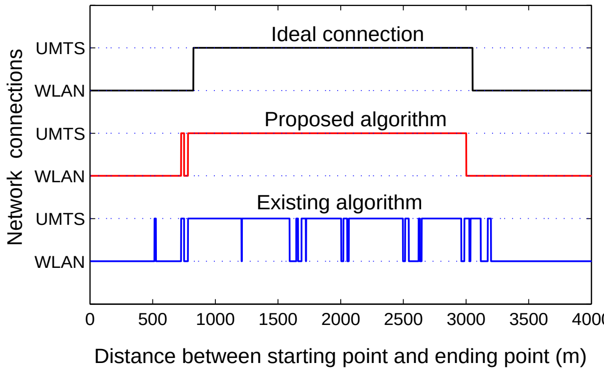

Fig. 6. Network connections for Path 1.

scenarios. The tolerance factor (TM) is set to 1, which means that only if the recent classified pattern completely matches the previous pattern, it will be valid.

In all scenarios, results of the proposed algorithm have been compared with the existing VHO algorithm. By the term existing algorithm, we refer to current available hysteresis based handoff and VHO algorithms, such as those in UMTS and Global System for Mobile Communications (GSM) standard [7], where a handoff is made by comparing different RSS values from different BSs. In the existing algorithm, if MS is in the lower layer and the lower layer signal becomes weaker than a threshold, handoff is made to the upper layer, and if the MS is in the upper layers and a stronger signal is detected in lower layer, handoff is made to lower layer. These two thresholds are both set to -45dB, which is the approximate carrier power at cell boundary in our simulation environment. For cells inside a layer, handoff is made to the BS which has the strongest signal plus a hysteresis value. This handoff is called horizontal handoff, and hysteresis is set to 15dB for both layers.

In the simulation environment, first the variables are defined, then PNN is trained with signal samples collected in the specified path. In online mode, at each iteration, the user location is updated and the new RSS matrix is calculated. If there are enough samples to construct the pattern vector, the latter is made and classified. If the tolerance factor is also

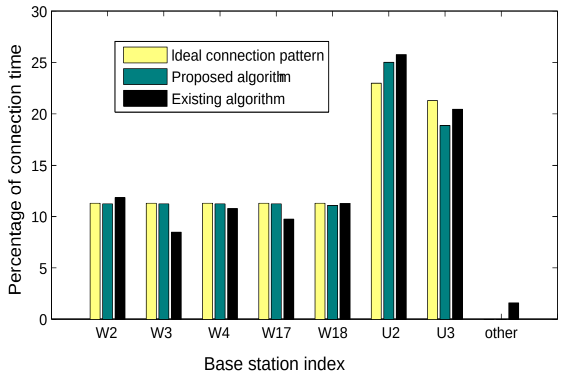

Fig. 7. Percentage of connection times for each BS in Path 1.

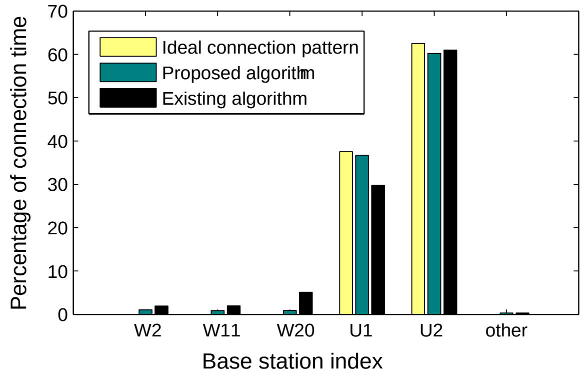

Fig. 9. Percentage of connection time for each BS in Path 2.

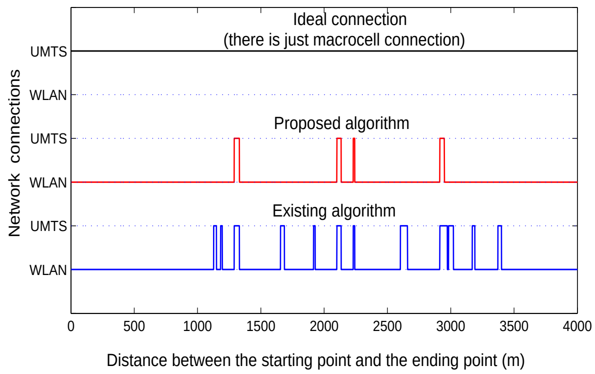

Fig. 8. Network connections for Path 2.

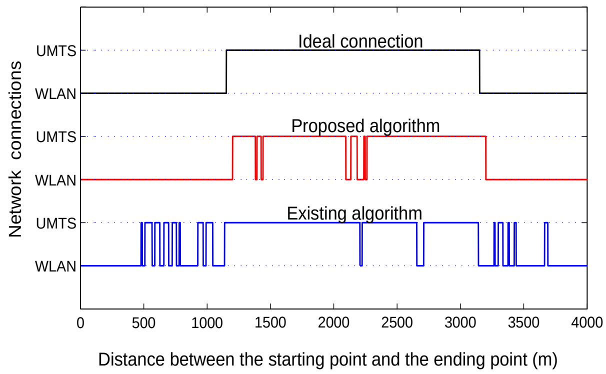

Fig. 10. Network connections for Path 3.

correct, the algorithm enters into the proposed VHO algorithm mode and decides about handoff according to cell boundaries defined with path blocks. If there are not enough samples or that the classified pattern is not correct, the program continues with the existing VHO algorithm.

IV. Simulation Results

A. Evaluation of the Proposed VHO Algorithm

We present simulation results pertaining to the optimization methods for the pattern classification proposed in section III.C along with the algorithm proposed in section II.A, within the simulation environment elaborated in section III.

Fig. 5 shows the effect of using different combinations of proposed optimization techniques on pattern detection error probability (DEP) versus averaging window size. Totally, 6 combinations have been considered and the pattern vector sequence is [WLAN (2 4 18)]. It is observed that the proposed optimization tools have a great effect on reducing the error probability, and their simultaneous use reduces the error probability to zero for averaging windows higher than 3.

We evaluate the performance of our VHO algorithm for four paths illustrated in Fig. 4. In Path 1, the emphasis is on maximizing WLAN or lower layer usage in order to maximize the received bandwidth and minimize the connection costs. For this path, we used signals for WLANs number 2, 4 and 18 to make the pattern vector (in some figures we have replaced WLAN with W and UMTS with U for more clarity). To reduce channel interference and increase QoS, handoff points are defined on cells (horizontal handoff) and layers (vertical handoff) boundaries.

In Fig. 6, networks connection for Path 1 is shown. The first plot shows the ideal connection for each of 4000 points in the path. The second plot shows the performance of the proposed algorithm, and the third one shows the performance of the existing algorithm. It is obvious that in the proposed algorithm unnecessary handoffs and ping-pong effect are reduced significantly. Similarly, in the proposed algorithm, crossover distance is much less than the existing algorithm and almost identical to the ideal connection pattern.

Fig. 7 shows the percentage of connection times for each BS in Path 1. For ideal planned connection scheme, there are only connections to WLANs 2, 3, 4, 17 and 18 (with the same connection time for each) and UMTS cells number 2 and 3. Comparing bars in Fig. 7, we observe that the proposed algorithm connection time is much similar to the ideal case and that it does not transfer unwanted connections to other BSs. Here we define a metric called, WLAN usage factor. It shows the percentage of time, during which a MS is connected to WLAN (for Path 1, a higher value is desirable). For the proposed algorithm, this factor is 56.1% and for the existing algorithm it is 53.4%, so we have 2.7% improvement. Unnecessary handoffs for Path 1 are 30 times for the existing

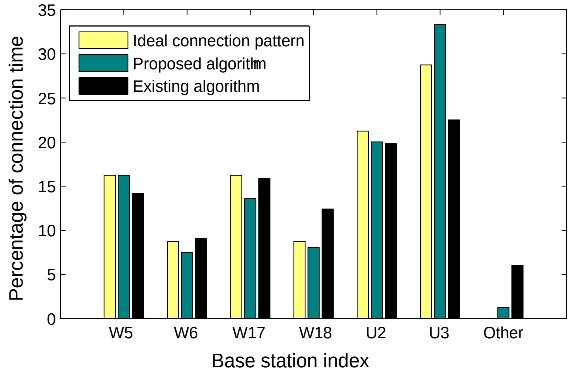

Fig. 11. Percentage of connection time for each BS in Path 3.

algorithm and 3 times only for the proposed algorithm; this also shows 90% reduction in ping-pong effect. If plots in Fig. 6 are compared, we note that the layer crossover distance is reduced 4 times.

Figs. 8 to 11 show similar graphs for Path 2 and Path 3. In Path 2, for ideal connection, no VHOs are considered because the status will not be stable. WLAN 11 and UMTSs 1 and 2 are used to build the pattern vector in Path 2. For this path, there was 66% reduction in horizontal handoffs and 70% reduction in ping-pong VHOs. Path 3 is similar to Path 1, however it is interesting for studying the effect of horizontal handoffs between WLANs. Cells considered for forming the patter vector are WLAN 2, 17 and UMTS 3 for this path and reduction values for horizontal handoff and VHO for this path are 100% and 40%, respectively. Path 4 is interesting to take just horizontal handoffs into consideration, which results in 76% reduction in ping-pong effect. Because Path 4 is far enough from WLANs, the number of VHOs is zero in this case.

V. Conclusion

A new location-based vertical handoff algorithm (VHO) has been proposed from physical layer point of view for wireless heterogeneous networks. This algorithm uses signal samples of different wireless technologies in the coverage area to construct a patter vector. Later, this vector is used for localizing the MS position by means of a probabilistic neural network. Location information is then applied to the VHO, for more exact decisions on the time to trigger the handoff procedure. Moreover, we proposed procedures for upward and downward vertical handoff between WLAN and UMTS from higher network layers point of view. In our simulations, we studied several paths in a hierarchial structure of UMTS and WLAN cells. For maximizing the user received bandwidth, the best strategy that can be defined is maximizing WLAN usage. Minimizing ping-pong handoffs between layers was another goal of this work. Our algorithm shows significant improvement over existing techniques, especially that we have designed it for handoff procedures in heterogeneous networks.

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