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Research Article

Vertical Handover Decision Algorithm Using Ants' Colonies for 4G Heterogeneous Wireless Networks

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With the development of 4G mobile telecommunication systems, providing users with the convenience of a seamless continuous connection is not enough anymore. Users want to be connected through the best available network with the best quality of service. It is necessary to have a good decision-making algorithm which decides whether it is necessary to perform handoff to another network, the best network to vertically perform handoff to, and the right time to initiate the handover. This paper proposes a new approach in which mobile terminals (MTs) continuously analyze the network and keep a database of the best available networks. The concept is based on QoS aware ant colony built on the vertical handoff mechanism that uses an updated version of ants' colony optimization decision algorithm (ACO_R), the dynamic and static factors such as RSS, the cost of service, bandwidth, the velocity of MT, the power consumption and security, and the module for predicting the traveling distance within an IEEE 802.11 WLAN cell. Simulation results show that we can not only meet the individual needs of users in terms of QoS, but also improve the whole system performance by reducing the number of handover failures and unnecessary handover instances by up to 95%.

1. Introduction

Mobility is a very important feature of a 4G wireless networks system. Mobile terminals should be able to choose the best network among the available networks including WLAN, WiMAX, and satellite systems and then make handover.

The traditional methods where the handover is performed on the basis of the evaluation of signal strength are not enough. They do not take into account various mobile user attachment options such as the current context or the attachment of the user options. 4G technologies must consider adaptive and intelligent approach for vertical handover and consider other factors such as monetary cost, security, power consumption, and the mobile terminal speed [1].

Thus, a more innovative approach is needed for vertical handoff protocols implementation to produce a satisfactory result for both, the user and the network. Ant colony approach can face the uncertainty of complex systems because of the facility of the ant colony theory to develop methods that can perform reasoning and solving problems that require human intelligence. Another reason behind the use of ant colony approach is the fact that, given the large numbers of connected MTs that we have today, using ant's colony adaptive method will offer the best QoS to all MTs continuously and a global optimization solution for the network. At the same time, using this approach will maximize the quality of service by minimizing the probability of unnecessary handover instances and handover failures from cellular networks to WLANs. Reducing the cost of the network and increasing the user satisfaction would be another benefit. The success of researches in which ants' colonies optimization was used to solve network issue such as "ant-swarm-inspired energy-aware routing protocol for wireless *ad hoc* networks," in which Sudip Misra et al. proposed an energy-aware routing protocol for wireless *ad hoc* networks [2], and "an ant-swarm-inspired energy-efficient *ad hoc* on-demand routing protocol for mobile *ad hoc* networks," proposed by Woungang et al. [3], encouraged us to use ants' colony in our work.

In 4G networks, the objective is to continuously find an optimal solution for the network. Even if MTs move, we need to reevaluate solutions. Metaheuristic used by ants' colony algorithm can be very helpful in solving this problem.

Through performance analysis, we show that our proposed method is successful not only in minimizing handover failures and unnecessary handover instances, but also in giving the best QoS for MTs.

The rest of the paper is organized as follows. In the next section, we give examples of existing approaches and summarize the existing mechanisms for vertical handover. We propose a new vertical handoff decision model for heterogeneous 4G networks in Section 3 and evaluate the performance of our new approach in Section 4. Section 5 concludes the paper with the future work.

2. Background and Related Work

Several methods and studies of vertical handover decision algorithm have been reported in the technical literature. A class of approach is based on RSS. This method selects the strongest received BS at all times [4–6]. It has been optimized by adapting RSS threshold [7] and also has been combined with other parameters such as user's velocity, location, network cost, and network load [8].

The second approach uses artificial intelligence techniques (complex and may be difficult to implement in practical systems) combining several parameters such as network conditions and mobile terminal's mobility in the handoff decision such as the neural network model which has been presented by Mrs. Chandralekha and Behera to process multicriteria vertical handoff decision metrics. An adaptive resonance theory (ART) has been designed as a modified type of competitive learning to overcome the problem of learning stability [9]. A VHO decision algorithm has been proposed which enables a wireless access network to maximize the collective battery lifetime of mobile nodes (MNs) and balance the overall load among all attachment points (e.g., base stations and access points) [10]. And a VHD scheme was proposed for optimizing the efficiency of vertical handover processes in the Fourth-Generation (4G) heterogeneous wireless networks by using three closely integrated modules: handover necessity estimation (HNE) determines whether handover is necessary to an available network, handover target selection chooses the "best" network among the available candidates based on a set of criteria, and handover triggering condition estimation determines the right moment to initiate handover out of the currently connected network [11, 12].

The third approach combines several metrics such as access cost, velocity of a host, power consumption, bandwidth, and quality of service in a cost function estimated for the available access networks [13]. We can have user-related cost function [14], network-related cost function [15, 16], or a combination of both [17, 18].

Simulation based performance evaluations of presented works demonstrate that the scheme proposed by Yan et al. [11] is the most complete solution by reducing the number of handover failures and unnecessary handover instances by up to 80% and 70%, respectively. However, there is still room for improvement, because even if with this algorithm we can minimize handover failures and unnecessary handover instances, it does not take advantage of the presence in the network of a very important number of MTs and the presence of various networks, because each time we choose the first network if it satisfies requirements, and we do not evaluate all available networks so we do not choose the overall best available network. MTs would choose the same network if they follow the same trajectories. This conducts us to overcrowding in one network and by the same way degrading the overall performance.

In our algorithm, we take advantage of both functions used in HNE to calculate the time threshold and traveling time prediction and then integrate them in a new algorithm that uses ACO_R to get the best solution for the overall network and not only one MT. Unlike HNE, our ACO_R based algorithm evaluates all available networks and chooses the best one.

We take advantage of the presence of a very important number of MTs to get global visibility of the network and the available solutions. If a new network becomes available, we evaluate it, and the entry regarding the new network is inserted in the archive table (maintain the list of the best available networks). By this, we optimize the use of network resources in addition to the overall network performance as we will show in our simulation where we can reduce the number of handover failures and unnecessary handover by up to 95% by using our VHD algorithm.

3. Ants Colony Based Handover Decision Method

Due to the challenging problems of criteria number and algorithms which can be used in network selection, we focus on selecting the appropriate criteria and defining a strategy to exploit those criteria [19]. According to the nature of the network selection problem, and in order to deal with the ping pong problem which causes higher number of handoffs and leads to increased power consumption and decreased throughput, we propose an intelligent network selection approach based on ACO_R algorithm.

Ant behaviour fascinates in many ways. They are distributed systems that, despite the simplicity of their individuals, present a structured social organization. Ant colonies can accomplish complex tasks that in some cases far exceed the individual capabilities of a single ant.

Ants deposit on the ground the pheromone trail (indirect communication way among ants) while searching for food source. Other ants are able to smell this pheromone and make probabilistic movement based on the intensity of pheromone to find the shortest paths between their nest and the food source; that is, they tend to follow the strongest pheromone concentrations. The French entomologist Grassé used the term stigmergy [20] to describe this particular type of indirect communication in which the "workers are stimulated by the performance they have achieved."

ACO algorithms use similar agents called artificial ants which have the properties of the real ants.

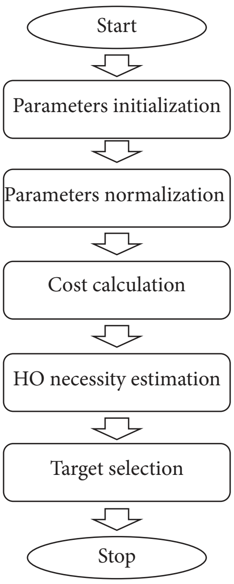

Figure 1: ACO_R based vertical HO process.

The differing characteristics of the artificial ants from the real ants were explained in [21]:

(i) The real ants will directly carry out evaluation. While artificial ants will evaluate a solution with respect to some quality measure, real ants directly evaluate the intensity of pheromone on their way from the nest to the food.

(ii) The real ants might not take the same path on their way to the food sources and return trip to their nest. Meanwhile, each of the artificial ants moves from the nest to the food sources and follows the same path to return.

(iii) While artificial ants only deposit artificial pheromone on their way back to the nest, the real ants lay pheromone whenever they move from and back to the nest.

Some capabilities that were added to the artificial ants are not found in the real ants to solve problems in engineering and computer science [22]:

(i) Memory is used by artificial ants to save the path that they have taken while constructing their solutions. The amount of pheromone is determined based on the quality of their solution, and they retrace the path in their memory to deposit it. This means that the intensity of pheromone depends on the quality of the solutions. The better the solutions, the more the pheromones received.

(ii) Pheromone evaporation is added to encourage exploration in order to prevent the colony from trapping in a suboptimal solution, whereas, in real ant colonies, pheromone evaporation is too slow to be a significant part of their search mechanism.

Ants algorithms represent a promising solution to select the most suitable network in terms of the quality of service (QoS) for mobile users and the whole network and also offer the possibility of reevaluating available solutions constantly.

The proposed approaches evaluate all the available networks and choose the best one. If a new network becomes available, we evaluate it, and the entry regarding the new network is inserted in the archive table (maintain the list of the best available networks). Even if the new network satisfies the required conditions in terms of handoff failure and unnecessary handoff probabilities, the handover to this new network is initiated only if it is the best available network (satisfaction of user requirements).

Our new approach does not only minimize the number of handover failures and unnecessary handover instances between cellular networks (LTE, WiMax, etc.) and WLANs, but also keep the global number of handoffs similar to the HNE approach while offering better QoS (high bandwidth) with lower cost and less power consumption. The process involves three steps: to calculate the cost factor of each candidate network by adopting a cost function, to choose the network with the time threshold calculation for minimizing handover failures, and to predict the traveling time to minimize unnecessary handover instances and optimize QoS.

The proposed VHD process is shown in Figure 1.

The handover decision process is explained below.

Step 1. The first step is to collect details of all available networks and to keep looking for new networks continuously. The inputs include the RSS samples, radius of the network, velocity of the MT, power consumption, handover latency, handover failure, and unnecessary handover probability requirements.

Step 2. Traveling time is predicted using the algorithm proposed by Yan et al. [11, 12]. The method relies on the

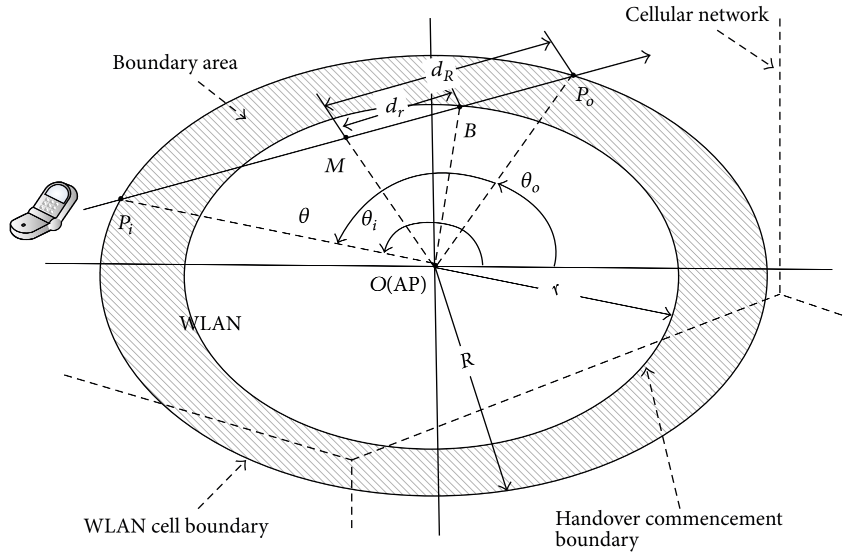

Figure 2: WLAN to cellular network (WiMax, LTE, etc.) handover necessity estimation mechanism.

estimation of WLAN traveling time (i.e., time that the mobile terminal is expected to spend within the WLAN cell) by using successive RSS measurements and the calculation of a time threshold. It is assumed that the MT starts receiving sufficiently strong signals (i.e., it "enters" the WLAN cell) at entry point P_i. The signal strength drops below the usable level at exit point P_o (arbitrarily, points P_i and P_o are chosen with equal probability). M is the middle point of the traveling trajectory, as shown in Figure 2.

If the system designer has a requirement of limiting the probability of handover failures under a threshold, we calculate the time threshold to keep the number of handover failures under a desirable threshold. Then, the time threshold is adjusted to make the ratio of the number of failed handover instances to the total number of handover instances below 1%. The time threshold is calculated using mathematical modelling and probability calculation as explained below.

Angles θ_i and θ_o are both uniformly distributed in $[0, 2\pi]$, and

$$\theta = |\theta_i - \theta_o|. \quad (1)$$

First of all, we calculate the probability density function (PDF) of θ.

By using the PDFs of the locations of P_i and P_o derived from method presented by Kay [23], and since the locations of P_i and P_o are independent of each other, their joint PDF can be given as follows:

$$f(\Theta_i, \Theta_o) = \begin{cases} \frac{1}{4\pi^2}, & 0 \le \Theta_i,\ \Theta_o \le 2\pi, \\ 0, & \text{otherwise}. \end{cases} \quad (2)$$

The probability that $\theta \le \Theta$, which is also the cumulative distribution function (CDF) of θ, can be derived using the following integral [24]:

$$F(\Theta) = P(\theta \le \Theta) = \iint_{\Omega} f(\Theta_i, \Theta_o)\, d\Theta_o\, d\Theta_i, \quad (3)$$

where Ω is the space of locations of entry and exit points P_i and P_o such that $\theta \le \Theta$ and $0 \le \Theta \le 2\pi$. $P(\theta \le \Theta) = 0$ for $\Theta \le 0$ and $P(\theta \le \Theta) = 1$ for $\Theta > 2\pi$. Equation (3) can be rewritten as

$$F(\Theta) = P(\theta \le \Theta) = 4\pi\Theta - 4\Theta^2, \quad 0 \le \Theta \le 2\pi. \quad (4)$$

The PDF of θ can be derived by taking the derivative of (4) and is given by

$$f(\Theta) = \begin{cases} \frac{1}{\pi}\left(1 - \frac{\Theta}{2\pi}\right), & 0 \le \Theta \le 2\pi, \\ 0, & \text{otherwise}. \end{cases} \quad (5)$$

Next, we use the PDF of θ and the expression of the traveling time t_{WLAN} as a function of θ to obtain the PDF of t_{WLAN}.

From the geometric configuration in Figure 2 and by using the cosine formula, the following equation is obtained:

$$(v t_{\text{WLAN}})^2 = 2R^2(1 - \cos\theta). \quad (6)$$

Thus,

$$t_{\text{WLAN}} = g(\theta) = \sqrt{\frac{2R^2}{v^2}(1 - \cos\theta)}. \quad (7)$$

Using the theorem stated in [25], the PDF of t_{WLAN} is expressed as

$$f(T) = \sum_{1} n \frac{f(\theta_n)}{|g'(\theta_n)|}, \quad (8)$$

where $\theta_1, \ldots, \theta_n$ are the roots of function $g(\theta)$ and $g'(\cdot)$ is the derivative of $g'(\cdot)$.

In (7), for $g(\theta)$, there are two roots, θ_1 and θ_2, which are expressed as

$$\theta_1 = \arccos\left(1 - \frac{v^2 t_{\mathrm{WLAN}}^2}{2R^2}\right),$$
$$\theta_2 = 2\pi - \arccos\left(1 - \frac{v^2 t_{\mathrm{WLAN}}^2}{2R^2}\right). \quad (9)$$

From (7), $g'(\theta)$ is expressed as

$$g'(\theta) = \frac{R\sin\theta}{v\sqrt{2(1-\cos\theta)}}, \quad (10)$$

$$\left|g'(\theta_1)\right| = \left|\frac{R\sin\left(\arccos\left(1 - v^2 t_{\mathrm{WLAN}}^2/2R^2\right)\right)}{v\sqrt{2\left[1-\cos\left(\arccos\left(1 - v^2 t_{\mathrm{WLAN}}^2/2R^2\right)\right)\right]}}\right| = R\sqrt{1 - \frac{v^2 t_{\mathrm{WLAN}}^2}{4R^2}}, \quad (11)$$

$$\left|g'(\theta_2)\right| = \left|\frac{R\sin\left(2\pi - \arccos\left(1 - v^2 t_{\mathrm{WLAN}}^2/2R^2\right)\right)}{v\sqrt{2\left[1-\cos\left(2\pi - \arccos\left(1 - v^2 t_{\mathrm{WLAN}}^2/2R^2\right)\right)\right]}}\right| = R\sqrt{1 - \frac{v^2 t^2}{4R^2}}, \quad (12)$$

$$f(\theta_1) = \frac{1}{\pi}\left[1 - \frac{\arccos\left(1 - v^2 t_{\mathrm{WLAN}}^2/2R^2\right)}{2\pi}\right], \quad (13)$$

$$f(\theta_2) = \frac{1}{\pi}\left[1 - \frac{2\pi - \arccos\left(1 - v^2 t_{\mathrm{WLAN}}^2/2R^2\right)}{2\pi}\right]. \quad (14)$$

Thus, using (8), (11), and (13), the PDF of t_{WLAN} is calculated by

$$f(T) = \begin{cases} \dfrac{f(\theta_1)}{|g'(\theta_1)|} + \dfrac{f(\theta_2)}{|g'(\theta_2)|}, & 0 \le T \le \dfrac{2R}{v}, \\ 0, & \text{otherwise} \end{cases} = \begin{cases} \dfrac{2}{\pi\sqrt{4R^2 - v^2\tau^2}}, & 0 \le T \le \dfrac{2R}{v}, \\ 0, & \text{otherwise.} \end{cases} \quad (15)$$

The third step is to use the PDF of t_{WLAN} to obtain the CDF of t_{WLAN}, which is derived from the integral of (15) as

$$F(T) = \Pr[t \le T] = \int_0^T f(T)\,dT = \begin{cases} 1, & \dfrac{2R}{v} < T, \\ \dfrac{2}{\pi}\arccos\left(\dfrac{vT}{2R}\right), & 0 \le T \le \dfrac{2R}{v}. \end{cases} \quad (16)$$

A handover failure occurs when the estimated traveling time t_{WLAN} is shorter than the handover latency from the cellular network to the WLAN, τ_i (handoff decision is taken and the MT initiates the handover procedure whenever t_{WLAN} is greater than time threshold parameter T_1). Thus, using (16), the probability of a handover failure for the method using the threshold T_1 is given by

$$P_f = \begin{cases} \dfrac{2}{\pi}\left[\arcsin\left(\dfrac{v\tau_i}{2R}\right) - \arcsin\left(\dfrac{vT_1}{2R}\right)\right], & 0 \le T_1 \le \tau_i, \\ 0, & \tau_i < T_1. \end{cases} \quad (17)$$

By using (17), an equation which can be used by the MT to calculate the value of T_1 for a particular value of P_f when $0 < P_f < 1$ is

$$T_1 = \frac{2R}{v}\sin\left(\arcsin\left(\frac{v\tau_i}{2R}\right) - \frac{\pi}{2}P_f\right). \quad (18)$$

To calculate T_1, the speed of MT v and the handover latency τ_i need to be obtained. In this research, the knowledge of v and τ_i is assumed. They can be measured by using accelerometers [26] and the technique described in [27], respectively.

To eliminate unnecessary handover instances, Yan et al. [11, 12] developed a VHD algorithm that takes into consideration the time the mobile terminal is expected to spend within a WLAN cell.

Handover to a WLAN is triggered if the WLAN coverage is available and the estimated traveling time inside the WLAN cell is larger than the time threshold. The estimated traveling time (t_{WLAN}) is given by

$$t_{\mathrm{WLAN}} = \frac{R^2 - l_{\mathrm{OS}}^2 + v^2\left(t_s - t_{P_i}\right)^2}{v^2\left(t_s - t_{in}\right)}, \quad (19)$$

where R is the radius of the WLAN cell, l_{OS} is the distance between the access point and where the mobile terminal takes an RSS sample, v is the velocity of the mobile terminal, and t_s and t_{P_i} are the times at which the RSS sample is taken and the mobile terminal enters the WLAN cell coverage, respectively. l_{OS} is estimated by using the RSS information and log-distance path loss model.

The time threshold (T_{WLAN}) is calculated based on various network parameters as

$$T_{\mathrm{WLAN}} = \frac{2R}{v}\sin\left(\sin^{-1}\left(\frac{v\tau}{2R}\right) - \frac{\pi}{2}P\right), \quad (20)$$

where τ_i, the handover, is the delay from the cellular network to the WLAN and P is the tolerable handover failure/unnecessary handover. Handover to the cellular network is initiated if the WLAN RSS is continuously fading and the mobile terminal reaches a handover commencement boundary area whose size is dynamic to the mobile terminal's speed.

Similar to the arguments used in the previous section, another parameter T_2 ($T_1 < T_2$) is introduced to minimize the probability of unnecessary handover instances. By using (16), the probability of unnecessary handover is calculated as

$$P_u = \begin{cases} \frac{2}{\pi}\left[\arcsin\left(\frac{v(\tau_i+\tau_o)}{2R}\right) - \arcsin\left(\frac{vT_2}{2R}\right)\right], & 0 \le T_2 \le (\tau_i+\tau_o), \\ 0, & (\tau_i+\tau_o) < T_2. \end{cases} \quad (21)$$

Thus,

$$T_2 = \frac{2R}{v}\sin\left(\arcsin\left(\frac{v(\tau_i+\tau_o)}{2R}\right) - \frac{\pi P_u}{2}\right). \quad (22)$$

Equation (22) is derived from (21) for a particular value of P_u when $0 < P_u < 1$.

Parameters T_1 and T_2 depend on values of constants P_f and P_u which are selected by system designers. They also depend on measurement of v, R, τ_i, and τ_o. Parameter T_2 can be further adjusted dynamically to encourage or discourage handover to WLAN by considering other performance criteria such as the network load.

Step 3. Cost calculation function takes user preferences (cost factors) and the power level of the MT as inputs. It evaluates the cost for making handover to any candidate network. Our function is based on Hasswa et al.'s handover decision algorithm in which the normalization and weights distribution methods are provided [28, 29]. A network quality factor is used to evaluate the performance of a handover target candidate as

$$Q_i = w_c C_i + w_s S_i + w_p P_i + w_d D_i + w_f F_i, \quad (23)$$

where Q_i is the quality factor of network i. C_i, S_i, P_i, D_i, and F_i stand for cost of service, security, power consumption, network condition, and network performance. w_c, w_s, w_p, w_d, and w_f are the weights of these network parameters.

A normalization procedure is used and the normalized quality factor for network n is calculated (each network parameter has a different unit) as

$$\begin{aligned} Q_i = {} & \frac{w_c(1/C_i)}{\max((1/C_1),\dots,(1/C_n))} + \frac{w_s S_i}{\max(S_1,\dots,S_n)} \\ & + \frac{w_p(1/P_i)}{\max((1/P_i),\dots,(1/P_n))} \\ & + \frac{w_d D_i}{\max(D_1,\dots,D_n)} + \frac{w_f F_i}{\max(F_1,\dots,F_n)}. \end{aligned} \quad (24)$$

The metrics used in our first experiment are bandwidth, RSS, velocity, cost of service, security, and power consumption.

We added conditions regarding the preferred bandwidth, monetary cost, security, and power consumption to the cost function so we can get better QoS.

If the solution does not meet required metrics values, we will increase the cost function value so we keep the best solutions up in the archive table.

Step 4. The necessity to perform handoff is estimated and only the targets with probability of HO lower than the specified threshold and which have lower unnecessary handoff probability are kept.

Step 5. The best target to perform handoff to is selected from the archive table (first target in the archive solution table) which has the lowest cost. The process is repeated n times which represents the number of new networks (APs) becoming available for each trajectory.

Steps 4 and 5 are based on updated ACO_R (Ant Colony Optimization for Continuous Domains) algorithm [30].

The ACO_R algorithm substitutes the discrete probability distributions used in ACO algorithms for combinatorial problems with probability density functions in the solution construction phase. To do so, the ACO_R algorithm stores a set of k solutions (solution archive or the algorithm's "pheromone model") that is used to create probability distribution of promising solutions over the searching space. The solution archive is filled with randomly generated solutions (from visible solution "AP"). The algorithm refines the solution archive by generating "m" new solutions iteratively and keeping only the best "k" solutions of $k + m$ available solutions. "k" solutions in the archive are sorted from best to worst according to their quality.

Solutions are generated using mixtures of weighted Gaussian functions on a coordinate-per-coordinate basis. The estimation of multimodal one-dimensional probability density functions (PDFs) is the core of the solution construction procedure. ACO_R mechanism based on a Gaussian kernel to do that is defined as a weighted sum of several Gaussian functions g_j^i, where j and i are, respectively, a solution index and a coordinate index. Hereafter, the Gaussian kernel for coordinate i is

$$G^i(x) = \sum_{j=1}^{k} w_j g_j^i(x) = \sum_{j=1}^{k} \frac{w_j 1}{\sigma_j^i\sqrt{2\pi}} e^{-(x-\mu_j^i)^2/2\sigma_j^{i\,2}}, \quad (25)$$

where $j \in \{1,\dots,k\}$, $i \in \{1,\dots,D\}$ with D being the problem dimensionality, and the ranking of solution j in the archive rank(j) is associated with a weight w_j. The weight is calculated using a Gaussian function:

$$W_j = \frac{1}{qk\sqrt{2\pi}} e^{-(\text{rank}(j)-1)^2/2q^2k^2}, \quad (26)$$

where q is an algorithm parameter.

During the solution generation process, each coordinate is treated independently. First, an archive solution is chosen with a probability pro rata to its weight. After that, the algorithm performs sampling around the selected solution component s_j^i using a Gaussian PDF with $\mu_j^i = s_j^i$ and σ_j^i equal to

$$\sigma_j^i = \delta \sum_{r=1}^{k} \frac{\left|s_r^i - s_j^i\right|}{k-1}, \quad (27)$$

which is the average distance between the ith variable of the solution s_j and the ith variable of the other solutions in the archive, multiplied by a parameter δ, which has the same effect as pheromone evaporation rate regulates the speed of convergence. The higher the value of $\delta \in (0,1)$, the lower the convergence speed of the algorithm, and hence the lower the learning rate. Parameter δ is also used to avoid unlimited accumulation of the pheromone trails and it enables the algorithm to "forget" bad decisions previously taken.

The solution generation process is repeated m times for each dimension $i = 1, \ldots, D$. In ACO_R, due to the specific way the pheromone model is represented in (i.e., as the solution archive), it is in fact possible to take into account the correlation between the decision variables. Each MS (ant) chooses a direction in the search space at each step of the construction process, by randomly selecting a solution s_d that is reasonably far away from the solution s_j chosen earlier as the mean of the Gaussian PDF. Then, vector $\overrightarrow{s_j s_d}$ becomes the chosen direction. The probability of choosing solution s_u at step i is the following:

$$P\left(s_d \mid s_j\right)_i = \frac{d\left(s_d, s_j\right)_i^4}{\sum_{r=1}^{k} d\left(s_r, s_j\right)_i^4}, \quad (28)$$

where function $d(\cdot,\cdot)_i$ returns the Euclidean distance in $(n-i+1)$-dimensional search subspace between two solutions of the archive T. Once this vector is chosen, the new orthogonal basis for the MSs (ants') coordinate system is created using the Gram-Schmidt process [31]. Then, all the current coordinates of all the solutions in the archive are rotated and recalculated according to this new orthogonal base. At the end of the solution construction process, the temporary values of the chosen variables are converted back into the original coordinate system.

4. Performance Analysis of the Proposed Scheme

4.1. Theoretical Analysis. In the fixed RSS threshold based method [32, 33], handover to the WLAN is initiated when the RSS from the WLAN is above RSS_fixed threshold. Using (16), the handover failure probability for the fixed RSS threshold based method is given by

$$P_{f\,\text{fixed}} = \begin{cases} 1, & v\tau_i > 2R_\text{fixed}, \\ \frac{2}{\pi}\sin^{-1}\left(\frac{v\tau_i}{2R_\text{fixed}}\right), & 0 \le v\tau_i \le 2R_\text{fixed}, \end{cases} \quad (29)$$

where R_fixed is the distance between the MT location and the AP of the WLAN cell when handover into the WLAN occurs in the fixed RSS threshold based method. The value of R_fixed is obtained by

$$R_\text{fixed} = 10^{(E_t - \text{RSS}_\text{fixed})/10\beta}. \quad (30)$$

In the hysteresis based method [34], handover to the WLAN is triggered when the RSS from the WLAN is above a threshold plus a hysteresis, $\text{RSS}_\text{hyst} + h_y$, where RSS_hyst is the RSS threshold and h_y is a constant representing the hysteresis.

Using (16), the handover failure probability for the hysteresis based method is given by

$$P_{f\,\text{hyst}} = \begin{cases} 1, & v\tau_i > 2R_\text{hyst}, \\ \frac{2}{\pi}\sin^{-1}\left(\frac{v\tau_i}{2R_\text{hyst}}\right), & 0 \le v\tau_i \le 2R_\text{hyst}, \end{cases} \quad (31)$$

where R_hyst is the distance between the MT location and the AP of the WLAN cell when handover into the WLAN occurs in the hysteresis based method. The value of R_hyst is obtained by

$$R_\text{hyst} = 10^{(E_t - \text{RSS}_\text{hyst} + h_y)/10\beta}. \quad (32)$$

Using (16), the unnecessary handover probability for the fixed RSS threshold based method is given by

$$P_{u_\text{fixed}} = \begin{cases} 1, & v\left(\tau_i + \tau_o\right) > 2R_\text{fixed}, \\ \frac{2}{\pi}\sin^{-1}\left(\frac{v\left(\tau_i + \tau_o\right)}{2R_\text{fixed}}\right), & 0 \le v\left(\tau_i + \tau_o\right) \le 2R_\text{fixed}. \end{cases} \quad (33)$$

The unnecessary handover probability for the hysteresis based method is given by

$$P_{u_\text{hyst}} = \begin{cases} 1, & v\left(\tau_i + \tau_o\right) > 2R_\text{hyst}, \\ \frac{2}{\pi}\sin^{-1}\left(\frac{v\left(\tau_i + \tau_o\right)}{2R_\text{hyst}}\right), & 0 \le v\left(\tau_i + \tau_o\right) \le 2R_\text{hyst}. \end{cases} \quad (34)$$

In the ACO_R and HNE based method, handover to a WLAN is triggered if the WLAN coverage is available and the estimated traveling time inside the WLAN cell is larger than the time threshold. The estimated traveling time (t_WLAN) is given in (18).

The probability of a handover failure and unnecessary handover for the ACO_R and HNE based method is given in (17) and (21).

4.2. Simulation Results. MATLAB was used to simulate 1000 random trajectories across WLAN cell coverage area. For each trajectory, 10, 20, 50, and 100 new solutions (solutions represent the available WLAN cell) are also generated with random trajectories (a random angle between 0 and 2π was generated representing the movement direction of the MT), for speeds from 1 km/h to 120 km/h in 1 km/h increments.

Table 1: Parameters used in the performance evaluation.

Parameter	Symbol	Value
WLAN radius	R	150 m
Handover delay from cellular network to WLAN	τ_i	2 S
Handover delay from WLAN to cellular network	τ_o	2 S
Tolerable handover failure probability	P_f	0.005
Tolerable unnecessary handover probability	P_u	0.005
Pheromone evaporation rate	X_i	0.85
Number of parameters	n_{Var}	5
Archive solution size	n_{Size}	From 10 to 100
Number of MTs	n_{Ants}	From 10 to 100
Factor of high importance level	i_H	0.8
Factor of medium importance level	i_M	0.4
Factor of low importance level	i_L	0.2
Number of high importance levels designated by the user	n_H	2 (bandwidth, monetary cost)
Number of medium importance levels designated by the user	n_M	2 (security, RSS)
Number of nonimportance levels designated by the user	n_L	1 (power consumption)

Different sizes (from 10 to 100) of the archive table are chosen (this means we can keep up with this number of solutions in the database).

In the cost calculation function used in our ACO_R based algorithm, we consider five parameters which are RSS, security, power consumption, monetary cost, and bandwidth as inputs.

The following assumptions are made:

(i) Values of parameters are chosen randomly from Range table defined at the beginning: bandwidth from 500 Kbps to 1000 Kbps, security level on a scale of 1 to 10, from very low to very high power consumption (on a scale of 1 to 10, from very low to very high), monetary cost between 1 and 10 (in MAD/minute), and RSS from 200 to 500. We consider that there is already a unified mechanism in the networks that give information about the security level and monetary cost of each network.

(ii) The weight factors of the five network parameters, available bandwidth, monetary cost, security, power consumption, and RSS, are w_B, w_M, w_S, w_P, and w_R, respectively, where $w_B + w_M + w_S + w_P + w_R = 1$.

(iii) The numbers of different importance levels the user has specified are n_H, n_M, and n_L, respectively, where $n_H + n_M + n_L = 5$ (since the total number of the network parameters that a user could specify is five).

(iv) The factors of the importance levels of high, medium, and low are i_H, i_M, and i_L, respectively, where their values are decided by the mobile system designer, and $0 < i_H < i_M < i_L < 1$.

(v) User expectations of bandwidth, monetary cost, security, and power consumption are specified so we can get desired QoS (bandwidth > 850; security level > 6; power consumption < 0.4; monetary cost < 4).

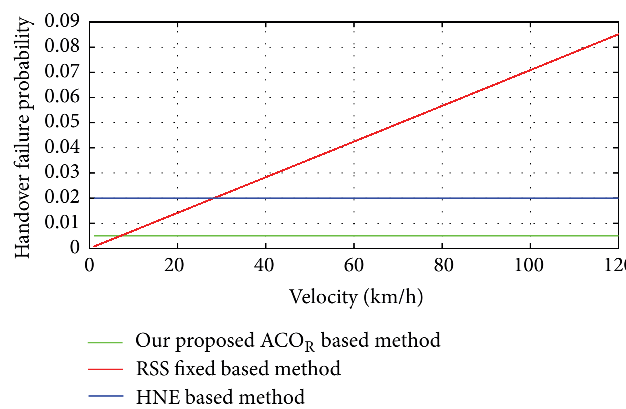

Figure 3: Handover failure probability for RSS based method, HNE based method, and our proposed ACO_R based method.

We evaluate the cost for making handover to each candidate network using (24). The network with the best satisfying QoS is chosen as handover target.

4.2.1. Evaluation Parameter. The parameters used in theoretical analysis and simulations are listed in Table 1.

4.2.2. Simulation Analysis. From Figures 3 and 4, it can be seen that, with our ACO_R approach, we can find a solution (new network) with handover failure probability less than the specified value (0.005) and unnecessary handover probability less than the specified threshold (0.005) independently of the mobile velocity. The parametric quantities examined are probability of handover failure and unnecessary handover, ratio of handoff failures and unnecessary handoff failures to the total number of handoffs, bandwidth, total number of handoffs, and cost of service.

In the simulations, we compare our proposed ACO_R method to RSS based method and HNE based method.

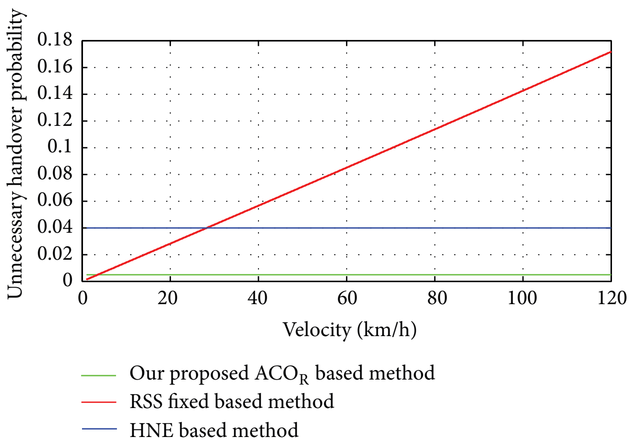

Figure 4: Unnecessary handover probability for RSS based method, HNE based method, and our proposed ACO$_R$ based method.

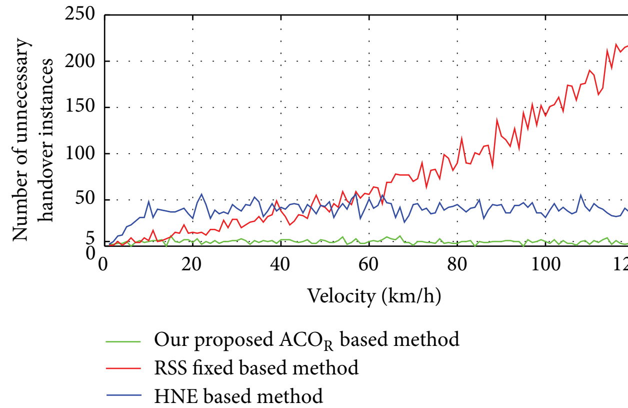

Figure 6: Number of unnecessary handover instances for RSS based method, HNE based method, and our proposed ACO$_R$ based method.

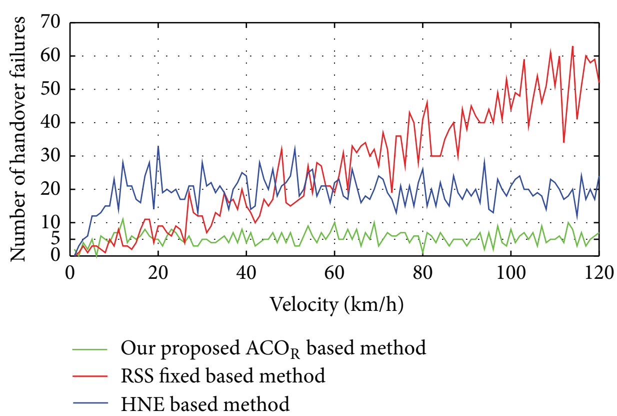

Figure 5: Number of handover failures for the RSS based method, HNE based method, and our proposed ACO$_R$ based method.

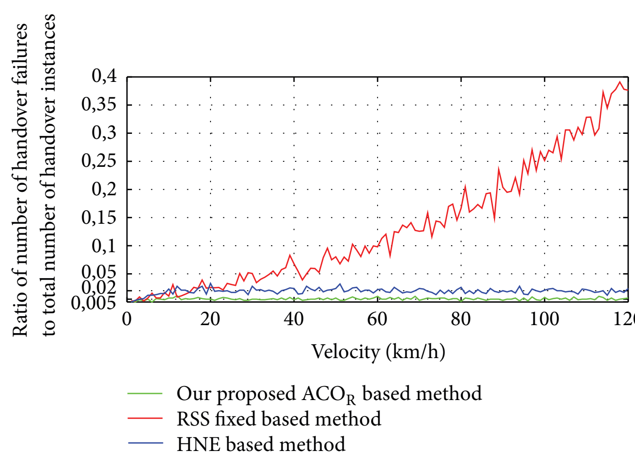

Figure 7: Ratio of the number of handover failures to the total number of handover instances.

In the RSS based method, handover is triggered when the RSS is above the specified threshold RSS value.

Since our approach is designed to keep the probability of handover failures and unnecessary handover instances below present levels, even though the velocity of the mobile increases, the probabilities remain the same. As illustrated by the figures (Figures 3 and 4), for higher velocities, our algorithm yields lower probability of handover failures and unnecessary handover instances than the RSS based method and HNE based method.

Otherwise, for velocities less than 8 km/h, RSS based methods yield marginally better results.

For a better observation of the performance comparison, the numbers of handover failures and unnecessary handover instances of the RSS threshold based method, HNE based method, and ACO$_R$ based method under different velocities of the MT are presented in Figures 5 and 6.

From the figures, it can be seen that, with ACO$_R$, handover failures and unnecessary handover instances are kept around the number of 5. ACO$_R$ is able to reduce the number of handover failures and unnecessary handover instances by up to 95%, when the velocity of the MT is up to 120 km/h.

Additionally, the ratios of the number of handover failures and unnecessary handover instances to the total number of handover instances are depicted in Figures 7, 8, and 9, respectively. As it can be seen, in ACO$_R$, the ratio of the number of handover failures and unnecessary handover instances to the total number of handover instances can be kept around the tolerable value of 0.005. ACO$_R$ yields much better performance than the other methods.

The power consumption, bandwidth, security, and cost of service are also depicted in Figures 10, 11, 12, and 13.

Guaranteeing a high level of security for some applications is an important issue to be tackled in the successful VHO in 4G networks, so confidentiality and integrity of the transmitted data can be critical. For this reason, a network with higher security level may be chosen over another one which would provide lower level of data security and as it can be seen in Figure 12, our ACO$_R$ based algorithm chooses each time the network with high security level no matter what the velocity of MT is.

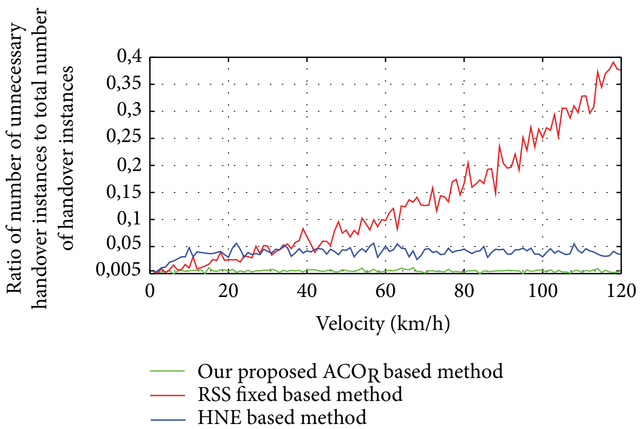

FIGURE 8: Ratio of the number of unnecessary handover instances to the total number of handover instances.

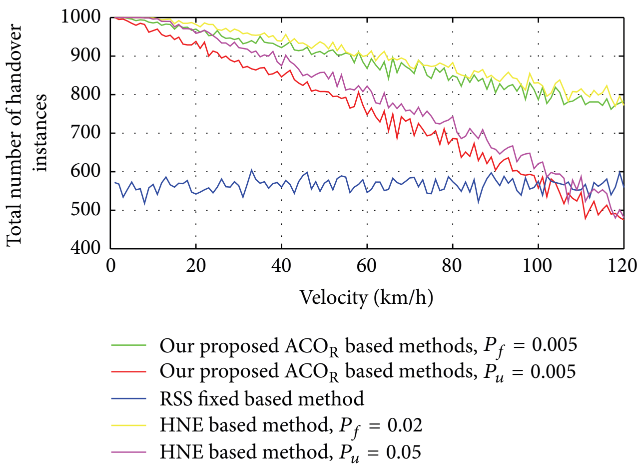

FIGURE 9: Total number of handover instances.

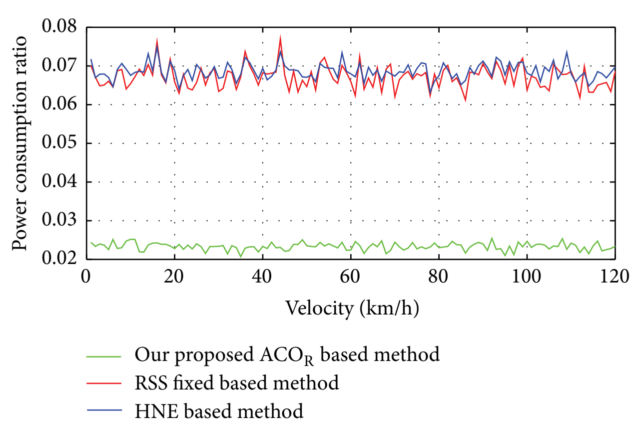

FIGURE 10: Average power consumption.

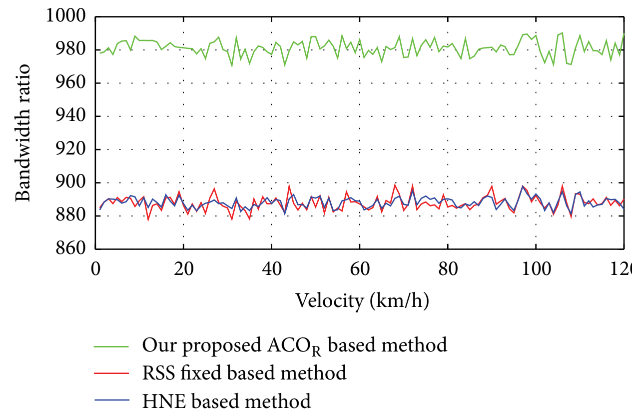

FIGURE 11: Average bandwidth.

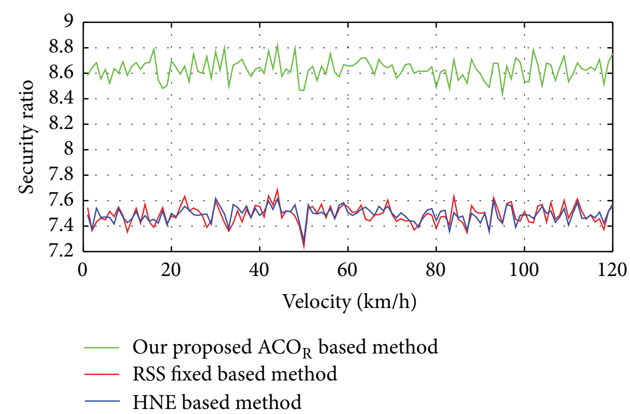

FIGURE 12: Average security level.

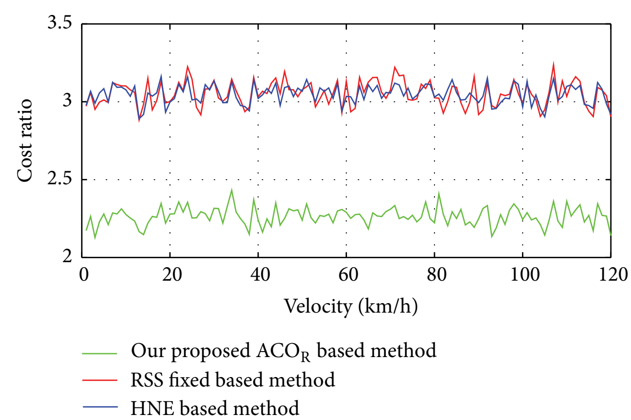

FIGURE 13: Average monetary cost of service.

As it can be seen, our proposed ACO_R based method yields much better performance than both RSS and HNE based method in terms of bandwidth, cost of service, security, and power consumption.

From the figures, it can be seen that, with ACO_R, we can not only reduce the number of handover failures and unnecessary handover instances by up to 95% regardless of the velocity of the MT, but also get better QoS in terms of bandwidth, security, power consumption, and cost of service.

For a better observation of the performance comparison, bandwidth, cost of service, security, and power consumption of the RSS threshold based method, HNE based method, and ACO_R based method under different number of MTs and archive solutions sizes are presented in Figures 14, 15, 16, 17, and 18.

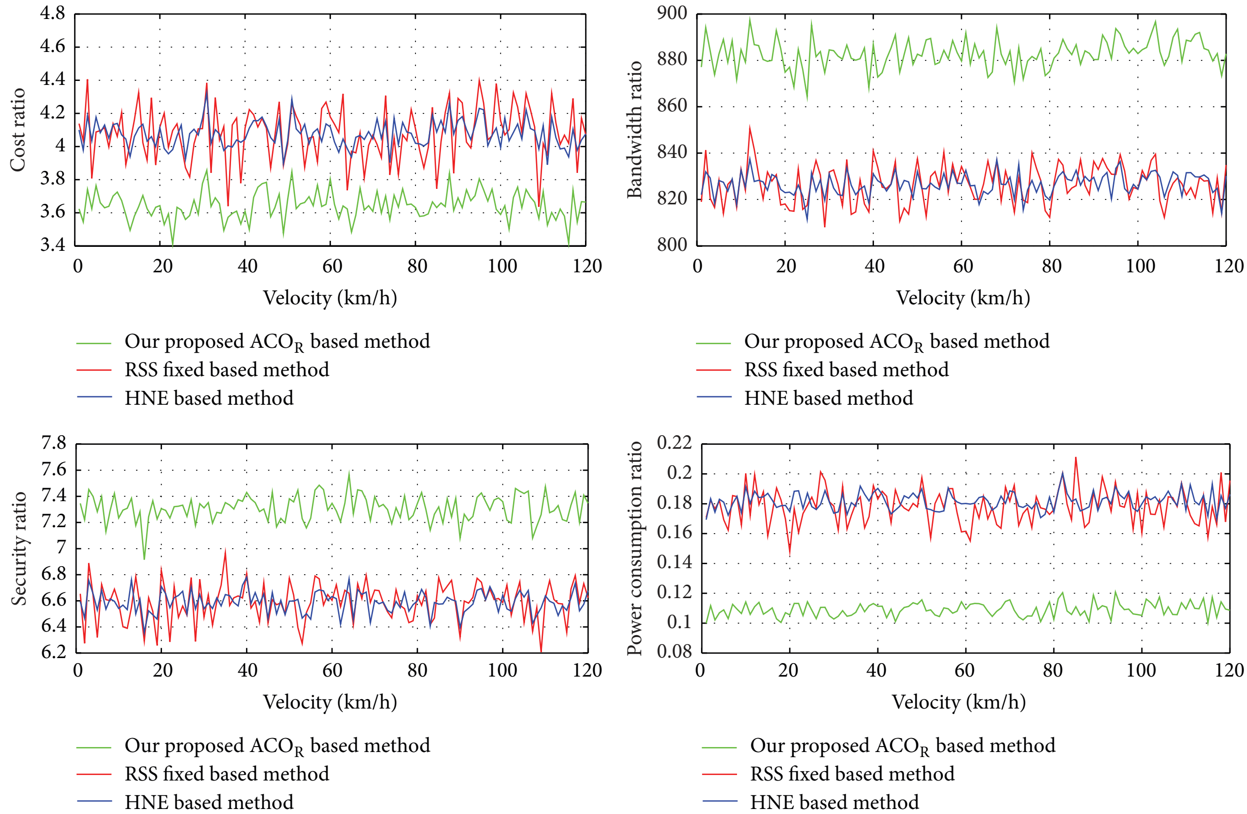

FIGURE 14: Simulation results for using 10 MTs and with archive solution table size of 10.

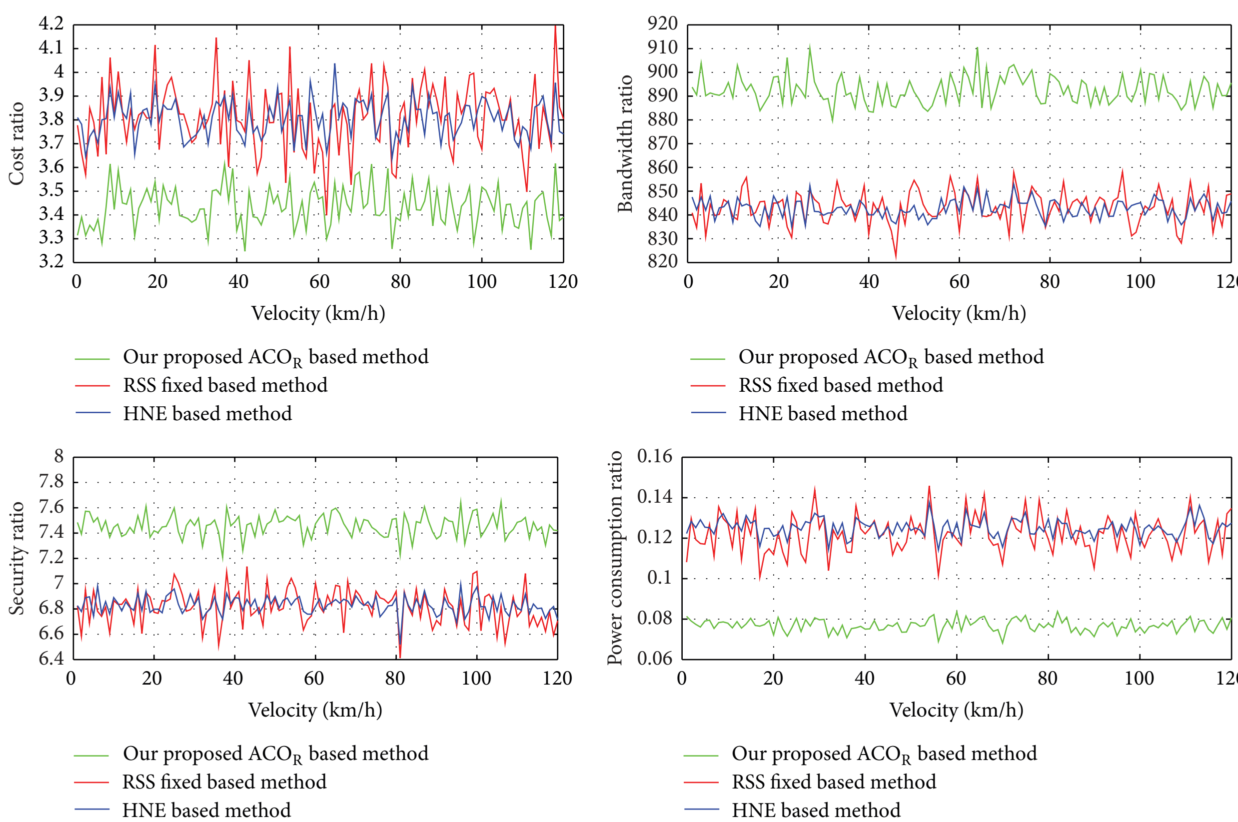

FIGURE 15: Simulation results for using 10 MTs and with archive solution table size of 20.

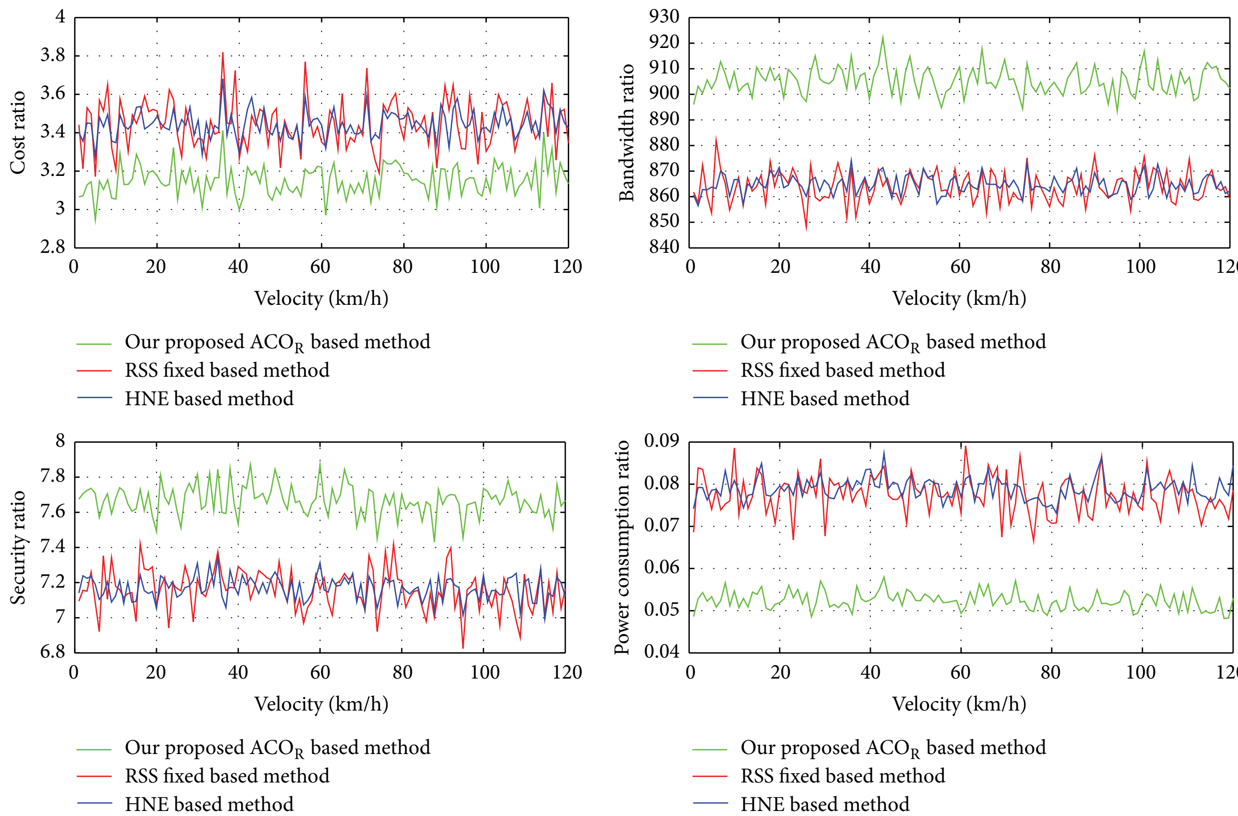

FIGURE 16: Simulation results for using 10 MTs and with archive solution table size of 50.

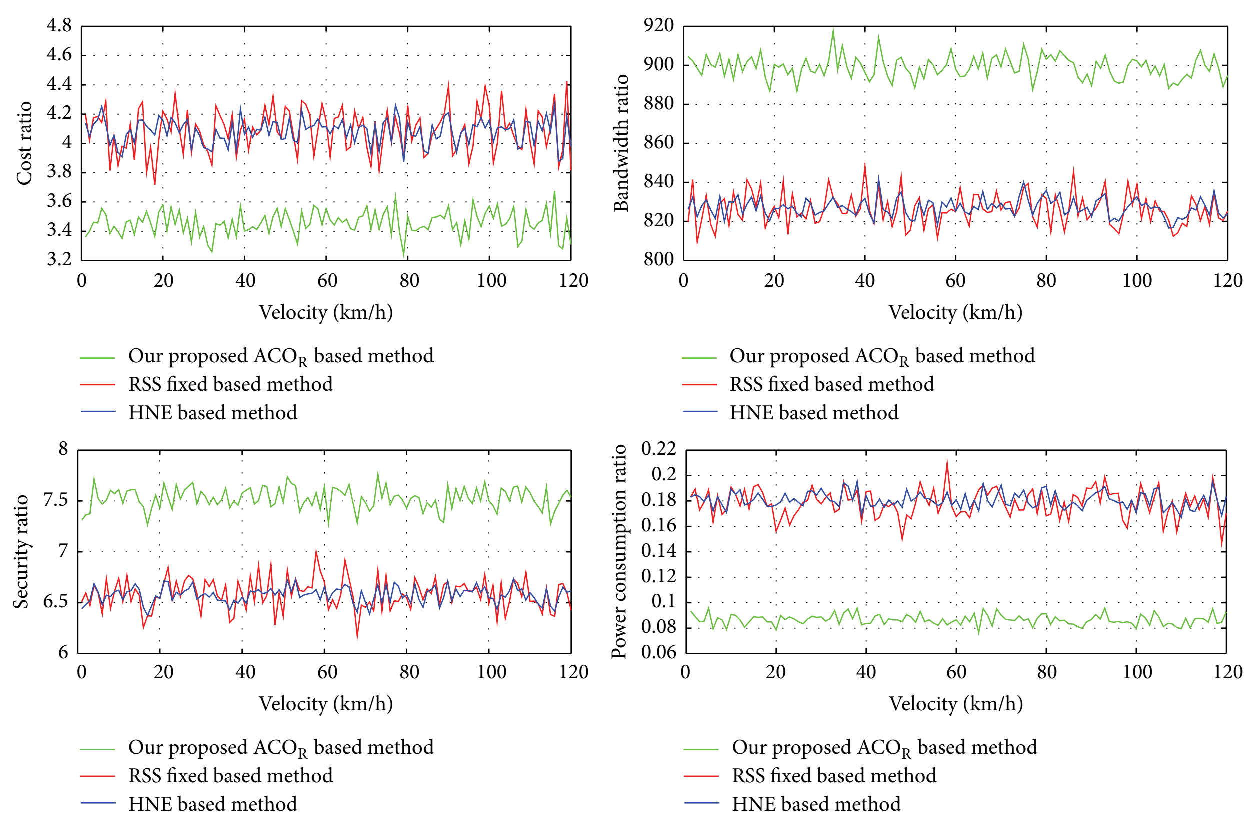

FIGURE 17: Simulation results for using 20 MTs and with archive solution table size of 10.

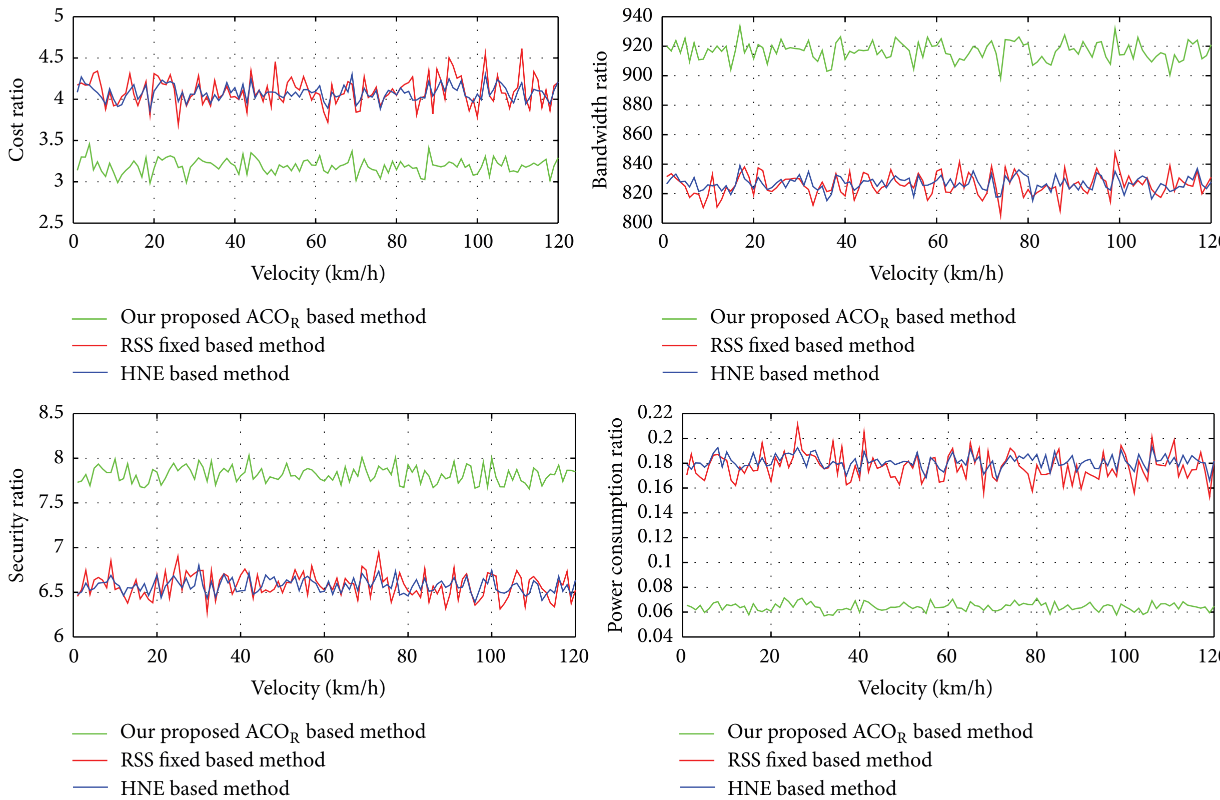

FIGURE 18: Simulation results for using 50 MTs and with archive solution table size of 10.

TABLE 2: Simulation results for different number of MTs and with different archive solution table sizes.

Number of MTs	Archive table size		Cost		Bandwidth		Security		Power consumption	
			HNE/RSS	ACO$_R$	HNE/RSS	ACO$_R$	HNE/RSS	ACO$_R$	HNE/RSS	ACO$_R$
100	10	~	4	3	830	930	6.5	8	0.17	0.05
100	20	~	3.7	2.7	840	940	6.7	8.3	0.12	0.03
100	50	~	3.4	2.5	860	960	7.2	8.4	0.075	0.025
100	100	~	3.1	2.4	880	970	7.4	8.5	0.055	0.02
50	100	~	3.1	2.6	880	955	7.4	8.4	0.055	0.025
20	100	~	3.1	2.7	880	930	7.4	8	0.055	0.035
10	100	~	3.1	2.9	880	915	7.4	7.8	0.055	0.043
50	10	~	4	3.2	830	920	6.5	7.7	0.17	0.07
50	20	~	3.8	3	840	930	6.8	8	0.12	0.042
50	50	~	3.4	2.7	870	950	7.2	8.2	0.075	0.032
20	50	~	3.4	3	860	920	7.1	7.9	0.075	0.042
20	20	~	3.8	3.2	840	910	6.8	7.7	0.12	0.06
20	10	~	4.1	3.5	830	900	6.6	7.5	0.18	0.09
10	10	~	4.1	3.6	825	880	6.6	7.3	0.18	0.11
10	20	~	3.8	3.4	840	890	6.8	7.5	0.12	0.08
10	50	~	3.4	3.1	865	905	7.2	7.7	0.078	0.052

Table 2 summarizes values of bandwidth, cost of service, security, and power consumption under different archive solution table sizes and number of MTs (solutions).

From the figures and the table, it can be seen that, by increasing the number of MTs, we obtain better performance with ACO$_R$ than RSS and HNE based method for which increasing the number of MTs has no effect. In the meantime, by increasing the size of the archive solutions table, we improve the results obtained by HNE and RSS based method over those obtained by our ACO$_R$ based method. Moreover, our method is still better. Our ACO_R based method seems to be more adequate for HO in 4th-generation networks.

5. Conclusion

The fourth generation of wireless networks is expected to include heterogeneous wireless networks that will coexist and use a common IP core to offer a diverse range of high data rate multimedia services to end users since the networks have characteristics that complement each other. To maintain the QoS and seamless connectivity between different technologies, we need to reduce the delay of HO to another technology and offer more choices to the MTs.

In this paper, we studied the basic concepts of different handover algorithms in heterogeneous wireless networks. On the basis of analysis of previous works, we proposed a new concept in which MTs can maintain a database (archive table) of available networks classified by their quality. We defined a new vertical handover mechanism that satisfies more metrics and offers better QoS using ant colony approach. In our future work, we will improve our approach by reducing the complexity of the algorithm and conducting tests against complex systems and architecture. Also, we will compare the performance of our algorithm with all existing approaches so we can conclude with the best approach that satisfies more metrics and helps us to get better QoS. To adapt our algorithm to work for all kinds of handover instances (vertical and horizontal) will be another area of improvement.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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