Mobility-based Network Selection Scheme in Heterogeneous Wireless Networks

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***Abstract*—Recently, network selection for heterogeneous wireless networks has been widely studied by categorizing and employing various factors to decide the best network. Mobility-related factors can be used to represent mobility features of mobile terminals (MTs) and mobility support capabilities of wireless networks, but they are complicated in usage and are not well used in related works. In this paper, we study the usage of these factors and provide a scheme to use them in the same way as other factors in a network selection framework. By analysis and simulations, we demonstrate that mobility-related factors should be considered in network selection schemes, and our scheme achieves the goal of selecting the most appropriate network for MTs with various mobility features.**

***Index Terms*—network selection; heterogeneous wireless networks; always best connected; vertical handover**

I. Introduction and Related Work

In the context of the present trend towards ubiquity of networks and global mobility of services, we see that network access is provided by a large diversity of technologies with coverage overlaps. In this heterogeneous wireless network (HWN) environment, the previous always connected concept becomes *always best connected* (*ABC*) which requires dynamic selection of the best network and access technology when multiple options are available simultaneously [1].

As commonly understood, network selection is to select the *best network* for a single-homed mobile terminal (MT) or an application of a multi-homed MT in HWNs [3] [4], which include universal mobile telecommunications system (UMTS), world-wide interoperability for microwave access (WiMAX), wireless local area network (WLAN), Bluetooth, etc. This selection considers various static and dynamic network-side criteria [2] [5], e.g. bandwidth, monetary cost, security level, power consumption capability, traffic load, etc. To combine multiple criteria together, adjustment (e.g. normalization) of these criteria is required. Meanwhile, certain weighting method (e.g. analytic hierarchy process (AHP) [4]) is required to decide their weights. Then, normalized values of these criteria of each network are combined as a coefficient based on their weights using certain ranking algorithm of multi-criteria decision making (MCDM) theory [3]–[6], e.g. simple additive weighting (SAW), multiplicative exponential weighting (MEW), technique for order preference by similarity to ideal solution (TOPSIS), grey relational analysis (GRA), etc. In the end, a rank of these networks is obtained based on their coefficients.

Network-side criteria, operator policies, terminal properties, customer preferences, application QoS levels, and vertical handover (VHO) properties are called by a joint name *factors* in this paper. Several of these factors are mobility-related, such as cell radius, coverage percentage, terminal velocity, horizontal handover (HHO) and VHO properties, etc. These factors can be gathered (e.g. by an MIH information server [7]) and used to represent MTs' mobility features and networks' mobility support capabilities, and are important for network selection. For example, according to these factors, high speed MTs should not select a network with small cell radius; otherwise, live applications will be severely disturbed by frequent handovers.

Unfortunately, only a few proposals in the literature considered mobility-related factors. For example, authors of [2] stated that some dynamic factors (e.g. terminal velocity, moving pattern, moving history and location information) should be considered by network selection schemes; a Markov decision process (MDP) model was proposed by [8] to take into account connection duration and VHO signaling load; the simulation in [9] used diameter of access point (AP); the study in [10] considered cellular diameter and handover latency; the simulation in [11] showed different schemes' network reselection frequencies; and the scheme proposed in [4] assumed that the availability of a hotspot means that not only signal strength is strong enough for transmitting data, but also the MT would stay in its coverage for enough time to reduce the possibility of frequent handover. However, none of the above proposals studied whether these mobility-related factors can be used in the same way as others. Therefore, in this paper, we are going to study the usage of these factors and propose an efficient scheme for mobility-based network selection.

The rest of the paper is organized as follows: in Section II, we analyze the usage of mobility-related factors; in Section III, our mobility-based network selection scheme is presented; finally, simulations results and further discussions are provided in Section IV.

II. Analysis on Using Mobility-related Factors in a Generic Framework

In the current literature, numerous recent proposals have accordant understandings on network selection [3]–[6]. Vari-

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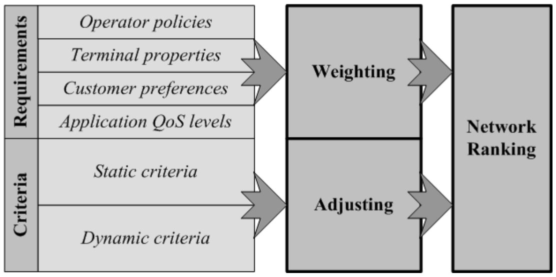


Fig. 1. A framework of network selection.

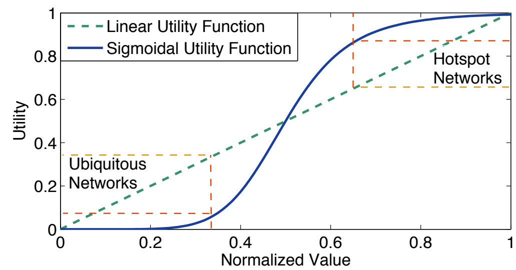


Fig. 2. Utilities of different networks through sigmoidal function.

ous factors and mathematical theories are used for this issue, which can be described by an MCDM-based network selection framework, as shown in Fig. 1.

In this framework, six groups of factors are considered: four groups of requirements (including operator policies, terminal properties, customer preferences and application QoS levels) are used for weighting; two groups of network-side criteria (static criteria and dynamic criteria) are adjusted by normalization, fuzzification or utility theory, then combined by certain MCDM network ranking algorithm. However, mobility-related criteria, especially VHO properties, cannot be covered by any of the two groups of criteria because VHO properties are not properties of certain network.

VHO properties include VHO signaling cost, latency, rate, etc., which are all important mobility-related criteria for network selection. However, the usage of these criteria in the above network selection framework is quite complicated. That is because VHO properties depend on not only the features of the MTs mobility and different networks' coverage but also the permutation of networks. A *permutation* here is an ordering of all the networks which represents these networks' priorities without considering their availability. At anytime and anywhere, the first available network in the permutation should be selected.

For example, in an HWNs with three networks, e.g. UMTS, WiMAX and WLAN, we consider the VHO operation when an MT moves into or out of WLAN hotspots. If the permutation 'UMTS>WiMAX>WLAN' (where '>' denotes that the left-side network has higher priority than the right-side one, so the left-side one should be selected when both of them are available) is used, no VHO will be performed because we assume UMTS is always available due to its ubiquity. By contrast, if the permutation 'WLAN>UMTS>WiMAX' is used, there could be frequent VHOs between WLAN and UMTS.

To sum up, different permutations lead to different VHO properties, hence different coefficients. Thus, when we use a ranking algorithm to select an alternative based on different networks' coefficients, this selected alternative is actually a permutation not a network. Thus, the selection of the best network becomes the selection of the best permutation when VHO properties are used in network ranking algorithms.

However, when the heterogeneous environment consists of N networks, the number of permutations will be the factorial of N. Thus, coefficients of a large number of permutations should be calculated and compared to find the best one. Moreover, the evaluation of VHO properties of each permutation is also complicated due to irregular coverage of networks and various moving patterns of MTs. To solve the above problems, this paper provides a solution to use mobility-related factors, especially VHO properties, in network ranking algorithms of the above framework.

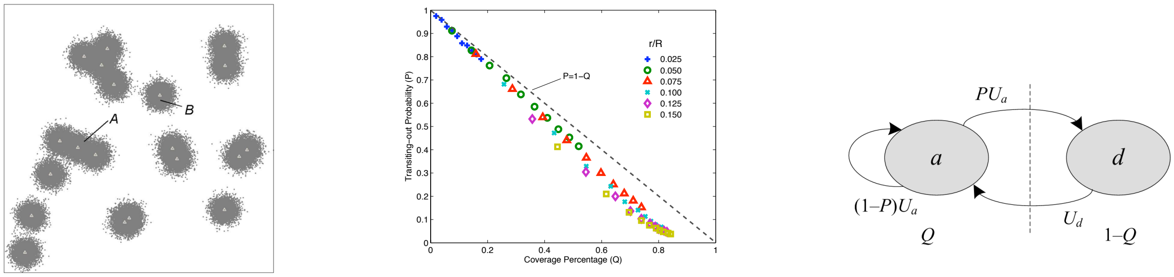
III. Mobility-based Network Selection

A. Model Establishment

Considering an HWNs with UMTS, WiMAX, WLAN and Bluetooth, these networks can be classified into two groups: *ubiquitous networks* (i.e. UMTS and WiMAX) and *hotspot networks* (i.e. WLAN and Bluetooth). Networks in the same group usually have similar values on many criteria, such as monetary cost, power consumption, security level, mobility support capability, etc. Based on the study of utility functions in [12], sigmoidal form utility functions as shown in Fig. 2 are suitable for adjusting values of various criteria. Due to the feature of sigmoidal function, utilities of networks in the same group become more similar, while the difference between different groups increases. This feature is also true for mobility-related criteria when passing through the sigmoidal function. Therefore, based on these criteria, it is easy to distinguish networks of different groups, but not easy for networks in the same group. Due to the above reasons, we study in this paper the case of an HWNs with two groups of networks: ubiquitous networks and hotspot networks. For more information on a generic mobility model in HWNs, the initial idea was presented in [13].

We assume the hotspot network's deployment is based on customers' requirements. For example, personal areas are covered by Bluetooth, coffee houses and offices are covered by WLAN, etc. According to the randomicity of distributions of customers, coffee houses, offices, etc., we assume that the deployment of hotspots obeys Poisson point process [14], and their deployment is independent of the ubiquitous network.

Fig. 3(a) shows a square area (can be imagined as a cell of the ubiquitous network) with the hotspot network's K hotspots distributed by Poisson point process. When a random walking MT leaves one of these hotspots, the probability of transiting directly into another hotspot equals exactly the percentage of the former hotspots border being covered by others. For



(a) Poisson point process (b) Monte Carlo simulation (c) Markov chain

Fig. 3. Mobility modeling in a 2-network HWN environment.

example, the border of hotspot 'A' in Fig. 3(a) is covered by two other hotspots, so the probability of directly transiting from this hotspot to another is large. By contrast, the MT has no possibility to transit directly to another hotspot when leaving hotspot 'B'. Thus, considering the randomicity of hotspots' distribution, the transiting-out probability can be expressed as

$$P = 1 - Q_{K-1} \approx 1 - Q, \tag{1}$$

where P is the *transiting-out probability* which represents the probability of transiting out of the coverage of the hotspot network when an MT moves out of a hotspot; Q is the *coverage percentage* which represents the percentage of the square area covered by the K hotspots; Q_{K-1} represents the coverage probability of $K-1$ hotspots, so Q_{K-1} approximately equals Q when K is a large number.

Fig. 3(b) shows a verification of (1) by Monte Carlo simulation. Given K hotspots, we firstly distribute them into a square area obeying Poisson point process. Secondly, we distribute N_{total} random points into the square area for statistic purpose. Thirdly, we count the number of points that fall in any of the hotspots as N_h, and Q is calculated as $\frac{N_h}{N_{total}}$. Fourthly, we count the number of points that fall on the border of any hotspot as N_b, and count specifically the points that are not only on the border of one hotspot but also covered by some other hotspots as N_{bh}. Finally, P is calculated as $\frac{N_{bh}}{N_b}$. Fig. 3(b) shows six groups of simulations with different $\frac{r}{R}$, where r and R are respectively the radius of hotspots and the equivalent radius of the whole square area that can be treated as the cell radius of certain ubiquitous network (e.g. UMTS). In each of the six groups, 10 simulations are performed (steadily increase the number of hotspots from 10 to 100). In each simulation, all the hotspots are distributed 100 times. And in each time, there are 90,000 (N_{total}) random points. We can see that the curves fit well to (1) when $\frac{r}{R}$ is small, and a little bit lower when $\frac{r}{R}$ increases. That is because we have to use a limited square area in our simulation instead of a really large area, so the border place has a smaller probability to be covered by these hotspots.

Fig. 3(c) shows a Markov chain that denotes the MT's movement among this networks hotspots. 'a' and 'd' represent separately the states that the MT is covered and uncovered by this network. U_a is the transiting rate from a hotspot (i.e. $\frac{1}{U_a}$ is the mean residence time within a hotspot), and U_d is the transiting rate from 'd' (i.e. $\frac{1}{U_d}$ is the mean residence time in the uncovered area). P is transiting-out probability, so the probability of moving directly to another hotspot is $1-P$. When the Markov chain is stationary, the transiting probability from 'a' to 'd' equals that from 'd' to 'a', written as

TABLE I
HANDOVER RATES AND COSTS

HO	HO Rate	Cost per HO
UBN → UBN	$U_a r/R$	X
HSN → HSN	$U_a(1-P)Q$	Y
HSN → UBN	$U_a PQ$	Z_1
UBN → HSN	$U_a(1-Q)$	Z_2

$$QPU_a = (1-Q)U_d. \tag{2}$$

Taking (1) into (2), we get

$$U_d = QU_a. \tag{3}$$

According to fluid flow model [15] and by assuming all the hotspots have circular coverage area, we get

$$U_a = \frac{2v}{\pi r}, \tag{4}$$

where r is the radius of hotspot and v is the velocity of MT.

Taking (4) into (3), we get

$$U_d = \frac{2Qv}{\pi r}. \tag{5}$$

B. Mobility-based network selection scheme

Handover rates for both HHO and VHO are summarized in TABLE I. And, we simply define costs of the four handovers as X, Y, Z_1 and Z_2, including signaling costs, latency, etc., because the evaluation of these costs is out of the scope of this paper. Now, we can evaluate average handover costs of different permutations. Two permutations are considered: 'ubiquitous networks better than hotspot networks (UBN>HSN)' and 'hotspot networks better than ubiquitous networks (HSN>UBN)'.

For permutation 'UBN>HSN', ubiquitous networks will be always used. Thus, the average handover cost HC contains only HHO cost among the cells of ubiquitous networks, which is

$$HC_{UBN>HSN} = \frac{2v}{\pi R} \cdot X. \tag{6}$$

By contrast, HC of the permutation 'HSN>UBN' contains the four parts as shown in TABLE I. To simplify the following derivation, we assume no hotspot spans two or more cells of a ubiquitous network [16], so we get HC as

$$\begin{aligned} HC_{HSN>UBN} = & \frac{2v}{\pi R} \cdot X + \frac{2v(1-P)Q}{\pi r} \cdot Y \\ & + \frac{2vPQ}{\pi r} \cdot Z_1 + \frac{2vQ(1-Q)}{\pi r} \cdot Z_2. \end{aligned} \tag{7}$$

Generally speaking, a network selection scheme will consider multiple criteria besides the average handover cost, so we suppose that the combination of all the other criteria is Oth_{UBN} for ubiquitous networks and Oth_{HSN} for hotspot networks with a combined weight of W_1, and HC has a weight of W_2 ($W_2 = 1 - W_1$). Therefore, taking SAW as an example, the total cost of 'UBN>HSN' can be expressed as

$$TC_{UBN>HSN} = \widetilde{HC}_{UBN>HSN} \cdot W_2 + \widetilde{Oth}_{UBN} \cdot W_1, \tag{8}$$

where $\widetilde{\ }$ represents the normalized value of HC or the combination of other criteria. Meanwhile, the total cost of 'HSN>UBN' is

$$\begin{aligned} TC_{HSN>UBN} = & \widetilde{HC}_{HSN>UBN} \cdot W_2 + [\widetilde{Oth}_{HSN} \cdot Q \\ & + \widetilde{Oth}_{UBN} \cdot (1-Q)] \cdot W_1. \end{aligned} \tag{9}$$

Hotspot networks are preferred to ubiquitous networks if they have a smaller total cost, written as

$$TC_{HSN>UBN} < TC_{UBN>HSN}. \tag{10}$$

Taking (8) and (9) into (10), we obtain the threshold as

$$W_2 < \frac{\widetilde{Oth}_{UBN-HSN}}{\widetilde{Oth}_{UBN-HSN} + \frac{QY+(1-Q)(Z_1+Z_2)}{Norm}}, \tag{11}$$

where $\widetilde{Oth}_{UBN-HSN}$ represents the difference between the other criteria's combination of ubiquitous networks ($\widetilde{Oth}_{UBN}$) and that of hotspot networks ($\widetilde{Oth}_{HSN}$), and $Norm = \sqrt{\frac{r^2X^2}{R^2} + \left\{\frac{rX}{R} + Q[QY + (1-Q)(Z_1+Z_2)]\right\}^2}$.

IV. Performance Evaluation

A. Configuration of the network selection simulator

In this section, we are going to establish a network selection simulator based on the framework shown in Fig. 1, in order to evaluate the performance of the above mobility-based network selection scheme. Detailed configurations of our simulator are explained as follows:

Criteria: besides the average handover cost, nine other criteria are considered, i.e. monetary cost, bandwidth, power consumption, security level, bit error rate, burst error rate, jitter, traffic load and signal strength.

Requirements: the terminal velocity is relatively high and the power condition is good; the customer prefers low price; and application flow is conversational.

Networks: the HWN environment is composed of four networks, i.e. Bluetooth, WLAN, WiMAX and UMTS.

Adjusting: criteria are adjusted firstly by normalization, then through sigmoidal utility functions as shown in Fig. 2.

Weighting: AHP is used to evaluate the weights.

Ranking: four MCDM algorithms, i.e. SAW, MEW, TOPSIS and GRA, are used for network ranking.

Matrix: an $m \times n$ value matrix is used to represent the values of different criteria of different networks, where m and n represent the number of networks and criteria, respectively. In our simulation, we suppose the values of the two dynamic criteria (i.e. traffic load and signal strength) of different networks are the same, in order that the results focus on the impact of the average handover cost. We also simply assume that costs per handover are ($X : Y : Z_1 : Z_2 = 2 : 3 : 4 : 4$) because performance evaluation of various handover strategies is out of the scope of this paper.

B. Simulation results and further discussions

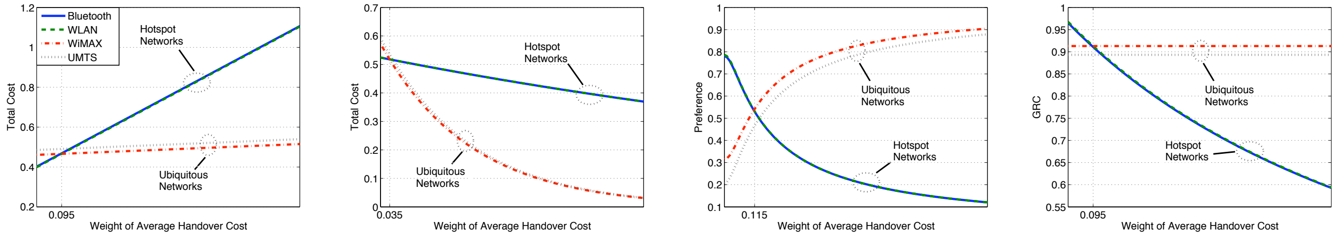
Simulation results in Fig. 4 and Fig. 5 show that the change of the four networks' coefficients along with the increase of the coverage percentage (Q) and the weight of average handover cost (W_2), respectively. For SAW and MEW, the coefficient is the total cost, so it is the smaller the better. For TOPSIS and GRA, the coefficient is the preference value, so it is the larger the better. Based on these figures, we have the following important observations:

- networks in the same group have similar performance;
- as shown in Fig. 5, along with the increase of hotspot networks' coverage, the advantage of hotspot networks gradually increases. Meanwhile, the advantage of ubiquitous networks decrease due to the normalization process;
- when the average handover cost is not considered (i.e. the weight of average handover cost equals 0 in Fig. 4, hotspot networks are generally better than ubiquitous networks;
- when the weight of the average handover cost increases, ubiquitous networks gradually have more chance to be selected, and the threshold between selecting the two groups of networks is also shown in Fig. 4;
- moreover, we can see that different MCDM algorithms have different coefficients and different thresholds, but the trends in these figures are all the same. SAW, TOPSIS and GRA have quite similar thresholds.

Seen from Fig. 5, deploying more hotspots will increase the benefit of hotspot networks. To further study this impact, we define the probability density function (PDF) of the MT velocity as $f(v)$ and the weight of HC as $\omega(v)$, MTs whose velocity is smaller than v_0, i.e. the threshold obtained by (11), will prefer hotspot networks. Therefore, the number of customers who prefer hotspot networks can be expressed as

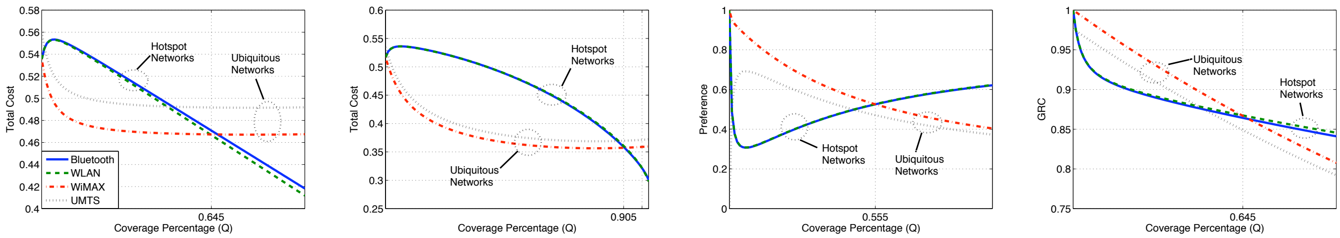
$$n(Q) = N_0 \int_0^{v_0} f(v) \mathrm{d}v, \tag{12}$$

where N_0 is the total number of customers, and $v_0 = \omega^{-1}\left(\frac{\widetilde{Oth}_{UBN-HSN}}{\widetilde{Oth}_{UBN-HSN} + \frac{QY+(1-Q)(Z_1+Z_2)}{Norm}}\right)$.



(a) SAW (b) MEW (c) TOPSIS (d) GRA

Fig. 4. Coefficients of various networks vs. Weight of average handover cost.



(a) SAW (b) MEW (c) TOPSIS (d) GRA

Fig. 5. Coefficients of various networks vs. Coverage percentage.

Furthermore, we can get hotspot networks' customer increment rate (CIR) as the derivative of (13) with respect to Q. However, deploying more hotspots cannot bring all the customers to choose this technology. Take $(Q = 1)$ into (11), we find that hotspot networks will never be preferred by those customers whose velocity is larger than the following value:

$$v > \omega^{-1}\left(\frac{1}{1+\frac{1}{\widetilde{Oth}_{UBN-HSN}\sqrt{\frac{r^2X^2}{R^2Y^2}+(\frac{rX}{RY}+1)^2}}}\right). \qquad (13)$$

V. Conclusions

In this paper, we studied the usage of mobility-related factors for network selection in HWNs and provided a scheme to use them in the same way as other factors in an MCDM-based generic framework. We classified wireless networks into two groups (hotspot networks and ubiquitous networks) and derived a threshold between them. By analysis and simulations, we demonstrated that mobility-related factors should be considered for network selection, and our scheme achieved the goal of selecting the appropriate network for MTs with various mobility features. Moreover, we discussed the impact on customers' preference of hotspot networks when deploying more hotspots.

Our near future work is firstly to study the scenario where more than two groups of wireless networks exist; then to combine the mobility-based scheme with the process of distinguishing networks within the same group; finally to further extend our study on network selection schemes to other aspects (e.g. network construction and pricing).

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