Best Permutation: A Novel Network Selection Scheme in Heterogeneous Wireless Networks

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ABSTRACT

Network selection in an environment of heterogeneous wireless networks (HWNs) has been widely studied, but mobility-related factors were not well considered by selection schemes in the literature. Since vertical handover (VHO) corresponds to permutation of networks, the selection of a network actually becomes the selection of a permutation when VHO properties are considered. In this paper, we propose a best permutation scheme (*Basic Besper*) for mobility-based network selection in a generic HWN environment and two methods (i.e. *Simplified Besper* and *Enhanced Besper*) to further improve the time complexity of Basic Besper. According to our performance evaluations, Bespers could always select the best network and permutation based on mobility-related factors and many advantages compared with classic best network schemes are demonstrated. Furthermore, the two methods (especially Enhanced Besper) could find the best network quite rapidly, which is important for the continuity of real-time applications during VHOs.

Categories and Subject Descriptors

C.2.3 [**Computer - Communication Networks**]: Network Operations—*Network Management*; C.2.5 [**Computer - Communication Networks**]: Local and Wide-Area Networks

General Terms

Algorithms

Keywords

network selection, heterogeneous wireless networks (HWNs), always best connected (ABC), vertical handover (VHO)

1. INTRODUCTION

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, a mobile terminal (MT) should perform network selection scheme, in order to be *always best connected* (ABC) to the most appropriate network and access technology when multiple options are available simultaneously [5].

As commonly understood, network selection is to select the *best network* based on various static or dynamic network-side attributes [9, 10, 3, 11, 7, 2, 1], e.g. bandwidth, monetary cost, power consumption capability, security level, bit error rate, jitter, traffic load, signal strength, etc. Meanwhile, weights of these attributes are evaluated based on both subjective and objective information, e.g. terminal properties, customer preferences, application QoS requirements, operator policies and values of these attributes themselves. Then, adjusted (e.g. normalized) values of these attributes of each network are combined as a total cost (or utility) based on their weights using certain ranking algorithm of multi-attribute decision making (MADM) theory, e.g. simple additive weighting (SAW), multiplicative exponential weighting (MEW), technique for order preference by similarity to ideal solution (TOPSIS), grey relational analysis (GRA), elimination and choice translating reality (ELECTRE), etc. In the end, a rank of all the available networks is obtained. This procedure can be summarized by the framework shown in Figure 1.

Network-side attributes, operator policies, terminal properties, customer preferences, application QoS requirements, 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., which are important for network selection. For example, according to these factors, high speed MTs should not select a network with small cell radius; otherwise, real-time applications will be severely disturbed by frequent handovers.

In the current literature, numerous researchers considered mobility-related factors in their proposals or simulations. For example, authors of [9] stated that some dynamic factors (e.g. terminal velocity, mov-ing pattern, moving history and location information) should be considered by network selection schemes; a Markov decision process (MDP) model was proposed by [12] to take into account connection duration and VHO signaling load; the simulation in [4] used diameter of access point (AP); the study in [13] considered cellular diameter and handover latency; the simulation in [6] showed different schemes' network re-selection frequencies;

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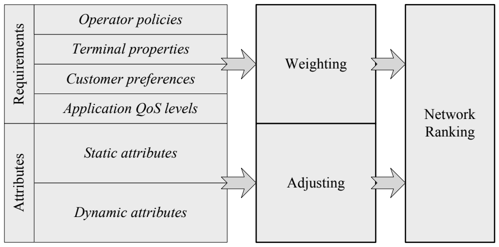


Figure 1: A framework of network selection.

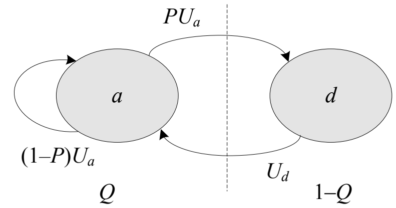


Figure 2: Transitions in a single network scenario.

and the scheme proposed in [10] 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, there is no specific study on how to appropriately use these factors in a network selection scheme, hence no permutation-based network selection scheme as presented in this paper has ever been proposed. According to our understanding, the usage of mobility-related factors (especially VHO properties) is quite complicated. That is because VHO depends on not only features of an MT's mobility and various networks' coverage but also permutation of networks. A *permutation* here is defined as an ordering of all the networks in a given area which represents these networks' priorities without considering their availability. At anytime and anywhere, the first available network in the permutation should be selected.

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

To sum up, different permutations lead to different average VHO costs, hence different total costs. Thus, when we use a ranking algorithm to select an alternative with the minimum total cost, the selected alternative is actually a permutation not a network. Therefore, the selection of the best network actually becomes the selection of the best permutation when VHO properties are considered in ranking algorithms. In a permutation-based network selection scheme, we could calculate total cost of each permutation, and compare to find the permutation with minimum total cost.

However, when the heterogeneous environment consists of n networks, the number of permutations will be the factorial of n. Thus, a large number of permutations' total costs should be calculated and compared to find the best one. Moreover, calculation of the average VHO cost of each permutation is also complicated due to irregular coverage of networks and various moving patterns of MTs.

To solve the time complexity problem of permutation-based schemes, our previous proposal [14] was to classify all the wireless networks into two groups, i.e. hotspot networks and ubiquitous networks. We modeled an MT's mobility in this 2-network environment and calculated a threshold between the two groups. When sigmoidal utility function is used to adjust attributes' normalized values, it works well to classify all the networks into the above two groups, because this function enlarges the difference of networks on its two sides. However, sigmoidal utility function is not always used. For QoS-related attributes (e.g. bandwidth), it is necessary to have a value better than a threshold, hence sigmoidal utility function is suitable; while for non-QoS-related attributes (e.g. monetary cost), sigmoidal utility function has no obvious advantage compared with linear utility function.

Mobility-related factors are non-QoS-related, so sigmoidal function might not be used for them. Hence, it is quite possible that networks are classified into more than two groups based on their mobility support capabilities. For example, a common classification of all the networks with four groups are wireless personal area network (WPAN), wireless local area network (WLAN), wireless metropolitan area network (WMAN) and wireless wide area network (WWAN). In a word, it is necessary to study the scenario when there are more than two groups of networks. Therefore, this paper discusses permutation-based network selection schemes in a generic scenario with N groups of networks.

The rest of this paper is organized as follow: in Section 2, we analyze the calculation of various permutations' total costs and provide closed-form of average VHO cost of a certain permutation in a generic scenario; then in Section 3, we present two methods to rapidly find the best permutation, which avoids the complicated calculation and comparison process of all the permutations' total costs; by simulations, we show in Section 4 that best permutation schemes have lots of advantages compared with classic best network schemes.

2. EVALUATING TOTAL COSTS OF PERMUTATIONS IN A GENERIC SCENARIO

In an HWNs with N groups of networks, an MT can be covered by any subset of these N groups. By assuming deployments of all the groups of networks are independent of one another, we could easily obtain the MT's mobility properties within these HWNs.

Figure 2 shows an MT's transitions within a single network environment. 'a' and 'd' represent separately the states that the MT is covered and uncovered by this network. U_a is the transiting-out rate from a cell of this network (i.e. $\frac{1}{U_a}$ is the mean cell residence time), and U_d is the transiting-in rate from 'd' to certain cell of the network (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 cell of this network (i.e. HHO within this network) is $(1-P)$. Q is the coverage percentage of this network.

For a generic scenario, we define a *state* as an area cov-

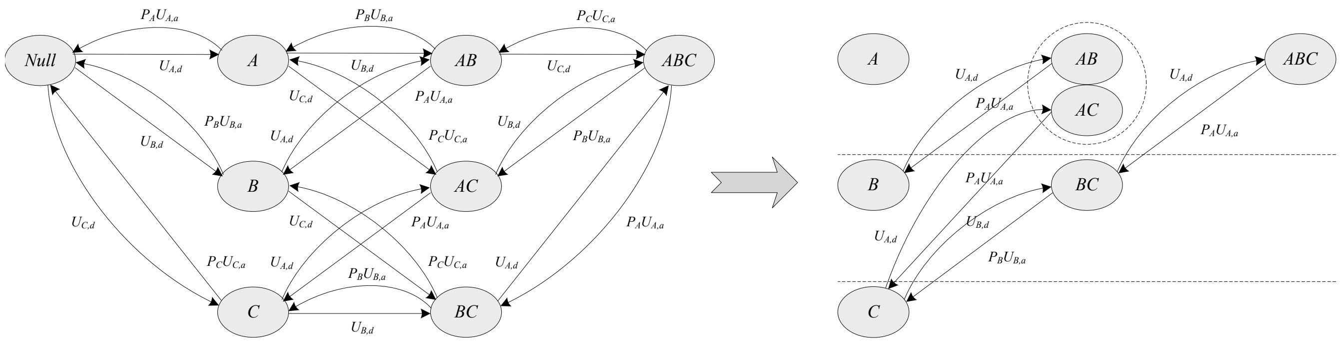


Figure 3: Transitions in a 3-network scenario.

Table 1: Symbols for A Generic Scenario

n	number of networks
N	number of groups of networks
M	number of attributes except HC
L	number of groups better than the ubiquitous
g_i	the ith group in a permutation
$U_{i,a}$	transiting-out rate from a cell of group i
$U_{i,d}$	transiting-in rate to certain cell of group i
P_i	transiting-out probability of group i
Q_i	coverage percentage of group i
r_i	cell radius of group i
hho_i	cost of HHO within group i
$vho_{i,j}$	cost of VHO from group i to group j
$v_{i,j}$	value of the jth attribute of the ith group
ω_{HC}	weight of HC
ω_i	weight of attribute i (except HC)
λ_i	arriving rate of the scheme trigger event i
μ_i	total transiting rate of group i
V	MT velocity

ered by the same groups of networks, so there are totally 2^N states for N groups of networks. Figure 3 shows transitions among the 2^3 states in the Markov chain of an HWNs with three groups of networks. Transition rates in this Markov chain are calculated based on the assumption that all networks' deployments are independent and Figure 2. Symbols used in this Markov chain and later derivations for a generic scenario are summarized in Table 1.

To calculate the average VHO cost of certain permutation, we combine the states which have both the same number of groups and the same first available group as one *big state*. Taking the scenario shown in Figure 3 as an example, state AB and state AC form a big state when permutation '$A > B > C$' is considered. Moreover, we assume a group of ubiquitous networks is always available, so the $Null$ state is eliminated. Thus, the total number of states decreases to $\frac{(N+1)N}{2}$. As shown in the right-side Markov chain of Figure 3, states in the same row have the same first available group. Thus, VHO is required when an MT transits into a state that contains a better first available group (i.e. from bottom-left to top-right) or a state that does not contain the former first available group (i.e. from top-right to bottom-left). Therefore, there is no need to consider all the transitions in the Markov chain, instead, the number of transitions leading to VHO can be decreased to $2 \cdot \sum_{j=1}^{N-1} \sum_{i=2}^{N} \left[(i-1) \cdot C_{N-i}^{j-1}\right]$. In the proposed scheme, the average VHO cost of a permutation is calculated by considering only the transitions that lead to VHOs.

Based on Figure 3, we now derive the formula of average handover cost. Handover cost is not only related with permutation, MT mobility and network coverage, but also related with mobility management strategy. However, performance evaluation of various mobility management strategies is out of the scope of this paper. Here, we only focus on transitions of an MT among HWNs, so that a generic scheme can be obtained. The derivation of the total cost of permutation '$g_1 > g_2 > ... > g_N$' is as follows:

There are two types of handovers, i.e. HHO and VHO, so the average handover cost contains both HHO and VHO costs. According to the Markov chain of Figure 2, the rate of HHO to another hotspot for group i is $Q_i(1-P_i)U_{i,a}$, so the average HHO cost in unit time can be calculated as

$$HC_{HHO} = \sum_{i=1}^{N} \Big\{ [\prod_{j=0}^{i-1}(1-Q_j)] Q_i (1-P_i) U_{i,a} \cdot hho_i \Big\}. \quad (1)$$

For VHO, when the MT moves from a state uncovered by the first i groups (i.e. $g_1, g_2, ..., g_i$) to a state covered by group i, it should handover to group i. Considering this VHO could be from any group of $(g_{i+1}, g_{i+2}, ..., g_N)$, the average cost of one VHO to group i can be expressed as

$$\begin{aligned} HC_{Single\_VHO}(i) = (1-Q_i)U_{i,d} \cdot [\prod_{j=1}^{i-1}(1-Q_j)] \cdot \\ \Big\{ vho_{i+1,i}Q_{i+1} + \sum_{k=i+2}^{N} \big[vho_{k,i} Q_k \prod_{j=i+1}^{k-1}(1-Q_j) \big] \Big\}, \end{aligned} \quad (2)$$

Thus, the average VHO cost of moving into a better group can be calculated by summing up costs of VHOs to any group of $(g_1, g_2, ..., g_{N-1})$, which can be written as

$$HC_{VHO}^{+} = \sum_{i=1}^{N-1} \Big\{ U_{i,d} \cdot \sum_{k=i+1}^{N} \big[vho_{k,i} Q_k \prod_{j=1}^{k-1}(1-Q_j) \big] \Big\}. \quad (3)$$

Similarly, the average VHO cost of moving out of the former first available group is calculated as

$$HC_{VHO}^{-} = \sum_{i=1}^{N-1} \Big\{ \frac{Q_i P_i U_{i,a}}{1-Q_i} \cdot \sum_{k=i+1}^{N} \big[vho_{i,k} Q_k \prod_{j=1}^{k-1}(1-Q_j) \big] \Big\}. \quad (4)$$

By combining (1), (3) and (4), the average handover cost is obtained as

$$HC = HC_{HHO} + HC^{+}_{VHO} + HC^{-}_{VHO}. \tag{5}$$

On the other hand, other attributes should also be evaluated. For permutation '$g_1 > g_2 > ... > g_N$', the other attributes are combined as

$$Oth = \sum_{i=1}^{N} \left[Oth_i \cdot Q_i \cdot \prod_{j=0}^{i-1}(1-Q_j)\right], \tag{6}$$

where $Oth_i = \sum_{j=1}^{M} v_{i,j}\omega_j$.

After HC and Oth are obtained as described above, the two parts of costs should be normalized and summed up. Therefore, the total cost of permutation '$g_1 > g_2 > ... > g_N$' is finally obtained as

$$TC = \widetilde{HC} \cdot \omega_{HC} + \widetilde{Oth} \cdot (1 - \omega_{HC}), \tag{7}$$

where $\widetilde{Attr}$ represents the normalized value of certain attribute or the combination of a group of attributes. The above formula uses simple additive weighting (SAW), other MADM algorithms as mentioned in the Introduction might also be utilized.

3. METHODS TO GET THE BEST PERMUTATION RAPIDLY

3.1 Simplified Besper

In classic best network schemes (*Besnets*), sorting algorithms, e.g. bubble sort, are used to get the rank of all the networks. In permutation-based scheme, it is not necessary to rank all the permutation because the best permutation is already the rank of all the groups of networks. Therefore, one basic best permutation scheme (*Basic Besper*) is to calculate total costs of all the permutations based on the results obtained in Section 2. Then, the permutation with the minimum total cost is selected as the best one. However, Basic Besper has an obvious problem, which is the time spent for all the calculations. Detailedly, when there are N groups of networks, the number of permutations is the factorial of N. Hence, Basic Besper has to calculate $N!$ permutations' total costs, and find the best one with $(N! - 1)$ pair-wise comparisons between them. This is not efficient for real-time network selection during VHOs.

Due to this reason, we propose a modified method (*Simplified Besper*) to find the best permutation in a quicker way. Since we assume the group of ubiquitous networks always exists, the first step of Simplified Besper is to decide the position of this group in the best permutation. This is achieved by comparing each non-ubiquitous group with the ubiquitous one, which has been studied in our previous work of a 2-network scenario and a threshold between the two groups was obtained [14]. For the generic scenario discussed in this paper, the threshold can be modified as

$$\theta_i = \omega_{HC}^{-1}\left(\frac{\widetilde{Oth}_{U-i}}{\widetilde{Oth}_{U-i} + \frac{Q_i hho_i + (1-Q_i)(vho_{i,U} + vho_{U,i})}{Norm}}\right), \tag{8}$$

where $\widetilde{Oth}_{U-i}$ represents the difference of all the other attributes' combinations between the ubiquitous group ($\widetilde{Oth}_U$) and group i ($\widetilde{Oth}_i$), $Norm$ is for normalization of HCs of different groups, and $\omega_{HC}(V)$ is a function of MT velocity.

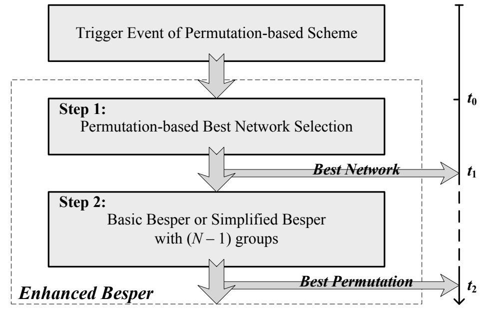


Figure 4: Procedure of Enhanced Besper.

Assuming $\omega_{HC}(V)$ is monotonically increasing, group i is found better than the ubiquitous group if V is smaller than θ_i.

By doing the above comparisons, we get L $(0 \le L \le N-1)$ groups better than the ubiquitous one, hence $(N - L - 1)$ groups worse. Due to the ubiquity of ubiquitous group, the groups worse than it has almost no opportunity to be used. Hence, the ordering of these groups is not as important as the better ones.

In the end, total costs of $L!$ permutations based on the L better groups are calculated, and the permutation with the minimum total cost will be selected.

Simplified Besper does not decrease the time complexity of Basic Besper (still $O(N!)$), but it really decreases the time cost for getting the best permutation in most scenarios. The number of permutations we need to consider decreases to $L!$, and the number of pair-wise comparisons decreases to $(L! - 1)$. Since the number of groups of networks is generally not large (e.g. four groups as WPAN, WLAN, WMAN and WWAN), this simplification is actually quite helpful to decrease the time cost.

3.2 Enhanced Besper

Compared with Basic Besper, Simplified Besper obviously decreases the time cost, but there is the possibility that its time cost is still large in some scenarios. For example, when the ubiquitous group is found to be the worst after comparisons with other groups, we still need to consider $(N - 1)!$ permutations in later calculations, which has no obvious advantage compared with the calculation of $N!$ permutations in Basic Besper. Therefore, we propose in this section a further modified method (*Enhanced Besper*) which contains two steps and is very practical for network selection with a time complexity of only $O(N)$ for getting the best group before VHO.

Step 1 : Figure 4 shows the procedure of Enhanced Besper. The first step is to find the best group by permutation-based pair-wise comparisons, which is different from Besnets because we consider VHO properties in this step.

Since we assume the deployments of networks are independent, the selection of a high rank group has nothing to do with a low rank group's coverage. By assuming that g_1 and g_2 are the best two groups, permutations '$g_1 > g_2 > g_3 > ... > g_N$' and '$g_2 > g_1 > g_3 > ... > g_N$' represent the two cases when g_1 and g_2 are the best, respectively. The ordering from g_3 to g_N is not important because they are low rank groups. Therefore, we obtain total costs of the two permutations as $TC_{g_1>g_2>g_3>...>g_N}$ and $TC_{g_2>g_1>g_3>...>g_N}$, where

TC of each permutation can be obtained based on the results in Section 2.

By comparing the two total costs above, we find the better permutation g_x of g_1 and g_2. Then, we compare g_x with g_3 by assuming g_x and g_3 are the best two groups in a similar way. Thus, we can compare through all the groups by $(N-1)$ comparisons and find the best one (g_x) at the end of Step 1.

The above procedure of Step 1 has a time complexity of $O(N)$, which is as fast as using Besnets to find the best group. However, when several groups have similar performance, it is possible that the best group got by this procedure is different from Basic Besper. Therefore, a more robust option for Step 1 is to do $N \times N$ pair-wise comparisons among all the groups, which is similar to ELECTRE [2] and has a time complexity of $O(N^2)$.

Step 2 : After Step 1, the MT performs VHO immediately. Then, Step 2 is performed to get the best permutation. We also provide two options for Step 2: a fast option is Simplified Besper; while a precise option is Basic Besper. Since the best group has been decided in Step 1, there is generally no need to consider it again in Step 2, which decreases the time cost of Step 2.

Since Enhanced Besper separates the task of getting the best permutation into two steps, it is quite suitable for practical usage. As shown in Figure 4, the scheme is triggered at t_0 and Step 1 is firstly processed. When Step 1 completes at t_1, a best group is obtained based on permutation-based pair-wise comparisons, and VHO is performed to a certain network in the best group. Then, Step 2 is processed to get the best permutation, which takes a relatively long time and ends up at t_2, but VHO is not disturbed by it.

4. PERFORMANCE EVALUATIONS

4.1 Configuration of network selection simulator

To evaluate the performance of Bespers, we establish in this section a network selection simulator, which is configured as follows:

Attributes: besides average handover cost, we also consider eight other attributes, i.e. monetary cost, bandwidth, power consumption capability, security level, bit error rate, jitter, traffic load and signal strength.

Weights: to calculate all the attributes' weights, we assume that the terminal velocity is relatively high, the power condition is good, the customer prefers low price and large bandwidth, the operator wants load balancing, application flows are streaming and conversational, etc. Based on these assumptions, AHP is used to calculate the weights [10].

Networks: for simulations of $N = 2$, the HWN environment is composed of WLAN and WWAN; for $N = 3$, of WPAN, WLAN and WWAN; for $N = 4$, of WPAN, WLAN, WMAN and WWAN.

Parameters: an $N \times (M + 1)$ value matrix is normalized and processed in our simulations. We assume firstly values of the two dynamic attributes (i.e. traffic load and signal strength) of various networks are the same, in order to focus on the effects of mobility-related factors. Secondly, $vho_{i,j}$ and hho_i are all assumed the same because the comparison of various mobility management strategies is out of the scope of this paper. Thirdly, by assuming the cells of all the networks are circular and according to fluid flow model [8], the transiting-out rate of a cell of group i is obtained as $U_{i,a} = 2V/\pi r_i$. Further assuming that the Markov chain shown in Figure 2 for each group is stationary, we get the transiting-in rate of group i as $U_{i,d} = 2Q_iV/\pi r_i$. And, coverage percentages of the four groups are assumed as 20%, 40%, 90% and 100%, respectively.

4.2 Advantages of Bespers

VHO rate and Total cost: Bespers take mobility-related factors into account, so a network is not preferred if it does not fit for the mobility requirement of MT, customer or applications. In numerous scenarios (e.g. an MT with high velocity), a network with small cells is not selected by Bespers, so the VHO rate is greatly decreased, as shown in Figure 5-b. Due to the same reason, Bespers usually have lower total cost than Besnet, as shown in Figure 5-a. Moreover, we can also see that the difference of total costs between Besper and Besnet becomes large when the weight of HC increases.

Scheme trigger rate: another important advantage of Bespers is the low trigger rate. As we know, any of the following events will trigger Besnet:

- *Event*-1: availability of one network;
- *Event*-2: parameter of terminal properties, applications, dynamic network properties or customer preferences.

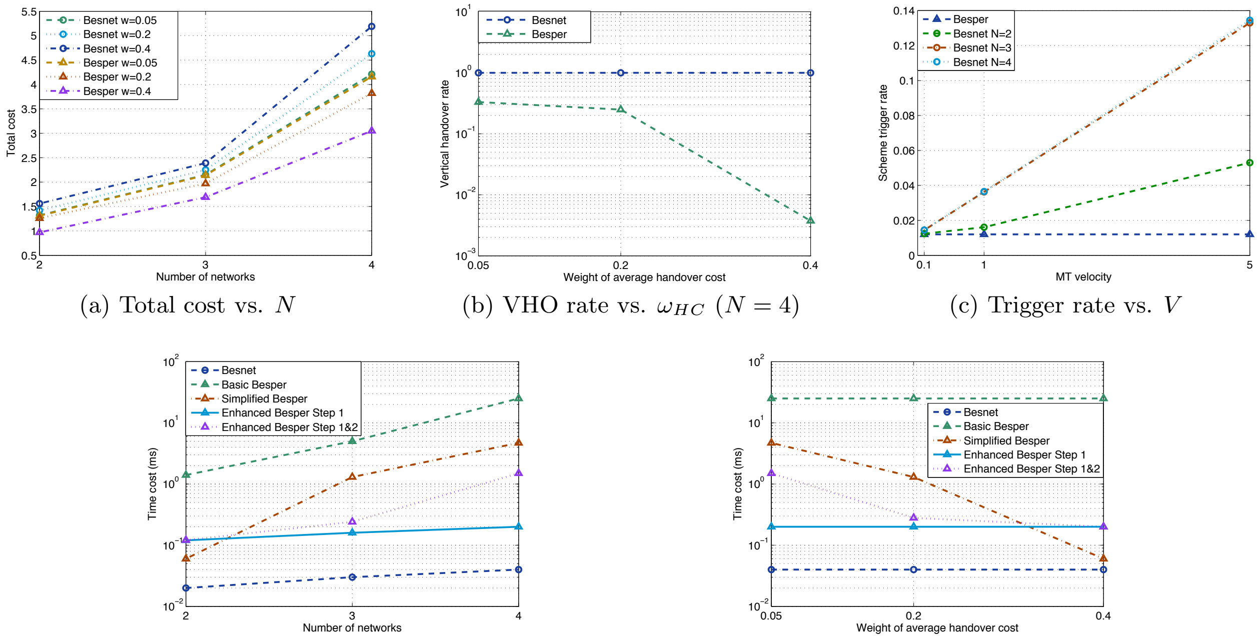
Since Bespers provide a permutation of all the groups, the first available group will be used when the MT moves across various states, e.g. states in Figure 3. Hence, the change of any network's availability will not trigger Bespers, which greatly decreases the trigger rate of the scheme (especially for high speed MTs).

Assuming the average arriving rates of Event-2 are $\lambda_1, \lambda_2, ..., \lambda_K$, respectively, the total trigger rate by Event-2 can be written as $\sum_{i=1}^{K} \lambda_i$. Total transitting rate for the ith group includes both transiting-in and -out rates which can be written as $\mu_i = Q_iP_iU_{i,a} + (1 - Q_i)U_{i,d}$ based on Figure 2. Since all the groups are assumed independent, the total trigger rate by Event-1 is $\sum_{i=1}^{N} \mu_i$.

To sum up, the trigger rate of Besnet is $\sum_{i=1}^{K} \lambda_i + \sum_{i=1}^{N} \mu_i$, while that of Besper is only $\sum_{i=1}^{K} \lambda_i$. Figure 5-c shows a comparison of trigger rates between Besnet and Besper. We can see that when the MT velocity or the number of networks is large, the trigger rate of Besper is much lower than Besnet.

Time complexity: a common problem of a permutation-based solution. As shown in Figure 5-d, the increment rate of the time cost of Basic Besper is more than exponential growth with respect to N. Seen from Figure 5-d and Figure 5-e, Simplified Besper and Enhanced Besper both have much lower time cost than Basic Besper, and the time cost for finding the best permutation decreases when the weight of HC is large. More important, time cost of Step 1 in Enhanced Besper increases linearly with respect to N, which is similar to that of Besnet. Therefore, the time complexity of permutation-based network selection schemes is not an issue any more.

Based on our simulation results, we obtain several important observations. For MTs that seldom move, Bespers and Besnets are similar; otherwise, Bespers are greatly better. For Basic Besper and Simplified Besper, networks should not be classified into too many groups; while for Enhanced Besper, the number of groups is not a problem because the time cost of its Step 1 is always small due to linear growth. Thus, instead of dividing networks into groups, we might use themselves directly in Enhanced Besper.



(a) Total cost vs. N

(b) VHO rate vs. ω_{HC} $(N = 4)$

(c) Trigger rate vs. V

(d) Time cost vs. N $(\omega_{HC} = 0.05)$

(e) Time cost vs. ω_{HC} $(N = 4)$

Figure 5: Performance comparisons between Besnet and Besper.

5. CONCLUSIONS

In this paper, we proposed a best permutation scheme (called Basic Besper) for mobility-based network selection, based on our analysis in a generic HWN environment. Two methods (i.e. Simplified Besper and Enhanced Besper) to decrease Basic Besper's processing time were also proposed. According to our performance evaluations, Bespers have numerous advantages compared with classic Besnet schemes, such as low total cost, low average VHO rate and low scheme trigger rate. Furthermore, Enhanced Besper could find the best network quite rapidly, which is important for the continuity of real-time applications during VHOs. Our near future work is to further evaluate the performance of Besper, to study its implementation and to extend it to network mobility (NEMO).

6. ACKNOWLEDGMENTS

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