

## Research Article

# A Novel PROMSIS Vertical Handoff Decision Algorithm for Heterogeneous Wireless Networks

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A novel preference ranking organization method by similarity to ideal solution (PROMSIS) vertical handoff algorithm is proposed for heterogeneous wireless networks, and its essential idea includes the preference structure of the PROMETHEE and the concept of Euclid distance of the TOPSIS. Four 3GPP defined traffic classes are considered in performance evaluation. An attribute matrix is constructed considering some major attributes. Handoff decision meeting multiattribute QoS requirement is made according to the traffic features. The weight relation of decision elements is determined with the least square (LS) approach. The final decision is made using the proposed PROMSIS algorithm based on the attribute matrix and weight vector. The simulation results have manifested that the proposed PROMSIS algorithm can provide satisfactory vertical handoff performance, and the LS-PROMSIS algorithm can be fit to the characteristics of the traffic.

## 1. Introduction

The architecture of the beyond 3rd generation (B3G) or 4th generation (4G) wireless networks aims at integrating various heterogeneous wireless access networks over an IP based backbone. To provide seamless mobility, one of the design issues is the vertical handoff support [1, 2], a multiple attributes decision subject. Since the handoff may happen in different RATs and management domains, handoff decision will depend on the combination of multiple attributes rather than a single parameter.

In general, the vertical handoff process can be divided into three main steps, namely, system discovery, handoff decision, and handoff execution. During the phase of system discovery, the networks may advertise the supported data rates and quality-of-service (QoS) parameters for different services. Because the users are mobile, the available collocated networks depend on the location of the user. The traffic load in each network may also change with time. Thus, this phase may be periodically invoked.

Various vertical handoff decision mechanisms have been proposed. In [3], a combining SINR based vertical handoff (CSVH) algorithm is proposed. It studies the combined

effects of SINR in different access networks, that is, in the source network and the equivalents in the target networks, compared with the RSS based vertical handoff algorithm. Further on, a multidimensional adaptive SINR based vertical handoff (MASVH) algorithm is proposed in [4]. In addition to the combined effects of SINR, it also takes account of the user required bandwidth, traffic cost, and resource utilization in the participating access networks. A parameter  $k$  is used in the MASVH algorithm to adjust the weight of multiple attributes. Nevertheless, no discussion elaborates on the determination of the optimal  $k$  value under different conditions, the relation between multiple attributes, the relative importance of each attribute, and the impact of system load. There are also some researchers focusing on solving the ping-pong effect. In [5], the user movement information is considered, and the residence time in a base station is estimated to avoid the unnecessary handoff.

In this paper, a novel algorithm, namely, the PROMSIS algorithm, is proposed to be applied in the vertical handoff decision technology based on the preference ranking organization method for enrichment evaluation (PROMETHEE) [6, 7] and the TOPSIS [8]. In TOPSIS, the level of the decision maker's participation is rather low in the process

of decision making, and the decision maker's preference information is not integrated into the method. So, we introduce the preference function associated with each criterion in PROMETHEE, integrate the preference structure of PROMETHEE into TOPSIS, and obtain PROMSIS as a result. The scenario analyzed is referred to in [4]. It considers multiple attributes, concluding in the combined effects of SINR in WLAN and WCDMA, the required bandwidth, service cost, and available bandwidth of the participating access networks, to make handoff decisions meeting multiattribute QoS requirement. An attribute matrix of alternative networks is established. An appropriate weight factor is assigned to each criterion to account for its importance. In the weight determining process, four 3GPP defined traffic classes [8] are considered and the least square (LS) weighted approach method [9] is adopted. Finally, how the connections are contained or rerouted is decided by the PROMSIS (or LS-PROMSIS) algorithm according to the attribute matrix and the weight vector.

## 2. PROMSIS and LS-PROMSIS Vertical Handoff Algorithm

The handoff metrics and QoS parameters are categorized into different groups (e.g., bandwidth, latency, power, price, security, reliability, availability, etc.). Some representative metrics approaches are considered in this paper.

Assuming that there are  $a$  BSs and  $b$  APs, all candidate BSs and APs for the user can be indexed by 1 to  $a + b$  in the set

$$\mathbf{P} = [\text{BS}_1, \text{BS}_2, \dots, \text{BS}_a; \text{AP}_1, \text{AP}_2, \dots, \text{AP}_b]. \quad (1)$$

For each handoff event, the best BS or AP from the candidate set  $\mathbf{P}$  for each user will be determined by the handoff algorithm considering the following criteria: SINR, the required bandwidth, traffic cost, and network available bandwidth.

*2.1. Attribute Matrix.* Let us presume  $R_{\text{AP}}$  and  $R_{\text{BS}}$  as the maximum achievable downlink data rates of WLAN and WCDMA. According to Shannon capacity, we have

$$\begin{aligned} R_{\text{AP}} &= W_{\text{AP}} \log_2 \left( 1 + \frac{\gamma_{\text{AP}}}{\Gamma_{\text{AP}}} \right), \\ R_{\text{BS}} &= W_{\text{BS}} \log_2 \left( 1 + \frac{\gamma_{\text{BS}}}{\Gamma_{\text{BS}}} \right), \end{aligned} \quad (2)$$

where  $\gamma_{\text{AP}}$  and  $\gamma_{\text{BS}}$  are the receiving SINR values from the coexisting networks. When the networks offer the same downlink data rate to the user; that is,  $R_{\text{AP}} = R_{\text{BS}}$ , we can solve the equation and get the relationship between  $\gamma_{\text{AP}}$  and  $\gamma_{\text{BS}}$  as

$$\gamma_{\text{BS}} = \Gamma_{\text{BS}} \left( \left( 1 + \frac{\gamma_{\text{AP}}}{\Gamma_{\text{AP}}} \right)^{W_{\text{AP}}/W_{\text{BS}}} - 1 \right), \quad (3)$$

where the carrier bandwidth is 22 MHz for WLAN  $W_{\text{AP}}$  and 5 MHz for WCDMA  $W_{\text{BS}}$ .  $\Gamma_{\text{AP}}$  is equal to 3 dB for WLAN, and  $\Gamma_{\text{BS}}$  is equal to 16 dB for WCDMA.

It is assumed that a BS is transmitted to merely one user via the HSDPA channel at a time, with the maximum power to achieve the optimal physical rate. The SINR  $\gamma_{\text{BS}_j,i}$  received by user  $i$  from WCDMA  $\text{BS}_j$  can be represented as

$$\gamma_{\text{BS}_j,i} = \frac{G_{\text{BS}_j,i} P_{\text{BS}_j,i}}{P_{\text{O}} + \sum_{k=1, k \neq j}^m (G_{\text{BS}_k,i} P_{\text{BS}_k,i}) + G_{\text{BS}_j,i} \alpha (P_{\text{BS}_j} - P_{\text{BS}_j,i})}, \quad (4)$$

where  $P_{\text{BS}_j}$  is the total transmitting power of  $\text{BS}_j$ ,  $P_{\text{BS}_j,i}$  is the transmitting power of  $\text{BS}_j$  to user  $i$ ,  $G_{\text{BS}_j,i}$  is the channel gain between user  $i$  and  $\text{BS}_j$ ,  $\alpha$  is the orthogonality factor equal to 0.4, and  $P_{\text{O}}$  is the thermal noise power equal to  $-99$  dBm.

For WLAN, the SINR  $\gamma_{\text{AP}_j,i}$  received by user  $i$  from WLAN  $\text{AP}_j$  can be represented as

$$\gamma_{\text{AP}_j,i} = \frac{G_{\text{AP}_j,i} P_{\text{AP}_j}}{P_{\text{B}} + \sum_{k=1, k \neq j}^n (G_{\text{AP}_k,i} P_{\text{AP}_k})}, \quad (5)$$

where  $P_{\text{AP}_j}$  is the transmitting power of  $\text{AP}_j$ ,  $G_{\text{AP}_j,i}$  is the channel gain between user  $i$  and  $\text{AP}_j$ , and  $P_{\text{B}}$  is the background noise power equal to  $-86$  dBm.

A macrocell propagation model for urban and suburban areas [3] is adopted, and for an antenna height of 15 meters the path loss is

$$\begin{aligned} \text{Path loss (dB)} &= 58.8 + 21 \log_{10}(f) \\ &+ 37.6 \log_{10}(R) + \log(F), \end{aligned} \quad (6)$$

where  $f$  is the carrier frequency (2 GHz for WCDMA and 2.4 GHz for WLAN),  $R$  is the distance in meters between the user and the BS or AP, and  $\log(F)$  is the log-normal distribution shadowing with standard deviation  $\sigma = 10$  dB.

Using (3), the SINR received from APs ( $\mathbf{S}_{\text{AP},i}$ ) is converted to the equivalent SINR ( $\mathbf{S}'_{\text{AP},i}$ ) to achieve the same data rate via BS.

The set of the SINR value  $\mathbf{S}_i$  of all BSs and APs in the candidate set  $\mathbf{P}$  for the user  $i$  can be represented by

$$\mathbf{S}_i = \mathbf{S}_{\text{BS},i} \cup \mathbf{S}'_{\text{AP},i}. \quad (7)$$

For a required bandwidth  $R_i$  for a user  $i$ , the minimum receiving SINR from BS ( $\gamma_{\text{min},i}$ ) can be calculated in Shannon equation.

Let us suppose  $\mathbf{C}$  to be the system cost vector. In order to directly associate the cost value with the SINR value, the cost per bit is converted to cost per SINR ( $\mathbf{C}_{\text{SINR}}$ ).

Let us suppose  $\mathbf{U}$  as the network available bandwidth vector represented by the available capacity of each candidate BS and AP.

Then, the attribute matrix is as follows:

$$\mathbf{R}_a = \begin{bmatrix} \mathbf{S} - \gamma_{\min} \\ 1 \\ \mathbf{C}_{\text{SINR}} \\ \mathbf{U} \end{bmatrix}^T$$

$$= \begin{matrix} & X_1 & X_2 & \cdots & X_n \\ A_1 & x_{11} & x_{12} & \cdots & x_{1n} \\ A_2 & x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \cdots & \cdots & \cdots & \cdots \\ A_m & x_{m1} & x_{m2} & \cdots & x_{mn} \end{matrix} = (x_{ij})_{m \times n}, \quad (8)$$

where  $A_1, A_2, \dots, A_m$  are feasible alternatives,  $m = a + b$ , and  $X_1, X_2, \dots, X_n$  are evaluation attributes,  $n = 3$ . Here,  $x_{ij}$  is the performance rating for alternative  $A_i$  under attribute  $X_j$ .

**2.2. Handoff Decision.** The proposed PROMSIS is also a multicriteria analysis approach, and its essence includes the preference structure of the PROMETHEE and the concept of Euclid distance of the TOPSIS. In the first place, it performs the comparison between every pair of solutions ( $a_i, a_r$ ) using a preference function  $p(d)$ , and  $d = f_j(a_i) - f_j(a_r)$  is the difference between the evaluations of two alternatives. Reference [7] contains many types of preference functions. This function  $p(d)$  reflects the preference level of  $a_i$  over  $a_r$  in the interval  $[0, 1]$ , in such a way that if  $p(d) = 0$ , then  $a_i$  is indifferent to  $a_r$ ; if  $p(d) = 1$ , then  $a_i$  is strictly preferred to  $a_r$ . PROMSIS consists of the following steps.

- (1) Construct the decision matrix  $\mathbf{R}_a$  and the weight vector  $\mathbf{w}$ .
- (2) Define the preference function for each attribute.
- (3) Define the preference index for each couple of alternatives:

$$n = V(a_i, a_r) = \sum_{j=1}^n w_j \cdot p_j(f_j(a_i) - f_j(a_r)). \quad (9)$$

The preference index is given in the intensity of preference of the decision maker for  $a_i$  over  $a_r$ . We have  $0 \leq V(a_i, a_r) \leq 1$ . The matrix  $\mathbf{V} = (v_{ir})_{m \times n}$  is obtained to calculate the weighted Euclidean distances.

- (4) The preference concept from PROMETHEE is presented as above, and now we use the concept of Euclid distance in TOPSIS to continue. Define the positive ideal point and the negative ideal point, and calculate the distance between each scheme and the positive/negative ideal point. Calculate the distance  $S_i^+$  between each scheme and the positive ideal point

and the distance  $S_i^-$  between each scheme and the negative ideal point:

$$S_i^+ = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^+)^2}, \quad i \in m, \quad (10)$$

$$S_i^- = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^-)^2}, \quad i \in m.$$

- (5) Calculate the relative approach degree  $C_i^+$  of each scheme to the ideal points:

$$C_i^+ = \frac{S_i^-}{(S_i^+ + S_i^-)}, \quad 0 < C_i^+ < 1, \quad i \in m. \quad (11)$$

- (6) Rank the schemes based on  $C_i^+$ . The larger is the  $C_i^+$ , the better is the scheme.

Above all, the proposed PROMSIS combines the qualitative and quantitative analysis. Preference comparison corresponds to the qualitative analysis. The Euclidean distance can describe the degree of preference through the quantity. So, the utility of the network can be achieved in both qualitative and quantitative aspects. And the final decision will be appropriate based on subjective and objective factors.

**2.3. Weight Vector.** There are a variety of weight methods, such as analytic hierarchy process (AHP) and the information Entropy weight method, some are subjective and others are objective. We can choose the appropriate weight method according to actual conditions. In the weight determining process, we apply the LS [9] to estimate the weights of decision elements introduced by Chu in 1979.

Firstly, the comparison matrix  $\mathbf{G}_c = (g_{ij})_{n \times n}$  is defined according to the relative importance. The judgments are ranked on a 9-point scale [7]. Numbers 1 to 9 are used to represent equal, weakly moderate, moderate, moderate plus, strong, very strong, very very strong, and extremely important to the objective, respectively. When an element is less important than another, the comparison result equals the reciprocal of one of the numbers. So for the matrix  $\mathbf{G}_c$  to be the diagonal elements are observed 1, demonstrating the elements' self-comparisons. The other entries in the matrix are symmetric with respect to the diagonal, as a result of the inverted comparisons.

Four traffic classes defined by 3GPP are taken into consideration, namely, the conversational, streaming, interactive, and background classes. Based on the traffic requirements, the comparison matrices for the four traffic classes according to the 9-point scale can be established.

The element  $g_{ij}$  of matrix  $\mathbf{G}_c$  shall be considered and desired to determine the weights  $w_i$ , such that, given  $g_{ij}$ ,  $g_{ij} \approx w_i/w_j$ .

The weights can be obtained by solving the constrained optimization problem

$$\min \mathbf{S} = \sum_{i=1}^n \sum_{j=1}^n (g_{ij}w_j - w_i)^2 \quad (12)$$

$$\text{s.t.} \quad \sum_{i=1}^n w_i = 1, \quad w_i > 0. \quad (13)$$

In order to minimize  $\mathbf{S}$ , form the sum

$$\mathbf{S}' = \sum_{i=1}^n \sum_{j=1}^n (g_{ij}w_j - w_i)^2 + 2l \sum_{i=1}^n w_i, \quad (14)$$

where  $l$  is the Lagrange multiplier. Differentiating  $\mathbf{S}'$  with respect to  $w_z$  ( $z = 1, 2, \dots, n$ ), the following set of equations is obtained:

$$\sum_{i=1}^n (g_{iz}w_z - w_i) g_{iz} - \sum_{j=1}^n (g_{zj}w_z - w_z) + l = 0. \quad (15)$$

Equations (15) and (13) form a set of  $n+1$  inhomogeneous linear equations with  $n+1$  unknowns.

By the way, using the numerical method to solve mathematical problems, due to almost inevitable rounding errors, the results obtained are generally inaccurate. Some other measures can be applied to estimate the error, but we will not go into detail here due to space limitations.

### 3. Simulation Results

In this research, we concentrate on the downlink traffic, since it normally requires higher bandwidth than uplink, especially for multimedia services such as video streaming through the HSDPA channel while connected to WCDMA.

The performance of different vertical handoff algorithms has been evaluated with the scenario illustrated in Figure 1, in which there are 7 BS and 12 AP placed at each WCDMA cell boundary. The WCDMA cell radius is 1200 meter. 200 randomly generated UEs are used inside the simulation area, whose position changes in the time interval depending on their moving speed and direction. The direction is uniformly distributed in the range of  $[0, 2\pi]$ , and the speed change rate is 5 per 100 seconds. The maximum user's moving speed is 80 km/hour. In the traffic generator module, for a mean session duration of 60 seconds and a certain given mean session arrival rate, user traffic is randomly generated with a Poisson arrival distribution. As revealed in Figure 1, the direction of the arrow represents the user's moving direction. The length of the arrow corresponds to the moving distance of the user in 20 seconds (supposing that the moving direction is fixed in the 20 seconds), so the larger one indicates the faster moving speed.

The V-shape with indifference criterion type preference function in PROMETHEE was adopted here. In case of this type, the thresholds of indifference  $q$  ( $q = 0.1$ ) and strict preference  $p$  ( $p = 0.5$ ) have to be separately selected.

The system performance for different session arrival rates is shown in Figure 2. The simulated algorithms include

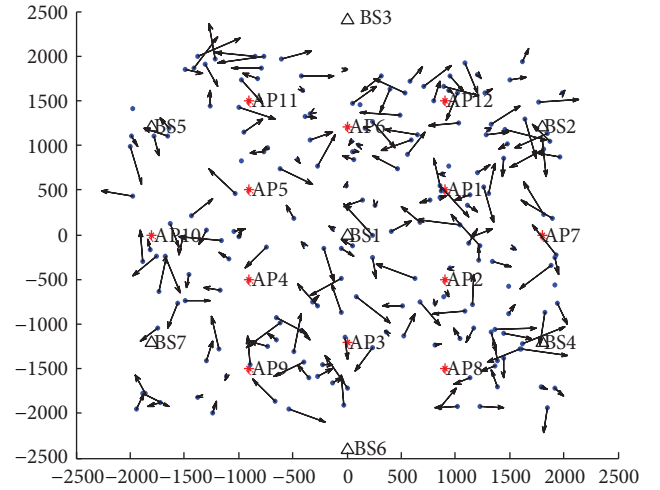


FIGURE 1: Simulation scenario.

the proposed LS-PROMSIS algorithm and the MASVH ( $k = 4$ ) algorithm [6]. The downlink system throughput of each algorithm is measured and shown in Figure 2(a). It demonstrates that the LS-PROMSIS algorithm for streaming traffic class achieves the highest throughput performance because “the available bandwidth” attribute has the greatest weight in the handoff criterion, so the network of the largest available bandwidth is selected considering the load balance. Likewise, the system dropping probability of this algorithm is the lowest. The dropping probability performance of each algorithm is exhibited in Figure 2(b). The average user traffic cost performance is presented in Figure 2(c). It is noted that the cost of the LS-PROMSIS algorithm for streaming traffic class is quite high, but the cost of the LS-PROMSIS algorithm for conversational traffic is the lowest. Since the attribute of user traffic cost covers the highest proportion in the handoff criterion, the network of the lowest cost is inclined to be selected. Figure 2(d) indicates the number of vertical handoff. It is revealed that the number of vertical handoffs of the LS-PROMSIS algorithm for streaming traffic class is the highest and that of the MASVH algorithm finishes the second. By the way, if the unnecessary handoff needs to be further decreased, the proposed MADM algorithm can be combined with the mobile prediction technique to mitigate the impact of the ping-pong effect.

### 4. Conclusions

In this paper, a novel PROMSIS vertical handoff algorithm is proposed and compared with the existing CSVH and MASVH algorithms. The vertical handoff of heterogeneous networks is a multiple attributes decision subject. With regard to the relations between all the attributes, the observed objects are the four 3GPP defined traffic classes. According to the features of diverse traffic classes, the weight of each attribute in the handoff criterion is determined by LS. The

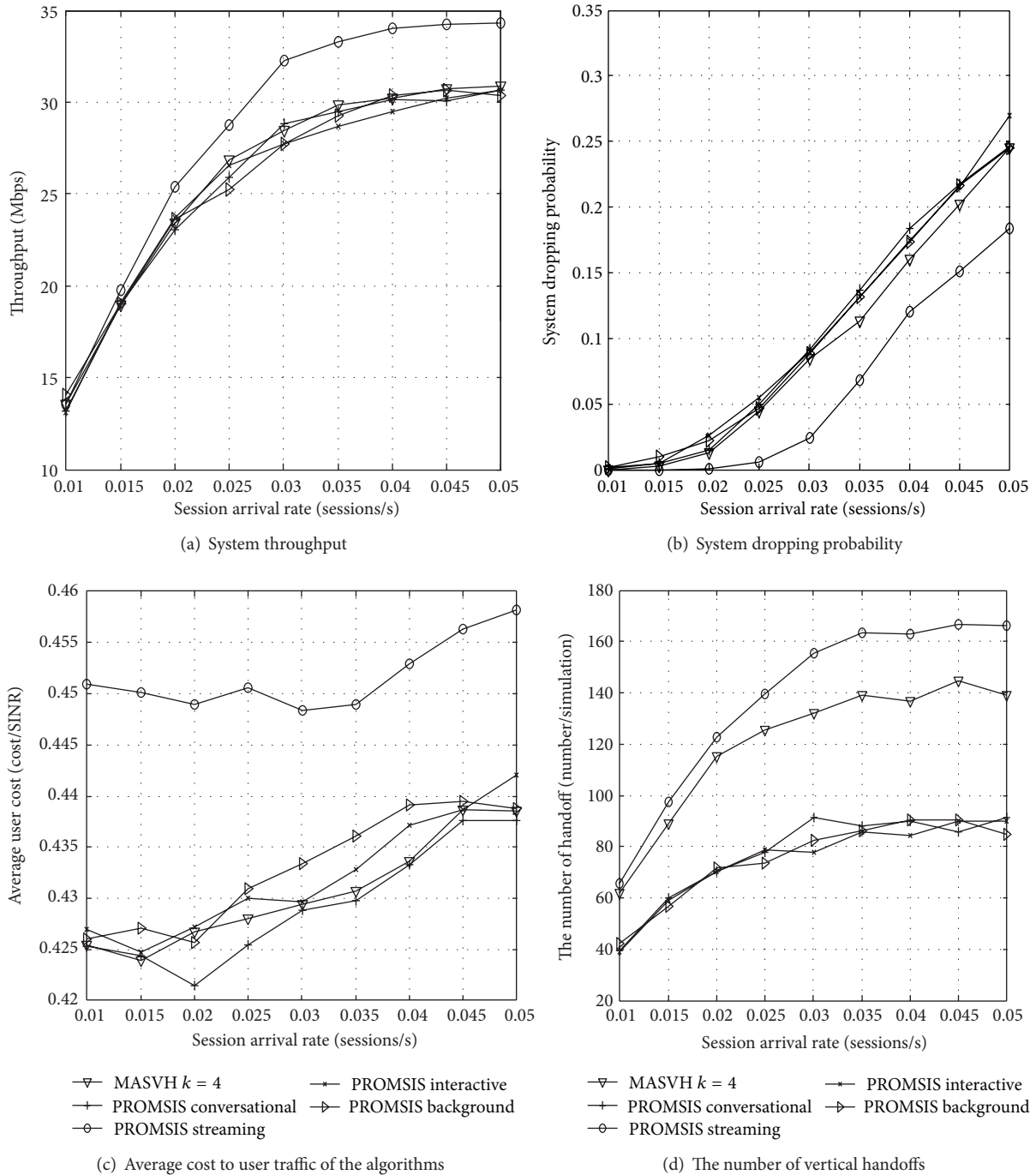


FIGURE 2: Performance of each algorithm.

simulation results display that the performance of the algorithm is affected by the allocated weight vector. Consequently in practice, we should consider both the characteristics of the traffic and the preference of the user and weigh the advantages and disadvantages before making the decision. According to the analysis and simulation results, the PROMSIS algorithm

can achieve the satisfactory performance for the network and the user.

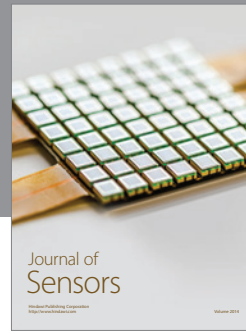
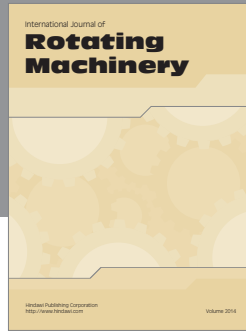
For future work, more comparisons with other vertical handoff methods will be further discussed and other techniques to solve the decision problem, such as the game theory, will also be taken into account.

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