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OWA operator based link prediction ensemble for social network

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ABSTRACT

The objective of link prediction for social network is to estimate the likelihood that a link exists between two nodes. Although there are many local information-based algorithms which have been proposed to handle this essential problem in the social network analysis, the empirical observations show that the stability of local information-based algorithm is usually very low, i.e., the variabilities of local information-based algorithms are high. Thus, motivated by obtaining a stable link predictor with low variance, this paper proposes a kind of ordered weighted averaging (OWA) operator based link prediction ensemble algorithm (LPE_{OWA}) for social network by assigning the aggregation weights for nine local information-based link prediction algorithms with three different OWA operators. The finally experimental results on benchmark social network datasets show that LPE_{OWA} obtains a more stable prediction performance and considerably improves the prediction accuracy which is measured by the area under the receiver operating characteristic curve (AUC) in comparison with nine individual prediction algorithms.
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1. Introduction

1.1. A brief review for link prediction algorithms

With the development of information technology and big data mining (Lin & Ryaboy, 2012), the social network analysis is attracting more and more attentions and becoming a research hot-spot of sociology and statistics. The social network analysis (Carrington, Scott, & Wasserman, 2005; Knoke & Yang, 2008; Soares & Prudêncio, 2013) refers to mine and discover the underlying knowledge from a social network diagram by using the mathematical and graphical techniques. The social network is represented as a graphic structure made up of a set of nodes and links, where nodes represent the individuals within network and links denote the relationships between individuals. The main studies of social network analysis include the identification of local/global patterns, location of social units, and modeling of dynamic network, etc., where the link prediction (Hasan & Zaki, 2011; Lü & Zhou, 2011) as a branch of network pattern recognition is the most fundamental and essential problem for the social network analysis.

The link prediction for social network attempts to estimate the existence likelihood s_{xy} of a link between two nodes x and y in social network. The essence of link prediction algorithm is to assign a score for the non-existent link in social network (Lü, Jin, & Zhou, 2009; Lü & Zhou, 2011; Zhou, Lü, & Zhang, 2009), where the score quantifies the existence likelihood of this non-existent link. Among all existing link prediction algorithms, similarity-based algorithm (Lü et al., 2009; Lü & Zhou, 2011) is a kind of simplest framework for the prediction of non-existent link. The score s_{xy} between nodes x and y is directly defined as the similarity between x and y. Similarity-based algorithms can further be classified into three categories: local information indices (Adamic & Adar, 2003; Jaccard, 1901; Leicht, Holme, & Newman, 2006; Lorrain & White, 1971; Ravasz, Somera, Mongru, Oltvai, & Barabási, 2002; Salton & McGill, 1983; Sørensen, 1948; Zhou et al., 2009), global information indices (Brin & Page, 1998; Chebotarev & Shamis, 1997; Fouss, Pirotte, Renders, & Saerens, 2007; Jeh & Widom, 2002; Klein & Randic, 1993; Leicht et al., 2006; Zhou, Ren, Medo, & Zhang, 2007) and quasi-local information indices (Liu & Lü, 2010; Lü et al., 2009; Zhou et al., 2009). In consideration of the simple implementation and less computational complexity, our tour of studies in this paper starts with the local information-based algorithms. There are 9 commonly-used local information-based algorithms as follows.

- Common neighbors (CN) (Lorrain & White, 1971) is the simplest and most direct method to calculate nodes' similarity. CN uses the number of common neighbors of x and y to represent the link likelihood. The more common neighbors of x and y have, the larger s_{xy} is.

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- Salton index (Salton & McGill, 1983) is also called cosine similarity, which can measure the intensive relationship between x and y with local information at a global level (Wagner & Leydesdorff, 2003).
- Jaccard index (Jaccard, 1901) is an oldest index which is defined as the size of the intersection divided by the size of the union of the sets of neighbors of x and y.
- Sørensen index (Sørensen, 1948) is proposed by Sørensen to estimate the similarity for ecological community data, which can be considered a semimetric version of the Jaccard index.
- Hub promoted index (HPI) (Ravasz et al., 2002) and Hub depressed index (HDI) (Lü & Zhou, 2011; Zhou et al., 2009) are two similarity measures which are proposed to quantify the topological overlap of substrate pairs in metabolic network. These two indices assign the lower scores for the link between nodes with high degrees.
- Leicht-Holme-Newman-I index (LHN-I) (Leicht et al., 2006) is proposed to deal with the social network in which the nodes x and y have the similiar structures with their common neighbors.
- Adamic–Adar index (AA) (Adamic & Adar, 2003) focuses on the link prediction by mining the information from links and text on a user's homepage to mailing lists the user subscribes.
- Resource allocation index (RA) (Zhou et al., 2009) proposed by Zhou, Lü, and Zhang considers the degrees of common neighbors of nodes x and y and the empirical results demonstrate that AA can obtain the better prediction performance in comparison with other 8 above-mentioned methods (Zhou et al., 2009).

In addition to similarity-based models, maximum likelihood models (Airoldi, Blei, Fienberg, & Xing, 2008; Clauset, Moore, & Newman, 2008) and probabilistic models (Getoor, 2000; Heckerman, Meek, & Koller, 2004; Yu, Chu, Yu, Tresp, & Xu, 2007) are two kinds of promising link prediction algorithms. Maximum likelihood methods calculate the scores for the non-existent links by maximizing the likelihood of observed structures which are presupposed according to some organization principles and include some necessary rules and parameters. The obvious disadvantage of maximum likelihood method is that it is very time-consuming. There are two representative maximum likelihood methods: hierarchical structure method (Clauset et al., 2008) and stochastic block method (Airoldi et al., 2008). Probabilistic models firstly learn the underlying structures from the observed networks and then predict the non-existent links with the learned structures. Three representative probabilistic models are probabilistic relational model (Getoor, 2000), probabilistic entity relationship model (Heckerman et al., 2004), and stochastic relational model (Yu et al., 2007). Here, we only give a brief introduction to the existing link prediction algorithms. For more detailed information, the audience can refer to Lü and Zhou's work (Lü & Zhou, 2011) which is a very good and valuable review to the link prediction in complex networks.

1.2. Research motivation and main contributions

The above-mentioned link prediction algorithms are all individual learning algorithms, that is to say, not the aggregation of different link prediction algorithms. So far, there are very few studies which have discussed the ensemble mechanism of link prediction algorithms. Here, the main question is whether it is necessary to study the link prediction ensemble? Although afore-mentioned local information-based algorithms are competent to obtain the acceptable prediction accuracy with low time-consumption (Lü et al., 2009; Zhao, Feng, Dong, Liang, & Xu, 2012), the empirical analysis in this study indicates that the stability of local information-based algorithm is poor, i.e., the prediction performances of local information-based algorithms vary intensively. This indicates that the variability of local information-based algorithms is high. Then, can we find some strategy to reduce the likelihood of choosing a worse link prediction algorithm and hence obtain a more stability link predictor?

As stated in Zhang and Ma (2012), ensemble learning is such a strategy which *is known to reduce the classifiers' variance and improve the decision system's robustness and accuracy*. In recent years, the studies regarding ensemble learning have obtained many satisfactorily theoretical and practical results, e.g., (Baumgartner & Serpen, 2013; Christou, Gekas, & Kyrikou, 2012; Seni & Elder, 2010; Zhang, Ling, Yang, Wang, & Li, 2012; Zhang & Ma, 2012; Zhou, 2012). The ensembles of some well-known machine learning algorithms (e.g., decision tree (Banfield, Hall, Bowyer, & Kegelmeyer, 2007), neural network (Zhou, Wu, & Tang, 2002), support vector machine (Kim, Pang, Je, Kim, & Bang, 2003), etc.) are all well and sophisticatedly studied, while the study of ensemble of link prediction algorithms is rare and fledgling. Such works could be found from the following literatures. Comar, Tan, and Jain (2011) proposed a cost-sensitive boosting based link prediction algorithm for community-level network. Pujari and Kanawati (2012a, 2012b) presented a supervised rank aggregation based link prediction for complex networks. These ensemble methods (i.e., Comar et al., 2011; Pujari & Kanawati, 2012a, 2012b) treat the link prediction as a supervised learning problem and do not construct the ensemble based on local information-based algorithms. Thus, they do not consider how to enhance the stabilities of local information-based algorithms.

Inspired by the outlook in Lü and Zhao's work (Lü & Zhou, 2011), i.e., "*we can implement many individual prediction algorithms and then try to select and organize them in a proper way. This so-called ensemble learning method can obtain better prediction performance than could be obtained from any of the individual algorithms.*", we design an ordered weighted averaging (OWA) operator (Filev & Yager, 1995, 1998; Yager, 1998) based link prediction ensemble algorithm (LPE_{OWA}) in this paper. Three different OWA operators, i.e., maximum entropy method (O'Hagan, 1988), minimum variance method (Fullér & Majlender, 2003) and chi-square method (Wang, Luo, & Liu, 2007), are respectively introduced to assign the aggregation weights for nine local information-based link prediction algorithms mentioned above. Based on the benchmark social network datasets obtained from Pajek datasets (2006), we compare the prediction performances of LPE_{OWA}s with individual link prediction algorithms, where the prediction performance is measured by the area under the receiver operating characteristic curve (AUC) (Bradley, 1997; Lü & Zhou, 2011; Zhao et al., 2012). The experimental results show that LPE_{OWA} can effectively reduce the variance of local information-based link prediction algorithm and improve the stability of link predictor. The rest of this paper is organized as follows. In Section 2, the theoretical and empirical analysis to nine local information-based link prediction algorithms are given. In Section 3, the new OWA operator based link prediction ensemble model (LPE_{OWA}) is presented. In Section 4, experimental comparisons are conducted to illustrate the feasibility of proposed ensemble model. Finally, conclusions are given in Section 5.

2. Analysis to local information-based link prediction algorithms

Before giving our description and discussion about the local information-based link prediction algorithms, we firstly provide a notation-list (Table 1) to explain the meanings of mathematical symbols applied afterwards. In this section, we firstly introduce the concepts of nine commonly used local information-based link

Table 1
The notation-list.

Notation	Meaning
$G = \langle V, E\rangle$	A social network graph
$A = (a_{xy})$	The adjacency matrix of G
V	The set of nodes in G
$E = E_{Train} \cup E_{Test}$	The set of links in G ($E_{Train} \cap E_{Test} = \emptyset$)
E_{Train}	The training set
E_{Test}	The testing set
U	The set containing all possible links of G
$E_{Predict} = U - E$	The set containing non-existent links of G
$x \in V$	A node x belonging to V
s_{xy}	The existence likelihood of link xy
$\Gamma(x)$	The set of neighbors of node x
$\|S\|$	The cardinality of set S
$k_x = \|\Gamma(x)\|$	The degree of node x

prediction algorithms and then analyze the characteristic of performance measure index-area under the receiver operating characteristic curve (AUC). Finally, the high prediction variances of local information-based link prediction algorithms are confirmed experimentally.

2.1. Nine basic algorithms

For a nonexistent link $xy \in E_{Predict}$, local information-based link prediction algorithms calculate the score s_{xy} for it to express the likelihood of its existence by considering the information of common nearest neighbors $\Gamma(x) \cap \Gamma(y)$ of nodes x and y. Fig. 1 presents an intuitive illustration on the local information-based link prediction. In fact, we can see that from Fig. 1 the local information-based link prediction algorithm takes into account all paths from x to y with two steps. There are nine frequently used local information-based link prediction algorithms as follows. Without loss of generality, we assume there is no isolated node in social network graph G for the sake of simplicity.

- Common neighbors (CN) (Lorrain & White, 1971) index is the most direct and simplest likelihood measure and defined as

$$s_{xy}^{CN} = \|\Gamma(x) \cap \Gamma(y)\|. \tag{1}$$

It is obvious that $s_{xy}^{CN} = \left(A^2\right)_{xy}$. And, s_{xy}^{CN} represents the number of paths from x to y with two steps in G. Thus, the minimum of s_{xy}^{CN} is 0, i.e., there is no any path with two steps between x and y; the maximum of s_{xy}^{CN} is $\|V\| - 2$, i.e., all the remaining nodes are served as the intermediate nodes from x and y. In summary, we get $s_{xy}^{CN} \in [0, \|V\| - 2]$.
- Salton index (Salton & McGill, 1983) considers the degrees of nodes and is defined as

$$s_{xy}^{Salton} = \frac{\|\Gamma(x) \cap \Gamma(y)\|}{\sqrt{k_x \times k_y}}. \tag{2}$$

In Eq. (2), $k_x = \|\Gamma(x)\| \in [1, \|V\| - 1]$ and $k_y = \|\Gamma(y)\| \in [1, \|V\| - 1]$. Then, $\sqrt{k_x \times k_y} \in [1, \|V\| - 1]$. Thus, $s_{xy}^{Salton} \in [0, \|V\| - 2]$.
- Jaccard index (Jaccard, 1901) is defined as

$$s_{xy}^{Jaccard} = \frac{\|\Gamma(x) \cap \Gamma(y)\|}{\|\Gamma(x) \cup \Gamma(y)\|}. \tag{3}$$

$\|\Gamma(x) \cup \Gamma(y)\| \in [1, \|V\|]$, so $s_{xy}^{Jaccard} \in [0, \|V\| - 2]$.
- Sørensen index (Sørensen, 1948) is defined as

$$s_{xy}^{Sørensen} = \frac{2\|\Gamma(x) \cap \Gamma(y)\|}{k_x + k_y}. \tag{4}$$

$k_x + k_y \in [2, 2(\|V\| - 1)]$, so $s_{xy}^{Sørensen} \in [0, \|V\| - 2]$.
- Hub promoted index (HPI) (Ravasz et al., 2002) is said to assign a higher score for link connecting to the nodes with high degrees (Zhao et al., 2012; Zhou et al., 2009) and defined as

$$s_{xy}^{HPI} = \frac{\|\Gamma(x) \cap \Gamma(y)\|}{\min\{k_x, k_y\}} \in [0, \|V\| - 2]. \tag{5}$$

- Hub depressed index (HDI) (Lü & Zhou, 2011; Zhou et al., 2009) is opposite to HPI and assigns a lower score for link connecting to the nodes with high degrees. The definition of HDI is

$$s_{xy}^{HDI} = \frac{\|\Gamma(x) \cap \Gamma(y)\|}{\max\{k_x, k_y\}} \in [0, \|V\| - 2]. \tag{6}$$

Now, we give some different understandings to the roles of HPI and HDI by analyzing the subgraphs in Figs. 2 and 3. For Fig. 2, the scores of link existence likelihoods between nodes x and y computed with HPI are $s_{x_a y_a}^{HPI} = \frac{2}{5} < s_{x_b y_b}^{HPI} = \frac{2}{3}$. And, for Fig. 3, the scores of link existence likelihoods between nodes x and y computed with HDI are $s_{x_a y_a}^{HDI} = \frac{2}{4} > s_{x_b y_b}^{HDI} = \frac{2}{6}$. By observing these results, we can find that HPI and HDI are all inclined to assign a low score for the link adjacent to the nodes with high degrees.
- Leicht–Holme–Newman-I index (LHN-I) (Leicht et al., 2006) is similar to the Salton index and defined as

$$s_{xy}^{LHN-I} = \frac{\|\Gamma(x) \cap \Gamma(y)\|}{k_x \times k_y} \in [0, \|V\| - 2]. \tag{7}$$

The main difference between Salton index and LHN-I index is the denominator of Eqs. (2) and (7): the former is $\sqrt{k_x \times k_y}$ and the latter $k_x \times k_y$. Because $k_x \times k_y \geqslant 1, k_x \times k_y \geqslant \sqrt{k_x \times k_y}$. Then, we can get $s_{xy}^{Salton} > s_{xy}^{LHNN-I}$ when $k_x \times k_y \neq 1$. That is to say, for a same link, Salton index always assigns a higher score compared with LHN-I index.
- Adamic–Adar index (AA) (Adamic & Adar, 2003) is defined as

$$s_{xy}^{AA} = \sum_{z \in \Gamma(x) \cap \Gamma(y)} \frac{1}{\log_2(k_z)}, \tag{8}$$

which considers the logarithms of degrees of common neighbors of x and y. Because $\|\Gamma(x) \cap \Gamma(y)\| \in [0, \|V\| - 2]$ and $k_z \in [2, \|V\| - 1]$, we can get $s_{xy}^{AA} \in \left[\frac{1}{\log_2(\|V\|-1)}, \|V\| - 2\right]$.

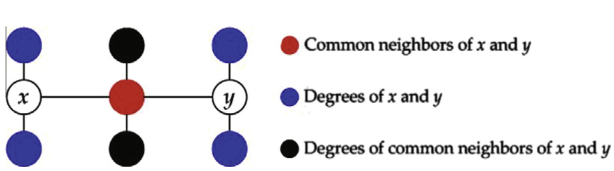
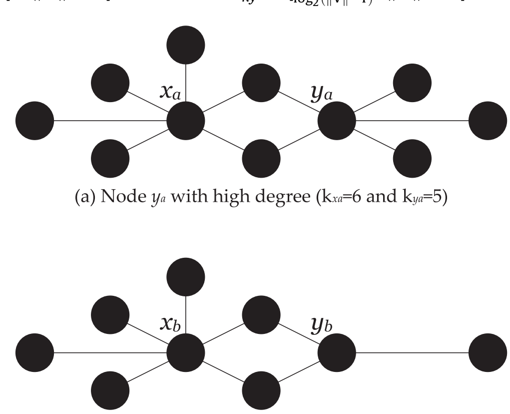
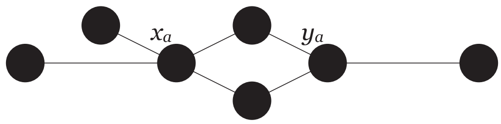


Fig. 1. Three kinds of local information.

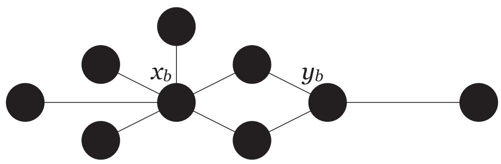


(b) Node y_b with low degree (k_{xb}=6 and k_{yb}=3)

Fig. 2. Link prediction with HPI.



(a) Node x_a with low degree (k_{xa}=4 and k_{ya}=3)



(b) Node x_b with high degree (k_{xb}=6 and k_{yb}=3)

Fig. 3. Link prediction with HDI.

- Resource allocation index (RA) (Zhou et al., 2009) is similar to AA index and defined as

$$s_{xy}^{RA} = \sum_{z \in \Gamma(x) \cap \Gamma(y)} \frac{1}{k_z} \in \left[\frac{1}{\|V\|-1}, \frac{\|V\|-2}{2}\right]. \tag{9}$$

AA and RA indices are all inclined to assign a low score for the link between x and y which have the common neighbors with high degrees. By comparing Eqs. (8) with (9), we can find $s_{xy}^{AA} > s_{xy}^{RA}$ when $\Gamma(x) \cap \Gamma(y) \neq \emptyset$.

2.2. Performance measure index-AUC

AUC (Bradley, 1997; Lü & Zhou, 2011; Zhao et al., 2012) is the prevalently used index to measure the performance of link prediction algorithm, which is defined as

$$\mathrm{AUC} = \frac{n_1 + 0.5 n_2}{n}, \tag{10}$$

where n is the number of independent comparisons including n_1 times the missing link having a higher score, n_2 times the missing link and nonexistent link having the same score, and n_3 times the missing link having a lower score, i.e., $n = n_1 + n_2 + n_3$. The missing link denotes the link in testing set E_{Test}, and nonexistent link is the link in $E_{Predict}$. AUC assumes that a good prediction algorithm is more likely to assign a higher score for the missing link compared with the nonexistent link.

Assume there are two different link prediction algorithms: AlgoA and AlgoB. If AlgoA obtains a better performance, i.e., larger AUC, than AlgoB on the same E_{Test} and $E_{Predict}$, we want to know what conclusions can be derived from the result $\mathrm{AUC}^{AlgoA} > \mathrm{AUC}^{AlgoB}$.

From the definition of Eq. (10), we know

$$\mathrm{AUC}^{AlgoA} = \frac{n_1^{AlgoA} + 0.5 n_2^{AlgoA}}{n} \tag{11}$$

and

$$\mathrm{AUC}^{AlgoB} = \frac{n_1^{AlgoB} + 0.5 n_2^{AlgoB}}{n}. \tag{12}$$

Because $\mathrm{AUC}^{AlgoA} > \mathrm{AUC}^{AlgoB}$, we can get

$$n_1^{AlgoA} - n_1^{AlgoB} > 0.5\left(n_2^{AlgoB} - n_2^{AlgoA}\right). \tag{13}$$

Case I: If $n_1^{AlgoA} - n_1^{AlgoB} = 0, n_2^{AlgoA} > n_2^{AlgoB}$ is obtained. Considering

$$n_1^{AlgoA} + n_2^{AlgoA} + n_3^{AlgoA} = n_1^{AlgoB} + n_2^{AlgoB} + n_3^{AlgoB}, \tag{14}$$

then, we get $n_3^{AlgoA} < n_3^{AlgoB}$.

Case II: If $n_1^{AlgoA} - n_1^{AlgoB} < 0, n_2^{AlgoA} > n_2^{AlgoB}$ is also obtained. By combining Eqs. (13)–(15) can be derived as

$$n_1^{AlgoA} - n_1^{AlgoB} > n_3^{AlgoA} - n_3^{AlgoB}, \tag{15}$$

i.e., $n_3^{AlgoA} < n_3^{AlgoB}$.

Case III-1: If $n_1^{AlgoA} - n_1^{AlgoB} > 0$ and $n_2^{AlgoA} = n_2^{AlgoB}, n_3^{AlgoA} < n_3^{AlgoB}$ certainly holds.

Case III-2: If $n_1^{AlgoA} - n_1^{AlgoB} > 0$ and $n_2^{AlgoA} > n_2^{AlgoB}, n_3^{AlgoA} < n_3^{AlgoB}$ certainly holds.

Case III-3: If $n_1^{AlgoA} - n_1^{AlgoB} > 0$ and $n_2^{AlgoA} < n_2^{AlgoB}$, the relationship between n_3^{AlgoA} and n_3^{AlgoB} is undefined.

These analytical results have been summarized in Table 2. As mentioned above, a better link prediction algorithm is assumed to assign a high score for the missing link in E_{Test} more easily. Thus, we think that the Case I and Case II are inadvisable for $\mathrm{AUC}^{AlgoA} > \mathrm{AUC}^{AlgoB}$, because $n_1^{AlgoA} = n_1^{AlgoB}$ and $n_1^{AlgoA} < n_1^{AlgoB}$ all deviate from the previous assumption. This deduction can be demonstrated by the following experimental results and analysis.

2.3. High prediction variance

In this section, we study the prediction variances of these nine local information-based link prediction algorithms. We select four benchmark social networks (Pajek datasets, 2006) as shown in Figs. 4–7 for our experimental datasets: World Soccer Data Paris 1998-WSDP98, Food Webs-ChesLower, and Graph Drawing Contests Data-C96 and B97. The detailed descriptions of these four networks are listed in Table 3, where $\langle k \rangle$ is the average degree of network and $E(G)$ is the network efficiency (Latora & Marchiori, 2001) which measures the capability of information exchange with this network. The definition of $E(G)$ is as follows:

$$E(G) = \frac{2}{\|V\|(\|V\|-1)} \sum_{x,y \in V} \frac{1}{d_{xy}}, \tag{16}$$

where d_{xy} is the shortest path between nodes x and y. Compared with WSDP98 and C96, we find that Cheslower and B97 are the more efficient networks. That is to say, the information can be exchanged more efficiently via the networks of Cheslower and B97.

The 10-fold cross-validation is used to test the AUC of link prediction algorithm. Firstly, the set E including all the existing links is randomly and averagely divided into 10 disjointed subsets (folds): $E = E_1 \cup E_2 \cup \cdots \cup E_{10}$ and $E_1 \cap E_2 \cap \cdots \cap E_{10} = \emptyset$. Then, we select the subset E_i $(1 \leqslant i \leqslant 10)$ as testing set E_{test} in sequence, the link in which is called missing link. Based on the E_{test}=E_i and $\|U - E\|$, AUC_i in Eq. (10) is calculated for ith fold dataset. Finally, 10 AUCs on 10 folds are averaged as the evaluation result of link prediction algorithm. The detailed experimental results on these 4 networks are summarized in Tables 4–7 respectively. By observing the results in Tables 4–7, we can get the following conclusions:

- AA and RA obtain the higher AUCs, CN the medium AUC and other 6 methods the lower AUCs. From Eqs. (1)–(9), we know that AA and RA consider the degrees of common neighbors of x and y (Black nodes in the second column of Fig. 1), CN considers the number of common neighbors of x and y (Red node in the second column of Fig. 1), and other methods consider the number of common neighbors of x and y and the degrees of x and y (Blue nodes in the first and third columns of Fig. 1) synchronously (The item $\|\Gamma(x) \cup \Gamma(y)\|$ in Jaccard index equals to $k_x + k_y$ when there are no common neighbors for x and y).
- For 2 different prediction algorithms AlgoA and AlgoB, if $\mathrm{AUC}^{AlgoA} > \mathrm{AUC}^{AlgoB}$, we can get $n_1^{AlgoA} > n_1^{AlgoB}$. For example, $\mathrm{AUC}^{AA} > \mathrm{AUC}^{CN}$ holds for the 4 aforementioned networks, then, we can find

Table 2
The derived results from $AUC^{AlgoA} > AUC^{AlgoB}$.

	Missing link having higher score	Missing link and nonexistent link having same score	Missing link having lower score
Case I	$n_1^{AlgoA} = n_1^{AlgoB}$	$n_2^{AlgoA} > n_2^{AlgoB}$	$n_3^{AlgoA} < n_3^{AlgoB}$
Case II	$n_1^{AlgoA} < n_1^{AlgoB}$	$n_2^{AlgoA} > n_2^{AlgoB}$	$n_3^{AlgoA} < n_3^{AlgoB}$
Case III-1	$n_1^{AlgoA} > n_1^{AlgoB}$	$n_2^{AlgoA} = n_2^{AlgoB}$	$n_3^{AlgoA} < n_3^{AlgoB}$
Case III-2	$n_1^{AlgoA} > n_1^{AlgoB}$	$n_2^{AlgoA} > n_2^{AlgoB}$	$n_3^{AlgoA} < n_3^{AlgoB}$
Case III-3	$n_1^{AlgoA} > n_1^{AlgoB}$	$n_2^{AlgoA} < n_2^{AlgoB}$	$n_3^{AlgoA} > n_3^{AlgoB}$ or $n_3^{AlgoA} = n_3^{AlgoB}$ or $n_3^{AlgoA} < n_3^{AlgoB}$

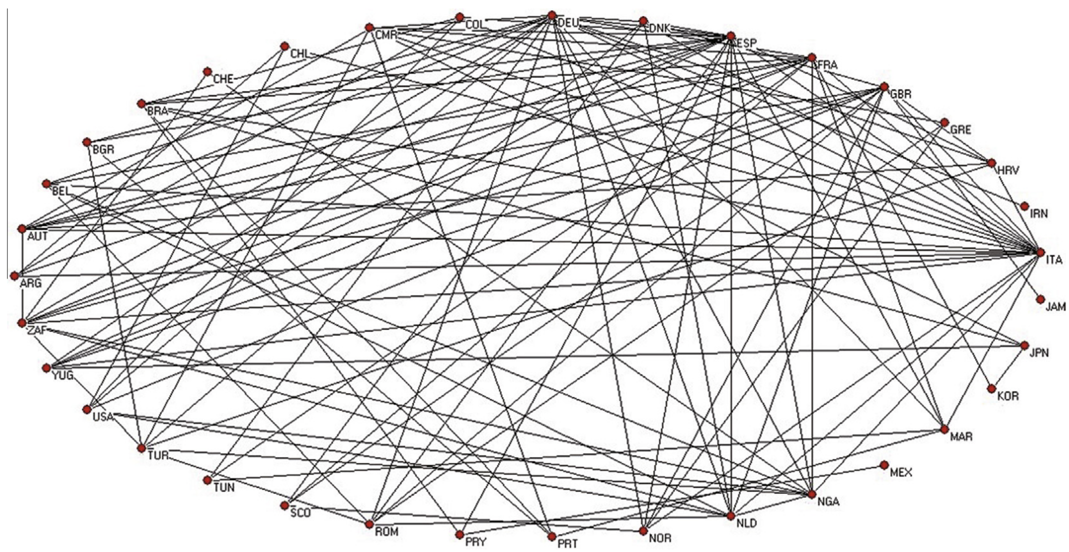


Fig. 4. Network of World Soccer Data Paris 1998-WSDP98.

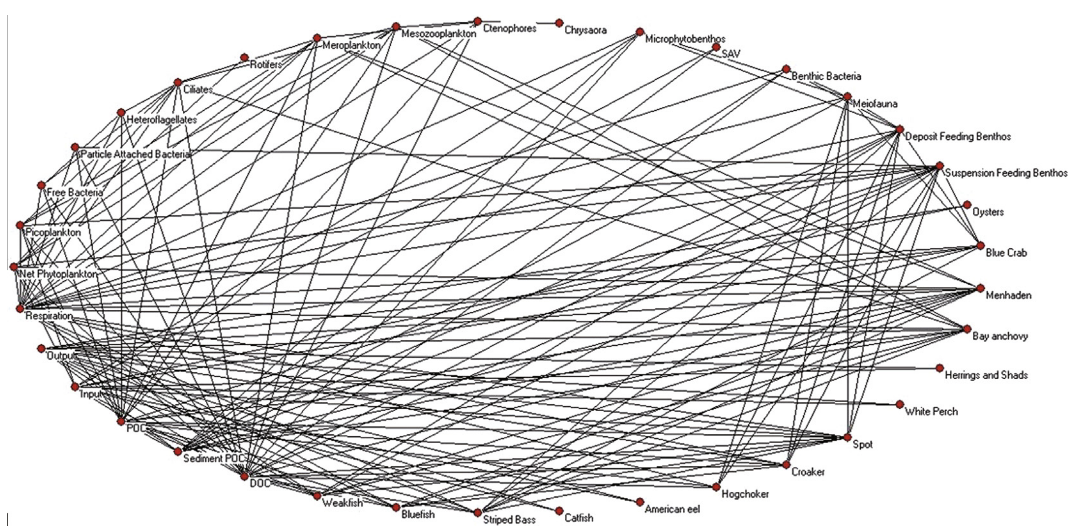


Fig. 5. Network of Food Webs-ChesLower.

$$n_1^{AA}(\mathrm{WSDP98}) = 3599 > n_1^{CN}(\mathrm{WSDP98}) = 3345,$$

$$n_1^{AA}(\mathrm{ChesLower}) = 6038 > n_1^{CN}(\mathrm{ChesLower}) = 5424,$$

$$n_1^{AA}(\mathrm{C96}) = 10,510 > n_1^{CN}(\mathrm{C96}) = 10,200$$

and

$$n_1^{AA}(\mathrm{B97}) = 19,998 > n_1^{CN}(\mathrm{B97}) = 17,399,$$

respectively. This empirical conclusion also reflects that increasing the number of missing links having higher scores is the key of improving the performance of link prediction algorithm from another perspective.

- The variability of local information-based link prediction algorithms are high. We can find that the prediction performances of different algorithms are varying dramatically. At least, this point is demonstrated on the 4 employed networks, of which

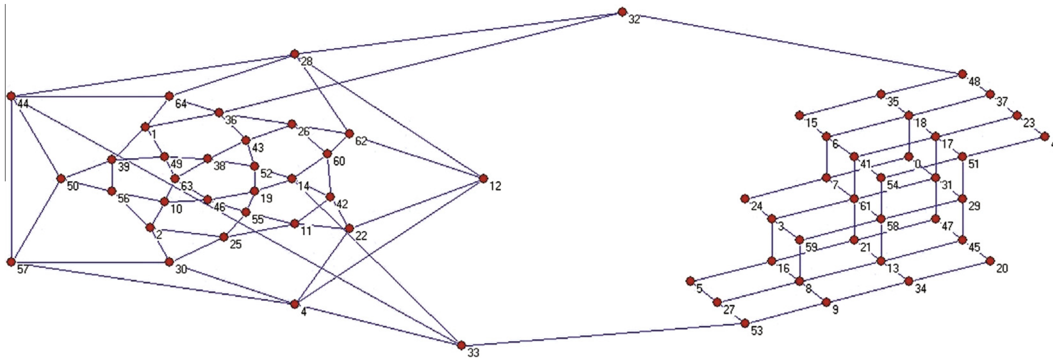


Fig. 6. Network of Graph Drawing Contests Data-C96.

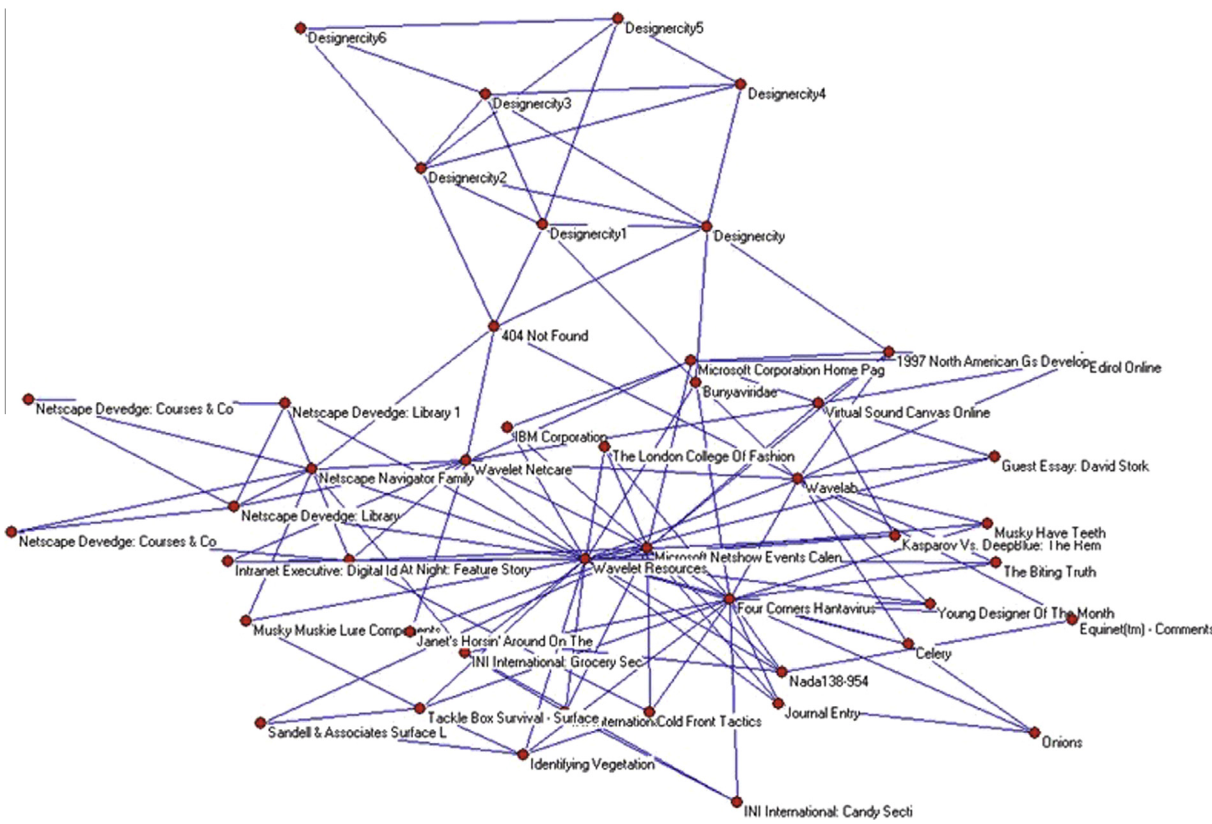


Fig. 7. Network of Graph Drawing Contests Data-B97.

Table 3
The detailed information regarding 4 networks.

Network	$\|V\|$	$\|E\|$	$\|U-E\|$	$\langle k\rangle = 2\frac{\|E\|}{\|V\|}$	$E(G)$
WSDP98	35	118	477	6.7429	0.6149
ChesLower	37	167	499	9.0270	0.6561
C96	65	125	1955	3.8462	0.5258
B97	46	264	903	11.4783	0.6469

the network efficiency is ranged from 0.5258 to 0.6561. Especially for the networks with higher efficiency, e.g., Cheslower and B97, this kind of variability is particularly outstanding.

From the foregoing analysis, we can find that (1) not any link prediction algorithm mentioned in Section 2.1 can consider the degrees of x and y, the common neighbors of x and y, and the degrees of common neighbors of x and y simultaneously; and (2) the link prediction algorithm is unstable and has high prediction variance. This may limit the prediction performances of local information-based link prediction algorithms to a certain degree.

3. Ordered weighted averaging (OWA) operator based link prediction ensemble

In this section, we firstly introduce the basic concept of OWA operator and then give an ensemble based link prediction algorithm (LPE_{OWA}) which relies on the OWA operator to aggregate 9 above-mentioned individual local information-based link prediction algorithms.

3.1. OWA operator

OWA operator (Yager, 1998) was firstly introduced by Yager and is a mostly used information aggregation technique. The

Table 4
Prediction performances of nine algorithms on the network of World Soccer Data Paris 1998-WSDP98.

	Fold 1	Fold 2	Fold 3	Fold 4	Fold 5	Fold 6	Fold 7	Fold 8	Fold 9	Fold 10	Average
CN	[3129 1018 1577 0.6356]	[2733 1155 1836 0.5784]	[3449 862 1413 0.6778]	[4151 656 917 0.7825]	[4229 629 866 0.7938]	[3351 921 1452 0.6659]	[3184 990 1550 0.6427]	[3763 779 1182 0.7255]	[3067 827 1353 0.6633]	[2397 1078 1772 0.5596]	[3345 892 1392 0.6725±0.0060]
Salton	[2626 346 2752 0.4890]	[2217 513 2994 0.4321]	[2959 509 2256 0.5614]	[3586 199 1939 0.6439]	[4096 17 1611 0.7171]	[2718 548 2458 0.5227]	[2856 381 2487 0.5322]	[3511 368 1845 0.6455]	[2550 525 2172 0.5360]	[2088 693 2466 0.4640]	[2921 410 2298 0.5544±0.0080]
Jaccard	[2694 356 2674 0.5017]	[2299 577 2848 0.4520]	[2988 520 2216 0.5674]	[3737 255 1732 0.6751]	[4179 53 1492 0.7347]	[2761 557 2406 0.5310]	[2997 438 2289 0.5618]	[3532 400 1792 0.6520]	[2552 560 2135 0.5397]	[2057 728 2462 0.4614]	[2980 444 2205 0.5677±0.0086]
Sørensen	[2694 356 2674 0.5017]	[2299 577 2848 0.4520]	[2988 520 2216 0.5674]	[3737 255 1732 0.6751]	[4179 53 1492 0.7347]	[2761 557 2406 0.5310]	[2997 438 2289 0.5618]	[3532 400 1792 0.6520]	[2552 560 2135 0.5397]	[2057 728 2462 0.4614]	[2980 444 2205 0.5677±0.0086]
HPI	[2586 657 2481 0.5092]	[2181 739 2804 0.4456]	[2803 571 2350 0.5396]	[3182 468 2074 0.5968]	[3537 351 1836 0.6486]	[2528 815 2381 0.5128]	[2703 682 2339 0.5318]	[3238 571 1915 0.6156]	[2477 736 2034 0.5422]	[2150 937 2160 0.4990]	[2739 653 2237 0.5441±0.0037]
HDI	[2624 391 2709 0.4926]	[2345 606 2773 0.4626]	[2887 556 2281 0.5529]	[3765 322 1637 0.6859]	[4187 123 1414 0.7422]	[2768 643 2313 0.5397]	[2969 529 2226 0.5649]	[3492 469 1763 0.6510]	[2517 539 2191 0.5311]	[1975 723 2549 0.4453]	[2953 490 2186 0.5668±0.0095]
LHN-I	[1937 361 3426 0.3699]	[1768 527 3429 0.3549]	[1853 523 3348 0.3694]	[2661 242 2821 0.4860]	[3305 80 2339 0.5844]	[1847 546 3331 0.3704]	[2221 408 3095 0.4237]	[2627 396 2701 0.4935]	[1703 523 3021 0.3744]	[1606 721 2920 0.3748]	[2153 433 3043 0.4201±0.0059]
AA	[3359 402 1963 0.6219]	[3182 522 2020 0.6015]	[3555 573 1596 0.6711]	[4344 248 1132 0.7806]	[4507 81 1136 0.7945]	[3664 517 1543 0.6853]	[3543 393 1788 0.6533]	[3951 366 1407 0.7222]	[3287 515 1445 0.6755]	[2596 729 1922 0.5642]	[3599 435 1595 0.6770±0.0054]
RA	[3224 402 2098 0.5984]	[3218 522 1984 0.6078]	[3538 573 1613 0.6682]	[4254 248 1222 0.7648]	[4425 81 1218 0.7801]	[3706 518 1500 0.6927]	[3510 393 1821 0.6475]	[3870 367 1487 0.7082]	[3303 516 1428 0.6787]	[2594 729 1924 0.5638]	[3564 435 1630 0.6710±0.0049]

Note: The quadruple denotes [n_1 n_2 n_3 AUC].

Table 5
Prediction performances of nine algorithms on the network of Food Webs-ChesLower.

	Fold 1	Fold 2	Fold 3	Fold 4	Fold 5	Fold 6	Fold 7	Fold 8	Fold 9	Fold 10	Average
CN	[6310 660 1513 0.7827]	[4900 877 2706 0.6293]	[6045 939 1499 0.7679]	[5277 840 2366 0.6716]	[5911 708 1864 0.7385]	[5482 943 2058 0.7018]	[5442 1003 2038 0.7006]	[5311 1007 1666 0.7283]	[4980 833 2171 0.6759]	[4581 853 2550 0.6272]	[5424 866 2043 0.7024±0.0028]
Salton	[4591 30 3862 0.5430]	[3858 55 4570 0.4580]	[4549 23 3911 0.5376]	[3944 50 4489 0.4679]	[4286 56 4141 0.5085]	[3692 13 4778 0.4360]	[3522 21 4940 0.4164]	[4382 40 3562 0.5514]	[3837 27 4120 0.4823]	[3383 23 4578 0.4252]	[4004 34 4295 0.4826±0.0025]
Jaccard	[4626 227 3630 0.5587]	[3971 154 4358 0.4772]	[4441 166 3876 0.5333]	[3622 178 4683 0.4375]	[4334 110 4039 0.5174]	[3486 129 4868 0.4185]	[3292 142 5049 0.3964]	[4357 131 3496 0.5539]	[3785 105 4094 0.4806]	[3278 81 4625 0.4156]	[3919 142 4272 0.4789±0.0036]
Sørensen	[4626 227 3630 0.5587]	[3971 154 4358 0.4772]	[4441 166 3876 0.5333]	[3622 178 4683 0.4375]	[4334 110 4039 0.5174]	[3486 129 4868 0.4185]	[3292 142 5049 0.3964]	[4357 131 3496 0.5539]	[3785 105 4094 0.4806]	[3278 81 4625 0.4156]	[3919 142 4272 0.4789±0.0036]
HPI	[3745 550 4188 0.4739]	[2884 370 5229 0.3618]	[4438 620 3425 0.5597]	[4501 482 3500 0.5590]	[3570 771 4142 0.4663]	[3614 403 4466 0.4498]	[4036 536 3911 0.5074]	[4087 670 3227 0.5539]	[3451 503 4030 0.4637]	[3272 404 4308 0.4351]	[3760 531 4043 0.4831±0.0040]
HDI	[4743 214 3526 0.5717]	[4254 204 4025 0.5135]	[4383 174 3926 0.5269]	[3400 115 4968 0.4076]	[4431 145 3907 0.5309]	[3557 55 4871 0.4226]	[3187 207 5089 0.3879]	[4238 163 3583 0.5410]	[3738 122 4124 0.4758]	[3286 83 4615 0.4168]	[3922 148 4263 0.4795±0.0043]
LHN-I	[1601 89 6793 0.1940]	[2083 82 6318 0.2504]	[1980 103 6400 0.2395]	[1557 121 6805 0.1907]	[1943 89 6451 0.2343]	[1368 61 7054 0.1649]	[1324 95 7064 0.1617]	[1908 139 5937 0.2477]	[1548 68 6368 0.1981]	[1133 31 6820 0.1439]	[1645 88 6601 0.2025±0.0015]
AA	[6855 5 1623 0.8084]	[5589 40 2854 0.6612]	[6478 247 1758 0.7782]	[5896 153 2434 0.7041]	[6491 31 1961 0.7670]	[6222 52 2209 0.7365]	[6238 81 2164 0.7401]	[5986 98 1900 0.7559]	[5499 112 2373 0.6958]	[5130 100 2754 0.6488]	[6038 92 2203 0.7296±0.0026]
RA	[6992 5 1486 0.8245]	[5643 40 2800 0.6676]	[6676 247 1560 0.8015]	[6001 153 2329 0.7164]	[6482 31 1970 0.7659]	[6241 52 2190 0.7388]	[6243 81 2159 0.7407]	[6041 98 1845 0.7628]	[5528 112 2344 0.6994]	[5220 100 2664 0.6601]	[6107 92 2135 0.7378±0.0029]

n-dimensional OWA operator is a mapping $\mathrm{F}:\Re^n\rightarrow\Re$ with an associated weight vector $\mathbf{w}=(w_1,w_2,\ldots,w_n)$ such that

$$\sum_{i=1}^{n} w_i = 1, w_i \in [0,1],\ i=1,2,\ldots,n \tag{17}$$

and

$$\mathrm{F}(a_1,a_2,\ldots,a_n)=\sum_{i=1}^{n} w_i b_i, \tag{18}$$

where b_i is the ith largest value of $a_1,a_2,\ldots,a_n$. The important issue of applying OWA operator is to determine the weight vector $\mathbf{w}$ of OWA operator.

In order to select the weight vector $\mathbf{w}$, two important measures Disp($\mathbf{w}$) and orness($\mathbf{w}$) are defined, where Disp($\mathbf{w}$) measures the degree to which all the aggregates are equally used and orness($\mathbf{w}$) measures the degree to which the aggregation is like an *or* operation. Based on the different designs of Disp($\mathbf{w}$), three commonly used methods for determining the weight vector of OWA operator can be found from the literatures.

Table 6
Prediction performances of nine algorithms on the network of Graph Drawing Contests Data-C96.

	Fold 1	Fold 2	Fold 3	Fold 4	Fold 5	Fold 6	Fold 7	Fold 8	Fold 9	Fold 10	Average
CN	[11900 11537 1978 0.6952]	[8500 14555 2360 0.6208]	[10200 13046 2169 0.6580]	[10200 13046 2169 0.6580]	[10200 13046 2169 0.6580]	[8500 12855 2105 0.6363]	[11900 9837 1723 0.7169]	[8500 12855 2105 0.6363]	[13600 8328 1532 0.7572]	[8500 12855 2105 0.6363]	[10200 12196 2042 0.6673±0.0018]
Salton	[12150 10819 2446 0.6909]	[8594 13905 2916 0.6117]	[10409 12422 2584 0.6539]	[10368 12329 2718 0.6505]	[10409 12422 2584 0.6539]	[8631 12265 2564 0.6293]	[12076 8999 2385 0.7065]	[8631 12265 2564 0.6293]	[13891 7516 2053 0.7523]	[8594 12205 2661 0.6264]	[10375 11515 2548 0.6605±0.0019]
Jaccard	[12150 10891 2374 0.6923]	[8594 13929 2892 0.6122]	[10409 12482 2524 0.6551]	[10368 12377 2670 0.6514]	[10409 12482 2524 0.6551]	[8631 12301 2528 0.6301]	[12076 9047 2337 0.7076]	[8631 12301 2528 0.6301]	[13891 7600 1969 0.7541]	[8594 12229 2637 0.6270]	[10375 11564 2498 0.6615±0.0019]
Sørensen	[12150 10891 2374 0.6923]	[8594 13929 2892 0.6122]	[10409 12482 2524 0.6551]	[10368 12377 2670 0.6514]	[10409 12482 2524 0.6551]	[8631 12301 2528 0.6301]	[12076 9047 2337 0.7076]	[8631 12301 2528 0.6301]	[13891 7600 1969 0.7541]	[8594 12229 2637 0.6270]	[10375 11564 2498 0.6615±0.0019]
HPI	[11928 11138 2349 0.6885]	[8520 14270 2625 0.6160]	[10224 12704 2487 0.6522]	[10220 12574 2621 0.6495]	[10224 12704 2487 0.6522]	[8520 12570 2370 0.6311]	[11928 9438 2094 0.7096]	[8520 12570 2370 0.6311]	[13632 7872 1956 0.7488]	[8520 12570 2370 0.6311]	[10224 11841 2373 0.6610±0.0018]
HDI	[12218 10973 2224 0.6966]	[8606 13999 2810 0.6140]	[10465 12553 2397 0.6587]	[10412 12486 2517 0.6553]	[10465 12553 2397 0.6587]	[8659 12366 2435 0.6327]	[12112 9139 2209 0.7111]	[8659 12366 2435 0.6327]	[13971 7693 1796 0.7595]	[8606 12299 2555 0.6290]	[10417 11643 2378 0.6648±0.0020]
LHN-I	[12150 10819 2446 0.6909]	[8594 13905 2916 0.6117]	[10409 12422 2584 0.6539]	[10368 12329 2718 0.6505]	[10409 12422 2584 0.6539]	[8631 12265 2564 0.6293]	[12076 8999 2385 0.7065]	[8631 12265 2564 0.6293]	[13891 7516 2053 0.7523]	[8594 12205 2661 0.6264]	[10375 11515 2548 0.6605±0.0019]
AA	[12215 10902 2298 0.6951]	[8693 14066 2656 0.6188]	[10510 12546 2359 0.6604]	[10510 12546 2359 0.6604]	[10566 12608 2241 0.6638]	[8805 12490 2165 0.6415]	[12271 9264 1925 0.7205]	[8749 12428 2283 0.6378]	[14032 7682 1746 0.7618]	[8749 12428 2283 0.6378]	[10510 11696 2232 0.6698±0.0019]
RA	[12215 10902 2298 0.6951]	[8693 14066 2656 0.6188]	[10510 12546 2359 0.6604]	[10510 12546 2359 0.6604]	[10566 12608 2241 0.6638]	[8805 12490 2165 0.6415]	[12271 9264 1925 0.7205]	[8749 12428 2283 0.6378]	[14032 7682 1746 0.7618]	[8749 12428 2283 0.6378]	[10510 11696 2232 0.6698±0.0019]

Table 7
Prediction performances of nine algorithms on the network of Graph Drawing Contests Data-B97.

	Fold 1	Fold 2	Fold 3	Fold 4	Fold 5	Fold 6	Fold 7	Fold 8	Fold 9	Fold 10	Average
CN	[19232 3378 1771 0.8581]	[17312 4318 2751 0.7986]	[17147 4372 2862 0.7930]	[17597 4200 2584 0.8079]	[17754 3789 1935 0.8369]	[16973 4151 2354 0.8113]	[17304 3961 2213 0.8214]	[17866 3482 2130 0.8351]	[16617 4140 2721 0.7959]	[16190 4631 2657 0.7882]	[17399 4042 2398 0.8146±0.0005]
Salton	[17989 610 5782 0.7503]	[17122 329 6930 0.7090]	[16694 590 7097 0.6968]	[16575 612 7194 0.6924]	[17803 212 5463 0.7628]	[15560 265 7653 0.6684]	[16895 161 6422 0.7230]	[16434 577 6467 0.7123]	[15095 955 7428 0.6633]	[15839 367 7272 0.6824]	[16601 468 6771 0.7061±0.0011]
Jaccard	[16913 715 6753 0.7084]	[16710 514 7157 0.6959]	[16249 833 7299 0.6835]	[15836 686 7859 0.6636]	[17464 481 5533 0.7541]	[14657 300 8521 0.6307]	[16081 319 7078 0.6917]	[16120 770 6588 0.7030]	[14395 1206 7877 0.6388]	[15163 574 7741 0.6581]	[15959 640 7241 0.6828±0.0013]
Sørensen	[16913 715 6753 0.7084]	[16710 514 7157 0.6959]	[16249 833 7299 0.6835]	[15836 686 7859 0.6636]	[17464 481 5533 0.7541]	[14657 300 8521 0.6307]	[16081 319 7078 0.6917]	[16120 770 6588 0.7030]	[14395 1206 7877 0.6388]	[15163 574 7741 0.6581]	[15959 640 7241 0.6828±0.0013]
HPI	[19350 1878 3153 0.8322]	[17551 2410 4420 0.7693]	[17574 2138 4669 0.7647]	[18052 2104 4225 0.7836]	[17499 2270 3709 0.7937]	[17253 2261 3964 0.7830]	[17849 1812 3817 0.7988]	[16418 1820 5240 0.7381]	[16088 2635 4755 0.7414]	[16780 2416 4282 0.7662]	[17441 2174 4223 0.7771±0.0008]
HDI	[16215 798 7368 0.6814]	[16333 527 7521 0.6807]	[15854 894 7633 0.6686]	[14978 1034 8369 0.6355]	[16984 487 6007 0.7338]	[13937 447 9094 0.6031]	[15088 713 7677 0.6578]	[16143 711 6624 0.7027]	[14087 1140 8251 0.6243]	[14947 607 7924 0.6496]	[15457 736 7647 0.6638±0.0015]
LHN-I	[15403 604 8374 0.6441]	[15306 428 8647 0.6366]	[14875 631 8875 0.6230]	[14428 704 9249 0.6062]	[15788 232 7458 0.6774]	[13568 298 9612 0.5842]	[14439 389 8650 0.6233]	[14049 597 8832 0.6111]	[13380 1004 9094 0.5913]	[14726 389 8363 0.6355]	[14596 528 8715 0.6233±0.0007]
AA	[21451 640 2290 0.8929]	[20514 330 3537 0.8482]	[19608 882 3891 0.8223]	[20133 798 3450 0.8421]	[20364 334 2780 0.8745]	[20024 288 3166 0.8590]	[20393 341 2744 0.8759]	[20239 587 2652 0.8745]	[18418 1284 3776 0.8118]	[18832 596 4050 0.8148]	[19998 608 3234 0.8516±0.0008]
RA	[21386 639 2356 0.8903]	[21125 330 2926 0.8732]	[19915 882 3584 0.8349]	[20254 797 3330 0.8471]	[20461 334 2683 0.8786]	[20459 288 2731 0.8775]	[20750 341 2387 0.8911]	[20607 587 2284 0.8902]	[18277 1284 3917 0.8058]	[18996 596 3886 0.8218]	[20223 608 3008 0.8611±0.0010]

- O'Hagan's maximum entropy method (MEM) (O'Hagan, 1988) is to solve the constrained nonlinear optimization model as follows:

$$\begin{aligned} &\text{Maximize} \quad \text{Disp}(\mathbf{w}) = -\sum_{i=1}^{n} w_i \ln(w_i) \\ &\text{s.t.} \qquad \text{orness}(\mathbf{w}) = \alpha = \tfrac{1}{n-1}\sum_{i=1}^{n}(n-i)w_i, \\ &\qquad\qquad \sum_{i=1}^{n} w_i = 1, \\ &\qquad\qquad w_i \in [0,1],\ i = 1,2,\ldots,n. \end{aligned} \tag{19}$$

- Fuller and Majlender's minimum variance method (MVM) (Fullér & Majlender, 2003) is to solve the following mathematical programming model:

$$\begin{aligned} &\text{Minimize} \quad \text{Disp}(\mathbf{w}) = \tfrac{1}{n}\sum_{i=1}^{n}\left(w_i - \tfrac{1}{n}\right)^2 \\ &\text{s.t.} \qquad \text{orness}(\mathbf{w}) = \alpha = \tfrac{1}{n-1}\sum_{i=1}^{n}(n-i)w_i, \\ &\qquad\qquad \sum_{i=1}^{n} w_i = 1, \\ &\qquad\qquad w_i \in [0,1],\ i = 1,2,\ldots,n. \end{aligned} \tag{20}$$

- Wang, Luo and Liu's chi-square method (CSM) (Wang et al., 2007) is to solve the following nonlinear programming model:

$$\begin{aligned} &\text{Minimize} \quad \text{Disp}(\mathbf{w}) = \sum_{i=1}^{n-1}\left(\tfrac{w_i}{w_{i+1}} + \tfrac{w_{i+1}}{w_i} - 2\right) \\ &\text{s.t.} \qquad \text{orness}(\mathbf{w}) = \alpha = \tfrac{1}{n-1}\sum_{i=1}^{n}(n-i)w_i, \\ &\qquad\qquad \sum_{i=1}^{n} w_i = 1, \\ &\qquad\qquad w_i \in [0,1],\ i = 1,2,\ldots,n. \end{aligned} \tag{21}$$

where α in Eqs. (19)–(21) is the optimism level factor, which controls the desired degree of orness. There are three special OWA operator weights which should be addressed when selecting the following optimism level factors:

- For MEM and MVM, $\alpha \in [0,1]$.
  1. When $\alpha = 0, \mathbf{w} = (0,\ldots,0,1)$. Then, OWA operator $F(a_1,a_2,\ldots,a_n) = \min_{i=1,2,\ldots,n}\{a_i\}$. This expresses the aggregation of $a_1,a_2,\ldots,a_n$ is to select the minimum of $a_1,a_2,\ldots,a_n$.
  2. When $\alpha = 1, \mathbf{w} = (1,0,\ldots,0)$. Then, OWA operator $F(a_1,a_2,\ldots,a_n) = \max_{i=1,2,\ldots,n}\{a_i\}$. This expresses the aggregation of $a_1,a_2,\ldots,a_n$ is to select the maximum of $a_1,a_2,\ldots,a_n$.
  3. When $\alpha = 0.5, \mathbf{w} = \left(\frac{1}{n},\frac{1}{n},\ldots,\frac{1}{n}\right)$. Then, OWA operator $F(a_1,a_2,\ldots,a_n) = \frac{1}{n}\sum_{i=1}^{n} a_i$. This expresses the aggregation of $a_1,a_2,\ldots,a_n$ equals to the arithmetic mean of $a_1,a_2,\ldots,a_n$.
- For CSM, $\alpha \in (0,1)$. $\alpha = 0$ and $\alpha = 1$ are inapplicable for the optimization model in Eq. (21). The case of $\alpha = 0.5$ is similar with MEM and MVM.

In this paper, LINGO software is used to solve the OWA operator weights corresponding to the three above-mentioned optimization problems.

3.2. OWA operator based link prediction ensemble-LPE$_{\text{OWA}}$

In order to make the link prediction ensemble more effective, we firstly normalize the link prediction algorithms introduced in Section 2.1 so that the scores representing likelihood of link existence can be located into the interval $[0,1]$. Let sn_{xy}^{CN}, sn_{xy}^{Salton}, sn_{xy}^{Jaccard}, $sn_{xy}^{\text{Sørensen}}$, sn_{xy}^{HPI}, sn_{xy}^{HDI}, $sn_{xy}^{\text{LHN-I}}$, sn_{xy}^{AA} and sn_{xy}^{RA} be the normalizations of s_{xy}^{CN}, s_{xy}^{Salton}, s_{xy}^{Jaccard}, $s_{xy}^{\text{Sørensen}}$, s_{xy}^{HPI}, s_{xy}^{HDI}, $s_{xy}^{\text{LHN-I}}$, s_{xy}^{AA} and s_{xy}^{RA}. In Section 2, we have analyzed the boundaries of these 9 algorithms, thus, the normalized link prediction algorithms can be obtained through the original link prediction algorithms divided by the respective maxima.

Then, we try to calculate the likelihood score of link existence through our proposed link prediction ensemble method-LPE$_{\text{OWA}}$. We denote this score as s_{xy}^{OWA} between nodes x and y, which is calculated as:

$$s_{xy}^{\text{OWA}} = \sum_{i=1}^{9}\left[w_i\left[\frac{s_{xy}^{(i)}}{\sum_{j=1}^{9} s_{xy}^{(j)}}\right]\right], \tag{22}$$

where $s_{xy}^{(i)}$ is the ith largest value of sn_{xy}^{CN}, sn_{xy}^{Salton}, sn_{xy}^{Jaccard}, $sn_{xy}^{\text{Sørensen}}$, sn_{xy}^{HPI}, sn_{xy}^{HDI}, $sn_{xy}^{\text{LHN-I}}$, sn_{xy}^{AA} and sn_{xy}^{RA}, the term $\frac{s_{xy}^{(i)}}{\sum_{j=1}^{9} s_{xy}^{(j)}}$ is supposed to be b_i in Eq. (18); w_i is the weight of OWA operator, $i = 1,2,\ldots,9$. In our study, we respectively use these different methods, i.e., MEM, MVM and CSM, to determine the wieght w_i and further compare their performances.

The purpose of normalization is to consider the likelihood score as the probability value, which makes it possible to compare the scores corresponding to the different link prediction algorithms. For the $k_x, k_y > 2$ and $k_x \neq k_y$, we can derive

$$\begin{aligned} 1 &< \min\{k_x,k_y\} < \sqrt{k_x k_y} < \frac{k_x + k_y}{2} < \max\{k_x,k_y\} \\ &< \|\Gamma(x)\cup\Gamma(y)\| < k_x k_y. \end{aligned} \tag{23}$$

Furthermore, we can get the following derivations:

$$s_{xy}^{\text{CN}} > s_{xy}^{\text{HPI}} > s_{xy}^{\text{Salton}} > s_{xy}^{\text{Sørensen}} > s_{xy}^{\text{HDI}} > s_{xy}^{\text{Jaccard}} > s_{xy}^{\text{LHN-I}} \tag{24}$$

and

$$\begin{aligned} sn_{xy}^{\text{CN}} &> sn_{xy}^{\text{HPI}} > sn_{xy}^{\text{Salton}} > sn_{xy}^{\text{Sørensen}} > sn_{xy}^{\text{HDI}} > sn_{xy}^{\text{Jaccard}} \\ &> sn_{xy}^{\text{LHN-I}}. \end{aligned} \tag{25}$$

For any node $z \in \|\Gamma(x)\cap\Gamma(y)\|$, when $k_z > 2$, we can obtain

$$1 > \frac{1}{\log_2 k_z} > \frac{1}{k_z}. \tag{26}$$

Because $s_{xy}^{\text{CN}} = \|\Gamma(x)\cap\Gamma(y)\| = \sum_{z\in\Gamma(x)\cap\Gamma(y)} 1$, we can derive

$$s_{xy}^{\text{CN}} > s_{xy}^{\text{AA}} > s_{xy}^{\text{RA}} \tag{27}$$

and

$$sn_{xy}^{\text{CN}} > sn_{xy}^{\text{AA}} > sn_{xy}^{\text{RA}}. \tag{28}$$

From Eqs. (25) and (28), we can find that the normalized link prediction algorithm based on local information entitled the number of common neighbors of nodes x and y (sn_{xy}^{CN}) can obtain a higher probability value in comparison with other link prediction algorithms based on the other two kinds of local information, i.e., the degrees of nodes x and y (sn_{xy}^{HPI}, sn_{xy}^{Salton}, $sn_{xy}^{\text{Sørensen}}$, sn_{xy}^{HDI}, sn_{xy}^{Jaccard} and $sn_{xy}^{\text{LHN-I}}$) and the degrees of common neighbors of nodes x and y (sn_{xy}^{AA} and sn_{xy}^{RA}). We think it is reasonable that sn_{xy}^{CN} obtains the higher likelihood score, because it is obvious and direct that a link will more likely exist between two nodes x and y if they have more common neighbors.

Table 8
Prediction performances of LPE_{OWA} and LPE_{AM} algorithms on the network of World Soccer Data Paris 1998-WSDP98.

LPE_{OWA} orness($\mathbf{w}$) = α	Fold 1	Fold 2	Fold 3	Fold 4	Fold 5	Fold 6	Fold 7	Fold 8	Fold 9	Fold 10	Average
Maximum entropy method											
0.55	[4567 339 818 0.8275]	[3924 507 1293 0.7298]	[4235 507 982 0.7842]	[4723 170 831 0.8400]	[4654 3 1067 0.8133]	[4130 507 1087 0.7658]	[3800 343 1581 0.6938]	[4232 339 1153 0.7690]	[3662 507 1078 0.7462]	[3066 676 1505 0.6488]	[4099 390 1140 0.7618±0.0036]
0.60	[4591 339 794 0.8317]	[3911 507 1306 0.7276]	[4239 507 978 0.7849]	[4725 170 829 0.8403]	[4661 3 1060 0.8146]	[4132 507 1085 0.7662]	[3794 343 1587 0.6928]	[4245 339 1140 0.7712]	[3666 507 1074 0.7470]	[3064 676 1507 0.6484]	[4103 390 1136 0.7624±0.0037]
0.65	[4599 339 786 0.8331]	[3894 507 1323 0.7246]	[4245 507 972 0.7859]	[4728 170 826 0.8408]	[4669 3 1052 0.8160]	[4116 507 1101 0.7634]	[3792 343 1589 0.6924]	[4253 339 1132 0.7726]	[3657 507 1083 0.7453]	[3061 676 1510 0.6478]	[4101 390 1137 0.7622±0.0038]
0.70	[4609 339 776 0.8348]	[3885 507 1332 0.7230]	[4249 507 968 0.7866]	[4749 170 805 0.8445]	[4693 3 1028 0.8201]	[4106 507 1111 0.7616]	[3788 343 1593 0.6917]	[4264 339 1121 0.7745]	[3647 507 1093 0.7434]	[3053 676 1518 0.6463]	[4104 390 1135 0.7627±0.0040]
0.75	[4615 339 770 0.8359]	[3860 507 1357 0.7186]	[4251 507 966 0.7869]	[4757 170 797 0.8459]	[4708 3 1013 0.8228]	[4078 507 1139 0.7567]	[3795 343 1586 0.6930]	[4292 339 1093 0.7794]	[3636 507 1104 0.7413]	[3035 676 1536 0.6428]	[4103 390 1136 0.7623±0.0043]
0.80	[4626 339 759 0.8378]	[3849 507 1368 0.7167]	[4252 507 965 0.7871]	[4748 170 806 0.8443]	[4716 3 1005 0.8242]	[4062 507 1155 0.7539]	[3805 343 1576 0.6947]	[4302 339 1083 0.7812]	[3617 507 1123 0.7377]	[3034 676 1537 0.6427]	[4101 390 1138 0.7620±0.0043]
0.85	[4623 339 762 0.8373]	[3796 507 1421 0.7075]	[4251 507 966 0.7869]	[4759 170 795 0.8463]	[4718 3 1003 0.8245]	[4028 507 1189 0.7480]	[3821 343 1560 0.6975]	[4299 339 1086 0.7807]	[3591 507 1149 0.7327]	[3033 676 1538 0.6425]	[4092 390 1147 0.7604±0.0045]
0.90	[4635 339 750 0.8394]	[3744 507 1473 0.6984]	[4256 507 961 0.7878]	[4751 170 803 0.8449]	[4705 3 1016 0.8222]	[3983 507 1234 0.7401]	[3840 343 1541 0.7008]	[4306 339 1079 0.7819]	[3572 507 1168 0.7291]	[3005 676 1566 0.6371]	[4080 390 1159 0.7582±0.0047]
0.92	[4637 339 748 0.8397]	[3728 507 1489 0.6956]	[4259 507 958 0.7883]	[4740 170 814 0.8429]	[4712 3 1009 0.8235]	[3951 507 1266 0.7345]	[3836 343 1545 0.7001]	[4308 339 1077 0.7822]	[3543 507 1197 0.7236]	[2994 676 1577 0.6350]	[4071 390 1168 0.7566±0.0049]
0.93	[4634 339 751 0.8392]	[3720 507 1497 0.6942]	[4259 507 958 0.7883]	[4727 170 827 0.8407]	[4696 3 1025 0.8207]	[3940 507 1277 0.7326]	[3846 343 1535 0.7019]	[4296 339 1089 0.7801]	[3542 507 1198 0.7234]	[2986 676 1585 0.6335]	[4065 390 1174 0.7555±0.0048]
0.94	[4633 339 752 0.8390]	[3695 507 1522 0.6898]	[4256 507 961 0.7878]	[4723 170 831 0.8400]	[4692 3 1029 0.8200]	[3923 507 1294 0.7296]	[3851 343 1530 0.7027]	[4294 339 1091 0.7798]	[3536 507 1204 0.7222]	[2976 676 1595 0.6316]	[4058 390 1181 0.7543±0.0049]
0.95	[4638 339 747 0.8399]	[3688 507 1529 0.6886]	[4254 507 963 0.7875]	[4717 170 837 0.8389]	[4696 3 1025 0.8207]	[3910 507 1307 0.7274]	[3855 343 1526 0.7034]	[4295 339 1090 0.7800]	[3522 507 1218 0.7196]	[2961 676 1610 0.6287]	[4054 390 1185 0.7535±0.0050]
0.96	[4636 339 749 0.8395]	[3681 507 1536 0.6874]	[4253 507 964 0.7873]	[4710 170 844 0.8377]	[4695 3 1026 0.8205]	[3895 507 1322 0.7248]	[3866 343 1515 0.7054]	[4295 339 1090 0.7800]	[3518 507 1222 0.7188]	[2945 676 1626 0.6257]	[4049 390 1189 0.7527±0.0051]
0.97	[4634 339 751 0.8392]	[3675 507 1542 0.6863]	[4249 507 968 0.7866]	[4696 170 858 0.8353]	[4697 3 1024 0.8208]	[3882 507 1335 0.7225]	[3867 343 1514 0.7055]	[4290 339 1095 0.7791]	[3517 507 1223 0.7186]	[2925 676 1646 0.6219]	[4043 390 1196 0.7516±0.0052]
0.98	[4635 339 750 0.8394]	[3678 507 1539 0.6868]	[4247 507 970 0.7863]	[4685 170 869 0.8333]	[4689 3 1032 0.8194]	[3866 507 1351 0.7197]	[3856 343 1525 0.7036]	[4289 339 1096 0.7789]	[3513 507 1227 0.7178]	[2914 676 1657 0.6198]	[4037 390 1202 0.7505±0.0052]
Minimum variance method											
0.55	[4544 339 841 0.8235]	[3933 507 1284 0.7314]	[4236 507 981 0.7843]	[4713 170 841 0.8382]	[4645 3 1076 0.8118]	[4121 507 1096 0.7642]	[3793 343 1588 0.6926]	[4226 339 1159 0.7679]	[3665 507 1075 0.7468]	[3070 676 1501 0.6495]	[4095 390 1144 0.7610±0.0035]
0.60	[4544 339 841 0.8235]	[3933 507 1284 0.7314]	[4236 507 981 0.7843]	[4713 170 841 0.8382]	[4645 3 1076 0.8118]	[4121 507 1096 0.7642]	[3793 343 1588 0.6926]	[4226 339 1159 0.7679]	[3665 507 1075 0.7468]	[3070 676 1501 0.6495]	[4095 390 1144 0.7610±0.0035]
0.65	[4544 339 841 0.8235]	[3933 507 1284 0.7314]	[4236 507 981 0.7843]	[4713 170 841 0.8382]	[4645 3 1076 0.8118]	[4121 507 1096 0.7642]	[3793 343 1588 0.6926]	[4226 339 1159 0.7679]	[3665 507 1075 0.7468]	[3070 676 1501 0.6495]	[4095 390 1144 0.7610±0.0035]
0.70	[4544 339 841 0.8235]	[3933 507 1284 0.7314]	[4236 507 981 0.7843]	[4713 170 841 0.8382]	[4645 3 1076 0.8118]	[4121 507 1096 0.7642]	[3793 343 1588 0.6926]	[4226 339 1159 0.7679]	[3665 507 1075 0.7468]	[3070 676 1501 0.6495]	[4095 390 1144 0.7610±0.0035]
0.75	[4541 339 844 0.8229]	[3930 507 1287 0.7309]	[4236 507 981 0.7843]	[4711 170 843 0.8379]	[4644 3 1077 0.8116]	[4119 507 1098 0.7639]	[3797 343 1584 0.6933]	[4221 339 1164 0.7670]	[3662 507 1078 0.7462]	[3071 676 1500 0.6497]	[4093 390 1146 0.7608±0.0034]
0.80	[4554 339 831 0.8252]	[3921 507 1296 0.7293]	[4234 507 983 0.7840]	[4717 170 837 0.8389]	[4642 3 1079 0.8112]	[4124 507 1093 0.7648]	[3788 343 1593 0.6917]	[4227 339 1158 0.7681]	[3662 507 1078 0.7462]	[3067 676 1504 0.6489]	[4094 390 1145 0.7608±0.0035]
0.85	[4588 339 797 0.8311]	[3893 507 1324 0.7244]	[4235 507 982 0.7842]	[4727 170 827 0.8407]	[4661 3 1060 0.8146]	[4119 507 1098 0.7639]	[3769 343 1612 0.6884]	[4246 339 1139 0.7714]	[3652 507 1088 0.7443]	[3055 676 1516 0.6467]	[4095 390 1144 0.7610±0.0039]
0.90	[4613 339 772 0.8355]	[3850 507 1367 0.7169]	[4247 507 970 0.7863]	[4764 170 790 0.8471]	[4704 3 1017 0.8221]	[4072 507 1145 0.7557]	[3789 343 1592 0.6919]	[4301 339 1084 0.7810]	[3602 507 1138 0.7348]	[3022 676 1549 0.6404]	[4096 390 1142 0.7612±0.0044]
0.92	[4626 339 759	[3809 507 1408	[4248 507 969	[4755 170 799	[4711 3 1010	[4042 507 1175	[3801 343 1580	[4297 339 1088	[3575 507 1165	[3015 676 1556	[4088 390 1151 0.7596±0.0046]

Table 8 (*continued*)

LPE_{OWA} orness($\mathbf{w}$) = α	Fold 1	Fold 2	Fold 3	Fold 4	Fold 5	Fold 6	Fold 7	Fold 8	Fold 9	Fold 10	Average
	0.8378]	0.7097]	0.7864]	0.8456]	0.8233]	0.7504]	0.6940]	0.7803]	0.7297]	0.6390]	
0.93	[4625 339 760 0.8376]	[3780 507 1437 0.7047]	[4248 507 969 0.7864]	[4755 170 799 0.8456]	[4712 3 1009 0.8235]	[4012 507 1205 0.7452]	[3809 343 1572 0.6954]	[4312 339 1073 0.7829]	[3564 507 1176 0.7276]	[2998 676 1573 0.6358]	[4082 390 1157 0.7585±0.0047]
0.94	[4631 339 754 0.8387]	[3750 507 1467 0.6994]	[4250 507 967 0.7868]	[4750 170 804 0.8447]	[4705 3 1016 0.8222]	[3984 507 1233 0.7403]	[3815 343 1566 0.6965]	[4312 339 1073 0.7829]	[3548 507 1192 0.7245]	[2989 676 1582 0.6341]	[4073 390 1165 0.7570±0.0048]
0.95	[4635 339 750 0.8394]	[3724 507 1493 0.6949]	[4251 507 966 0.7869]	[4730 170 824 0.8412]	[4702 3 1019 0.8217]	[3954 507 1263 0.7351]	[3825 343 1556 0.6982]	[4315 339 1070 0.7835]	[3538 507 1202 0.7226]	[2971 676 1600 0.6306]	[4065 390 1174 0.7554±0.0050]
0.96	[4635 339 750 0.8394]	[3690 507 1527 0.6889]	[4255 507 962 0.7876]	[4727 170 827 0.8407]	[4690 3 1031 0.8196]	[3930 507 1287 0.7309]	[3832 343 1549 0.6994]	[4325 339 1060 0.7852]	[3526 507 1214 0.7203]	[2965 676 1606 0.6295]	[4058 390 1181 0.7542±0.0051]
0.97	[4637 339 748 0.8397]	[3681 507 1536 0.6874]	[4252 507 965 0.7871]	[4703 170 851 0.8365]	[4687 3 1034 0.8191]	[3899 507 1318 0.7255]	[3863 343 1518 0.7048]	[4299 339 1086 0.7807]	[3515 507 1225 0.7182]	[2933 676 1638 0.6234]	[4047 390 1192 0.7522±0.0051]
0.98	[4637 339 748 0.8397]	[3675 507 1542 0.6863]	[4248 507 969 0.7864]	[4693 170 861 0.8347]	[4694 3 1027 0.8203]	[3873 507 1344 0.7209]	[3868 343 1513 0.7057]	[4291 339 1094 0.7793]	[3513 507 1227 0.7178]	[2915 676 1656 0.6200]	[4041 390 1198 0.7511±0.0052]
Chi-square method											
0.55	[4498 339 887 0.8154]	[3936 507 1281 0.7319]	[4227 507 990 0.7828]	[4699 170 855 0.8358]	[4644 3 1077 0.8116]	[4114 507 1103 0.7630]	[3796 343 1585 0.6931]	[4212 339 1173 0.7655]	[3655 507 1085 0.7449]	[3061 676 1510 0.6478]	[4084 390 1155 0.7592±0.0033]
0.60	[4543 339 842 0.8233]	[3927 507 1290 0.7303]	[4231 507 986 0.7835]	[4710 170 844 0.8377]	[4650 3 1071 0.8126]	[4122 507 1095 0.7644]	[3785 343 1596 0.6912]	[4229 339 1156 0.7684]	[3659 507 1081 0.7457]	[3063 676 1508 0.6482]	[4092 390 1147 0.7605±0.0035]
0.65	[4579 339 806 0.8296]	[3908 507 1309 0.7270]	[4233 507 984 0.7838]	[4727 170 827 0.8407]	[4654 3 1067 0.8133]	[4125 507 1092 0.7649]	[3774 343 1607 0.6893]	[4241 339 1144 0.7705]	[3657 507 1083 0.7453]	[3057 676 1514 0.6470]	[4096 390 1143 0.7611±0.0038]
0.70	[4600 339 785 0.8332]	[3881 507 1336 0.7223]	[4244 507 973 0.7857]	[4741 170 813 0.8431]	[4677 3 1044 0.8173]	[4107 507 1110 0.7618]	[3784 343 1597 0.6910]	[4260 339 1125 0.7738]	[3643 507 1097 0.7426]	[3047 676 1524 0.6451]	[4098 390 1140 0.7616±0.0040]
0.75	[4617 339 768 0.8362]	[3861 507 1356 0.7188]	[4250 507 967 0.7868]	[4753 170 801 0.8452]	[4720 3 1001 0.8249]	[4076 507 1141 0.7564]	[3791 343 1590 0.6923]	[4296 339 1089 0.7801]	[3630 507 1110 0.7401]	[3030 676 1541 0.6419]	[4102 390 1136 0.7623±0.0043]
0.80	[4628 339 757 0.8381]	[3825 507 1392 0.7125]	[4248 507 969 0.7864]	[4759 170 795 0.8463]	[4712 3 1009 0.8235]	[4047 507 1170 0.7513]	[3805 343 1576 0.6947]	[4305 339 1080 0.7817]	[3598 507 1142 0.7340]	[3028 676 1543 0.6415]	[4096 390 1143 0.7610±0.0044]
0.85	[4634 339 751 0.8392]	[3761 507 1456 0.7013]	[4253 507 964 0.7873]	[4756 170 798 0.8457]	[4710 3 1011 0.8231]	[3998 507 1219 0.7427]	[3820 343 1561 0.6973]	[4309 339 1076 0.7824]	[3573 507 1167 0.7293]	[3015 676 1556 0.6390]	[4083 390 1156 0.7587±0.0047]
0.90	[4635 339 750 0.8394]	[3717 507 1500 0.6937]	[4259 507 958 0.7883]	[4725 170 829 0.8403]	[4695 3 1026 0.8205]	[3935 507 1282 0.7317]	[3846 343 1535 0.7019]	[4296 339 1089 0.7801]	[3539 507 1201 0.7228]	[2984 676 1587 0.6331]	[4063 390 1176 0.7552±0.0048]
0.92	[4637 339 748 0.8397]	[3691 507 1526 0.6891]	[4254 507 963 0.7875]	[4717 170 837 0.8389]	[4700 3 1021 0.8214]	[3914 507 1303 0.7281]	[3854 343 1527 0.7033]	[4293 339 1092 0.7796]	[3525 507 1215 0.7201]	[2967 676 1604 0.6299]	[4055 390 1184 0.7538±0.0050]
0.93	[4637 339 748 0.8397]	[3686 507 1531 0.6882]	[4254 507 963 0.7875]	[4718 170 836 0.8391]	[4694 3 1027 0.8203]	[3904 507 1313 0.7263]	[3861 343 1520 0.7045]	[4293 339 1092 0.7796]	[3520 507 1220 0.7192]	[2957 676 1614 0.6280]	[4052 390 1186 0.7532±0.0050]
0.94	[4637 339 748 0.8397]	[3681 507 1536 0.6874]	[4253 507 964 0.7873]	[4709 170 845 0.8375]	[4703 3 1018 0.8219]	[3893 507 1324 0.7244]	[3866 343 1515 0.7054]	[4294 339 1091 0.7798]	[3518 507 1222 0.7188]	[2945 676 1626 0.6257]	[4050 390 1189 0.7528±0.0051]
0.95	[4637 339 748 0.8397]	[3679 507 1538 0.6870]	[4251 507 966 0.7869]	[4702 170 852 0.8363]	[4700 3 1021 0.8214]	[3885 507 1332 0.7230]	[3867 343 1514 0.7055]	[4288 339 1097 0.7787]	[3519 507 1221 0.7190]	[2930 676 1641 0.6228]	[4046 390 1193 0.7520±0.0052]
0.96	[4637 339 748 0.8397]	[3681 507 1536 0.6874]	[4250 507 967 0.7868]	[4692 170 862 0.8346]	[4699 3 1022 0.8212]	[3881 507 1336 0.7223]	[3862 343 1519 0.7047]	[4292 339 1093 0.7794]	[3516 507 1224 0.7184]	[2924 676 1647 0.6217]	[4043 390 1195 0.7516±0.0052]
0.97	[4636 339 749 0.8395]	[3680 507 1537 0.6872]	[4248 507 969 0.7864]	[4683 170 871 0.8330]	[4688 3 1033 0.8193]	[3870 507 1347 0.7204]	[3856 343 1525 0.7036]	[4289 339 1096 0.7789]	[3513 507 1227 0.7178]	[2917 676 1654 0.6204]	[4038 390 1201 0.7507±0.0052]
0.98	[4637 339 748 0.8397]	[3673 507 1544 0.6860]	[4246 507 971 0.7861]	[4670 170 884 0.8307]	[4680 3 1041 0.8179]	[3846 507 1371 0.7162]	[3860 343 1521 0.7043]	[4282 339 1103 0.7777]	[3509 507 1231 0.7171]	[2907 676 1664 0.6184]	[4031 390 1208 0.7494±0.0052]
LPE_{AM}	[2753 1008 1963 0.5690]	[2834 1003 1887 0.5827]	[2636 933 2155 0.5420]	[1955 1299 2470 0.4550]	[3569 755 1400 0.6895]	[2907 966 1851 0.5922]	[2756 1132 1836 0.5804]	[2943 1182 1599 0.6174]	[2461 1015 1771 0.5658]	[2528 1055 1664 0.5823]	[2734 1035 1860 0.5776±0.0034]

Table 9
Prediction performances of LPE_{OWA} and LPE_{AM} algorithms on the network of Food Webs-ChesLower.

LPE_{OWA} orness($\mathbf{w}$) = α	Fold 1	Fold 2	Fold 3	Fold 4	Fold 5	Fold 6	Fold 7	Fold 8	Fold 9	Fold 10	Average
Maximum entropy method											
0.55	[7103 3 1377 0.8375]	[5531 10 2942 0.6526]	[7283 10 1190 0.8591]	[6369 14 2100 0.7516]	[6060 6 2417 0.7147]	[7282 3 1198 0.8586]	[7002 4 1477 0.8257]	[6674 4 1306 0.8362]	[6072 7 1905 0.7610]	[5911 9 2064 0.7409]	[6529 7 1798 0.7838±0.0049]
0.60	[7126 3 1354 0.8402]	[5554 10 2919 0.6553]	[7289 10 1184 0.8598]	[6343 14 2126 0.7486]	[6073 6 2404 0.7163]	[7289 3 1191 0.8594]	[6988 4 1491 0.8240]	[6683 4 1297 0.8373]	[6072 7 1905 0.7610]	[5891 9 2084 0.7384]	[6531 7 1796 0.7840±0.0049]
0.65	[7131 3 1349 0.8408]	[5578 10 2895 0.6581]	[7278 10 1195 0.8585]	[6337 14 2132 0.7478]	[6108 6 2369 0.7204]	[7311 3 1169 0.8620]	[6966 4 1513 0.8214]	[6687 4 1293 0.8378]	[6071 7 1906 0.7608]	[5899 9 2076 0.7394]	[6537 7 1790 0.7847±0.0048]
0.70	[7124 3 1356 0.8400]	[5574 10 2899 0.6577]	[7263 10 1210 0.8568]	[6316 14 2153 0.7454]	[6131 6 2346 0.7231]	[7326 3 1154 0.8638]	[6950 4 1529 0.8195]	[6680 4 1300 0.8369]	[6067 7 1910 0.7603]	[5896 9 2079 0.7390]	[6533 7 1794 0.7842±0.0047]
0.75	[7137 3 1343 0.8415]	[5614 10 2859 0.6624]	[7246 10 1227 0.8548]	[6260 14 2209 0.7388]	[6153 6 2324 0.7257]	[7346 3 1134 0.8661]	[6938 4 1541 0.8181]	[6683 4 1297 0.8373]	[6069 7 1908 0.7606]	[5878 9 2097 0.7368]	[6532 7 1794 0.7842±0.0047]
0.80	[7145 3 1335 0.8424]	[5636 10 2837 0.6650]	[7200 10 1273 0.8493]	[6202 14 2267 0.7319]	[6166 6 2311 0.7272]	[7381 3 1099 0.8703]	[6909 4 1570 0.8147]	[6682 4 1298 0.8372]	[6084 7 1893 0.7625]	[5843 9 2132 0.7324]	[6525 7 1802 0.7833±0.0047]
0.85	[7135 3 1345 0.8413]	[5686 10 2787 0.6709]	[7172 10 1301 0.8460]	[6157 14 2312 0.7266]	[6233 6 2244 0.7351]	[7367 3 1113 0.8686]	[6862 4 1617 0.8091]	[6660 4 1320 0.8344]	[6097 7 1880 0.7641]	[5849 9 2126 0.7332]	[6522 7 1805 0.7829±0.0043]
0.90	[7113 3 1367 0.8387]	[5694 10 2779 0.6718]	[7092 10 1381 0.8366]	[6059 14 2410 0.7151]	[6262 6 2215 0.7385]	[7333 3 1147 0.8646]	[6800 4 1679 0.8018]	[6621 4 1359 0.8295]	[6096 7 1881 0.7640]	[5800 9 2175 0.7270]	[6487 7 1839 0.7788±0.0042]
0.92	[7088 3 1392 0.8357]	[5702 10 2771 0.6728]	[7065 10 1408 0.8334]	[5977 14 2492 0.7054]	[6252 6 2225 0.7374]	[7321 3 1159 0.8632]	[6775 4 1704 0.7989]	[6604 4 1376 0.8274]	[6085 7 1892 0.7626]	[5758 9 2217 0.7218]	[6463 7 1864 0.7759±0.0042]
0.93	[7068 3 1412 0.8334]	[5712 10 2761 0.6739]	[7061 10 1412 0.8330]	[5950 14 2519 0.7022]	[6256 6 2221 0.7378]	[7310 3 1170 0.8619]	[6754 4 1725 0.7964]	[6584 4 1396 0.8249]	[6079 7 1898 0.7618]	[5747 9 2228 0.7204]	[6452 7 1874 0.7746±0.0041]
0.94	[7048 3 1432 0.8310]	[5700 10 2773 0.6725]	[7023 10 1450 0.8285]	[5907 14 2562 0.6972]	[6249 6 2228 0.7370]	[7298 3 1182 0.8605]	[6744 4 1735 0.7952]	[6574 4 1406 0.8236]	[6070 7 1907 0.7607]	[5733 9 2242 0.7186]	[6435 7 1892 0.7725±0.0042]
0.95	[7033 3 1447 0.8292]	[5689 10 2784 0.6712]	[6993 10 1480 0.8249]	[5877 14 2592 0.6936]	[6240 6 2237 0.7359]	[7272 3 1208 0.8574]	[6731 4 1748 0.7937]	[6551 4 1429 0.8208]	[6061 7 1916 0.7596]	[5714 9 2261 0.7162]	[6416 7 1910 0.7703±0.0041]
0.96	[7009 3 1471 0.8264]	[5680 10 2793 0.6702]	[6969 10 1504 0.8221]	[5824 14 2645 0.6874]	[6260 6 2217 0.7383]	[7256 3 1224 0.8555]	[6710 4 1769 0.7912]	[6540 4 1440 0.8194]	[6064 7 1913 0.7600]	[5692 9 2283 0.7135]	[6400 7 1926 0.7684 0.0041]
0.97	[6984 3 1496 0.8235]	[5694 10 2779 0.6718]	[6955 10 1518 0.8205]	[5761 14 2708 0.6799]	[6247 6 2230 0.7368]	[7234 3 1246 0.8529]	[6705 4 1774 0.7906]	[6531 4 1449 0.8183]	[6053 7 1924 0.7586]	[5646 9 2329 0.7077]	[6381 7 1945 0.7661±0.0042]
0.98	[6945 3 1535 0.8189]	[5679 10 2794 0.6700]	[6924 10 1549 0.8168]	[5682 14 2787 0.6706]	[6251 6 2226 0.7372]	[7199 3 1281 0.8488]	[6677 4 1802 0.7873]	[6503 4 1477 0.8148]	[6040 7 1937 0.7570]	[5618 9 2357 0.7042]	[6352 7 1975 0.7626±0.0042]
Minimum variance method											
0.55	[7092 3 1388 0.8362]	[5524 10 2949 0.6518]	[7274 10 1199 0.8581]	[6379 14 2090 0.7528]	[6039 6 2438 0.7122]	[7269 3 1211 0.8571]	[7018 4 1461 0.8275]	[6655 4 1325 0.8338]	[6068 7 1909 0.7605]	[5924 9 2051 0.7425]	[6524 7 1802 0.7832±0.0049]
0.60	[7092 3 1388 0.8362]	[5524 10 2949 0.6518]	[7274 10 1199 0.8581]	[6379 14 2090 0.7528]	[6039 6 2438 0.7122]	[7269 3 1211 0.8571]	[7018 4 1461 0.8275]	[6655 4 1325 0.8338]	[6068 7 1909 0.7605]	[5924 9 2051 0.7425]	[6524 7 1802 0.7832±0.0049]
0.65	[7092 3 1388 0.8362]	[5524 10 2949 0.6518]	[7274 10 1199 0.8581]	[6379 14 2090 0.7528]	[6039 6 2438 0.7122]	[7269 3 1211 0.8571]	[7018 4 1461 0.8275]	[6655 4 1325 0.8338]	[6068 7 1909 0.7605]	[5924 9 2051 0.7425]	[6524 7 1802 0.7832±0.0049]
0.70	[7092 3 1388 0.8362]	[5524 10 2949 0.6518]	[7274 10 1199 0.8581]	[6379 14 2090 0.7528]	[6039 6 2438 0.7122]	[7269 3 1211 0.8571]	[7018 4 1461 0.8275]	[6655 4 1325 0.8338]	[6068 7 1909 0.7605]	[5924 9 2051 0.7425]	[6524 7 1802 0.7832±0.0049]
0.75	[7067 3 1413 0.8333]	[5497 10 2976 0.6486]	[7270 10 1203 0.8576]	[6381 14 2088 0.7530]	[6002 6 2475 0.7079]	[7268 3 1212 0.8569]	[6991 4 1488 0.8244]	[6647 4 1333 0.8328]	[6057 7 1920 0.7591]	[5914 9 2061 0.7413]	[6509 7 1817 0.7815±0.0050]
0.80	[7064 3 1416 0.8329]	[5503 10 2970 0.6493]	[7263 10 1210 0.8568]	[6363 14 2106 0.7509]	[6020 6 2457 0.7100]	[7267 3 1213 0.8568]	[6982 4 1497 0.8233]	[6645 4 1335 0.8325]	[6053 7 1924 0.7586]	[5908 9 2067 0.7405]	[6507 7 1820 0.7812±0.0049]
0.85	[7119 3 1361 0.8394]	[5570 10 2903 0.6572]	[7267 10 1206 0.8572]	[6337 14 2132 0.7478]	[6094 6 2383 0.7187]	[7305 3 1175 0.8613]	[6952 4 1527 0.8198]	[6671 4 1309 0.8358]	[6054 7 1923 0.7587]	[5891 9 2084 0.7384]	[6526 7 1800 0.7834±0.0047]
0.90	[7149 3 1331 0.8429]	[5638 10 2835 0.6652]	[7210 10 1263 0.8505]	[6276 14 2193 0.7407]	[6162 6 2315 0.7267]	[7351 3 1129 0.8667]	[6936 4 1543 0.8179]	[6665 4 1315 0.8350]	[6046 7 1931 0.7577]	[5829 9 2146 0.7306]	[6526 7 1800 0.7834±0.0046]
0.92	[7157 3 1323	[5715 10 2758	[7171 10 1302	[6232 14 2237	[6200 6 2277	[7347 3 1133	[6910 4 1569	[6660 4 1320	[6061 7 1916	[5808 9 2167	[6526 7 1800 0.7834±0.0043]

Table 9 (*continued*)

LPE_{OWA} orness($\mathbf{w}$) = α	Fold 1	Fold 2	Fold 3	Fold 4	Fold 5	Fold 6	Fold 7	Fold 8	Fold 9	Fold 10	Average
	0.8439]	0.6743]	0.8459]	0.7355]	0.7312]	0.8663]	0.8148]	0.8344]	0.7596]	0.7280]	
0.93	[7158 3 1322 0.8440]	[5716 10 2757 0.6744]	[7118 10 1355 0.8397]	[6159 14 2310 0.7269]	[6248 6 2229 0.7369]	[7340 3 1140 0.8654]	[6874 4 1605 0.8106]	[6648 4 1332 0.8329]	[6087 7 1890 0.7628]	[5802 9 2173 0.7273]	[6515 7 1811 0.7821±0.0042]
0.94	[7133 3 1347 0.8410]	[5720 10 2753 0.6749]	[7107 10 1366 0.8384]	[6103 14 2366 0.7203]	[6262 6 2215 0.7385]	[7324 3 1156 0.8636]	[6811 4 1668 0.8031]	[6634 4 1346 0.8312]	[6081 7 1896 0.7621]	[5776 9 2199 0.7240]	[6495 7 1831 0.7797±0.0041]
0.95	[7112 3 1368 0.8386]	[5722 10 2751 0.6751]	[7089 10 1384 0.8363]	[6043 14 2426 0.7132]	[6282 6 2195 0.7409]	[7307 3 1173 0.8615]	[6771 4 1708 0.7984]	[6611 4 1369 0.8283]	[6088 7 1889 0.7630]	[5757 9 2218 0.7216]	[6478 7 1848 0.7777±0.0041]
0.96	[7084 3 1396 0.8353]	[5715 10 2758 0.6743]	[7035 10 1438 0.8299]	[5978 14 2491 0.7055]	[6271 6 2206 0.7396]	[7294 3 1186 0.8600]	[6714 4 1765 0.7917]	[6592 4 1388 0.8259]	[6089 7 1888 0.7631]	[5743 9 2232 0.7199]	[6452 7 1875 0.7745±0.0040]
0.97	[7031 3 1449 0.8290]	[5703 10 2770 0.6729]	[6985 10 1488 0.8240]	[5847 14 2622 0.6901]	[6262 6 2215 0.7385]	[7256 3 1224 0.8555]	[6696 4 1783 0.7896]	[6556 4 1424 0.8214]	[6060 7 1917 0.7595]	[5691 9 2284 0.7134]	[6409 7 1918 0.7694±0.0041]
0.98	[6967 3 1513 0.8215]	[5698 10 2775 0.6723]	[6933 10 1540 0.8179]	[5727 14 2742 0.6759]	[6245 6 2232 0.7365]	[7213 3 1267 0.8505]	[6680 4 1799 0.7877]	[6518 4 1462 0.8166]	[6061 7 1916 0.7596]	[5635 9 2340 0.7064]	[6368 7 1959 0.7645±0.0041]
Chi-square method											
0.55	[7034 3 1446 0.8294]	[5462 10 3011 0.6445]	[7281 10 1192 0.8589]	[6371 14 2098 0.7519]	[5955 6 2522 0.7023]	[7219 3 1261 0.8512]	[6976 4 1503 0.8226]	[6635 4 1345 0.8313]	[6017 7 1960 0.7541]	[5885 9 2090 0.7377]	[6484 7 1843 0.7784±0.0051]
0.60	[7087 3 1393 0.8356]	[5507 10 2966 0.6498]	[7270 10 1203 0.8576]	[6378 14 2091 0.7527]	[6021 6 2456 0.7101]	[7258 3 1222 0.8558]	[6982 4 1497 0.8233]	[6643 4 1337 0.8323]	[6038 7 1939 0.7567]	[5899 9 2076 0.7394]	[6508 7 1818 0.7813±0.0049]
0.65	[7118 3 1362 0.8393]	[5554 10 2919 0.6553]	[7265 10 1208 0.8570]	[6361 14 2108 0.7507]	[6077 6 2400 0.7167]	[7287 3 1193 0.8592]	[6964 4 1515 0.8212]	[6663 4 1317 0.8348]	[6053 7 1924 0.7586]	[5883 9 2092 0.7374]	[6523 7 1804 0.7830±0.0048]
0.70	[7138 3 1342 0.8416]	[5594 10 2879 0.6600]	[7252 10 1221 0.8555]	[6324 14 2145 0.7463]	[6112 6 2365 0.7209]	[7324 3 1156 0.8636]	[6954 4 1525 0.8200]	[6680 4 1300 0.8369]	[6057 7 1920 0.7591]	[5885 9 2090 0.7377]	[6532 7 1794 0.7842±0.0047]
0.75	[7144 3 1336 0.8423]	[5623 10 2850 0.6634]	[7235 10 1238 0.8535]	[6283 14 2186 0.7415]	[6157 6 2320 0.7262]	[7353 3 1127 0.8670]	[6932 4 1547 0.8174]	[6679 4 1301 0.8368]	[6073 7 1904 0.7611]	[5865 9 2110 0.7352]	[6534 7 1792 0.7844±0.0046]
0.80	[7154 3 1326 0.8435]	[5655 10 2818 0.6672]	[7207 10 1266 0.8502]	[6177 14 2292 0.7290]	[6205 6 2272 0.7318]	[7366 3 1114 0.8685]	[6885 4 1594 0.8119]	[6662 4 1318 0.8347]	[6075 7 1902 0.7613]	[5850 9 2125 0.7333]	[6524 7 1803 0.7831±0.0045]
0.85	[7120 3 1360 0.8395]	[5705 10 2768 0.6731]	[7103 10 1370 0.8379]	[6071 14 2398 0.7165]	[6260 6 2217 0.7383]	[7339 3 1141 0.8653]	[6820 4 1659 0.8042]	[6631 4 1349 0.8308]	[6098 7 1879 0.7642]	[5806 9 2169 0.7278]	[6495 7 1831 0.7798±0.0042]
0.90	[7066 3 1414 0.8331]	[5713 10 2760 0.6741]	[7051 10 1422 0.8318]	[5935 14 2534 0.7005]	[6246 6 2231 0.7366]	[7315 3 1165 0.8625]	[6752 4 1727 0.7962]	[6589 4 1391 0.8255]	[6079 7 1898 0.7618]	[5744 9 2231 0.7200]	[6449 7 1877 0.7742±0.0042]
0.92	[7041 3 1439 0.8302]	[5689 10 2784 0.6712]	[7006 10 1467 0.8265]	[5883 14 2586 0.6943]	[6242 6 2235 0.7362]	[7280 3 1200 0.8584]	[6737 4 1742 0.7944]	[6559 4 1421 0.8218]	[6068 7 1909 0.7605]	[5726 9 2249 0.7177]	[6423 7 1903 0.7711±0.0041]
0.93	[7019 3 1461 0.8276]	[5685 10 2788 0.6708]	[6989 10 1484 0.8245]	[5848 14 2621 0.6902]	[6243 6 2234 0.7363]	[7276 3 1204 0.8579]	[6737 4 1742 0.7944]	[6550 4 1430 0.8206]	[6067 7 1910 0.7603]	[5700 9 2275 0.7145]	[6411 7 1915 0.7697±0.0042]
0.94	[7007 3 1473 0.8262]	[5681 10 2792 0.6703]	[6970 10 1503 0.8222]	[5824 14 2645 0.6874]	[6258 6 2219 0.7381]	[7254 3 1226 0.8553]	[6710 4 1769 0.7912]	[6541 4 1439 0.8195]	[6064 7 1913 0.7600]	[5673 9 2302 0.7111]	[6398 7 1928 0.7681±0.0042]
0.95	[6986 3 1494 0.8237]	[5700 10 2773 0.6725]	[6960 10 1513 0.8211]	[5769 14 2700 0.6809]	[6250 6 2227 0.7371]	[7244 3 1236 0.8541]	[6706 4 1773 0.7908]	[6540 4 1440 0.8194]	[6062 7 1915 0.7597]	[5650 9 2325 0.7082]	[6387 7 1940 0.7667±0.0042]
0.96	[6964 3 1516 0.8211]	[5692 10 2781 0.6716]	[6942 10 1531 0.8189]	[5733 14 2736 0.6766]	[6255 6 2222 0.7377]	[7225 3 1255 0.8519]	[6697 4 1782 0.7897]	[6520 4 1460 0.8169]	[6058 7 1919 0.7592]	[5635 9 2340 0.7064]	[6372 7 1954 0.7650±0.0042]
0.97	[6947 3 1533 0.8191]	[5673 10 2800 0.6693]	[6924 10 1549 0.8168]	[5678 14 2791 0.6702]	[6250 6 2227 0.7371]	[7201 3 1279 0.8491]	[6680 4 1799 0.7877]	[6501 4 1479 0.8145]	[6037 7 1940 0.7566]	[5620 9 2355 0.7045]	[6351 7 1975 0.7625±0.0042]
0.98	[6921 3 1559 0.8160]	[5663 10 2810 0.6682]	[6914 10 1559 0.8156]	[5623 14 2846 0.6637]	[6244 6 2233 0.7364]	[7175 3 1305 0.8460]	[6645 4 1834 0.7836]	[6482 4 1498 0.8121]	[6022 7 1955 0.7547]	[5604 9 2371 0.7025]	[6329 7 1997 0.7599±0.0043]
LPE_{AM}	[3505 1495 3483 0.5013]	[4024 2019 2440 0.5934]	[3069 1735 3679 0.4640]	[2842 1888 3753 0.4463]	[3437 1974 3072 0.5215]	[2738 1796 3949 0.4286]	[2700 1883 3900 0.4293]	[4286 1514 2184 0.6316]	[3562 1855 2567 0.5623]	[3233 1644 3107 0.5079]	[3340 1780 3213 0.5086 0.0049]

Table 10
Prediction performances of LPE_{OWA} and LPE_{AM} algorithms on the network of Graph Drawing Contests Data-C96.

LPE_{OWA} orness($\mathbf{w}$) = α	Fold 1	Fold 2	Fold 3	Fold 4	Fold 5	Fold 6	Fold 7	Fold 8	Fold 9	Fold 10	Average
Maximum entropy method											
0.55	[12643 10554 2218 0.7051]	[9282 13757 2376 0.6359]	[10878 12229 2308 0.6686]	[11025 12164 2226 0.6731]	[10914 12273 2228 0.6709]	[9221 12163 2076 0.6523]	[12895 8816 1749 0.7376]	[9210 12142 2108 0.6514]	[14480 7267 1713 0.7721]	[9293 12078 2089 0.6535]	[10984 11344 2109 0.6820±0.0019]
0.60	[12659 10554 2202 0.7057]	[9286 13757 2372 0.6360]	[10894 12229 2292 0.6692]	[11037 12164 2214 0.6736]	[10934 12273 2208 0.6717]	[9233 12163 2064 0.6528]	[12907 8816 1737 0.7381]	[9222 12142 2096 0.6519]	[14504 7267 1689 0.7731]	[9297 12078 2085 0.6537]	[10997 11344 2096 0.6826±0.0019]
0.65	[12663 10554 2198 0.7059]	[9298 13757 2360 0.6365]	[10898 12229 2288 0.6694]	[11042 12164 2209 0.6738]	[10938 12273 2204 0.6718]	[9241 12163 2056 0.6531]	[12919 8816 1725 0.7386]	[9230 12142 2088 0.6522]	[14508 7267 1685 0.7733]	[9309 12078 2073 0.6542]	[11005 11344 2089 0.6829±0.0019]
0.70	[12679 10554 2182 0.7065]	[9310 13757 2348 0.6370]	[10906 12229 2280 0.6697]	[11050 12164 2201 0.6741]	[10938 12273 2204 0.6718]	[9241 12163 2056 0.6531]	[12927 8816 1717 0.7389]	[9234 12142 2084 0.6524]	[14516 7267 1677 0.7736]	[9317 12078 2065 0.6546]	[11012 11344 2081 0.6832±0.0019]
0.75	[12704 10554 2157 0.7075]	[9330 13757 2328 0.6378]	[10924 12229 2262 0.6704]	[11063 12164 2188 0.6746]	[10954 12273 2188 0.6725]	[9238 12163 2059 0.6530]	[12922 8816 1722 0.7387]	[9266 12142 2052 0.6538]	[14544 7267 1649 0.7748]	[9302 12078 2080 0.6539]	[11025 11344 2069 0.6837±0.0019]
0.80	[12750 10554 2111 0.7093]	[9375 13757 2283 0.6395]	[10896 12229 2290 0.6693]	[11058 12164 2193 0.6744]	[10827 12273 2315 0.6675]	[9159 12163 2138 0.6496]	[12915 8816 1729 0.7384]	[9189 12142 2129 0.6505]	[14466 7267 1727 0.7715]	[9345 12078 2037 0.6558]	[10998 11344 2095 0.6826±0.0019]
0.85	[12718 10554 2143 0.7080]	[9367 13757 2291 0.6392]	[10864 12229 2322 0.6681]	[11034 12164 2217 0.6735]	[10787 12273 2355 0.6659]	[9135 12163 2162 0.6486]	[12891 8816 1753 0.7374]	[9165 12142 2153 0.6494]	[14418 7267 1775 0.7695]	[9337 12078 2045 0.6554]	[10972 11344 2122 0.6815±0.0018]
0.90	[12702 10554 2159 0.7074]	[9348 13757 2310 0.6385]	[10848 12229 2338 0.6674]	[11020 12164 2231 0.6729]	[10769 12273 2373 0.6652]	[9113 12163 2184 0.6477]	[12861 8816 1783 0.7361]	[9150 12142 2168 0.6488]	[14398 7267 1795 0.7686]	[9311 12078 2071 0.6543]	[10952 11344 2141 0.6807±0.0018]
0.92	[12694 10554 2167 0.7071]	[9346 13757 2312 0.6384]	[10840 12229 2346 0.6671]	[11012 12164 2239 0.6726]	[10759 12273 2383 0.6648]	[9107 12163 2190 0.6474]	[12855 8816 1789 0.7358]	[9144 12142 2174 0.6486]	[14386 7267 1807 0.7681]	[9309 12078 2073 0.6542]	[10945 11344 2148 0.6804±0.0018]
0.93	[12702 10554 2159 0.7074]	[9352 13757 2306 0.6386]	[10844 12229 2342 0.6673]	[11016 12164 2235 0.6728]	[10759 12273 2383 0.6648]	[9107 12163 2190 0.6474]	[12859 8816 1785 0.7360]	[9146 12142 2172 0.6486]	[14390 7267 1803 0.7683]	[9313 12078 2069 0.6544]	[10949 11344 2144 0.6806±0.0018]
0.94	[12699 10554 2162 0.7073]	[9348 13757 2310 0.6385]	[10841 12229 2345 0.6671]	[11013 12164 2238 0.6726]	[10756 12273 2386 0.6647]	[9101 12163 2196 0.6472]	[12850 8816 1794 0.7356]	[9145 12142 2173 0.6486]	[14387 7267 1806 0.7681]	[9304 12078 2078 0.6540]	[10944 11344 2149 0.6804±0.0018]
0.95	[12699 10554 2162 0.7073]	[9348 13757 2310 0.6385]	[10841 12229 2345 0.6671]	[11013 12164 2238 0.6726]	[10756 12273 2386 0.6647]	[9101 12163 2196 0.6472]	[12850 8816 1794 0.7356]	[9145 12142 2173 0.6486]	[14387 7267 1806 0.7681]	[9304 12078 2078 0.6540]	[10944 11344 2149 0.6804±0.0018]
0.96	[12707 10554 2154 0.7076]	[9353 13757 2305 0.6387]	[10845 12229 2341 0.6673]	[11015 12164 2236 0.6727]	[10756 12273 2386 0.6647]	[9101 12163 2196 0.6472]	[12854 8816 1790 0.7358]	[9146 12142 2172 0.6486]	[14391 7267 1802 0.7683]	[9308 12078 2074 0.6542]	[10948 11344 2146 0.6805±0.0018]
0.97	[12715 10554 2146 0.7079]	[9361 13757 2297 0.6390]	[10849 12229 2337 0.6675]	[11012 12164 2239 0.6726]	[10756 12273 2386 0.6647]	[9101 12163 2196 0.6472]	[12858 8816 1786 0.7360]	[9150 12142 2168 0.6488]	[14395 7267 1798 0.7685]	[9312 12078 2070 0.6543]	[10951 11344 2142 0.6806±0.0018]
0.98	[12749 10554 2112 0.7093]	[9342 13757 2316 0.6382]	[10854 12229 2332 0.6677]	[11017 12164 2234 0.6728]	[10732 12273 2410 0.6637]	[9053 12163 2244 0.6451]	[12815 8816 1829 0.7341]	[9126 12142 2192 0.6478]	[14400 7267 1793 0.7687]	[9269 12078 2113 0.6525]	[10936 11344 2158 0.6800±0.0019]
Minimum variance method											
0.55	[12643 10554 2218 0.7051]	[9282 13757 2376 0.6359]	[10878 12229 2308 0.6686]	[11025 12164 2226 0.6731]	[10914 12273 2228 0.6709]	[9221 12163 2076 0.6523]	[12895 8816 1749 0.7376]	[9210 12142 2108 0.6514]	[14480 7267 1713 0.7721]	[9293 12078 2089 0.6535]	[10984 11344 2109 0.6820±0.0019]
0.60	[12643 10554 2218 0.7051]	[9282 13757 2376 0.6359]	[10878 12229 2308 0.6686]	[11025 12164 2226 0.6731]	[10914 12273 2228 0.6709]	[9221 12163 2076 0.6523]	[12895 8816 1749 0.7376]	[9210 12142 2108 0.6514]	[14480 7267 1713 0.7721]	[9293 12078 2089 0.6535]	[10984 11344 2109 0.6820±0.0019]
0.65	[12643 10554 2218	[9282 13757 2376	[10878 12229 2308	[11025 12164 2226	[10914 12273 2228	[9221 12163 2076	[12895 8816 1749	[9210 12142 2108	[14480 7267 1713	[9293 12078 2089	[10984 11344 2109 0.6820±0.0019]

Table 10 (*continued*)

LPE_{OWA} orness($\mathbf{w}$) = α	Fold 1	Fold 2	Fold 3	Fold 4	Fold 5	Fold 6	Fold 7	Fold 8	Fold 9	Fold 10	Average
	0.7051]	0.6359]	0.6686]	0.6731]	0.6709]	0.6523]	0.7376]	0.6514]	0.7721]	0.6535]	
0.70	[12643	[9282	[10878	[11025	[10914	[9221	[12895	[9210	[14480	[9293	[10984 11344
	10554	13757	12229	12164	12273	12163	8816	12142	7267	12078	2109
	2218	2376	2308	2226	2228	2076	1749	2108	1713	2089	0.6820±0.0019]
	0.7051]	0.6359]	0.6686]	0.6731]	0.6709]	0.6523]	0.7376]	0.6514]	0.7721]	0.6535]	
0.75	[12641	[9281	[10877	[11022	[10914	[9221	[12894	[9210	[14479	[9292	[10983 11344
	10554	13757	12229	12164	12273	12163	8816	12142	7267	12078	2110
	2220	2377	2309	2229	2228	2076	1750	2108	1714	2090	0.6820±0.0019]
	0.7050]	0.6358]	0.6686]	0.6730]	0.6709]	0.6523]	0.7375]	0.6514]	0.7721]	0.6535]	
0.80	[12639	[9280	[10876	[11021	[10914	[9221	[12893	[9210	[14478	[9291	[10982 11344
	10554	13757	12229	12164	12273	12163	8816	12142	7267	12078	2111
	2222	2378	2310	2230	2228	2076	1751	2108	1715	2091	0.6820±0.0019]
	0.7049]	0.6358]	0.6685]	0.6729]	0.6709]	0.6523]	0.7375]	0.6514]	0.7720]	0.6535]	
0.85	[12659	[9286	[10894	[11037	[10934	[9233	[12907	[9222	[14504	[9297	[10997 11344
	10554	13757	12229	12164	12273	12163	8816	12142	7267	12078	2096
	2202	2372	2292	2214	2208	2064	1737	2096	1689	2085	0.6826±0.0019]
	0.7057]	0.6360]	0.6692]	0.6736]	0.6717]	0.6528]	0.7381]	0.6519]	0.7731]	0.6537]	
0.90	[12719	[9325	[10936	[11075	[10963	[9256	[12952	[9249	[14556	[9332	[11036 11344
	10554	13757	12229	12164	12273	12163	8816	12142	7267	12078	2057
	2142	2333	2250	2176	2179	2041	1692	2069	1637	2050	0.6842±0.0019]
	0.7081]	0.6376]	0.6709]	0.6751]	0.6728]	0.6538]	0.7400]	0.6530]	0.7753]	0.6552]	
0.92	[12750	[9375	[10896	[11059	[10827	[9159	[12915	[9189	[14466	[9345	[10998 11344
	10554	13757	12229	12164	12273	12163	8816	12142	7267	12078	2095
	2111	2283	2290	2192	2315	2138	1729	2129	1727	2037	0.6826±0.0019]
	0.7093]	0.6395]	0.6693]	0.6744]	0.6675]	0.6496]	0.7384]	0.6505]	0.7715]	0.6558]	
0.93	[12746	[9374	[10892	[11055	[10822	[9156	[12912	[9186	[14460	[9344	[10995 11344
	10554	13757	12229	12164	12273	12163	8816	12142	7267	12078	2099
	2115	2284	2294	2196	2320	2141	1732	2132	1733	2038	0.6824±0.0019]
	0.7091]	0.6395]	0.6692]	0.6743]	0.6673]	0.6495]	0.7383]	0.6503]	0.7712]	0.6557]	
0.94	[12702	[9347	[10848	[11020	[10769	[9113	[12861	[9149	[14398	[9311	[10952 11344
	10554	13757	12229	12164	12273	12163	8816	12142	7267	12078	2141
	2159	2311	2338	2231	2373	2184	1783	2169	1795	2071	0.6807±0.0018]
	0.7074]	0.6384]	0.6674]	0.6729]	0.6652]	0.6477]	0.7361]	0.6488]	0.7686]	0.6543]	
0.95	[12702	[9348	[10848	[11018	[10769	[9113	[12861	[9150	[14398	[9311	[10952 11344
	10554	13757	12229	12164	12273	12163	8816	12142	7267	12078	2141
	2159	2310	2338	2233	2373	2184	1783	2168	1795	2071	0.6807±0.0018]
	0.7074]	0.6385]	0.6674]	0.6728]	0.6652]	0.6477]	0.7361]	0.6488]	0.7686]	0.6543]	
0.96	[12699	[9348	[10841	[11013	[10756	[9101	[12850	[9145	[14387	[9304	[10944 11344
	10554	13757	12229	12164	12273	12163	8816	12142	7267	12078	2149
	2162	2310	2345	2238	2386	2196	1794	2173	1806	2078	0.6804±0.0018]
	0.7073]	0.6385]	0.6671]	0.6726]	0.6647]	0.6472]	0.7356]	0.6486]	0.7681]	0.6540]	
0.97	[12707	[9353	[10845	[11015	[10756	[9101	[12854	[9146	[14391	[9308	[10948 11344
	10554	13757	12229	12164	12273	12163	8816	12142	7267	12078	2146
	2154	2305	2341	2236	2386	2196	1790	2172	1802	2074	0.6805±0.0018]
	0.7076]	0.6387]	0.6673]	0.6727]	0.6647]	0.6472]	0.7358]	0.6486]	0.7683]	0.6542]	
0.98	[12715	[9361	[10849	[11012	[10756	[9101	[12858	[9150	[14395	[9312	[10951 11344
	10554	13757	12229	12164	12273	12163	8816	12142	7267	12078	2142
	2146	2297	2337	2239	2386	2196	1786	2168	1798	2070	0.6806±0.0018]
	0.7079]	0.6390]	0.6675]	0.6726]	0.6647]	0.6472]	0.7360]	0.6488]	0.7685]	0.6543]	
Chi-square method											
0.55	[12629	[9269	[10871	[11016	[10914	[9221	[12888	[9204	[14473	[9286	[10977 11344
	10554	13757	12229	12164	12273	12163	8816	12142	7267	12078	2116
	2232	2389	2315	2235	2228	2076	1756	2114	1720	2096	0.6818±0.0019]
	0.7045]	0.6354]	0.6683]	0.6728]	0.6709]	0.6523]	0.7373]	0.6511]	0.7718]	0.6532]	
0.60	[12639	[9280	[10876	[11023	[10914	[9221	[12893	[9210	[14478	[9291	[10983 11344
	10554	13757	12229	12164	12273	12163	8816	12142	7267	12078	2111
	2222	2378	2310	2228	2228	2076	1751	2108	1715	2091	0.6820±0.0019]
	0.7049]	0.6358]	0.6685]	0.6730]	0.6709]	0.6523]	0.7375]	0.6514]	0.7720]	0.6535]	
0.65	[12659	[9286	[10894	[11037	[10934	[9233	[12907	[9222	[14504	[9297	[10997 11344
	10554	13757	12229	12164	12273	12163	8816	12142	7267	12078	2096
	2202	2372	2292	2214	2208	2064	1737	2096	1689	2085	0.6826±0.0019]
	0.7057]	0.6360]	0.6692]	0.6736]	0.6717]	0.6528]	0.7381]	0.6519]	0.7731]	0.6537]	
0.70	[12663	[9292	[10896	[11039	[10934	[9233	[12909	[9226	[14506	[9299	[11000 11344
	10554	13757	12229	12164	12273	12163	8816	12142	7267	12078	2094
	2198	2366	2290	2212	2208	2064	1735	2092	1687	2083	0.6827±0.0019]
	0.7059]	0.6363]	0.6693]	0.6737]	0.6717]	0.6528]	0.7382]	0.6520]	0.7732]	0.6538]	
0.75	[12710	[9333	[10927	[11066	[10954	[9238	[12925	[9266	[14547	[9305	[11027 11344
	10554	13757	12229	12164	12273	12163	8816	12142	7267	12078	2066
	2151	2325	2259	2185	2188	2059	1719	2052	1646	2077	0.6838±0.0019]
	0.7077]	0.6379]	0.6705]	0.6747]	0.6725]	0.6530]	0.7388]	0.6538]	0.7750]	0.6540]	
0.80	[12750	[9375	[10896	[11058	[10827	[9159	[12915	[9189	[14466	[9345	[10998 11344
	10554	13757	12229	12164	12273	12163	8816	12142	7267	12078	2095
	2111	2283	2290	2193	2315	2138	1729	2129	1727	2037	0.6826±0.0019]

(*continued on next page*)

Table 10 (*continued*)

LPE_{OWA} orness($\mathbf{w}$) = α	Fold 1	Fold 2	Fold 3	Fold 4	Fold 5	Fold 6	Fold 7	Fold 8	Fold 9	Fold 10	Average
	0.7093]	0.6395]	0.6693]	0.6744]	0.6675]	0.6496]	0.7384]	0.6505]	0.7715]	0.6558]	
0.85	[12702 10554 2159 0.7074]	[9349 13757 2309 0.6385]	[10848 12229 2338 0.6674]	[11020 12164 2231 0.6729]	[10769 12273 2373 0.6652]	[9113 12163 2184 0.6477]	[12861 8816 1783 0.7361]	[9151 12142 2167 0.6488]	[14398 7267 1795 0.7686]	[9311 12078 2071 0.6543]	[10952 11344 2141 0.6807±0.0018]
0.90	[12702 10554 2159 0.7074]	[9354 13757 2304 0.6387]	[10844 12229 2342 0.6673]	[11016 12164 2235 0.6728]	[10759 12273 2383 0.6648]	[9107 12163 2190 0.6474]	[12859 8816 1785 0.7360]	[9148 12142 2170 0.6487]	[14390 7267 1803 0.7683]	[9313 12078 2069 0.6544]	[10949 11344 2144 0.6806±0.0018]
0.92	[12699 10554 2162 0.7073]	[9348 13757 2310 0.6385]	[10841 12229 2345 0.6671]	[11013 12164 2238 0.6726]	[10756 12273 2386 0.6647]	[9101 12163 2196 0.6472]	[12850 8816 1794 0.7356]	[9145 12142 2173 0.6486]	[14387 7267 1806 0.7681]	[9304 12078 2078 0.6540]	[10944 11344 2149 0.6804±0.0018]
0.93	[12699 10554 2162 0.7073]	[9349 13757 2309 0.6385]	[10841 12229 2345 0.6671]	[11011 12164 2240 0.6726]	[10756 12273 2386 0.6647]	[9101 12163 2196 0.6472]	[12850 8816 1794 0.7356]	[9146 12142 2172 0.6486]	[14387 7267 1806 0.7681]	[9304 12078 2078 0.6540]	[10944 11344 2149 0.6804±0.0018]
0.94	[12707 10554 2154 0.7076]	[9353 13757 2305 0.6387]	[10845 12229 2341 0.6673]	[11015 12164 2236 0.6727]	[10756 12273 2386 0.6647]	[9101 12163 2196 0.6472]	[12854 8816 1790 0.7358]	[9146 12142 2172 0.6486]	[14391 7267 1802 0.7683]	[9308 12078 2074 0.6542]	[10948 11344 2146 0.6805±0.0018]
0.95	[12715 10554 2146 0.7079]	[9361 13757 2297 0.6390]	[10849 12229 2337 0.6675]	[11012 12164 2239 0.6726]	[10756 12273 2386 0.6647]	[9101 12163 2196 0.6472]	[12858 8816 1786 0.7360]	[9150 12142 2168 0.6488]	[14395 7267 1798 0.7685]	[9312 12078 2070 0.6543]	[10951 11344 2142 0.6806±0.0018]
0.96	[12715 10554 2146 0.7079]	[9361 13757 2297 0.6390]	[10849 12229 2337 0.6675]	[11012 12164 2239 0.6726]	[10756 12273 2386 0.6647]	[9101 12163 2196 0.6472]	[12858 8816 1786 0.7360]	[9150 12142 2168 0.6488]	[14395 7267 1798 0.7685]	[9312 12078 2070 0.6543]	[10951 11344 2142 0.6806±0.0018]
0.97	[12749 10554 2112 0.7093]	[9342 13757 2316 0.6382]	[10854 12229 2332 0.6677]	[11017 12164 2234 0.6728]	[10732 12273 2410 0.6637]	[9053 12163 2244 0.6451]	[12815 8816 1829 0.7341]	[9126 12142 2192 0.6478]	[14400 7267 1793 0.7687]	[9269 12078 2113 0.6525]	[10936 11344 2158 0.6800±0.0019]
0.98	[12765 10554 2096 0.7099]	[9346 13757 2312 0.6384]	[10870 12229 2316 0.6683]	[11029 12164 2222 0.6733]	[10752 12273 2390 0.6645]	[9065 12163 2232 0.6456]	[12827 8816 1817 0.7347]	[9138 12142 2180 0.6483]	[14424 7267 1769 0.7697]	[9273 12078 2109 0.6527]	[10949 11344 2144 0.6805±0.0019]
LPE_{AM}	[17646 6120 1649 0.8147]	[8823 14110 2482 0.6247]	[10715 12645 2055 0.6704]	[10715 12645 2055 0.6704]	[8914 14205 2296 0.6302]	[12516 9385 1559 0.7335]	[5221 15530 2709 0.5535]	[8914 12505 2041 0.6465]	[8823 12410 2227 0.6406]	[14317 7825 1318 0.7770]	[10660 11738 2039 0.6762 0.0061]

4. Experimental comparison and analysis

4.1. Ensemble with all 9 individual algorithms

In this section, we test the prediction performance (i.e., AUC) of LPE_{OWA} based on the social networks mentioned in Section 2.3. The 10-fold cross-validation is also used to conduct the experimental comparisons. The detailed results are summarized in Tables 8–11. According to the comparative results in Tables 8–11, we explain the experimental setup and further give our analysis. The optimal weights of MEM, MVM and CSM corresponding to 15 different optimal level factors (i.e., α=0.55, 0.60, 0.65, 0.70, 0.75, 0.80, 0.85, 0.90, 0.92, 0.93, 0.94, 0.95, 0.96, 0.97 and 0.98) are solved respectively by using LINGO software. The LPE_{OWA}s with different associated weights are evaluated on the same testing set. There is no special reason for the selection of α. We only want to check the impact of this parameter on the performance of LPE_{OWA}. In addition, we also conduct the comparison among LPE_{OWA}, arithmetic mean based link prediction ensemble (LPE_{AM}), and weighted arithmetic mean based link prediction ensemble (LPE_{WAM}). The illustrations based on the experimental results in Tables 8–11 are also presented in Figs. 8–11. By comparing the detailed results in Tables 8–11 with ones in Tables 4–7, we can get the following observations:

- The performances of LPE_{OWA}s on WSDP98, ChesLower and C96 networks are better than any individual local-information based link prediction algorithm. This indicates that our proposed ensemble strategy is not only feasible but also effective for these 3 networks. The ensemble with these 9 algorithms can not obtain higher AUCs on B97 network.
- For WSDP98, ChesLower and C96 networks (Figs. 8–10), AUCs of LPE_{OWA}s based on the associated weights solved with MEM, MVM and CSM all keep the tendencies of first increase and then decrease with the increase of α. The performances of MEM based LPE_{OWA}s are superior to MVM and CSM based ones. For B97 network, the AUCs of MEM, MVM and CSM based LPE_{OWA}s all decrease gradually with the increase of α. The performances of MVM based LPE_{OWA}s are better than MVM and CSM based ones.
- LPE_{OWA} is obviously better than LPE_{AM}. For example, the prediction accuracies of LPE_{AM} on WSDP98, ChesLower, C96, and B97 are 0.5776, 0.5086, 0.6762, and 0.7746 respectively. However, the lowest accuracies of LPE_{OWA} on these four networks, i.e., 0.7494, 0.7599, 0.6800, and 0.8056, are also higher than LPE_{AM}.
- In order to compare LPE_{OWA} with LPE_{WAM}, we generated 1000 different weight vectors to construct LPE_{WAM}. The comparative results on WSDP98 (Fig. 12) and ChesLower (Fig. 13) show that LPE_{OWA} is statistically better than LPE_{WAM}: the numbers of

Table 11
Prediction performances of LPE_{OWA} and LPE_{AM} algorithms on the network of Graph Drawing Contests Data-B97.

LPE_{OWA} orness($\mathbf{w}$) = α	Fold 1	Fold 2	Fold 3	Fold 4	Fold 5	Fold 6	Fold 7	Fold 8	Fold 9	Fold 10	Average
Maximum entropy method											
0.55	[20048 431 3902 0.8311]	[20456 15 3910 0.8393]	[20070 447 3864 0.8323]	[20670 446 3265 0.8569]	[19487 16 3975 0.8304]	[20965 14 2499 0.8933]	[20176 13 3289 0.8596]	[19998 423 3057 0.8608]	[18953 870 3655 0.8258]	[19553 51 3874 0.8339]	[20038 273 3529 0.8463±0.0004]
0.60	[19984 431 3966 0.8285]	[20433 15 3933 0.8384]	[20028 447 3906 0.8306]	[20612 446 3323 0.8546]	[19448 16 4014 0.8287]	[20936 14 2528 0.8920]	[20133 13 3332 0.8578]	[19982 423 3073 0.8601]	[18939 870 3669 0.8252]	[19541 51 3886 0.8334]	[20004 273 3563 0.8449±0.0004]
0.65	[19909 431 4041 0.8254]	[20416 15 3950 0.8377]	[19968 447 3966 0.8282]	[20532 446 3403 0.8513]	[19412 16 4050 0.8272]	[20913 14 2551 0.8910]	[20077 13 3388 0.8554]	[19979 423 3076 0.8600]	[18936 870 3672 0.8251]	[19552 51 3875 0.8339]	[19969 273 3597 0.8435±0.0004]
0.70	[19808 431 4142 0.8213]	[20396 15 3970 0.8369]	[19841 447 4093 0.8230]	[20458 446 3477 0.8482]	[19356 16 4106 0.8248]	[20872 14 2592 0.8893]	[20018 13 3447 0.8529]	[19926 423 3129 0.8577]	[18924 870 3684 0.8246]	[19569 51 3858 0.8346]	[19917 273 3650 0.8413±0.0005]
0.75	[19748 431 4202 0.8188]	[20322 15 4044 0.8338]	[19788 447 4146 0.8208]	[20433 446 3502 0.8472]	[19329 16 4133 0.8236]	[20853 14 2611 0.8885]	[19959 13 3506 0.8504]	[19899 423 3156 0.8566]	[18906 870 3702 0.8238]	[19563 51 3864 0.8343]	[19880 273 3687 0.8398±0.0005]
0.80	[19646 431 4304 0.8146]	[20292 15 4074 0.8326]	[19730 447 4204 0.8184]	[20261 446 3674 0.8402]	[19284 16 4178 0.8217]	[20798 14 2666 0.8861]	[19852 13 3613 0.8458]	[19809 423 3246 0.8527]	[18855 870 3753 0.8216]	[19503 51 3924 0.8318]	[19803 273 3764 0.8366±0.0005]
0.85	[19420 431 4530 0.8054]	[20215 15 4151 0.8294]	[19592 447 4342 0.8127]	[20157 446 3778 0.8359]	[19181 16 4281 0.8173]	[20709 14 2755 0.8824]	[19714 13 3751 0.8400]	[19725 423 3330 0.8492]	[18800 870 3808 0.8193]	[19467 51 3960 0.8302]	[19698 273 3869 0.8322±0.0005]
0.90	[19251 431 4699 0.7984]	[20039 15 4327 0.8222]	[19447 447 4487 0.8068]	[19953 446 3982 0.8275]	[19027 16 4435 0.8108]	[20602 14 2862 0.8778]	[19523 13 3942 0.8318]	[19595 423 3460 0.8436]	[18751 870 3857 0.8172]	[19424 51 4003 0.8284]	[19561 273 4005 0.8265±0.0005]
0.92	[19106 431 4844 0.7925]	[19952 15 4414 0.8186]	[19360 447 4574 0.8032]	[19884 446 4051 0.8247]	[18929 16 4533 0.8066]	[20536 14 2928 0.8750]	[19414 13 4051 0.8272]	[19524 423 3531 0.8406]	[18710 870 3898 0.8154]	[19391 51 4036 0.8270]	[19481 273 4086 0.8231±0.0005]
0.93	[19041 431 4909 0.7898]	[19908 15 4458 0.8168]	[19341 447 4593 0.8024]	[19830 446 4105 0.8225]	[18892 16 4570 0.8050]	[20505 14 2959 0.8737]	[19332 13 4133 0.8237]	[19477 423 3578 0.8386]	[18692 870 3916 0.8147]	[19372 51 4055 0.8262]	[19439 273 4128 0.8213±0.0005]
0.94	[19003 431 4947 0.7883]	[19855 15 4511 0.8147]	[19305 447 4629 0.8010]	[19790 446 4145 0.8208]	[18855 16 4607 0.8034]	[20436 14 3028 0.8707]	[19292 13 4173 0.8220]	[19377 423 3678 0.8343]	[18643 870 3965 0.8126]	[19344 51 4083 0.8250]	[19390 273 4177 0.8193±0.0005]
0.95	[18909 431 5041 0.7844]	[19812 15 4554 0.8129]	[19228 447 4706 0.7978]	[19738 446 4197 0.8187]	[18814 16 4648 0.8017]	[20373 14 3091 0.8680]	[19239 13 4226 0.8197]	[19324 423 3731 0.8321]	[18615 870 3993 0.8114]	[19316 51 4111 0.8238]	[19337 273 4230 0.8171±0.0005]
0.96	[18765 431 5185 0.7785]	[19699 15 4667 0.8083]	[19152 447 4782 0.7947]	[19660 446 4275 0.8155]	[18742 16 4720 0.7986]	[20324 14 3140 0.8660]	[19174 13 4291 0.8170]	[19252 423 3803 0.8290]	[18581 870 4027 0.8099]	[19277 51 4150 0.8222]	[19263 273 4304 0.8140±0.0005]
0.97	[18696 431 5254 0.7757]	[19623 15 4743 0.8052]	[19057 447 4877 0.7908]	[19534 446 4401 0.8103]	[18647 16 4815 0.7946]	[20253 14 3211 0.8629]	[19065 13 4400 0.8123]	[19189 423 3866 0.8263]	[18534 870 4074 0.8079]	[19256 51 4171 0.8213]	[19185 273 4381 0.8107±0.0006]
0.98	[18557 431 5393 0.7700]	[19523 15 4843 0.8011]	[18990 447 4944 0.7881]	[19437 446 4498 0.8064]	[18567 16 4895 0.7912]	[20215 14 3249 0.8613]	[18955 13 4510 0.8076]	[19125 423 3930 0.8236]	[18516 870 4092 0.8072]	[19231 51 4196 0.8202]	[19112 273 4455 0.8077±0.0006]
Minimum variance method											
0.55	[20095 431 3855 0.8330]	[20489 15 3877 0.8407]	[20082 447 3852 0.8328]	[20719 446 3216 0.8589]	[19493 16 3969 0.8306]	[21000 14 2464 0.8948]	[20235 13 3230 0.8621]	[20013 423 3042 0.8614]	[18964 870 3644 0.8263]	[19562 51 3865 0.8343]	[20065 273 3501 0.8475±0.0005]
0.60	[20095 431 3855 0.8330]	[20489 15 3877 0.8407]	[20082 447 3852 0.8328]	[20719 446 3216 0.8589]	[19493 16 3969 0.8306]	[21000 14 2464 0.8948]	[20235 13 3230 0.8621]	[20013 423 3042 0.8614]	[18964 870 3644 0.8263]	[19562 51 3865 0.8343]	[20065 273 3501 0.8475±0.0005]
0.65	[20095 431 3855 0.8330]	[20489 15 3877 0.8407]	[20082 447 3852 0.8328]	[20719 446 3216 0.8589]	[19493 16 3969 0.8306]	[21000 14 2464 0.8948]	[20235 13 3230 0.8621]	[20013 423 3042 0.8614]	[18964 870 3644 0.8263]	[19562 51 3865 0.8343]	[20065 273 3501 0.8475±0.0005]
0.70	[20095 431 3855 0.8330]	[20489 15 3877 0.8407]	[20082 447 3852 0.8328]	[20719 446 3216 0.8589]	[19493 16 3969 0.8306]	[21000 14 2464 0.8948]	[20235 13 3230 0.8621]	[20013 423 3042 0.8614]	[18964 870 3644 0.8263]	[19562 51 3865 0.8343]	[20065 273 3501 0.8475±0.0005]
0.75	[20074 431 3876 0.8322]	[20437 15 3929 0.8385]	[20056 447 3878 0.8318]	[20710 446 3225 0.8586]	[19492 16 3970 0.8306]	[21004 14 2460 0.8949]	[20215 13 3250 0.8613]	[19993 423 3062 0.8606]	[18962 870 3646 0.8262]	[19565 51 3862 0.8344]	[20051 273 3516 0.8469±0.0005]
0.80	[20061 431 3889 0.8317]	[20464 15 3902 0.8396]	[20096 447 3838 0.8334]	[20708 446 3227 0.8585]	[19494 16 3968 0.8306]	[20972 14 2492 0.8936]	[20186 13 3279 0.8601]	[19993 423 3062 0.8606]	[18963 870 3645 0.8262]	[19545 51 3882 0.8336]	[20048 273 3518 0.8468±0.0004]
0.85	[20006 431 3944 0.8294]	[20449 15 3917 0.8390]	[20036 447 3898 0.8310]	[20614 446 3321 0.8546]	[19488 16 3974 0.8304]	[20923 14 2541 0.8915]	[20146 13 3319 0.8584]	[20020 423 3035 0.8617]	[18955 870 3653 0.8259]	[19589 51 3838 0.8354]	[20023 273 3544 0.8457±0.0004]
0.90	[19832 431 4118 0.8223]	[20399 15 3967 0.8370]	[19885 447 4049 0.8248]	[20417 446 3518 0.8466]	[19396 16 4066 0.8265]	[20840 14 2624 0.8879]	[19955 13 3510 0.8502]	[20033 423 3022 0.8623]	[18958 870 3650 0.8260]	[19577 51 3850 0.8349]	[19929 273 3637 0.8418±0.0004]
0.92	[19637 431 4313	[20320 15 4046	[19752 447 4182	[20304 446 3631	[19326 16 4136	[20763 14 2701	[19811 13 3654	[19947 423 3108	[18915 870 3693	[19553 51 3874	[19833 273 3734

(continued on next page)

Table 11 (*continued*)

LPE_{OWA} orness($\mathbf{w}$) = α	Fold 1	Fold 2	Fold 3	Fold 4	Fold 5	Fold 6	Fold 7	Fold 8	Fold 9	Fold 10	Average
	0.8143]	0.8337]	0.8193]	0.8419]	0.8235]	0.8847]	0.8441]	0.8586]	0.8242]	0.8339]	0.8378±0.0004]
0.93	[19469 431 4481 0.8074]	[20250 15 4116 0.8309]	[19642 447 4292 0.8148]	[20175 446 3760 0.8366]	[19258 16 4204 0.8206]	[20717 14 2747 0.8827]	[19674 13 3791 0.8383]	[19841 423 3214 0.8541]	[18853 870 3755 0.8215]	[19511 51 3916 0.8321]	[19739 273 3828 0.8339±0.0005]
0.94	[19316 431 4634 0.8011]	[20186 15 4180 0.8282]	[19531 447 4403 0.8102]	[20031 446 3904 0.8307]	[19131 16 4331 0.8152]	[20622 14 2842 0.8787]	[19572 13 3893 0.8339]	[19722 423 3333 0.8490]	[18824 870 3784 0.8203]	[19481 51 3946 0.8308]	[19642 273 3925 0.8298±0.0005]
0.95	[19178 431 4772 0.7954]	[20013 15 4353 0.8212]	[19438 447 4496 0.8064]	[19908 446 4027 0.8257]	[19014 16 4448 0.8102]	[20550 14 2914 0.8756]	[19397 13 4068 0.8265]	[19598 423 3457 0.8437]	[18761 870 3847 0.8176]	[19453 51 3974 0.8296]	[19531 273 4036 0.8252±0.0005]
0.96	[19050 431 4900 0.7902]	[19914 15 4452 0.8171]	[19338 447 4596 0.8023]	[19831 446 4104 0.8225]	[18942 16 4520 0.8071]	[20487 14 2977 0.8729]	[19323 13 4142 0.8233]	[19473 423 3582 0.8384]	[18678 870 3930 0.8141]	[19398 51 4029 0.8273]	[19443 273 4123 0.8215±0.0005]
0.97	[18795 431 5155 0.7797]	[19742 15 4624 0.8100]	[19157 447 4777 0.7949]	[19642 446 4293 0.8148]	[18754 16 4708 0.7991]	[20346 14 3118 0.8669]	[19149 13 4316 0.8159]	[19275 423 3780 0.8300]	[18592 870 4016 0.8104]	[19294 51 4133 0.8229]	[19275 273 4292 0.8145±0.0005]
0.98	[18585 431 5365 0.7711]	[19576 15 4790 0.8032]	[19017 447 4917 0.7892]	[19507 446 4428 0.8092]	[18610 16 4852 0.7930]	[20236 14 3228 0.8622]	[19020 13 4445 0.8104]	[19156 423 3899 0.8249]	[18533 870 4075 0.8079]	[19242 51 4185 0.8207]	[19148 273 4418 0.8092±0.0006]
Chi-square method											
0.55	[20210 431 3740 0.8378]	[20561 15 3805 0.8436]	[20133 447 3801 0.8349]	[20758 446 3177 0.8605]	[19571 16 3891 0.8339]	[21037 14 2427 0.8963]	[20307 13 3158 0.8652]	[20057 423 2998 0.8633]	[18983 870 3625 0.8271]	[19579 51 3848 0.8350]	[20120 273 3447 0.8498±0.0005]
0.60	[20113 431 3837 0.8338]	[20525 15 3841 0.8422]	[20104 447 3830 0.8337]	[20715 446 3220 0.8588]	[19533 16 3929 0.8323]	[20994 14 2470 0.8945]	[20233 13 3232 0.8621]	[20040 423 3015 0.8626]	[18964 870 3644 0.8263]	[19567 51 3860 0.8345]	[20079 273 3488 0.8481±0.0004]
0.65	[20007 431 3943 0.8294]	[20460 15 3906 0.8395]	[20059 447 3875 0.8319]	[20644 446 3291 0.8559]	[19489 16 3973 0.8304]	[20935 14 2529 0.8920]	[20155 13 3310 0.8587]	[20018 423 3037 0.8616]	[18955 870 3653 0.8259]	[19568 51 3859 0.8345]	[20029 273 3538 0.8460±0.0004]
0.70	[19904 431 4046 0.8252]	[20424 15 3942 0.8380]	[19936 447 3998 0.8269]	[20514 446 3421 0.8505]	[19424 16 4038 0.8277]	[20889 14 2575 0.8900]	[20085 13 3380 0.8558]	[20002 423 3053 0.8610]	[18942 870 3666 0.8253]	[19580 51 3847 0.8351]	[19970 273 3597 0.8435±0.0004]
0.75	[19751 431 4199 0.8189]	[20359 15 4007 0.8353]	[19801 447 4133 0.8213]	[20392 446 3543 0.8455]	[19358 16 4104 0.8249]	[20837 14 2627 0.8878]	[19950 13 3515 0.8500]	[19920 423 3135 0.8575]	[18906 870 3702 0.8238]	[19572 51 3855 0.8347]	[19885 273 3682 0.8400±0.0005]
0.80	[19572 431 4378 0.8116]	[20261 15 4105 0.8313]	[19680 447 4254 0.8164]	[20211 446 3724 0.8381]	[19218 16 4244 0.8189]	[20765 14 2699 0.8847]	[19813 13 3652 0.8442]	[19816 423 3239 0.8530]	[18854 870 3754 0.8216]	[19496 51 3931 0.8315]	[19769 273 3798 0.8351±0.0005]
0.85	[19324 431 4626 0.8014]	[20068 15 4298 0.8234]	[19491 447 4443 0.8086]	[20047 446 3888 0.8314]	[19061 16 4401 0.8122]	[20642 14 2822 0.8795]	[19562 13 3903 0.8335]	[19617 423 3438 0.8446]	[18763 870 3845 0.8177]	[19441 51 3986 0.8291]	[19602 273 3965 0.8281±0.0005]
0.90	[19034 431 4916 0.7895]	[19873 15 4493 0.8154]	[19335 447 4599 0.8022]	[19814 446 4121 0.8218]	[18880 16 4582 0.8045]	[20470 14 2994 0.8722]	[19310 13 4155 0.8227]	[19428 423 3627 0.8365]	[18679 870 3929 0.8141]	[19373 51 4054 0.8262]	[19420 273 4147 0.8205±0.0005]
0.92	[18935 431 5015 0.7855]	[19833 15 4533 0.8138]	[19241 447 4693 0.7983]	[19749 446 4186 0.8192]	[18825 16 4637 0.8022]	[20401 14 3063 0.8692]	[19247 13 4218 0.8201]	[19324 423 3731 0.8321]	[18622 870 3986 0.8117]	[19323 51 4104 0.8241]	[19350 273 4217 0.8176±0.0005]
0.93	[18870 431 5080 0.7828]	[19755 15 4611 0.8106]	[19212 447 4722 0.7972]	[19717 446 4218 0.8178]	[18785 16 4677 0.8005]	[20368 14 3096 0.8678]	[19203 13 4262 0.8182]	[19295 423 3760 0.8308]	[18605 870 4003 0.8110]	[19300 51 4127 0.8231]	[19311 273 4256 0.8160±0.0005]
0.94	[18760 431 5190 0.7783]	[19698 15 4668 0.8082]	[19146 447 4788 0.7945]	[19639 446 4296 0.8147]	[18724 16 4738 0.7979]	[20328 14 3136 0.8661]	[19166 13 4299 0.8166]	[19242 423 3813 0.8286]	[18566 870 4042 0.8093]	[19267 51 4160 0.8217]	[19254 273 4313 0.8136±0.0006]
0.95	[18726 431 5224 0.7769]	[19629 15 4737 0.8054]	[19098 447 4836 0.7925]	[19572 446 4363 0.8119]	[18682 16 4780 0.7961]	[20264 14 3200 0.8634]	[19109 13 4356 0.8142]	[19198 423 3857 0.8267]	[18552 870 4056 0.8087]	[19260 51 4167 0.8214]	[19209 273 4358 0.8117±0.0005]
0.96	[18641 431 5309 0.7734]	[19585 15 4781 0.8036]	[19026 447 4908 0.7895]	[19511 446 4424 0.8094]	[18609 16 4853 0.7930]	[20243 14 3221 0.8625]	[19036 13 4429 0.8111]	[19147 423 3908 0.8245]	[18527 870 4081 0.8076]	[19241 51 4186 0.8206]	[19157 273 4410 0.8095±0.0006]
0.97	[18566 431 5384 0.7703]	[19526 15 4840 0.8012]	[18990 447 4944 0.7881]	[19440 446 4495 0.8065]	[18562 16 4900 0.7910]	[20218 14 3246 0.8614]	[18955 13 4510 0.8076]	[19123 423 3932 0.8235]	[18519 870 4089 0.8073]	[19229 51 4198 0.8201]	[19113 273 4454 0.8077±0.0006]
0.98	[18464 431 5486 0.7661]	[19473 15 4893 0.7990]	[18947 447 4987 0.7863]	[19412 446 4523 0.8053]	[18489 16 4973 0.7878]	[20182 14 3282 0.8599]	[18893 13 4572 0.8050]	[19066 423 3989 0.8211]	[18478 870 4130 0.8056]	[19218 51 4209 0.8196]	[19062 273 4504 0.8056±0.0006]
LPE_{AM}	[17551 3279 3551 0.7871]	[18256 3088 3037 0.8121]	[18155 3449 2777 0.8154]	[16780 3813 3788 0.7664]	[17285 2830 3363 0.7965]	[16094 3357 4027 0.7570]	[14760 3986 4732 0.7136]	[16199 3607 3672 0.7668]	[16193 3153 4132 0.7569]	[16095 4148 3235 0.7739]	[16737 3471 3631 0.7746 0.0009]

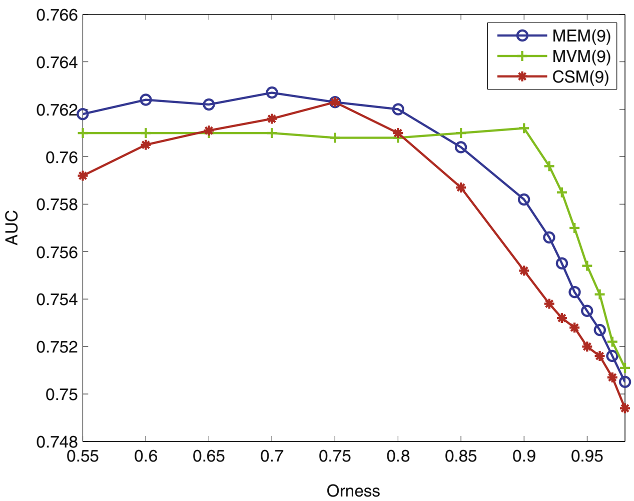


Fig. 8. Comparative results of $\mathrm{LPE_{OWA}}$s on WSDP98.

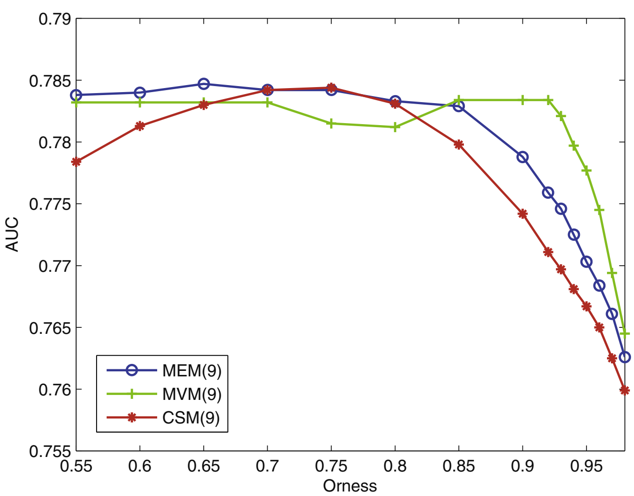


Fig. 9. Comparative results of $\mathrm{LPE_{OWA}}$s on ChesLower.

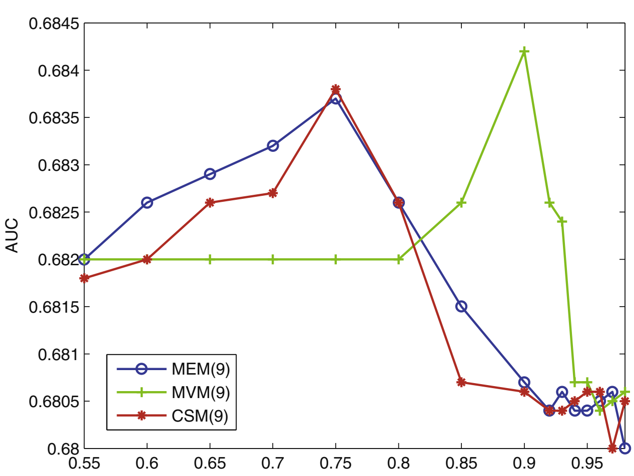


Fig. 10. Comparative results of $\mathrm{LPE_{OWA}}$s on C96.

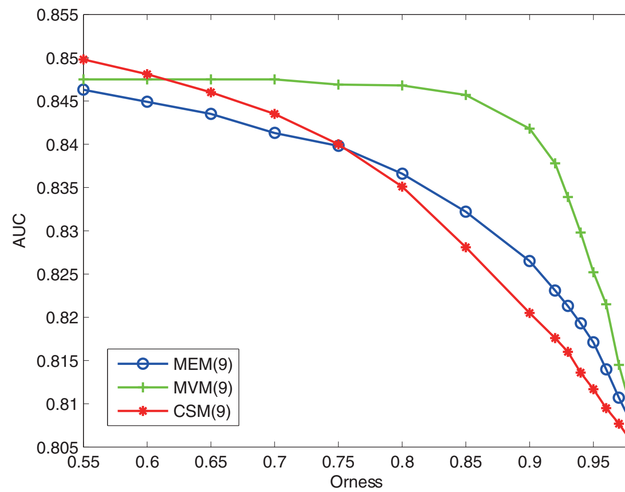


Fig. 11. Comparative results of $\mathrm{LPE_{OWA}}$s on B97.

$\mathrm{LPE_{OWA}}$ obtaining higher AUCs than $\mathrm{LPE_{WAM}}$ are 992 and 991 respectively on WSDP98 and ChesLower networks. The experimental results on WSDP98 as shown in Fig. 12 present that there are 992 and 910 pentagrams (AUCs of $\mathrm{LPE_{WAM}}$) which are located below red line (Maximal AUCs of $\mathrm{LPE_{OWA}}$) and black line (Minimal AUCs of $\mathrm{LPE_{OWA}}$) respectively. And, the results on ChesLower as shown in Fig. 13 show that there are 991 and 898 pentagrams which are located below red line and black line respectively. This reflects that the lowest prediction accuracies of $\mathrm{LPE_{OWA}}$ are also obviously better than $\mathrm{LPE_{WAM}}$. The experiment tells us that the exhaustive search must find the optimal weight vectors to design the link prediction ensemble, but it is infeasible due to high running time. OWA can indeed provide us a feasible and efficient weight vector to aggregate different individual prediction algorithms with acceptable accuracy and low computational complexity.

Three advantages of $\mathrm{LPE_{OWA}}$ can be concluded by summarizing these experimental results: (1) $\mathrm{LPE_{OWA}}$ obtains the higher prediction accuracies compared with any individual algorithm through increasing the numbers (i.e., n_1s) of missing links having higher scores. For example, n_1s on any fold in Tables 4–6 are larger than the corresponding ones in Tables 8–10. (2) $\mathrm{LPE_{OWA}}$ reduces the possibility that user selects a weak link prediction algorithm and thus improve the high variability. (3) $\mathrm{LPE_{OWA}}$ is more stable in comparison with individual algorithm because of the lower prediction variances. In addition, the computational complexity of $\mathrm{LPE_{OWA}}$ is $O(\|V\|)$ which is same as the individual algorithm. The selection of parameter α plays a positive impact on the performance of $\mathrm{LPE_{OWA}}$, i.e., the larger α gives rise to higher prediction accuracy through more emphasizing the individual algorithm with higher probability.

4.2. Ensemble with some of 9 individual algorithms

Our experiments also test the performances of three different kinds of ensemble algorithms: the ensemble of sn_{xy}^{CN}, sn_{xy}^{HPI}, $sn_{xy}^{\mathrm{Salton}}$, $sn_{xy}^{\mathrm{Sørensen}}$, sn_{xy}^{HDI}, $sn_{xy}^{\mathrm{Jaccard}}$ and $sn_{xy}^{\mathrm{LHN-I}}$, the ensemble of sn_{xy}^{AA}, sn_{xy}^{HPI}, $sn_{xy}^{\mathrm{Salton}}$, $sn_{xy}^{\mathrm{Sørensen}}$, sn_{xy}^{HDI}, $sn_{xy}^{\mathrm{Jaccard}}$ and $sn_{xy}^{\mathrm{LHN-I}}$, and the ensemble of sn_{xy}^{RA}, sn_{xy}^{HPI}, $sn_{xy}^{\mathrm{Salton}}$, $sn_{xy}^{\mathrm{Sørensen}}$, sn_{xy}^{HDI}, $sn_{xy}^{\mathrm{Jaccard}}$ and $sn_{xy}^{\mathrm{LHN-I}}$. We denote these 3 ensemble algorithms as $\mathrm{LPE_{OWA}}(7a)$, $\mathrm{LPE_{OWA}}(7b)$ and $\mathrm{LPE_{OWA}}(7c)$ respectively. In fact, we can find that $\mathrm{LPE_{OWA}}(7a)$ is the ensemble of a number of common neighbors of x and y and degrees of x and y, while $\mathrm{LPE_{OWA}}(7b)$ and $\mathrm{LPE_{OWA}}(7c)$ are the ensembles of degrees of x and y and degrees of common neighbors of x and y.

Here, we only consider using MEM in Eq. (19) to determine the associate weights for OWA operator due to its better performance

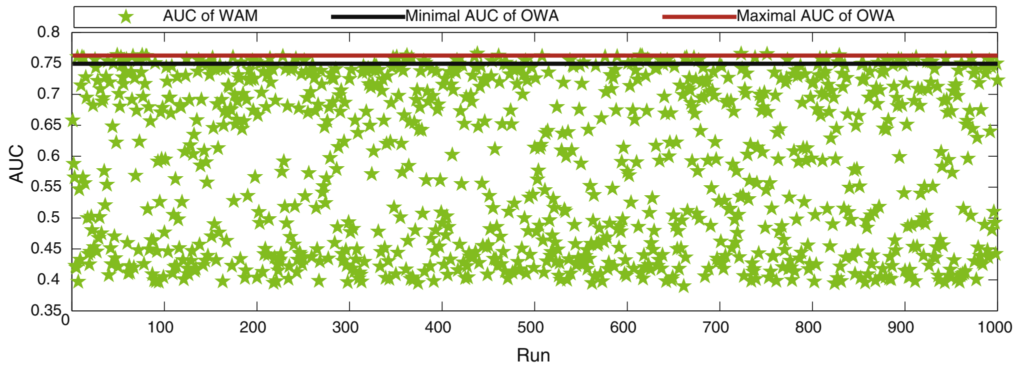


Fig. 12. 1000 AUCs of $\mathrm{LPE}_{\mathrm{WAM}}$ on WSDP98.

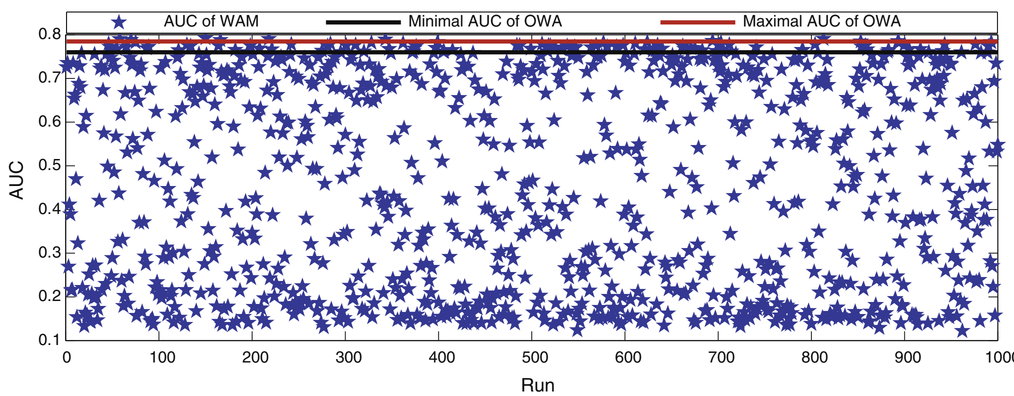


Fig. 13. 1000 AUCs of $\mathrm{LPE}_{\mathrm{WAM}}$ on ChesLower.

Table 12
Prediction performances of $\mathrm{LPE}_{\mathrm{OWA}}(7a)$ algorithm on 4 social networks.

$\mathrm{Orness}(\mathbf{w}) = \alpha$	Fold 1	Fold 2	Fold 3	Fold 4	Fold 5	Fold 6	Fold 7	Fold 8	Fold 9	Fold 10	Average
WSDP98 network											
0.55	[4512 343 869 0.8182]	[3983 509 1232 0.7403]	[4218 508 998 0.7813]	[4689 192 843 0.8360]	[4643 7 1074 0.8118]	[4126 511 1087 0.7655]	[3879 362 1483 0.7093]	[4226 344 1154 0.7683]	[3684 508 1055 0.7505]	[3096 691 1460 0.6559]	[4106 398 1126 0.7637±0.0029]
0.60	[4517 343 864 0.8191]	[3984 509 1231 0.7405]	[4219 508 997 0.7814]	[4693 192 839 0.8367]	[4648 7 1069 0.8126]	[4137 511 1076 0.7674]	[3876 362 1486 0.7088]	[4234 344 1146 0.7697]	[3688 508 1051 0.7513]	[3096 691 1460 0.6559]	[4109 398 1122 0.7643±0.0029]
0.65	[4520 343 861 0.8196]	[3979 509 1236 0.7396]	[4220 508 996 0.7816]	[4699 192 833 0.8377]	[4651 7 1066 0.8132]	[4137 511 1076 0.7674]	[3882 362 1480 0.7098]	[4241 344 1139 0.7710]	[3684 508 1055 0.7505]	[3095 691 1461 0.6557]	[4111 398 1120 0.7646±0.0030]
0.70	[4532 343 849 0.8217]	[3983 509 1232 0.7403]	[4220 508 996 0.7816]	[4710 192 822 0.8396]	[4668 7 1049 0.8161]	[4140 511 1073 0.7679]	[3885 362 1477 0.7103]	[4245 344 1135 0.7717]	[3683 508 1056 0.7503]	[3095 691 1461 0.6557]	[4116 398 1115 0.7655±0.0031]
0.75	[4543 343 838 0.8236]	[3986 509 1229 0.7408]	[4222 508 994 0.7820]	[4734 192 798 0.8438]	[4667 7 1050 0.8160]	[4147 511 1066 0.7691]	[3889 362 1473 0.7110]	[4248 344 1132 0.7722]	[3686 508 1053 0.7509]	[3092 691 1464 0.6551]	[4121 398 1110 0.7665±0.0031]
0.80	[4543 343 838 0.8236]	[3978 509 1237 0.7394]	[4229 508 987 0.7832]	[4739 192 793 0.8447]	[4683 7 1034 0.8187]	[4152 511 1061 0.7700]	[3891 362 1471 0.7114]	[4247 344 1133 0.7720]	[3684 508 1055 0.7505]	[3097 691 1459 0.6561]	[4124 398 1107 0.7670±0.0032]
0.85	[4545 343 836 0.8240]	[3974 509 1241 0.7387]	[4232 508 984 0.7837]	[4753 192 779 0.8471]	[4682 7 1035 0.8186]	[4154 511 1059 0.7704]	[3890 362 1472 0.7112]	[4248 344 1132 0.7722]	[3681 508 1058 0.7500]	[3093 691 1463 0.6553]	[4125 398 1106 0.7671±0.0033]
0.90	[4559 343 822 0.8264]	[3977 509 1238 0.7393]	[4229 508 987 0.7832]	[4754 192 778 0.8473]	[4714 7 1003 0.8242]	[4162 511 1051 0.7718]	[3890 362 1472 0.7112]	[4277 344 1103 0.7773]	[3680 508 1059 0.7498]	[3085 691 1471 0.6538]	[4133 398 1098 0.7684±0.0034]
0.92	[4558 343 823 0.8263]	[3984 509 1231 0.7405]	[4227 508 989 0.7828]	[4759 192 773 0.8482]	[4722 7 995 0.8256]	[4160 511 1053 0.7714]	[3891 362 1471 0.7114]	[4279 344 1101 0.7776]	[3674 508 1065 0.7486]	[3078 691 1478 0.6525]	[4133 398 1098 0.7685±0.0035]
0.93	[4559 343 822 0.8264]	[3981 509 1234 0.7400]	[4227 508 989 0.7828]	[4760 192 772 0.8484]	[4730 7 987 0.8270]	[4158 511 1055 0.7711]	[3886 362 1476 0.7105]	[4271 344 1109 0.7762]	[3672 508 1067 0.7482]	[3078 691 1478 0.6525]	[4132 398 1099 0.7683±0.0035]
0.94	[4562 343	[3984 509	[4225 508	[4769 192	[4735 7	[4157 511	[3888 362	[4266 344	[3661 508	[3079 691	[4133 398 1099

Table 12 (*continued*)

Orness($\mathbf{w}$) = α	Fold 1	Fold 2	Fold 3	Fold 4	Fold 5	Fold 6	Fold 7	Fold 8	Fold 9	Fold 10	Average
	819 0.8270]	1231 0.7405]	991 0.7825]	763 0.8499]	982 0.8278]	1056 0.7709]	1474 0.7109]	1114 0.7753]	1078 0.7461]	1477 0.6527]	0.7684±0.0035]
0.95	[4570 343 811 0.8284]	[3973 509 1242 0.7386]	[4223 508 993 0.7821]	[4774 192 758 0.8508]	[4733 7 984 0.8275]	[4157 511 1056 0.7709]	[3892 362 1470 0.7116]	[4259 344 1121 0.7741]	[3658 508 1081 0.7456]	[3080 691 1476 0.6528]	[4132 398 1099 0.7682±0.0036]
0.96	[4570 343 811 0.8284]	[3957 509 1258 0.7358]	[4220 508 996 0.7816]	[4785 192 747 0.8527]	[4727 7 990 0.8264]	[4156 511 1057 0.7707]	[3898 362 1464 0.7126]	[4261 344 1119 0.7745]	[3654 508 1085 0.7448]	[3072 691 1484 0.6513]	[4130 398 1101 0.7679±0.0036]
0.97	[4570 343 811 0.8284]	[3948 509 1267 0.7342]	[4219 508 997 0.7814]	[4790 192 742 0.8536]	[4733 7 984 0.8275]	[4152 511 1061 0.7700]	[3898 362 1464 0.7126]	[4264 344 1116 0.7750]	[3649 508 1090 0.7439]	[3069 691 1487 0.6508]	[4129 398 1102 0.7677±0.0037]
0.98	[4576 343 805 0.8294]	[3936 509 1279 0.7321]	[4218 508 998 0.7813]	[4795 192 737 0.8545]	[4741 7 976 0.8289]	[4153 511 1060 0.7702]	[3897 362 1465 0.7124]	[4261 344 1119 0.7745]	[3644 508 1095 0.7429]	[3062 691 1494 0.6494]	[4128 398 1103 0.7676±0.0038]
ChesLower network											
0.55	[7225 16 1242 0.8526]	[5782 21 2680 0.6828]	[7347 12 1124 0.8668]	[6438 22 2023 0.7602]	[6247 17 2219 0.7374]	[7323 7 1153 0.8637]	[7158 12 1313 0.8445]	[6826 11 1147 0.8556]	[6207 17 1760 0.7785]	[5947 14 2023 0.7457]	[6650 15 1668 0.7988±0.0043]
0.60	[7237 16 1230 0.8541]	[5816 21 2646 0.6868]	[7349 12 1122 0.8670]	[6437 22 2024 0.7601]	[6262 17 2204 0.7392]	[7337 7 1139 0.8653]	[7140 12 1331 0.8424]	[6838 11 1135 0.8572]	[6218 17 1749 0.7799]	[5952 14 2018 0.7464]	[6659 15 1660 0.7998±0.0042]
0.65	[7249 16 1218 0.8555]	[5842 21 2620 0.6899]	[7362 12 1109 0.8686]	[6448 22 2013 0.7614]	[6273 17 2193 0.7405]	[7355 7 1121 0.8674]	[7139 12 1332 0.8423]	[6837 11 1136 0.8570]	[6224 17 1743 0.7806]	[5957 14 2013 0.7470]	[6669 15 1650 0.8010±0.0042]
0.70	[7258 16 1209 0.8565]	[5867 21 2595 0.6929]	[7369 12 1102 0.8694]	[6444 22 2017 0.7609]	[6273 17 2193 0.7405]	[7364 7 1112 0.8685]	[7132 12 1339 0.8414]	[6842 11 1131 0.8577]	[6225 17 1742 0.7807]	[5958 14 2012 0.7471]	[6673 15 1645 0.8016±0.0042]
0.75	[7269 16 1198 0.8578]	[5887 21 2575 0.6952]	[7369 12 1102 0.8694]	[6430 22 2031 0.7593]	[6286 17 2180 0.7420]	[7380 7 1096 0.8704]	[7129 12 1342 0.8411]	[6855 11 1118 0.8593]	[6218 17 1749 0.7799]	[5970 14 2000 0.7486]	[6679 15 1639 0.8023±0.0041]
0.80	[7290 16 1177 0.8603]	[5941 21 2521 0.7016]	[7344 12 1127 0.8664]	[6424 22 2037 0.7586]	[6319 17 2147 0.7459]	[7383 7 1093 0.8707]	[7110 12 1361 0.8389]	[6853 11 1120 0.8590]	[6213 17 1754 0.7792]	[5962 14 2008 0.7476]	[6684 15 1635 0.8028±0.0039]
0.85	[7307 16 1160 0.8623]	[5989 21 2473 0.7072]	[7341 12 1130 0.8661]	[6387 22 2074 0.7542]	[6345 17 2121 0.7490]	[7398 7 1078 0.8725]	[7106 12 1365 0.8384]	[6845 11 1128 0.8580]	[6235 17 1732 0.7820]	[5959 14 2011 0.7472]	[6691 15 1627 0.8037±0.0038]
0.90	[7329 16 1138 0.8649]	[6007 21 2455 0.7094]	[7311 12 1160 0.8625]	[6349 22 2112 0.7497]	[6362 17 2104 0.7510]	[7395 7 1081 0.8722]	[7095 12 1376 0.8371]	[6834 11 1139 0.8567]	[6250 17 1717 0.7839]	[5950 14 2020 0.7461]	[6688 15 1630 0.8033±0.0038]
0.92	[7333 16 1134 0.8654]	[6010 21 2452 0.7097]	[7297 12 1174 0.8609]	[6347 22 2114 0.7495]	[6372 17 2094 0.7522]	[7382 7 1094 0.8706]	[7082 12 1389 0.8356]	[6819 11 1154 0.8548]	[6237 17 1730 0.7823]	[5940 14 2030 0.7449]	[6682 15 1637 0.8026±0.0037]
0.93	[7331 16 1136 0.8651]	[6015 21 2447 0.7103]	[7297 12 1174 0.8609]	[6345 22 2116 0.7493]	[6379 17 2087 0.7530]	[7374 7 1102 0.8697]	[7073 12 1398 0.8345]	[6804 11 1169 0.8529]	[6246 17 1721 0.7834]	[5935 14 2035 0.7442]	[6680 15 1639 0.8023±0.0037]
0.94	[7335 16 1132 0.8656]	[6016 21 2446 0.7104]	[7283 12 1188 0.8592]	[6330 22 2131 0.7475]	[6393 17 2073 0.7546]	[7380 7 1096 0.8704]	[7065 12 1406 0.8335]	[6813 11 1160 0.8540]	[6241 17 1726 0.7828]	[5932 14 2038 0.7439]	[6679 15 1640 0.8022±0.0037]
0.95	[7334 16 1133 0.8655]	[6015 21 2447 0.7103]	[7278 12 1193 0.8587]	[6328 22 2133 0.7473]	[6400 17 2066 0.7555]	[7379 7 1097 0.8703]	[7061 12 1410 0.8331]	[6811 11 1162 0.8538]	[6237 17 1730 0.7823]	[5923 14 2047 0.7427]	[6677 15 1642 0.8019±0.0037]
0.96	[7331 16 1136 0.8651]	[6018 21 2444 0.7107]	[7268 12 1203 0.8575]	[6312 22 2149 0.7454]	[6412 17 2054 0.7569]	[7370 7 1106 0.8692]	[7046 12 1425 0.8313]	[6808 11 1165 0.8534]	[6230 17 1737 0.7814]	[5911 14 2059 0.7412]	[6671 15 1648 0.8012±0.0036]
0.97	[7332 16 1135 0.8653]	[6017 21 2445 0.7105]	[7256 12 1215 0.8561]	[6305 22 2156 0.7445]	[6409 17 2057 0.7565]	[7358 7 1118 0.8678]	[7035 12 1436 0.8300]	[6806 11 1167 0.8531]	[6219 17 1748 0.7800]	[5904 14 2066 0.7404]	[6664 15 1654 0.8004±0.0036]
0.98	[7332 16 1135 0.8653]	[6025 21 2437 0.7115]	[7243 12 1228 0.8545]	[6286 22 2175 0.7423]	[6413 17 2053 0.7570]	[7356 7 1120 0.8676]	[7025 12 1446 0.8288]	[6787 11 1186 0.8508]	[6216 17 1751 0.7796]	[5897 14 2073 0.7395]	[6658 15 1660 0.7997±0.0036]
C96 network											
0.55	[12472 10819 2124 0.7036]	[9224 13905 2286 0.6365]	[10710 12422 2283 0.6658]	[10894 12329 2192 0.6712]	[10710 12422 2283 0.6658]	[9086 12265 2109 0.6487]	[12748 8999 1713 0.7352]	[9086 12265 2109 0.6487]	[14234 7516 1710 0.7669]	[9224 12205 2031 0.6533]	[10839 11515 2084 0.6796±0.0018]
0.60	[12472 10819 2124 0.7036]	[9224 13905 2286 0.6365]	[10710 12422 2283 0.6658]	[10894 12329 2192 0.6712]	[10710 12422 2283 0.6658]	[9086 12265 2109 0.6487]	[12748 8999 1713 0.7352]	[9086 12265 2109 0.6487]	[14234 7516 1710 0.7669]	[9224 12205 2031 0.6533]	[10839 11515 2084 0.6796±0.0018]
0.65	[12472 10819 2124 0.7036]	[9224 13905 2286 0.6365]	[10710 12422 2283 0.6658]	[10894 12329 2192 0.6712]	[10710 12422 2283 0.6658]	[9086 12265 2109 0.6487]	[12748 8999 1713 0.7352]	[9086 12265 2109 0.6487]	[14234 7516 1710 0.7669]	[9224 12205 2031 0.6533]	[10839 11515 2084 0.6796±0.0018]
0.70	[12472	[9224	[10710	[10894	[10710	[9086	[12748	[9086	[14234	[9224	[10839 11515

(*continued on next page*)

Table 12 (*continued*)

Orness(**w**) = α	Fold 1	Fold 2	Fold 3	Fold 4	Fold 5	Fold 6	Fold 7	Fold 8	Fold 9	Fold 10	Average
	10819 2124 0.7036]	13905 2286 0.6365]	12422 2283 0.6658]	12329 2192 0.6712]	12422 2283 0.6658]	12265 2109 0.6487]	8999 1713 0.7352]	12265 2109 0.6487]	7516 1710 0.7669]	12205 2031 0.6533]	2084 0.6796±0.0018]
0.75	[12476 10819 2120 0.7037]	[9236 13905 2274 0.6370]	[10714 12422 2279 0.6659]	[10898 12329 2188 0.6714]	[10714 12422 2279 0.6659]	[9094 12265 2101 0.6490]	[12760 8999 1701 0.7357]	[9094 12265 2101 0.6490]	[14238 7516 1706 0.7671]	[9236 12205 2019 0.6538]	[10846 11515 2077 0.6799±0.0018]
0.80	[12476 10819 2120 0.7037]	[9236 13905 2274 0.6370]	[10714 12422 2279 0.6659]	[10898 12329 2188 0.6714]	[10714 12422 2279 0.6659]	[9094 12265 2101 0.6490]	[12760 8999 1701 0.7357]	[9094 12265 2101 0.6490]	[14238 7516 1706 0.7671]	[9236 12205 2019 0.6538]	[10846 11515 2077 0.6799±0.0018]
0.85	[12482 10819 2114 0.7040]	[9238 13905 2272 0.6370]	[10719 12422 2274 0.6661]	[10902 12329 2184 0.6715]	[10719 12422 2274 0.6661]	[9097 12265 2098 0.6492]	[12764 8999 1697 0.7359]	[9097 12265 2098 0.6492]	[14245 7516 1699 0.7674]	[9238 12205 2017 0.6539]	[10850 11515 2073 0.6800±0.0018]
0.90	[12542 10819 2054 0.7063]	[9258 13905 2252 0.6378]	[10769 12422 2224 0.6681]	[10945 12329 2141 0.6732]	[10769 12422 2224 0.6681]	[9127 12265 2068 0.6504]	[12804 8999 1657 0.7376]	[9127 12265 2068 0.6504]	[14315 7516 1629 0.7704]	[9258 12205 1997 0.6548]	[10891 11515 2031 0.6817±0.0018]
0.92	[12542 10819 2054 0.7063]	[9258 13905 2252 0.6378]	[10769 12422 2224 0.6681]	[10945 12329 2141 0.6732]	[10769 12422 2224 0.6681]	[9127 12265 2068 0.6504]	[12804 8999 1657 0.7376]	[9127 12265 2068 0.6504]	[14315 7516 1629 0.7704]	[9258 12205 1997 0.6548]	[10891 11515 2031 0.6817±0.0018]
0.93	[12542 10819 2054 0.7063]	[9258 13905 2252 0.6378]	[10769 12422 2224 0.6681]	[10945 12329 2141 0.6732]	[10769 12422 2224 0.6681]	[9127 12265 2068 0.6504]	[12804 8999 1657 0.7376]	[9127 12265 2068 0.6504]	[14315 7516 1629 0.7704]	[9258 12205 1997 0.6548]	[10891 11515 2031 0.6817±0.0018]
0.94	[12614 10819 1982 0.7092]	[9282 13905 2228 0.6388]	[10829 12422 2164 0.6705]	[10993 12329 2093 0.6751]	[10829 12422 2164 0.6705]	[9163 12265 2032 0.6520]	[12852 8999 1609 0.7396]	[9163 12265 2032 0.6520]	[14399 7516 1545 0.7740]	[9282 12205 1973 0.6558]	[10941 11515 1982 0.6837±0.0019]
0.95	[12614 10819 1982 0.7092]	[9282 13905 2228 0.6388]	[10829 12422 2164 0.6705]	[10993 12329 2093 0.6751]	[10829 12422 2164 0.6705]	[9163 12265 2032 0.6520]	[12852 8999 1609 0.7396]	[9163 12265 2032 0.6520]	[14399 7516 1545 0.7740]	[9282 12205 1973 0.6558]	[10941 11515 1982 0.6837±0.0019]
0.96	[12614 10819 1982 0.7092]	[9282 13905 2228 0.6388]	[10829 12422 2164 0.6705]	[10993 12329 2093 0.6751]	[10829 12422 2164 0.6705]	[9163 12265 2032 0.6520]	[12852 8999 1609 0.7396]	[9163 12265 2032 0.6520]	[14399 7516 1545 0.7740]	[9282 12205 1973 0.6558]	[10941 11515 1982 0.6837±0.0019]
0.97	[12614 10819 1982 0.7092]	[9282 13905 2228 0.6388]	[10829 12422 2164 0.6705]	[10993 12329 2093 0.6751]	[10829 12422 2164 0.6705]	[9163 12265 2032 0.6520]	[12852 8999 1609 0.7396]	[9163 12265 2032 0.6520]	[14399 7516 1545 0.7740]	[9282 12205 1973 0.6558]	[10941 11515 1982 0.6837±0.0019]
0.98	[12614 10819 1982 0.7092]	[9282 13905 2228 0.6388]	[10829 12422 2164 0.6705]	[10993 12329 2093 0.6751]	[10829 12422 2164 0.6705]	[9163 12265 2032 0.6520]	[12852 8999 1609 0.7396]	[9163 12265 2032 0.6520]	[14399 7516 1545 0.7740]	[9282 12205 1973 0.6558]	[10941 11515 1982 0.6837±0.0019]
B97 network											
0.55	[20597 516 3268 0.8554]	[20957 277 3147 0.8652]	[20446 573 3362 0.8504]	[20910 538 2933 0.8687]	[19777 153 3548 0.8456]	[21276 136 2066 0.9091]	[20709 134 2635 0.8849]	[20208 467 2803 0.8707]	[19112 930 3436 0.8338]	[19774 250 3454 0.8476]	[20377 397 3065 0.8631±0.0005]
0.60	[20570 516 3295 0.8543]	[20927 277 3177 0.8640]	[20450 573 3358 0.8505]	[20900 538 2943 0.8683]	[19747 153 3578 0.8443]	[21249 136 2093 0.9080]	[20714 134 2630 0.8851]	[20226 467 2785 0.8714]	[19107 930 3441 0.8336]	[19776 250 3452 0.8476]	[20367 397 3075 0.8627±0.0005]
0.65	[20565 516 3300 0.8541]	[20924 277 3180 0.8639]	[20444 573 3364 0.8503]	[20894 538 2949 0.8680]	[19757 153 3568 0.8448]	[21243 136 2099 0.9077]	[20710 134 2634 0.8850]	[20235 467 2776 0.8718]	[19106 930 3442 0.8336]	[19770 250 3458 0.8474]	[20365 397 3077 0.8626±0.0005]
0.70	[20573 516 3292 0.8544]	[20935 277 3169 0.8643]	[20447 573 3361 0.8504]	[20876 538 2967 0.8673]	[19756 153 3569 0.8447]	[21231 136 2111 0.9072]	[20701 134 2643 0.8846]	[20246 467 2765 0.8723]	[19114 930 3434 0.8339]	[19763 250 3465 0.8471]	[20364 397 3078 0.8626±0.0005]
0.75	[20584 516 3281 0.8548]	[20944 277 3160 0.8647]	[20444 573 3364 0.8503]	[20894 538 2949 0.8680]	[19788 153 3537 0.8461]	[21212 136 2130 0.9064]	[20688 134 2656 0.8840]	[20300 467 2711 0.8746]	[19145 930 3403 0.8353]	[19741 250 3487 0.8462]	[20374 397 3068 0.8630±0.0005]
0.80	[20593 516 3272 0.8552]	[20932 277 3172 0.8642]	[20445 573 3363 0.8503]	[20878 538 2965 0.8674]	[19796 153 3529 0.8464]	[21186 136 2156 0.9053]	[20689 134 2655 0.8841]	[20299 467 2712 0.8745]	[19148 930 3400 0.8354]	[19742 250 3486 0.8462]	[20371 397 3071 0.8629±0.0004]
0.85	[20556 516 3309 0.8537]	[20954 277 3150 0.8651]	[20416 573 3392 0.8491]	[20842 538 3001 0.8659]	[19807 153 3518 0.8469]	[21161 136 2181 0.9042]	[20674 134 2670 0.8834]	[20324 467 2687 0.8756]	[19127 930 3421 0.8345]	[19727 250 3501 0.8456]	[20359 397 3083 0.8624±0.0004]
0.90	[20534 516 3331 0.8528]	[20947 277 3157 0.8648]	[20423 573 3385 0.8494]	[20849 538 2994 0.8662]	[19836 153 3489 0.8481]	[21130 136 2212 0.9029]	[20639 134 2705 0.8819]	[20352 467 2659 0.8768]	[19114 930 3434 0.8339]	[19730 250 3498 0.8457]	[20355 397 3086 0.8623±0.0004]
0.92	[20530 516 3335 0.8526]	[20967 277 3137 0.8657]	[20403 573 3405 0.8486]	[20847 538 2996 0.8661]	[19850 153 3475 0.8487]	[21096 136 2246 0.9014]	[20626 134 2718 0.8814]	[20357 467 2654 0.8770]	[19104 930 3444 0.8335]	[19730 250 3498 0.8457]	[20351 397 3091 0.8621±0.0004]

Table 12 (*continued*)

Orness(**w**) = α	Fold 1	Fold 2	Fold 3	Fold 4	Fold 5	Fold 6	Fold 7	Fold 8	Fold 9	Fold 10	Average
0.93	[20554 516 3311 0.8536]	[20935 277 3169 0.8643]	[20432 573 3376 0.8498]	[20846 538 2997 0.8660]	[19866 153 3459 0.8494]	[21080 136 2262 0.9008]	[20645 134 2699 0.8822]	[20357 467 2654 0.8770]	[19081 930 3467 0.8325]	[19718 250 3510 0.8452]	[20351 397 3090 0.8621±0.0004]
0.94	[20545 516 3320 0.8532]	[20908 277 3196 0.8632]	[20415 573 3393 0.8491]	[20845 538 2998 0.8660]	[19899 153 3426 0.8508]	[21110 136 2232 0.9020]	[20649 134 2695 0.8824]	[20394 467 2617 0.8786]	[19081 930 3467 0.8325]	[19744 250 3484 0.8463]	[20359 397 3083 0.8624±0.0004]
0.95	[20521 516 3344 0.8523]	[20908 277 3196 0.8632]	[20406 573 3402 0.8487]	[20833 538 3010 0.8655]	[19878 153 3447 0.8499]	[21092 136 2250 0.9013]	[20625 134 2719 0.8813]	[20401 467 2610 0.8789]	[19086 930 3462 0.8327]	[19736 250 3492 0.8459]	[20349 397 3093 0.8620±0.0004]
0.96	[20503 516 3362 0.8515]	[20893 277 3211 0.8626]	[20395 573 3413 0.8483]	[20810 538 3033 0.8646]	[19895 153 3430 0.8506]	[21099 136 2243 0.9016]	[20604 134 2740 0.8804]	[20412 467 2599 0.8794]	[19068 930 3480 0.8320]	[19733 250 3495 0.8458]	[20341 397 3101 0.8617±0.0004]
0.97	[20507 516 3358 0.8517]	[20886 277 3218 0.8623]	[20389 573 3419 0.8480]	[20802 538 3041 0.8642]	[19914 153 3411 0.8515]	[21094 136 2248 0.9014]	[20606 134 2738 0.8805]	[20423 467 2588 0.8798]	[19067 930 3481 0.8319]	[19752 250 3476 0.8466]	[20344 397 3098 0.8618±0.0004]
0.98	[20503 516 3362 0.8515]	[20887 277 3217 0.8624]	[20384 573 3424 0.8478]	[20780 538 3063 0.8633]	[19936 153 3389 0.8524]	[21086 136 2256 0.9010]	[20571 134 2773 0.8790]	[20454 467 2557 0.8811]	[19059 930 3489 0.8316]	[19746 250 3482 0.8464]	[20341 397 3101 0.8617±0.0004]

in comparison with MVM and CSM in the aforementioned experiments. The 10-fold cross-validation is also performed for the 4 above-mentioned social networks. The experimental results are summarized in Tables 12–14. The vivid comparisons corresponding to the 4 networks are depicted in Figs. 14–17, where MEM(9) denotes the MEM based LPE_{OWA}, MEM(7a), MEM(7b) and MEM(7c) denote MEM based $LPE_{OWA}(7a)$, $LPE_{OWA}(7b)$ and $LPE_{OWA}(7c)$ respectively. By observing Tables 12–14 and Figs. 14–17, we can find that

- For WSDP98 and ChesLower networks (Figs. 14 and 15), $LPE_{OWA}(7a)$ further improves the performances of link prediction ensemble algorithm, i.e. MEM based LPE_{OWA} $(7a)$ obtains the higher AUCs than MEM based LPE_{OWA}.
- For C96 network (Fig. 16), AUCs of MEM based LPE_{OWA} $(7a)$, $LPE_{OWA}(7b)$ and $LPE_{OWA}(7c)$ gradually increase with the increase of α. MEM based LPE_{OWA} obtains the better performances than other three ensemble algorithms.

Table 13
Prediction performances of $LPE_{OWA}(7b)$ algorithm on 4 social networks.

Orness(**w**) = α	Fold 1	Fold 2	Fold 3	Fold 4	Fold 5	Fold 6	Fold 7	Fold 8	Fold 9	Fold 10	Average
WSDP98 network											
0.55	[4046 339 1339 0.7365]	[3709 507 1508 0.6923]	[3843 507 1374 0.7157]	[4285 170 1269 0.7635]	[4352 3 1369 0.7606]	[3872 507 1345 0.7207]	[3640 343 1741 0.6659]	[3916 339 1469 0.7137]	[3438 507 1302 0.7035]	[2913 676 1658 0.6196]	[3801 390 1437 0.7092±0.0019]
0.60	[4034 339 1351 0.7344]	[3702 507 1515 0.6910]	[3851 507 1366 0.7171]	[4292 170 1262 0.7647]	[4348 3 1373 0.7599]	[3872 507 1345 0.7207]	[3644 343 1737 0.6666]	[3909 339 1476 0.7125]	[3442 507 1298 0.7043]	[2904 676 1667 0.6179]	[3800 390 1439 0.7089±0.0019]
0.65	[4021 339 1364 0.7321]	[3690 507 1527 0.6889]	[3861 507 1356 0.7188]	[4292 170 1262 0.7647]	[4351 3 1370 0.7604]	[3875 507 1342 0.7213]	[3636 343 1745 0.6652]	[3893 339 1492 0.7097]	[3443 507 1297 0.7045]	[2888 676 1683 0.6148]	[3795 390 1444 0.7080±0.0020]
0.70	[4013 339 1372 0.7307]	[3679 507 1538 0.6870]	[3865 507 1352 0.7195]	[4297 170 1257 0.7655]	[4367 3 1354 0.7632]	[3882 507 1335 0.7225]	[3625 343 1756 0.6633]	[3898 339 1487 0.7106]	[3448 507 1292 0.7055]	[2867 676 1704 0.6108]	[3794 390 1445 0.7079±0.0021]
0.75	[4004 339 1381 0.7291]	[3682 507 1535 0.6875]	[3869 507 1348 0.7202]	[4289 170 1265 0.7642]	[4379 3 1342 0.7653]	[3888 507 1329 0.7235]	[3613 343 1768 0.6612]	[3903 339 1482 0.7115]	[3451 507 1289 0.7060]	[2861 676 1710 0.6097]	[3794 390 1445 0.7078±0.0022]
0.80	[3990 339 1395 0.7267]	[3679 507 1538 0.6870]	[3873 507 1344 0.7209]	[4298 170 1256 0.7657]	[4393 3 1328 0.7677]	[3899 507 1318 0.7255]	[3597 343 1784 0.6584]	[3917 339 1468 0.7139]	[3454 507 1286 0.7066]	[2842 676 1729 0.6061]	[3794 390 1445 0.7078±0.0023]
0.85	[3975 339 1410 0.7241]	[3678 507 1539 0.6868]	[3882 507 1335 0.7225]	[4309 170 1245 0.7676]	[4420 3 1301 0.7724]	[3902 507 1315 0.7260]	[3582 343 1799 0.6557]	[3924 339 1461 0.7151]	[3469 507 1271 0.7095]	[2826 676 1745 0.6030]	[3797 390 1442 0.7083±0.0025]
0.90	[3966 339 1419 0.7225]	[3690 507 1527 0.6889]	[3884 507 1333 0.7228]	[4337 170 1217 0.7725]	[4445 3 1276 0.7768]	[3911 507 1306 0.7276]	[3593 343 1788 0.6577]	[3926 339 1459 0.7155]	[3448 507 1292 0.7055]	[2818 676 1753 0.6015]	[3802 390 1437 0.7091±0.0027]
0.92	[3967 339 1418 0.7227]	[3690 507 1527 0.6889]	[3894 507 1323 0.7246]	[4345 170 1209 0.7739]	[4452 3 1269 0.7780]	[3913 507 1304 0.7279]	[3585 343 1796 0.6563]	[3936 339 1449 0.7172]	[3436 507 1304 0.7032]	[2816 676 1755 0.6011]	[3803 390 1435 0.7094±0.0027]
0.93	[3969 339 1416 0.7230]	[3692 507 1525 0.6893]	[3896 507 1321 0.7249]	[4350 170 1204 0.7748]	[4453 3 1268 0.7782]	[3911 507 1306 0.7276]	[3589 343 1792 0.6570]	[3936 339 1449 0.7172]	[3435 507 1305 0.7030]	[2811 676 1760 0.6002]	[3804 390 1435 0.7095±0.0028]
0.94	[3973 339 1412 0.7237]	[3694 507 1523 0.6896]	[3895 507 1322 0.7248]	[4350 170 1204 0.7748]	[4459 3 1262 0.7793]	[3908 507 1309 0.7270]	[3582 343 1799 0.6557]	[3940 339 1445 0.7179]	[3433 507 1307 0.7026]	[2812 676 1759 0.6003]	[3805 390 1434 0.7096±0.0028]
0.95	[3976 339 1409 0.7242]	[3693 507 1524 0.6895]	[3890 507 1327 0.7239]	[4357 170 1197 0.7760]	[4467 3 1254 0.7807]	[3921 507 1296 0.7293]	[3582 343 1799 0.6557]	[3952 339 1433 0.7200]	[3436 507 1304 0.7032]	[2811 676 1760 0.6002]	[3809 390 1430 0.7103±0.0029]

(*continued on next page*)

Table 13 (*continued*)

Orness($\mathbf{w}$) = α	Fold 1	Fold 2	Fold 3	Fold 4	Fold 5	Fold 6	Fold 7	Fold 8	Fold 9	Fold 10	Average
0.96	[3983 339 1402 0.7255]	[3693 507 1524 0.6895]	[3895 507 1322 0.7248]	[4361 170 1193 0.7767]	[4467 3 1254 0.7807]	[3922 507 1295 0.7295]	[3574 343 1807 0.6544]	[3956 339 1429 0.7207]	[3441 507 1299 0.7041]	[2805 676 1766 0.5990]	[3810 390 1429 0.7105±0.0029]
0.97	[3979 339 1406 0.7248]	[3695 507 1522 0.6898]	[3900 507 1317 0.7256]	[4363 170 1191 0.7771]	[4479 3 1242 0.7828]	[3929 507 1288 0.7307]	[3572 343 1809 0.6540]	[3966 339 1419 0.7225]	[3440 507 1300 0.7039]	[2802 676 1769 0.5984]	[3813 390 1426 0.7110±0.0030]
0.98	[3975 339 1410 0.7241]	[3693 507 1524 0.6895]	[3907 507 1310 0.7269]	[4371 170 1183 0.7785]	[4494 3 1227 0.7854]	[3928 507 1289 0.7305]	[3566 343 1815 0.6530]	[3975 339 1410 0.7241]	[3439 507 1301 0.7037]	[2795 676 1776 0.5971]	[3814 390 1425 0.7113±0.0031]
ChesLower network											
0.55	[6730 3 1750 0.7935]	[5227 10 3246 0.6168]	[6881 10 1592 0.8117]	[6339 14 2130 0.7481]	[5660 6 2817 0.6676]	[6682 3 1798 0.7879]	[6840 4 1639 0.8066]	[6274 4 1706 0.7861]	[5612 7 2365 0.7033]	[5532 9 2443 0.6934]	[6178 7 2149 0.7415±0.0045]
0.60	[6735 3 1745 0.7941]	[5238 10 3235 0.6181]	[6908 10 1565 0.8149]	[6350 14 2119 0.7494]	[5688 6 2789 0.6709]	[6698 3 1782 0.7898]	[6848 4 1631 0.8075]	[6282 4 1698 0.7871]	[5615 7 2362 0.7037]	[5524 9 2451 0.6924]	[6189 7 2138 0.7428±0.0046]
0.65	[6751 3 1729 0.7960]	[5281 10 3192 0.6231]	[6949 10 1524 0.8198]	[6363 14 2106 0.7509]	[5689 6 2788 0.6710]	[6733 3 1747 0.7939]	[6826 4 1653 0.8049]	[6284 4 1696 0.7873]	[5586 7 2391 0.7001]	[5539 9 2436 0.6943]	[6200 7 2126 0.7441±0.0045]
0.70	[6760 3 1720 0.7971]	[5284 10 3189 0.6235]	[6981 10 1492 0.8235]	[6370 14 2099 0.7517]	[5700 6 2777 0.6723]	[6749 3 1731 0.7958]	[6822 4 1657 0.8044]	[6305 4 1675 0.7900]	[5590 7 2387 0.7006]	[5535 9 2440 0.6938]	[6210 7 2117 0.7453±0.0046]
0.75	[6775 3 1705 0.7988]	[5305 10 3168 0.6260]	[7021 10 1452 0.8282]	[6365 14 2104 0.7511]	[5736 6 2741 0.6765]	[6775 3 1705 0.7988]	[6797 4 1682 0.8015]	[6336 4 1644 0.7938]	[5588 7 2389 0.7003]	[5542 9 2433 0.6947]	[6224 7 2102 0.7470±0.0046]
0.80	[6791 3 1689 0.8007]	[5344 10 3129 0.6306]	[7034 10 1439 0.8298]	[6379 14 2090 0.7528]	[5774 6 2703 0.6810]	[6786 3 1694 0.8001]	[6767 4 1712 0.7979]	[6362 4 1618 0.7971]	[5603 7 2374 0.7022]	[5564 9 2411 0.6975]	[6240 7 2086 0.7490±0.0044]
0.85	[6814 3 1666 0.8034]	[5404 10 3069 0.6376]	[7081 10 1392 0.8353]	[6421 14 2048 0.7578]	[5813 6 2664 0.6856]	[6832 3 1648 0.8056]	[6742 4 1737 0.7950]	[6378 4 1602 0.7991]	[5627 7 2350 0.7052]	[5571 9 2404 0.6983]	[6268 7 2058 0.7523±0.0043]
0.90	[6864 3 1616 0.8093]	[5440 10 3033 0.6419]	[7122 10 1351 0.8402]	[6436 14 2033 0.7595]	[5832 6 2645 0.6878]	[6860 3 1620 0.8089]	[6713 4 1766 0.7916]	[6382 4 1598 0.7996]	[5656 7 2321 0.7089]	[5555 9 2420 0.6963]	[6286 7 2040 0.7544±0.0044]
0.92	[6886 3 1594 0.8119]	[5467 10 3006 0.6451]	[7146 10 1327 0.8430]	[6435 14 2034 0.7594]	[5846 6 2631 0.6895]	[6854 3 1626 0.8081]	[6687 4 1792 0.7885]	[6381 4 1599 0.7995]	[5663 7 2314 0.7097]	[5555 9 2420 0.6963]	[6292 7 2034 0.7551±0.0043]
0.93	[6883 3 1597 0.8116]	[5478 10 2995 0.6464]	[7169 10 1304 0.8457]	[6442 14 2027 0.7602]	[5841 6 2636 0.6889]	[6856 3 1624 0.8084]	[6684 4 1795 0.7882]	[6377 4 1603 0.7990]	[5677 7 2300 0.7115]	[5561 9 2414 0.6971]	[6297 7 2030 0.7557±0.0043]
0.94	[6910 3 1570 0.8147]	[5499 10 2974 0.6488]	[7173 10 1300 0.8462]	[6440 14 2029 0.7600]	[5841 6 2636 0.6889]	[6861 3 1619 0.8090]	[6673 4 1806 0.7869]	[6376 4 1604 0.7988]	[5694 7 2283 0.7136]	[5572 9 2403 0.6985]	[6304 7 2022 0.7565±0.0043]
0.95	[6931 3 1549 0.8172]	[5514 10 2959 0.6506]	[7172 10 1301 0.8460]	[6465 14 2004 0.7629]	[5854 6 2623 0.6904]	[6869 3 1611 0.8099]	[6679 4 1800 0.7876]	[6390 4 1590 0.8006]	[5704 7 2273 0.7149]	[5569 9 2406 0.6981]	[6315 7 2012 0.7578±0.0042]
0.96	[6941 3 1539 0.8184]	[5533 10 2940 0.6528]	[7172 10 1301 0.8460]	[6467 14 2002 0.7632]	[5871 6 2606 0.6924]	[6873 3 1607 0.8104]	[6664 4 1815 0.7858]	[6404 4 1576 0.8024]	[5680 7 2297 0.7119]	[5561 9 2414 0.6971]	[6317 7 2010 0.7580±0.0042]
0.97	[6956 3 1524 0.8202]	[5544 10 2929 0.6541]	[7176 10 1297 0.8465]	[6460 14 2009 0.7623]	[5874 6 2603 0.6928]	[6875 3 1605 0.8106]	[6614 4 1865 0.7799]	[6400 4 1580 0.8019]	[5681 7 2296 0.7120]	[5563 9 2412 0.6973]	[6314 7 2012 0.7578±0.0042]
0.98	[6964 3 1516 0.8211]	[5560 10 2913 0.6560]	[7192 10 1281 0.8484]	[6466 14 2003 0.7631]	[5874 6 2603 0.6928]	[6862 3 1618 0.8091]	[6594 4 1885 0.7776]	[6398 4 1582 0.8016]	[5684 7 2293 0.7124]	[5566 9 2409 0.6977]	[6316 7 2010 0.7580±0.0042]
C96 network											
0.55	[12513 10554 2348 0.7000]	[9192 13757 2466 0.6323]	[10775 12229 2411 0.6645]	[10927 12164 2324 0.6693]	[10820 12273 2322 0.6672]	[9159 12163 2138 0.6496]	[12802 8816 1842 0.7336]	[9115 12142 2203 0.6473]	[14341 7267 1852 0.7662]	[9236 12078 2146 0.6511]	[10888 11344 2205 0.6781±0.0018]
0.60	[12526 10554 2335 0.7005]	[9194 13757 2464 0.6324]	[10780 12229 2406 0.6647]	[10932 12164 2319 0.6694]	[10817 12273 2325 0.6671]	[9153 12163 2144 0.6494]	[12801 8816 1843 0.7335]	[9112 12142 2206 0.6472]	[14346 7267 1847 0.7664]	[9235 12078 2147 0.6511]	[10890 11344 2204 0.6782±0.0018]
0.65	[12554 10554 2307 0.7016]	[9201 13757 2457 0.6327]	[10808 12229 2378 0.6658]	[10953 12164 2298 0.6703]	[10852 12273 2290 0.6684]	[9174 12163 2123 0.6503]	[12822 8816 1822 0.7344]	[9133 12142 2185 0.6481]	[14388 7267 1805 0.7682]	[9242 12078 2140 0.6514]	[10913 11344 2181 0.6791±0.0018]
0.70	[12554 10554 2307 0.7016]	[9201 13757 2457 0.6327]	[10808 12229 2378 0.6658]	[10953 12164 2298 0.6703]	[10852 12273 2290 0.6684]	[9174 12163 2123 0.6503]	[12822 8816 1822 0.7344]	[9133 12142 2185 0.6481]	[14388 7267 1805 0.7682]	[9242 12078 2140 0.6514]	[10913 11344 2181 0.6791±0.0018]
0.75	[12554 10554	[9201 13757	[10808 12229	[10953 12164	[10852 12273	[9174 12163	[12822 8816	[9133 12142	[14388 7267	[9242 12078	[10913 11344 2181

Table 13 (*continued*)

Orness(**w**) = α	Fold 1	Fold 2	Fold 3	Fold 4	Fold 5	Fold 6	Fold 7	Fold 8	Fold 9	Fold 10	Average
	2307 0.7016]	2457 0.6327]	2378 0.6658]	2298 0.6703]	2290 0.6684]	2123 0.6503]	1822 0.7344]	2185 0.6481]	1805 0.7682]	2140 0.6514]	0.6791±0.0018]
0.80	[12554 10554 2307 0.7016]	[9201 13757 2457 0.6327]	[10808 12229 2378 0.6658]	[10953 12164 2298 0.6703]	[10852 12273 2290 0.6684]	[9174 12163 2123 0.6503]	[12822 8816 1822 0.7344]	[9133 12142 2185 0.6481]	[14388 7267 1805 0.7682]	[9242 12078 2140 0.6514]	[10913 11344 2181 0.6791±0.0018]
0.85	[12554 10554 2307 0.7016]	[9199 13757 2459 0.6326]	[10808 12229 2378 0.6658]	[10953 12164 2298 0.6703]	[10852 12273 2290 0.6684]	[9174 12163 2123 0.6503]	[12822 8816 1822 0.7344]	[9131 12142 2187 0.6480]	[14388 7267 1805 0.7682]	[9242 12078 2140 0.6514]	[10912 11344 2181 0.6791±0.0018]
0.90	[12570 10554 2291 0.7022]	[9207 13757 2451 0.6329]	[10824 12229 2362 0.6665]	[10967 12164 2284 0.6708]	[10872 12273 2270 0.6692]	[9186 12163 2111 0.6508]	[12834 8816 1810 0.7350]	[9147 12142 2171 0.6487]	[14412 7267 1781 0.7692]	[9246 12078 2136 0.6515]	[10927 11344 2167 0.6797±0.0019]
0.92	[12570 10554 2291 0.7022]	[9207 13757 2451 0.6329]	[10826 12229 2360 0.6666]	[10968 12164 2283 0.6709]	[10877 12273 2265 0.6694]	[9189 12163 2108 0.6509]	[12835 8816 1809 0.7350]	[9151 12142 2167 0.6488]	[14416 7267 1777 0.7694]	[9245 12078 2137 0.6515]	[10928 11344 2165 0.6798±0.0019]
0.93	[12598 10554 2263 0.7033]	[9145 13757 2513 0.6305]	[10854 12229 2332 0.6677]	[10989 12164 2262 0.6717]	[10912 12273 2230 0.6708]	[9210 12163 2087 0.6518]	[12856 8816 1788 0.7359]	[9103 12142 2215 0.6468]	[14458 7267 1735 0.7712]	[9252 12078 2130 0.6518]	[10938 11344 2156 0.6801±0.0019]
0.94	[12606 10554 2255 0.7036]	[9147 13757 2511 0.6306]	[10862 12229 2324 0.6680]	[10997 12164 2254 0.6720]	[10922 12273 2220 0.6712]	[9216 12163 2081 0.6521]	[12862 8816 1782 0.7361]	[9109 12142 2209 0.6471]	[14470 7267 1723 0.7717]	[9254 12078 2128 0.6519]	[10945 11344 2149 0.6804±0.0019]
0.95	[12610 10554 2251 0.7038]	[9151 13757 2507 0.6307]	[10864 12229 2322 0.6681]	[11001 12164 2250 0.6722]	[10922 12273 2220 0.6712]	[9216 12163 2081 0.6521]	[12864 8816 1780 0.7362]	[9111 12142 2207 0.6471]	[14472 7267 1721 0.7718]	[9256 12078 2126 0.6520]	[10947 11344 2147 0.6805±0.0019]
0.96	[12610 10554 2251 0.7038]	[9151 13757 2507 0.6307]	[10864 12229 2322 0.6681]	[11005 12164 2246 0.6723]	[10922 12273 2220 0.6712]	[9216 12163 2081 0.6521]	[12864 8816 1780 0.7362]	[9111 12142 2207 0.6471]	[14472 7267 1721 0.7718]	[9256 12078 2126 0.6520]	[10947 11344 2146 0.6805±0.0019]
0.97	[12636 10554 2225 0.7048]	[9161 13757 2497 0.6311]	[10883 12229 2303 0.6688]	[11021 12164 2230 0.6729]	[10937 12273 2205 0.6718]	[9225 12163 2072 0.6525]	[12880 8816 1764 0.7369]	[9120 12142 2198 0.6475]	[14497 7267 1696 0.7728]	[9266 12078 2116 0.6524]	[10963 11344 2131 0.6812±0.0020]
0.98	[12636 10554 2225 0.7048]	[9161 13757 2497 0.6311]	[10883 12229 2303 0.6688]	[11021 12164 2230 0.6729]	[10937 12273 2205 0.6718]	[9225 12163 2072 0.6525]	[12880 8816 1764 0.7369]	[9120 12142 2198 0.6475]	[14497 7267 1696 0.7728]	[9266 12078 2116 0.6524]	[10963 11344 2131 0.6812±0.0020]
B97 network											
0.55	[21247 431 2703 0.8803]	[21898 15 2468 0.8985]	[20898 447 3036 0.8663]	[21262 446 2673 0.8812]	[20360 16 3102 0.8675]	[21735 14 1729 0.9261]	[21481 13 1984 0.9152]	[20430 423 2625 0.8792]	[19305 870 3303 0.8408]	[20250 51 3177 0.8636]	[20887 273 2680 0.8819±0.0006]
0.60	[21268 431 2682 0.8812]	[21914 15 2452 0.8991]	[20915 447 3019 0.8670]	[21267 446 2668 0.8814]	[20379 16 3083 0.8683]	[21727 14 1737 0.9257]	[21488 13 1977 0.9155]	[20458 423 2597 0.8804]	[19311 870 3297 0.8410]	[20243 51 3184 0.8633]	[20897 273 2670 0.8823±0.0006]
0.65	[21284 431 2666 0.8818]	[21913 15 2453 0.8991]	[20918 447 3016 0.8671]	[21264 446 2671 0.8813]	[20407 16 3055 0.8695]	[21712 14 1752 0.9251]	[21490 13 1975 0.9156]	[20491 423 2564 0.8818]	[19288 870 3320 0.8401]	[20241 51 3186 0.8632]	[20901 273 2666 0.8825±0.0006]
0.70	[21290 431 2660 0.8821]	[21951 15 2415 0.9006]	[20918 447 3016 0.8671]	[21260 446 2675 0.8811]	[20411 16 3051 0.8697]	[21689 14 1775 0.9241]	[21505 13 1960 0.9162]	[20536 423 2519 0.8837]	[19306 870 3302 0.8408]	[20242 51 3185 0.8633]	[20911 273 2656 0.8829±0.0006]
0.75	[21296 431 2654 0.8823]	[21967 15 2399 0.9013]	[20928 447 3006 0.8675]	[21272 446 2663 0.8816]	[20448 16 3014 0.8713]	[21692 14 1772 0.9242]	[21514 13 1951 0.9166]	[20602 423 2453 0.8865]	[19301 870 3307 0.8406]	[20264 51 3163 0.8642]	[20928 273 2638 0.8836±0.0006]
0.80	[21318 431 2632 0.8832]	[22009 15 2357 0.9030]	[20958 447 2976 0.8688]	[21290 446 2645 0.8824]	[20489 16 2973 0.8730]	[21677 14 1787 0.9236]	[21518 13 1947 0.9168]	[20630 423 2425 0.8877]	[19309 870 3299 0.8410]	[20268 51 3159 0.8644]	[20947 273 2620 0.8844±0.0006]
0.85	[21328 431 2622 0.8836]	[22044 15 2322 0.9045]	[20960 447 2974 0.8689]	[21281 446 2654 0.8820]	[20531 16 2931 0.8748]	[21664 14 1800 0.9230]	[21531 13 1934 0.9173]	[20683 423 2372 0.8900]	[19293 870 3315 0.8403]	[20269 51 3158 0.8644]	[20958 273 2608 0.8849±0.0006]
0.90	[21351 431 2599 0.8846]	[22034 15 2332 0.9040]	[20979 447 2955 0.8696]	[21289 446 2646 0.8823]	[20599 16 2863 0.8777]	[21643 14 1821 0.9221]	[21509 13 1956 0.9164]	[20751 423 2304 0.8929]	[19261 870 3347 0.8389]	[20206 51 3221 0.8617]	[20962 273 2604 0.8850±0.0006]
0.92	[21370 431 2580 0.8853]	[22028 15 2338 0.9038]	[20996 447 2938 0.8703]	[21291 446 2644 0.8824]	[20628 16 2834 0.8790]	[21611 14 1853 0.9208]	[21500 13 1965 0.9160]	[20782 423 2273 0.8942]	[19260 870 3348 0.8389]	[20196 51 3231 0.8613]	[20966 273 2600 0.8852±0.0006]
0.93	[21368 431 2582 0.8853]	[22023 15 2343 0.9036]	[21012 447 2922 0.8710]	[21295 446 2640 0.8826]	[20651 16 2811 0.8799]	[21580 14 1884 0.9195]	[21494 13 1971 0.9158]	[20816 423 2239 0.8956]	[19267 870 3341 0.8392]	[20210 51 3217 0.8619]	[20972 273 2595 0.8854±0.0006]
0.94	[21374	[22020	[21014	[21291	[20674 16	[21573	[21476	[20840	[19266	[20212	[20974 273 2593

(*continued on next page*)

Table 13 (*continued*)

Orness(**w**) = α	Fold 1	Fold 2	Fold 3	Fold 4	Fold 5	Fold 6	Fold 7	Fold 8	Fold 9	Fold 10	Average
	431 2576 0.8855]	15 2346 0.9035]	447 2920 0.8711]	446 2644 0.8824]	2788 0.8809]	14 1891 0.9192]	13 1989 0.9150]	423 2215 0.8966]	870 3342 0.8391]	51 3215 0.8620]	0.8855±0.0006]
0.95	[21355 431 2595 0.8847]	[22035 15 2331 0.9041]	[21013 447 2921 0.8710]	[21286 446 2649 0.8822]	[20702 16 2760 0.8821]	[21568 14 1896 0.9189]	[21477 13 1988 0.9150]	[20849 423 2206 0.8970]	[19242 870 3366 0.8381]	[20219 51 3208 0.8623]	[20975 273 2592 0.8856±0.0006]
0.96	[21361 431 2589 0.8850]	[22041 15 2325 0.9043]	[21028 447 2906 0.8716]	[21274 446 2661 0.8817]	[20717 16 2745 0.8827]	[21573 14 1891 0.9192]	[21478 13 1987 0.9151]	[20874 423 2181 0.8981]	[19233 870 3375 0.8377]	[20213 51 3214 0.8620]	[20979 273 2587 0.8857±0.0006]
0.97	[21356 431 2594 0.8848]	[22031 15 2335 0.9039]	[21034 447 2900 0.8719]	[21280 446 2655 0.8820]	[20749 16 2713 0.8841]	[21568 14 1896 0.9189]	[21445 13 2020 0.9137]	[20914 423 2141 0.8998]	[19225 870 3383 0.8374]	[20226 51 3201 0.8626]	[20983 273 2584 0.8859±0.0006]
0.98	[21348 431 2602 0.8844]	[22035 15 2331 0.9041]	[21054 447 2880 0.8727]	[21269 446 2666 0.8815]	[20806 16 2656 0.8865]	[21576 14 1888 0.9193]	[21439 13 2026 0.9134]	[20950 423 2105 0.9013]	[19206 870 3402 0.8366]	[20239 51 3188 0.8631]	[20992 273 2574 0.8863±0.0006]

Table 14
Prediction performances of $LPE_{OWA}(7c)$ algorithm on 4 social networks.

Orness(**w**) = α	Fold 1	Fold 2	Fold 3	Fold 4	Fold 5	Fold 6	Fold 7	Fold 8	Fold 9	Fold 10	Average
WSDP98 network											
0.55	[3603 339 1782 0.6591]	[3407 507 1810 0.6395]	[3491 507 1726 0.6542]	[3929 170 1625 0.7013]	[4254 3 1467 0.7434]	[3514 507 1703 0.6582]	[3458 343 1923 0.6341]	[3491 339 1894 0.6395]	[3169 507 1571 0.6523]	[2706 676 1865 0.5801]	[3502 390 1737 0.6562±0.0018]
0.60	[3555 339 1830 0.6507]	[3385 507 1832 0.6357]	[3483 507 1734 0.6528]	[3908 170 1646 0.6976]	[4240 3 1481 0.7410]	[3510 507 1707 0.6575]	[3446 343 1935 0.6320]	[3491 339 1894 0.6395]	[3164 507 1576 0.6513]	[2692 676 1879 0.5775]	[3487 390 1751 0.6535±0.0018]
0.65	[3534 339 1851 0.6470]	[3368 507 1849 0.6327]	[3478 507 1739 0.6519]	[3879 170 1675 0.6925]	[4237 3 1484 0.7405]	[3488 507 1729 0.6537]	[3440 343 1941 0.6309]	[3486 339 1899 0.6386]	[3146 507 1594 0.6479]	[2683 676 1888 0.5758]	[3474 390 1765 0.6511±0.0018]
0.70	[3520 339 1865 0.6446]	[3353 507 1864 0.6301]	[3478 507 1739 0.6519]	[3868 170 1686 0.6906]	[4235 3 1486 0.7401]	[3484 507 1733 0.6530]	[3434 343 1947 0.6299]	[3477 339 1908 0.6371]	[3122 507 1618 0.6433]	[2661 676 1910 0.5716]	[3463 390 1776 0.6492±0.0019]
0.75	[3500 339 1885 0.6411]	[3328 507 1889 0.6257]	[3476 507 1741 0.6516]	[3866 170 1688 0.6903]	[4228 3 1493 0.7389]	[3475 507 1742 0.6514]	[3424 343 1957 0.6281]	[3456 339 1929 0.6334]	[3110 507 1630 0.6410]	[2651 676 1920 0.5697]	[3451 390 1787 0.6471±0.0019]
0.80	[3476 339 1909 0.6369]	[3321 507 1896 0.6245]	[3477 507 1740 0.6517]	[3851 170 1703 0.6876]	[4231 3 1490 0.7394]	[3459 507 1758 0.6486]	[3413 343 1968 0.6262]	[3451 339 1934 0.6325]	[3098 507 1642 0.6387]	[2628 676 1943 0.5653]	[3441 390 1798 0.6451±0.0020]
0.85	[3451 339 1934 0.6325]	[3304 507 1913 0.6215]	[3476 507 1741 0.6516]	[3832 170 1722 0.6843]	[4228 3 1493 0.7389]	[3458 507 1759 0.6484]	[3406 343 1975 0.6250]	[3456 339 1929 0.6334]	[3079 507 1661 0.6351]	[2611 676 1960 0.5620]	[3430 390 1809 0.6433±0.0021]
0.90	[3427 339 1958 0.6283]	[3279 507 1938 0.6171]	[3470 507 1747 0.6505]	[3819 170 1735 0.6820]	[4232 3 1489 0.7396]	[3457 507 1760 0.6482]	[3389 343 1992 0.6220]	[3452 339 1933 0.6327]	[3071 507 1669 0.6336]	[2598 676 1973 0.5596]	[3419 390 1819 0.6414±0.0022]
0.92	[3419 339 1966 0.6269]	[3271 507 1946 0.6157]	[3476 507 1741 0.6516]	[3815 170 1739 0.6813]	[4240 3 1481 0.7410]	[3448 507 1769 0.6467]	[3386 343 1995 0.6215]	[3452 339 1933 0.6327]	[3061 507 1679 0.6317]	[2595 676 1976 0.5590]	[3416 390 1823 0.6408±0.0022]
0.93	[3414 339 1971 0.6260]	[3270 507 1947 0.6156]	[3477 507 1740 0.6517]	[3811 170 1743 0.6806]	[4244 3 1477 0.7417]	[3440 507 1777 0.6453]	[3382 343 1999 0.6208]	[3454 339 1931 0.6330]	[3063 507 1677 0.6321]	[2592 676 1979 0.5584]	[3415 390 1824 0.6405±0.0022]
0.94	[3410 339 1975 0.6253]	[3270 507 1947 0.6156]	[3480 507 1737 0.6523]	[3809 170 1745 0.6803]	[4243 3 1478 0.7415]	[3440 507 1777 0.6453]	[3375 343 2006 0.6196]	[3456 339 1929 0.6334]	[3061 507 1679 0.6317]	[2578 676 1993 0.5557]	[3412 390 1827 0.6401±0.0023]
0.95	[3414 339 1971 0.6260]	[3267 507 1950 0.6150]	[3481 507 1736 0.6524]	[3810 170 1744 0.6805]	[4241 3 1480 0.7412]	[3442 507 1775 0.6456]	[3362 343 2019 0.6173]	[3453 339 1932 0.6329]	[3052 507 1688 0.6300]	[2573 676 1998 0.5548]	[3410 390 1829 0.6396±0.0023]
0.96	[3408 339 1977 0.6250]	[3257 507 1960 0.6133]	[3484 507 1733 0.6530]	[3786 170 1768 0.6763]	[4252 3 1469 0.7431]	[3442 507 1775 0.6456]	[3357 343 2024 0.6164]	[3460 339 1925 0.6341]	[3045 507 1695 0.6286]	[2570 676 2001 0.5542]	[3406 390 1833 0.6390±0.0023]
0.97	[3403 339 1982 0.6241]	[3255 507 1962 0.6129]	[3494 507 1723 0.6547]	[3787 170 1767 0.6765]	[4256 3 1465 0.7438]	[3435 507 1782 0.6444]	[3358 343 2023 0.6166]	[3467 339 1918 0.6353]	[3026 507 1714 0.6250]	[2563 676 2008 0.5529]	[3404 390 1834 0.6386±0.0024]
0.98	[3402 339 1983 0.6240]	[3243 507 1974 0.6108]	[3497 507 1720 0.6552]	[3781 170 1773 0.6754]	[4263 3 1458 0.7450]	[3436 507 1781 0.6446]	[3356 343 2025 0.6163]	[3464 339 1921 0.6348]	[3024 507 1716 0.6246]	[2552 676 2019 0.5508]	[3402 390 1837 0.6381±0.0025]
ChesLower network											
0.55	[4953 3 3527 0.5841]	[2661 10 5812 0.3143]	[5377 10 3096 0.6344]	[5346 14 3123 0.6310]	[4317 6 4160 0.5093]	[4730 3 3750 0.5578]	[5834 4 2645 0.6880]	[4671 4 3309 0.5853]	[3742 7 4235 0.4691]	[4273 9 3702 0.5358]	[4590 7 3736 0.5509±0.0110]
0.60	[4942 3 3538 0.5828]	[2650 10 5823 0.3130]	[5324 10 3149 0.6282]	[5336 14 3133 0.6298]	[4295 6 4182 0.5067]	[4705 3 3775 0.5548]	[5799 4 2680 0.6838]	[4655 4 3325 0.5833]	[3729 7 4248 0.4675]	[4250 9 3725 0.5329]	[4569 7 3758 0.5483±0.0109]

Table 14 (*continued*)

Orness($\mathbf{w}$) = α	Fold 1	Fold 2	Fold 3	Fold 4	Fold 5	Fold 6	Fold 7	Fold 8	Fold 9	Fold 10	Average
0.65	[4925 3 3555 0.5807]	[2649 10 5824 0.3129]	[5289 10 3184 0.6241]	[5321 14 3148 0.6281]	[4254 6 4223 0.5018]	[4672 3 3808 0.5509]	[5793 4 2686 0.6831]	[4646 4 3334 0.5822]	[3703 7 4274 0.4642]	[4226 9 3749 0.5299]	[4548 7 3779 0.5458$\pm$0.0108]
0.70	[4902 3 3578 0.5780]	[2636 10 5837 0.3113]	[5253 10 3220 0.6198]	[5287 14 3182 0.6241]	[4239 6 4238 0.5001]	[4651 3 3829 0.5484]	[5747 4 2732 0.6777]	[4622 4 3358 0.5792]	[3663 7 4314 0.4592]	[4193 9 3782 0.5257]	[4519 7 3807 0.5424$\pm$0.0107]
0.75	[4855 3 3625 0.5725]	[2646 10 5827 0.3125]	[5225 10 3248 0.6165]	[5272 14 3197 0.6223]	[4180 6 4297 0.4931]	[4636 3 3844 0.5467]	[5717 4 2762 0.6742]	[4610 4 3370 0.5777]	[3641 7 4336 0.4565]	[4162 9 3813 0.5219]	[4494 7 3832 0.5394$\pm$0.0105]
0.80	[4829 3 3651 0.5694]	[2634 10 5839 0.3111]	[5177 10 3296 0.6109]	[5255 14 3214 0.6203]	[4130 6 4347 0.4872]	[4609 3 3871 0.5435]	[5673 4 2806 0.6690]	[4596 4 3384 0.5759]	[3651 7 4326 0.4577]	[4121 9 3854 0.5167]	[4468 7 3859 0.5362$\pm$0.0103]
0.85	[4827 3 3653 0.5692]	[2654 10 5819 0.3135]	[5145 10 3328 0.6071]	[5238 14 3231 0.6183]	[4080 6 4397 0.4813]	[4604 3 3876 0.5429]	[5657 4 2822 0.6671]	[4592 4 3388 0.5754]	[3642 7 4335 0.4566]	[4086 9 3889 0.5123]	[4453 7 3874 0.5344$\pm$0.0101]
0.90	[4802 3 3678 0.5663]	[2710 10 5763 0.3201]	[5103 10 3370 0.6021]	[5238 14 3231 0.6183]	[4039 6 4438 0.4765]	[4592 3 3888 0.5415]	[5614 4 2865 0.6620]	[4584 4 3396 0.5744]	[3612 7 4365 0.4528]	[4053 9 3922 0.5082]	[4435 7 3892 0.5322$\pm$0.0097]
0.92	[4786 3 3694 0.5644]	[2714 10 5759 0.3205]	[5080 10 3393 0.5994]	[5233 14 3236 0.6177]	[4032 6 4445 0.4757]	[4593 3 3887 0.5416]	[5612 4 2867 0.6618]	[4571 4 3409 0.5728]	[3601 7 4376 0.4515]	[4030 9 3945 0.5053]	[4425 7 3901 0.5311$\pm$0.0096]
0.93	[4777 3 3703 0.5633]	[2725 10 5748 0.3218]	[5059 10 3414 0.5970]	[5224 14 3245 0.6166]	[4023 6 4454 0.4746]	[4576 3 3904 0.5396]	[5601 4 2878 0.6605]	[4569 4 3411 0.5725]	[3597 7 4380 0.4510]	[4013 9 3962 0.5032]	[4416 7 3910 0.5300$\pm$0.0095]
0.94	[4758 3 3722 0.5611]	[2735 10 5738 0.3230]	[5047 10 3426 0.5955]	[5213 14 3256 0.6153]	[4015 6 4462 0.4737]	[4588 3 3892 0.5410]	[5583 4 2896 0.6584]	[4571 4 3409 0.5728]	[3590 7 4387 0.4501]	[3998 9 3977 0.5013]	[4410 7 3917 0.5292$\pm$0.0094]
0.95	[4767 3 3713 0.5621]	[2731 10 5742 0.3225]	[5031 10 3442 0.5937]	[5208 14 3261 0.6148]	[4002 6 4475 0.4721]	[4590 3 3890 0.5413]	[5580 4 2899 0.6580]	[4544 4 3436 0.5694]	[3568 7 4409 0.4473]	[3983 9 3992 0.4994]	[4400 7 3926 0.5281$\pm$0.0094]
0.96	[4765 3 3715 0.5619]	[2736 10 5737 0.3231]	[5013 10 3460 0.5915]	[5193 14 3276 0.6130]	[3986 6 4491 0.4702]	[4571 3 3909 0.5390]	[5574 4 2905 0.6573]	[4525 4 3455 0.5670]	[3551 7 4426 0.4452]	[3977 9 3998 0.4987]	[4389 7 3937 0.5267$\pm$0.0093]
0.97	[4770 3 3710 0.5625]	[2734 10 5739 0.3229]	[4985 10 3488 0.5882]	[5175 14 3294 0.6109]	[3987 6 4490 0.4704]	[4560 3 3920 0.5377]	[5564 4 2915 0.6561]	[4512 4 3468 0.5654]	[3528 7 4449 0.4423]	[3952 9 4023 0.4956]	[4377 7 3950 0.5252$\pm$0.0093]
0.98	[4782 3 3698 0.5639]	[2782 10 5691 0.3285]	[4972 10 3501 0.5867]	[5157 14 3312 0.6087]	[3979 6 4498 0.4694]	[4551 3 3929 0.5367]	[5563 4 2916 0.6560]	[4509 4 3471 0.5650]	[3522 7 4455 0.4416]	[3868 9 4107 0.4850]	[4369 7 3958 0.5242$\pm$0.0091]
C96 network											
0.55	[12561 10554 2300 0.7019]	[9131 13757 2527 0.6299]	[10827 12229 2359 0.6666]	[10966 12164 2285 0.6708]	[10890 12273 2252 0.6699]	[9201 12163 2096 0.6514]	[12840 8816 1804 0.7352]	[9086 12142 2232 0.6461]	[14421 7267 1772 0.7696]	[9246 12078 2136 0.6515]	[10917 11344 2176 0.6793$\pm$0.0019]
0.60	[12562 10554 2299 0.7019]	[9133 13757 2525 0.6300]	[10828 12229 2358 0.6666]	[10967 12164 2284 0.6708]	[10891 12273 2251 0.6700]	[9203 12163 2094 0.6515]	[12843 8816 1801 0.7353]	[9087 12142 2231 0.6461]	[14422 7267 1771 0.7696]	[9249 12078 2133 0.6517]	[10919 11344 2175 0.6794$\pm$0.0019]
0.65	[12560 10554 2301 0.7018]	[9129 13757 2529 0.6298]	[10826 12229 2360 0.6666]	[10965 12164 2286 0.6707]	[10889 12273 2253 0.6699]	[9199 12163 2098 0.6513]	[12837 8816 1807 0.7351]	[9085 12142 2233 0.6460]	[14420 7267 1773 0.7695]	[9243 12078 2139 0.6514]	[10915 11344 2178 0.6792$\pm$0.0019]
0.70	[12556 10554 2305 0.7017]	[9121 13757 2537 0.6295]	[10822 12229 2364 0.6664]	[10961 12164 2290 0.6706]	[10885 12273 2257 0.6697]	[9191 12163 2106 0.6510]	[12825 8816 1819 0.7346]	[9081 12142 2237 0.6459]	[14416 7267 1777 0.7694]	[9231 12078 2151 0.6509]	[10909 11344 2184 0.6790$\pm$0.0019]
0.75	[12556 10554 2305 0.7017]	[9121 13757 2537 0.6295]	[10822 12229 2364 0.6664]	[10961 12164 2290 0.6706]	[10885 12273 2257 0.6697]	[9191 12163 2106 0.6510]	[12825 8816 1819 0.7346]	[9081 12142 2237 0.6459]	[14416 7267 1777 0.7694]	[9231 12078 2151 0.6509]	[10909 11344 2184 0.6790$\pm$0.0019]
0.80	[12552 10554 2309 0.7015]	[9119 13757 2539 0.6295]	[10820 12229 2366 0.6663]	[10958 12164 2293 0.6705]	[10885 12273 2257 0.6697]	[9191 12163 2106 0.6510]	[12823 8816 1821 0.7345]	[9081 12142 2237 0.6459]	[14414 7267 1779 0.7693]	[9229 12078 2153 0.6508]	[10907 11344 2186 0.6789$\pm$0.0019]
0.85	[12556 10554 2305 0.7017]	[9117 13757 2541 0.6294]	[10822 12229 2364 0.6664]	[10960 12164 2291 0.6705]	[10885 12273 2257 0.6697]	[9191 12163 2106 0.6510]	[12825 8816 1819 0.7346]	[9077 12142 2241 0.6457]	[14416 7267 1777 0.7694]	[9231 12078 2151 0.6509]	[10908 11344 2185 0.6789$\pm$0.0019]
0.90	[12572 10554 2289 0.7023]	[9125 13757 2533 0.6297]	[10830 12229 2356 0.6667]	[10970 12164 2281 0.6709]	[10885 12273 2257 0.6697]	[9191 12163 2106 0.6510]	[12833 8816 1811 0.7349]	[9077 12142 2241 0.6457]	[14424 7267 1769 0.7697]	[9239 12078 2143 0.6512]	[10915 11344 2179 0.6792$\pm$0.0019]
0.92	[12592 10554	[9130 13757	[10850 12229	[10985 12164	[10910 12273	[9206 12163	[12848 8816	[9092 12142	[14454 7267	[9244 12078	[10931 11344 2162

(*continued on next page*)

Table 14 (*continued*)

Orness($\mathbf{w}$) = α	Fold 1	Fold 2	Fold 3	Fold 4	Fold 5	Fold 6	Fold 7	Fold 8	Fold 9	Fold 10	Average
	2269 0.7031]	2528 0.6299]	2336 0.6675]	2266 0.6715]	2232 0.6707]	2091 0.6516]	1796 0.7355]	2226 0.6463]	1739 0.7710]	2138 0.6514]	0.6799±0.0019]
0.93	[12592 10554 2269 0.7031]	[9130 13757 2528 0.6299]	[10850 12229 2336 0.6675]	[10985 12164 2266 0.6715]	[10910 12273 2232 0.6707]	[9206 12163 2091 0.6516]	[12848 8816 1796 0.7355]	[9092 12142 2226 0.6463]	[14454 7267 1739 0.7710]	[9244 12078 2138 0.6514]	[10931 11344 2162 0.6799±0.0019]
0.94	[12600 10554 2261 0.7034]	[9132 13757 2526 0.6300]	[10858 12229 2328 0.6678]	[10993 12164 2258 0.6718]	[10920 12273 2222 0.6711]	[9212 12163 2085 0.6519]	[12854 8816 1790 0.7358]	[9098 12142 2220 0.6466]	[14466 7267 1727 0.7715]	[9246 12078 2136 0.6515]	[10938 11344 2155 0.6801±0.0019]
0.95	[12604 10554 2257 0.7036]	[9134 13757 2524 0.6300]	[10860 12229 2326 0.6679]	[10995 12164 2256 0.6719]	[10920 12273 2222 0.6711]	[9212 12163 2085 0.6519]	[12856 8816 1788 0.7359]	[9098 12142 2220 0.6466]	[14468 7267 1725 0.7716]	[9248 12078 2134 0.6516]	[10940 11344 2154 0.6802±0.0020]
0.96	[12620 10554 2241 0.7042]	[9139 13757 2519 0.6302]	[10876 12229 2310 0.6685]	[11007 12164 2244 0.6724]	[10940 12273 2202 0.6719]	[9224 12163 2073 0.6524]	[12868 8816 1776 0.7364]	[9111 12142 2207 0.6471]	[14492 7267 1701 0.7726]	[9252 12078 2130 0.6518]	[10953 11344 2140 0.6808±0.0020]
0.97	[12640 10554 2221 0.7050]	[9146 13757 2512 0.6305]	[10892 12229 2294 0.6692]	[11020 12164 2231 0.6729]	[10955 12273 2187 0.6725]	[9233 12163 2064 0.6528]	[12881 8816 1763 0.7370]	[9120 12142 2198 0.6475]	[14514 7267 1679 0.7736]	[9259 12078 2123 0.6521]	[10966 11344 2127 0.6813±0.0020]
0.98	[12658 10554 2203 0.7057]	[9154 13757 2504 0.6308]	[10903 12229 2283 0.6696]	[11030 12164 2221 0.6733]	[10960 12273 2182 0.6727]	[9236 12163 2061 0.6529]	[12891 8816 1753 0.7374]	[9123 12142 2195 0.6477]	[14527 7267 1666 0.7741]	[9267 12078 2115 0.6524]	[10975 11344 2118 0.6817±0.0020]
B97 network											
0.55	[20482 431 3468 0.8489]	[21156 15 3210 0.8680]	[20392 447 3542 0.8456]	[21182 446 2753 0.8779]	[19548 16 3914 0.8329]	[21227 14 2237 0.9044]	[20733 13 2732 0.8834]	[19467 423 3588 0.8382]	[18864 870 3744 0.8220]	[19493 51 3934 0.8314]	[20254 273 3312 0.8553±0.0007]
0.60	[20520 431 3430 0.8505]	[21195 15 3171 0.8696]	[20431 447 3503 0.8472]	[21187 446 2748 0.8781]	[19608 16 3854 0.8355]	[21226 14 2238 0.9044]	[20734 13 2731 0.8834]	[19503 423 3552 0.8397]	[18881 870 3727 0.8227]	[19485 51 3942 0.8310]	[20277 273 3290 0.8562±0.0007]
0.65	[20522 431 3428 0.8506]	[21233 15 3133 0.8712]	[20419 447 3515 0.8467]	[21157 446 2778 0.8769]	[19610 16 3852 0.8356]	[21249 14 2215 0.9054]	[20754 13 2711 0.8843]	[19549 423 3506 0.8417]	[18884 870 3724 0.8229]	[19471 51 3956 0.8304]	[20285 273 3282 0.8565±0.0007]
0.70	[20555 431 3395 0.8519]	[21266 15 3100 0.8725]	[20462 447 3472 0.8484]	[21154 446 2781 0.8768]	[19672 16 3790 0.8382]	[21301 14 2163 0.9076]	[20773 13 2692 0.8851]	[19628 423 3427 0.8450]	[18907 870 3701 0.8238]	[19522 51 3905 0.8326]	[20324 273 3243 0.8582±0.0007]
0.75	[20620 431 3330 0.8546]	[21277 15 3089 0.8730]	[20485 447 3449 0.8494]	[21152 446 2783 0.8767]	[19695 16 3767 0.8392]	[21320 14 2144 0.9084]	[20835 13 2630 0.8877]	[19671 423 3384 0.8469]	[18906 870 3702 0.8238]	[19525 51 3902 0.8327]	[20349 273 3218 0.8592±0.0007]
0.80	[20656 431 3294 0.8561]	[21255 15 3111 0.8721]	[20521 447 3413 0.8508]	[21179 446 2756 0.8778]	[19693 16 3769 0.8391]	[21332 14 2132 0.9089]	[20833 13 2632 0.8876]	[19728 423 3327 0.8493]	[18928 870 3680 0.8247]	[19547 51 3880 0.8337]	[20367 273 3199 0.8600±0.0007]
0.85	[20684 431 3266 0.8572]	[21321 15 3045 0.8748]	[20542 447 3392 0.8517]	[21171 446 2764 0.8775]	[19770 16 3692 0.8424]	[21387 14 2077 0.9112]	[20847 13 2618 0.8882]	[19806 423 3249 0.8526]	[18939 870 3669 0.8252]	[19587 51 3840 0.8354]	[20405 273 3161 0.8616±0.0007]
0.90	[20734 431 3216 0.8593]	[21370 15 2996 0.8768]	[20563 447 3371 0.8526]	[21155 446 2780 0.8768]	[19831 16 3631 0.8450]	[21434 14 2030 0.9132]	[20873 13 2592 0.8893]	[19888 423 3167 0.8561]	[18921 870 3687 0.8244]	[19599 51 3828 0.8359]	[20437 273 3130 0.8629±0.0007]
0.92	[20750 431 3200 0.8599]	[21382 15 2984 0.8773]	[20567 447 3367 0.8527]	[21162 446 2773 0.8771]	[19818 16 3644 0.8445]	[21442 14 2022 0.9136]	[20855 13 2610 0.8886]	[19935 423 3120 0.8581]	[18946 870 3662 0.8255]	[19639 51 3788 0.8376]	[20450 273 3117 0.8635±0.0007]
0.93	[20759 431 3191 0.8603]	[21394 15 2972 0.8778]	[20561 447 3373 0.8525]	[21150 446 2785 0.8766]	[19819 16 3643 0.8445]	[21431 14 2033 0.9131]	[20841 13 2624 0.8880]	[19943 423 3112 0.8584]	[18927 870 3681 0.8247]	[19643 51 3784 0.8377]	[20447 273 3120 0.8634±0.0007]
0.94	[20775 431 3175 0.8609]	[21393 15 2973 0.8778]	[20559 447 3375 0.8524]	[21138 446 2797 0.8761]	[19873 16 3589 0.8468]	[21424 14 2040 0.9128]	[20831 13 2634 0.8875]	[19987 423 3068 0.8603]	[18929 870 3679 0.8248]	[19697 51 3730 0.8400]	[20461 273 3106 0.8639±0.0006]
0.95	[20786 431 3164 0.8614]	[21409 15 2957 0.8784]	[20556 447 3378 0.8523]	[21115 446 2820 0.8752]	[19888 16 3574 0.8474]	[21450 14 2014 0.9139]	[20827 13 2638 0.8874]	[20010 423 3045 0.8613]	[18950 870 3658 0.8257]	[19695 51 3732 0.8400]	[20469 273 3098 0.8643±0.0006]
0.96	[20803 431 3147 0.8621]	[21415 15 2951 0.8787]	[20554 447 3380 0.8522]	[21109 446 2826 0.8749]	[19922 16 3540 0.8489]	[21465 14 1999 0.9146]	[20825 13 2640 0.8873]	[20028 423 3027 0.8621]	[18972 870 3636 0.8266]	[19703 51 3724 0.8403]	[20480 273 3087 0.8648±0.0006]
0.97	[20847 431 3103 0.8639]	[21434 15 2932 0.8794]	[20548 447 3386 0.8520]	[21084 446 2851 0.8739]	[19921 16 3541 0.8488]	[21463 14 2001 0.9145]	[20837 13 2628 0.8878]	[20072 423 2983 0.8639]	[19009 870 3599 0.8282]	[19705 51 3722 0.8404]	[20492 273 3075 0.8653±0.0006]
0.98	[20856 431 3094 0.8643]	[21427 15 2939 0.8791]	[20536 447 3398 0.8515]	[21077 446 2858 0.8736]	[19941 16 3521 0.8497]	[21450 14 2014 0.9139]	[20834 13 2631 0.8877]	[20107 423 2948 0.8654]	[19011 870 3597 0.8283]	[19775 51 3652 0.8434]	[20501 273 3065 0.8657±0.0006]

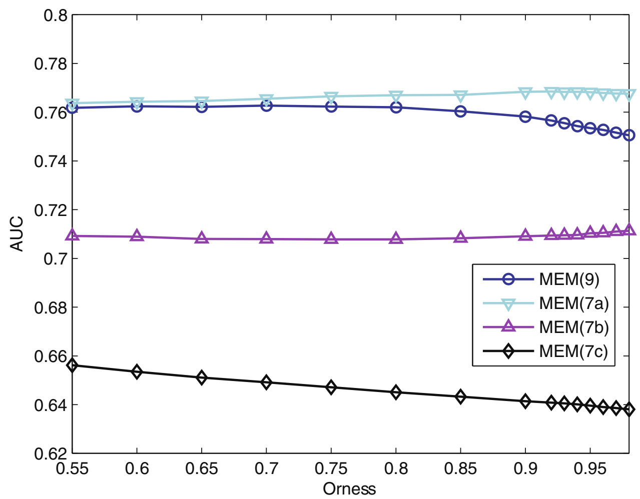


Fig. 14. Comparative results of LPE_{OWA}s on WSDP98.

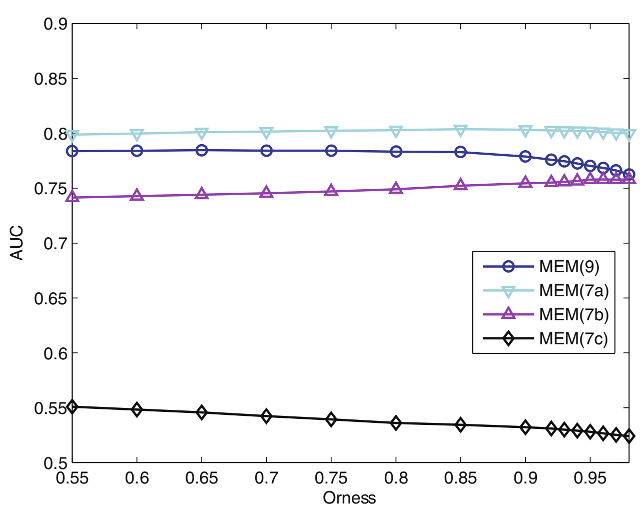


Fig. 15. Comparative results of LPE_{OWA}s on ChesLower.

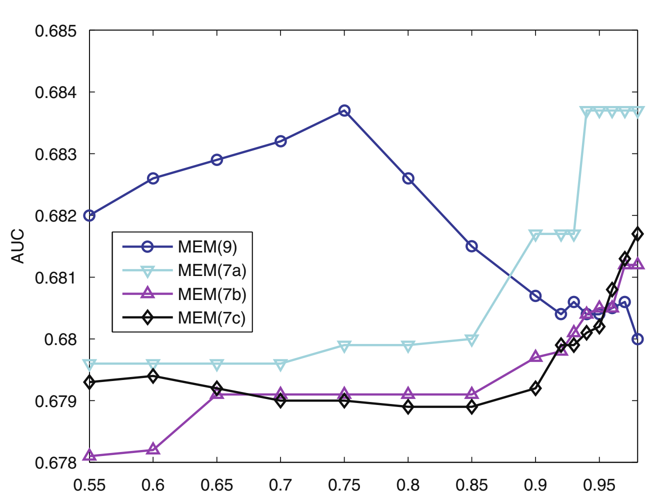


Fig. 16. Comparative results of LPE_{OWA}s on C96.

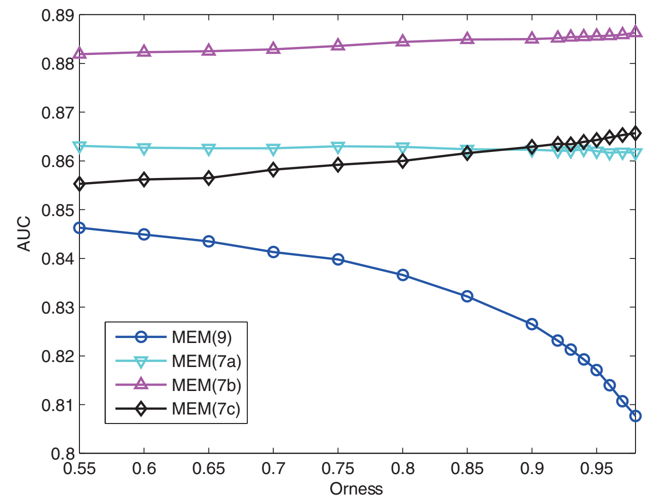


Fig. 17. Comparative results of LPE_{OWA}s on B97.

- For B97 network (Fig. 17), the AUCs of MEM based $LPE_{OWA}(7a)$, $LPE_{OWA}(7b)$ and $LPE_{OWA}(7c)$ also gradually increase with the increase of α. This is opposite to the variation tendency of AUCs of MEM based LPE_{OWA}. MEM based LPE_{OWA} obtains the worse performances than other three ensemble algorithms.

4.3. Analysis to the experimental results

Here, we try to give some elementary explanations to the above-mentioned results. We think the prediction performance of LPE_{OWA} is dependent on the specific characteristics of the social network.

Firstly, LPE_{OWA} obtains the lower AUCs on B97 network. From Table 3 we can find the average degree of B97 is 11.4783. The statistical result shows that there are only 4 nodes in B97 of which the degrees are larger than 11.4783. However, the efficiency of B97 is not low. This indicates that the nodes in B97 network have no obvious characteristic of local information, i.e. the algorithm considering the number of common neighbors of nodes x and y, the degrees of nodes x and y and the degrees of common neighbors of nodes x and y simultaneously is not suitable for the link prediction of network with high average degree and high efficiency. This is also demonstrated by the better performances of $LPE_{OWA}(7a)$ (the number of common neighbors of nodes x and y and the degrees of nodes x and y), $LPE_{OWA}(7b)$ (the number of common neighbors of nodes x and y and the degrees of common neighbors of nodes x and y) and $LPE_{OWA}(7c)$ (the number of common neighbors of nodes x and y and the degrees of common neighbors of nodes x and y) obtain the better prediction performances on this network.

Secondly, LPE_{OWA} obtains the better performances on WSDP98 and ChesLower networks and its performances are further improved by $LPE_{OWA}(7a)$ on these two networks. This indicates that the number of common neighbors of nodes x and y and the degrees of nodes x and y are two more typical characteristics of WSDP98 and ChesLower networks in comparison with the degrees of common neighbors of nodes x and y. The statistical results of WSDP98 and ChesLower reflect that there are about half nodes (14 and 14 respectively) of which the degrees are larger than 6.7429 and 9.0270.

Thirdly, LPE_{OWA} on C96 network obtains the better performances than all individual algorithms and $LPE_{OWA}(7a)$, $LPE_{OWA}(7b)$ and $LPE_{OWA}(7c)$. C96 has 47 nodes whose degrees are larger than 3.8463. It means that the nodes in C96 have the similar local information, i.e., three aforementioned local information all play the important roles on the performances of link prediction algorithms. LPE_{OWA} merges these three kinds of local information together and thus increases the prediction accuracies.

5. Conclusion and future work

In this paper, we design the ensemble strategy for the local information-based link prediction algorithms based on OWA operator. The experimental results demonstrate the feasibility and effectiveness of our method. A number of enhancements and future research can be summarized as follows: (1) test the performance of proposed ensemble algorithm on the large scale social networks, (2) improve the ensemble learning process with the supervised learning methods (e.g., bagging and boosting), and (3) consider to improve the prediction performance of event-based link prediction algorithm (Soares & Prudêncio, 2013) with OWA operator based aggregation.

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