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Research on China's city network based on users' friend relationships in online social networks: a case study of Sina Weibo

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Abstract Cities no longer develop independently but exist in a large city network in the globalization era because of the rapid development of information and communication technologies. Instead of attribute data, relational data has been widely recognized as an improved tool to analyze the importance of a city in a city network. This study attempts to analyze China's city network based on users' friend relationships in Sina Weibo, the most popular online social networking service in China. By collecting friend relationship data from 20 users located in the selected 51 cities, a city network is built based on connections in the virtual world. Findings show that although microblog users build friend relationships with other users located almost everywhere, significant variations exist regarding the closeness of such connections. In particular, a limited number of cities accumulate the majority of top connections; the limited number indicates the significant power of these key cities in the city network. These top connections are also highly related to cities located in Eastern China. The regression model demonstrates that a city with a higher of per capita GDP exerts a powerful influence in the city network. Compared with a prefecture-level city, a municipality directly under central government is considerably powerful. Therefore, the importance of a city in the real world has significant influence on the power of that city in the city network based on online social networking connections.

Keywords City network · Space of flows · Information and communication technologies (ICTs) · Online social networks · China

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Introduction

In the globalization era, cities no longer develop independently but rather exist in a complicated city network. Since the 1990s, the rapid global development of information and communication technologies (ICTs) has facilitated the interactions among cities, regions, and countries (Graham and Marvin 1996; Zhen and Liu 2007). Thus, cities should be studied in the context of intercity networking rather than as individual locations and thereby, focusing on the external relations of a city in the city network is necessary (Taylor 2004). The idea of space of flows

(Castells 1996) has resulted in cities accumulating and retaining control and power because of what flows through them and not what they statistically contain (Taylor 2009). Central place theory has been adopted to analyze the hierarchies of cities in a region or country for a long time. However, this theory need to be developed further because it only indicates how good a city is based on its attribute data but fails to reveal how important of a city in terms of its relations with other cities (Taylor et al. 2010). This limitation and the innovative work of Taylor and his team (i.e., Globalization and World City Networks) have transformed the city network into a popular research topic in the field of urban and regional studies (e.g., Beaverstock et al. 2000; Derudder and Witlox 2005; Taylor et al. 2010).

The data used in the existing research on city network are mainly limited to economic and transportation sphere (e.g., multinational corporations, advanced produce service, and traffic flows). The economic sphere is considered because the initial identification of the formation of world cities in the globalization era is based on the new international division of labor, that is, the reconstruction of the world economy (Friedman 2006). In this process, the command-and-control systems, which are implied in the organization of multinational corporations all over the world (i.e., the location of headquarters and branches), have been extensively used to analyze the importance of cities; world cities are considered command-and-control points. Among the various types of multinational corporations, advanced producer-service firms that provide professional, financial, and creative services for business have been regarded as the key in leading global economic development (Sassen 2001). Firms' office networks that cover major cities globally have also attracted the attention of many geographers in analyzing global, national, and regional city networks (e.g., Sui and Wheeler 1993; Sassen 2001; Shearmur and Doloreux 2008; Yin et al. 2011; Yang and Yeh 2013). The advancement of transportation technologies has led to increasing traffic flows (including flows of both people and goods) among cities over the world. Information on traffic flows has been broadly used in assessing spatial patterns in the global, national, and regional city networks (e.g., Goetz 1992; Shin and Timberlake 2000; Matsumoto 2004; Derudder and Witlox 2005; Jin and Wang 2005). To date, the existing literature on city networks has focused disproportionate attention to Western countries, such as the US and European countries (Taylor et al. 2014). The rapid urbanization in China since the beginning of the reform and opening in 1978, as well as the rise of China's cities in the global city network, calls for timely scholarly research. In the existing literature, scholars have attempted to study the national and regional city networks in China mainly based on transportation infrastructure, advanced producer service, and traffic flows (Jin and Wang 2005; Zhang 2006; Yin et al. 2011).

The Internet's increasingly important role in the people's daily lives in the Information Age has led several scholars to analyze city network by assessing the Internet infrastructure and flows of information (e.g., Mitchelson and Wheeler 1994; Townsend 2001; Zook 2001; Malecki 2002; Wang and Ning 2006; Zhen et al. 2015). Apart from the technological infrastructure of information systems and telecommunications, social practices based on these material arrangements are important in understanding the space of flows and, ultimately, the city network (Castells 1996). However, these social practices have not been studied well in academia because of the lack of related data sources. Accordingly, the present study aims to fill in this research gap by estimating the city network based on users' friend relationships in an online social network. Online social networking sites (e.g., Twitter, Facebook, and Sina Weibo) have gained global popularity (Thulin and Vilhelmson 2005; China National Network Information Center 2011), and the online traces from online activities left by users (e.g., interactions among users, geographical location in user's profiles) provide geographers with a large amount of data, particularly geographical information (Wilson and Graham 2013; Wang et al. 2015). The present study analyzes the social network of Sina Weibo. Similar to twitter, Sina Weibo provides an Internet platform for registered users to release real-time news with a limit of 140 words. Sina Weibo is popular and is the most representative online social networking site in China when data were collected in 2011. The survey report of the China National Network Information Center (CNNIC) showed that the number of microblog users reached 195 million with a penetration rate of 40.2 % for Internet users (China National Network Information Center 2011). Among various microblog websites, Sina Weibo was

the first one established and has become the most popular social media platform registering nearly 212 millions visits per month in 2010.[1] Thus, Sina Weibo is representative of the situation of social networks on the Internet, and adopting this microblog for the present study facilitates the estimation of city network in the analysis.

Data and methodology

Research design

The relationships between users of Sina Weibo include three types, namely, follower, following, and friend. Figure 1 shows that follower and following denote a unidirectional relationship between users. For example, if A follows B, then B does not have to follow A. In this case, A is one of B's followers and can read, forward, and reply each tweet of B; for A, B is one of A's followings. If A and B follows each other, then for both A and B, they are one of each other's friends. A friend relationship based on two-way "follows" is relatively stronger compared with the follower and following relationship. Moreover, a friend relationship between A and B represents a bidirectional transmission of information through reading, replying to, and forwarding each other's tweets. This example establishes that a friend relationship between users in cities A and city B implies a bidirectional transmission of information between the two cities from a geographical perspective. Consequently, friend relationships among Sina Weibo users reflect relationships among cities where these users are located; hence, the number of friend relationships reflects the closeness among cities. Therefore, the city network can be built based on friend relationships among Sina Weibo users.

It would be better to include all Sina Weibo users located in almost every prefecture-level cities or above in China in the study. However, collecting such a large amount of data is difficult or even impossible, particularly because such data continue to increase almost every minute. By contrast, the distribution of users among cities is uneven (Wang et al. 2013), and the number of friend relationships shows a distinctive hierarchy that is further elaborated in the later analysis. Rather than a full-scale analysis of Sina Weibo users, the present study aims to investigate the city network based on users from 51 selected sample cities.

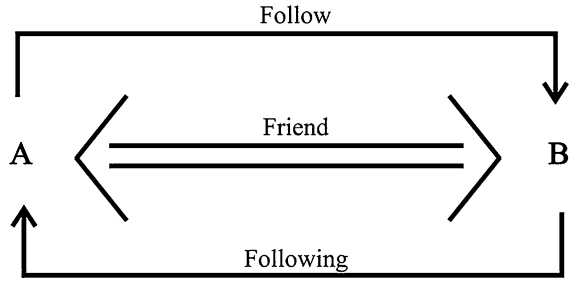

Fig. 1 The relationship between users based on user A

Data collection

The selection of cities

Cities of higher hierarchy are considered in this explorative research because of the long tail distribution of Sina Weibo users in cities in China's cities. In further research, a database including additional cities can be recorded and analyzed. In the first round of selection, 41 cities which are the top 100 cities in terms of the number of internet users, population size, and GDP in 2010 were selected. The second round of selection aims to guarantee fair opportunity for each province by selecting the provincial capital of 5 provinces without cities selected in the first round. In addition, another 5 PCs from 5 provinces were added to enrich the samples of these cities. Finally, 51 cities were selected for the present study (Table 1).

The selection of Sina Weibo users

A total of 20 Sina Weibo users were selected for each selected city. First, the name of selected city was used as a filter criterion to "search user" on the Sina Weibo site; the site returned a list of users within the specified geographical location and randomly listed them in web pages. Each web page listed 20 users, and only the first 100 web pages of the search results were publicly available. Second, no more than one user was selected in the order in which users appear on the list in each web page. The selected user had to meet two

[1] The survey report on the first year of microblog use in China (*Zhongguo weibo yuannian shichang baipishu*). Assessed 29 December 2014, from http://www.slideshare.net/lxm19871231/ss-5245420.

Table 1 The 51 selected cities in China

City name	GDP rank (2010)	City name	GDP rank (2010)	City name	GDP rank (2010)
Shanghai	1	Dalian	14	Xuzhou	35
Tianjin	6	Chengdu	13	Liuzhou	92
Beijing	2	Xi-an	29	Daqing	40
Kunming	51	Jinan	22	Hefei	41
Wenzhou	32	Shijiazhuang	26	Urumqi	88
Guangzhou	3	Handan	45	Lanzhou	107
Changchun	28	Harbin	24	Guiyang	98
Shenzhen	4	Taiyuan	64	Jilin	66
Chongqing	7	Fuzhou	31	Hohhot	62
Suzhou	5	Nanchang	50	Baoji	121
Hangzhou	8	Changsha	20	Haikou	206
Wuhan	12	Tangshan	18	Xiangfan	77
Qingdao	10	Yantai	21	Changzhi	130
Ningbo	15	Nanning	65	Sanming	124
Nanjing	17	Xiamen	55	Xining	205
Zhengzhou	23	Lianyungang	101	Yinchuan	182
Shenyang	16	Guilin	103	Lhasa	280

The GDP ranking is based on statistics published in the *China City Statistic Book* (National Bureau of Statistics 2011)

conditions: (1) the user had to be a normal user but not a celebrity because a celebrity's online social networking site functions similar to an advertisement platform rather than for making friends; and (2) the user had to be relatively active on the site with no less than 400 followers and 400 followings and no less than 6 tweets per day. If a user failed to meet these requirements, then he was excluded in the study, and subsequent users were considered one by one until one user has fulfilled the conditions. When no user in the resulting list met the requirements, the latter web pages of the result were supplemented until 20 users were selected. Finally, 1020 samples from 51 cities were selected. Although extensive effort have been exerted in collecting the samples, the present study does not claim performing a random sampling of all Sina Weibo users in China (excluding friend relationships with users in Hong Kong, Macau, Taiwan,[2] and in other countries). The findings and discussion are based on the sample collected in the present study.

Collection of friend relationship of the 1020 samples

A simple website crawler application was used to automatically record the ID of followers and followings of the 1020 samples. Friends were identified from the comparison of the ID of followers and followings. The geographical location of these friends were recorded as well. Finally, 243,451 friend relationships were identified. Of the total number of friend relationships, 183,597 (approximately 75 %) were located in the 51 cities. This number verifies the long tail distribution of users and the uneven distribution of friend relationship.

Measuring indicators

For each city i, the percentage of the number of friend relationships between city i and j for the total friend relationships between city i and other 50 cities were adopted to represent the relatively closeness of the directional linkage from city j to i. The formula is as follows,

[2] In this study, China refers to Mainland China, that is, excluding Hong Kong, Macau, and Taiwan. This consideration does not deny these administrative units are integral parts of China. However, Sina Weibo is not popular enough in these regions.

$$V'_{ij} = \frac{V_{ij}}{\sum_{j \neq i}^{50} V_{ij}} \times 100$$

where V_{ij} is the number of friend relationships between city i and j, and V'_{ij} is the normalized number.

Second, for both city i and j, the product of V'_{ij} and V'_{ji} was calculated to indicate the connection between cities i and j. The higher the product of R_{ij}, the more closeness is observed between Sina Weibo users in cities i and j. This large product indicates a close linkage between cities i and j in the city network. The formula is as follows,

$$R_{ij} = V'_{ij} \times V'_{ji}$$

Thereafter, a matrix of relatively closeness of the undirectional linkage was formulated; the matrix was imported into the UCINET. By adopting Bonacich's approach, the normalized Bonacich power (NBP) of each city i was calculated. NBP denotes the power (or importance) of a city in the city network. In Bonacich's approach, the power of an actor in a network is not only depend on the number of connections it has with other actors but also on how it is connected to the central others. Therefore, both centrality and power were functions of the connections of actors in one's neighborhood (Bonacich 1987). Moreover, instead of merely scaling (assigning numbers to) connections based on the existence of a relationship or not (i.e., assigning the value one when a relationship exists, and assigning zero when a relationship does not exist), the closeness of relations (i.e., R_{ij} in the present study) is considered in NBP. The higher the NBP of city i, the more powerful (or important) the city i is in the city network.

China's city network based on online social networks

Characteristics of the city network

Unlike the command-and-control systems exhibited in multinational cooperations, a user's choice of whom to follow (i.e., building a connection with another user) is public in Sina Weibo. Therefore, the city network should be flat without centers or hierarchies based on users' friend relationship in the virtual space. However, the results indicate a city network that is highly controlled by a few centers that concentrate connections with others in the city network.

NBP and the city hierarchy in the city network

Figure 2 exhibits the NBP rankings of the 51 cities in the city network and again reveals a long tail distribution of cities. As the rankings progressed, NBP started to decrease significantly until the cut-off point of 5.65 (the NBP of Fuzhou). After this point, NBP maintained slight decreases. The NBP rankings showed a logarithmic distribution: $y = -5.977 \times \ln(x) + 21.78$; Where y is the NBP of a city and x is the corresponding ranking of the city. The goodness of fit test showed that R-square = 0.7791.

In line with the traditional classification of city hierarchy into (sub) national center, (sub) regional center, local center, and local node (Jin and Wang 2005; Gu and Pang 2008), the present study divided the 51 cities into six levels of importance based on their corresponding NBP using Jenks natural breaks classification method (see Table 2 for summary). This method seeks to reduce the variance within classes and maximize the variance between classes to determine the best arrangement of values into different classes (Jenks and Caspall 1971). To further subdivide the city level, the cities' network connectivity was sequenced. Table 2 shows that Beijing is evidently the national center with an NBP of 37.54. The value of Beijing's NBP is over twice that of Shanghai, the second-ranked city in the network. The huge gap between the first and the second cities indicates Beijing's strong power and control over the city network based on users' friendships in Sina Weibo. With an NBP value between 13.50 and 18.01, Shanghai, Guangzhou, and Shenzhen are the sub-national centers. Interestingly, Beijing, Shanghai, Guangzhou, and Shenzhen are designated as the traditional tier one cities. Therefore, the same four cities are highlighted in the city network based on virtual space (i.e., the connections of Sina Weibo users' friend relationships) and the real world (i.e., the population and economy). The similarity seems to imply that the importance of cities in the real world influences the power of cities in the virtual world. The NBP value of Guangzhou (the fourth-ranked city and last among the sub-national centers) is nearly twice that of Chengdu (the fifth-ranked city and top regional centers).

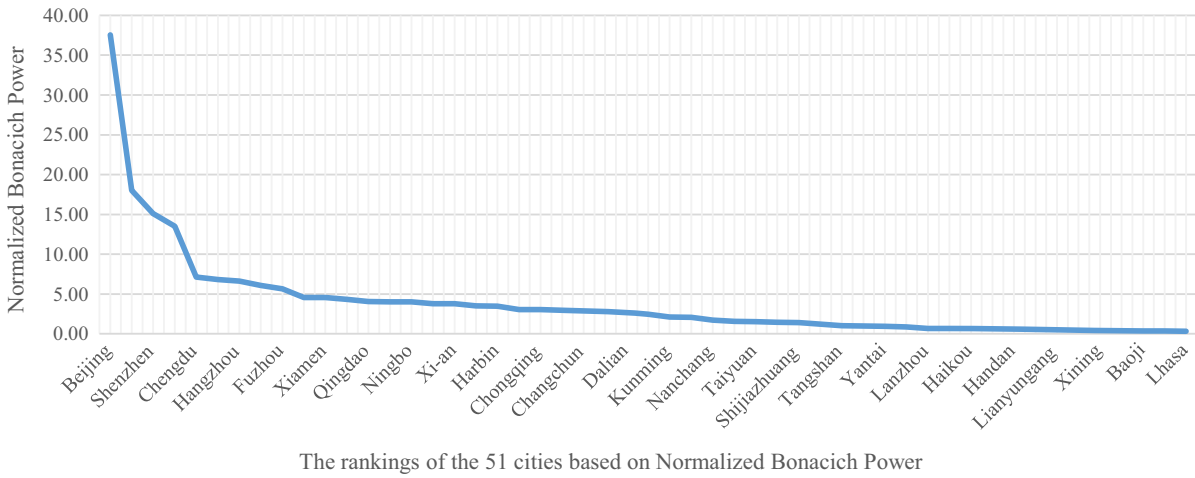

Fig. 2 The NBP rankings of the 51 cities in the network

Table 2 NBP-based classification of the importance of cities in the network

Level	NBP	Cities
National center	37.54	Beijing
Sub national centers	13.50–18.01	Shanghai, Shenzhen, Guangzhou
Regional centers	5.65–7.12	Chengdu, Tianjin, Hangzhou, Wuhan, Fuzhou
Sub regional centers	2.71–4.57	Zhengzhou, Xiamen, Nanjing, Qindao, Nanning, Ningbo, Suzhou, Xi-an, Ji-nan, Harbin, Shenyang, Chongqing, Wenzhou, Changchun, Changsha, Dalian
Local centers	1.01–2.46	Liuzhou, Kunming, Guilin, Nanchang, Hefei, Taiyuan, Jilin, Shijiazhuang, Xuzhou, Tangshan
Local nodes	0.33–0.47	Urumqi, Yantai, Guiyang, Lanzhou, Changzhi, Xiangyang, Haikou, Handan, Sanming, Lianyungang, Daqing, Xining, Huhhot, Baoji, Yinchuan, Lhasa

With NBP values between 5.65 and 7.12, Chengdu, Tianjin, Hangzhou, Wuhan, Fuzhou, Zhengzhou, Xiamen, Nanjing, Qingdao, and Nanning are designated as regional centers. These cities are located in different well-known urban regions in China as identified by Fang (2011). Fang's definition and classification of urban regions have been acknowledged by the National Development and Reform Commission in China and highly cited by academia. For example, in the present study, Chengdu and Nanning are the regional centers of Chengdu–Chongqing and Guangxi regions in the Western China,[3] respectively; Wuhan and Zhengzhou are the regional centers of Wuhan region and Central Plain area in Central China, respectively; Tianjin, Hangzhou and Nanjing, Fuzhou and Xiamen, and Qingdao are the regional centers of Beijing–Tianjin–Hebei region, Yangtze River Delta, west coast area of the strait in Fujian, and the Shandong Peninsula area in Eastern China, respectively. The same regions and their respective major cities are identified in Fang's

[3] The division of China into Eastern, Central, and Western China can be traced back to the "seventh 5-year plan" in 1986 and have been extensively used thereafter not only in academic research but also in policy making in China's regional development. Eastern China includes Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan; Central China includes Anhui, Heilongjiang, He-nan, Hubei, Hunan, Jiangxi, Jilin, and Shanxi; and Western China includes Chongqing, Guangxi, Guizhou, Inner Mongolia, Ningxia, Qinghai, Gansu, Shaanxi, Sichuan, Tibet, Xinjiang, and Yunnan.

research based on aggregative indicators, such as population, economy, and urbanization perspectives. The same cities are identified in the present research based on Sina Weibo users' friend relationships. This similarity further suggests that the city network based on virtual relations is highly influenced by the real world situation in China. Hence, a city that is important in the real world is also important in the city network built through virtual connections in Sina Weibo.

City connection in the city network

Theoretically, a total of 1275 connections exist among the 51 cities (C_{51}^2) in the city network. The present study's statistics indicate that the R_{ij} of 102 connections are 0, accounting for approximately 8 % of the total. This low occurrence of zero user relationships between cities indicates that Sina Weibo users tend to have friend relationships with users located almost everywhere in China. This evidence further confirms that extensive relationships can be built in the virtual world because less expenses and time are necessary to overcome spatial distance and build virtual friendships compared with building relationships in the real world. However, significant variations are revealed once the closeness of connections is considered (see Figs. 3, 4). In particular, only 25 % of these connections have a value of R_{ij} over 1.0. Hence, 75 % of these connections are, de facto, substantially weak. Therefore, although almost every city is connected with each other, they are connected in significantly different degrees in terms of closeness.

Even among the top 25 % of connections with a value of R_{ij} above 1.0 (i.e., a total of 319 connections), the variation is also rather pronounced, which could be pinpointed by several cut-off points. The median value of R_{ij} of these 319 connections is 2.24. Figure 4 shows that the median value of R_{ij} of the top 5 % and top 1 % of the total connections (i.e., the top 20 and 4 % of these 319 connections) are 12.45 and 37.17, respectively. Among the top 5 % of the connections (total of 64 connections), Beijing (the national center) accumulates 28 connections, having nearly half of all connections (43.8 %). The three sub-national centers registered 20 connections, taking up 31.3 % of all connections. Among the top 1 % of connections (i.e., a total of 12 connections), the percentage of connections with Beijing is 66.7 %, whereas the total percentage of connections with the three sub-national centers is 58.3 %. A high percentage of the top connections concentrated in a limited number of cities. This concentration demonstrates the dominant role these key cities play in the city network based on Sina Web uses r' friend relationships.

The top 5 % connections are highly related with cities located in Eastern China. The number of connections among cities located in Eastern China is 34, accounting for over half (53.1 %) of the 64 connections for the total 5 %. The number of connections between cities located in Eastern and Central China is 15 for a share of 23.4 %, whereas the connections between cities located in Eastern and Western China total 8 for a 12.5 % share. Hence, approximately 90 % of the top 5 % connections are with cities located in Eastern China, thereby indicating the important role of Eastern China in the city network based on users' friend relationships in the virtual world.

Regression analysis on the power of a city in the city network

Regression analysis was conducted to gain an improved understanding of the relationship between the power of a city in the city network and its importance based on the attribute data. The dependent variable was the NBP value of these 51 cities. The independent variables were the attribute data that have been extensively used to analyze the importance of a city, namely, population size (POP), per capita GDP (PGDP), and political status [cities are classified from higher to lower political status according to China's special institution context: municipality directly under Central Government (MDCG), vice-provincial city (VCC), provincial capital city (PCC), and prefecture-level city (PC)].

Table 3 summarizes the results of the power of a city in the city network. PGDP is a statistically significant factor in accounting for the power of a city in the city network. The higher the PGDP of a city, the more powerful of that city in the city network. Although a city with a large POP tends to be a statistically significant factor, when the variable of political status is controlled, POP is no longer statistically significant. This finding implies Sina Weibo users tend to build friend relationships with users located in a more economically developed cities.

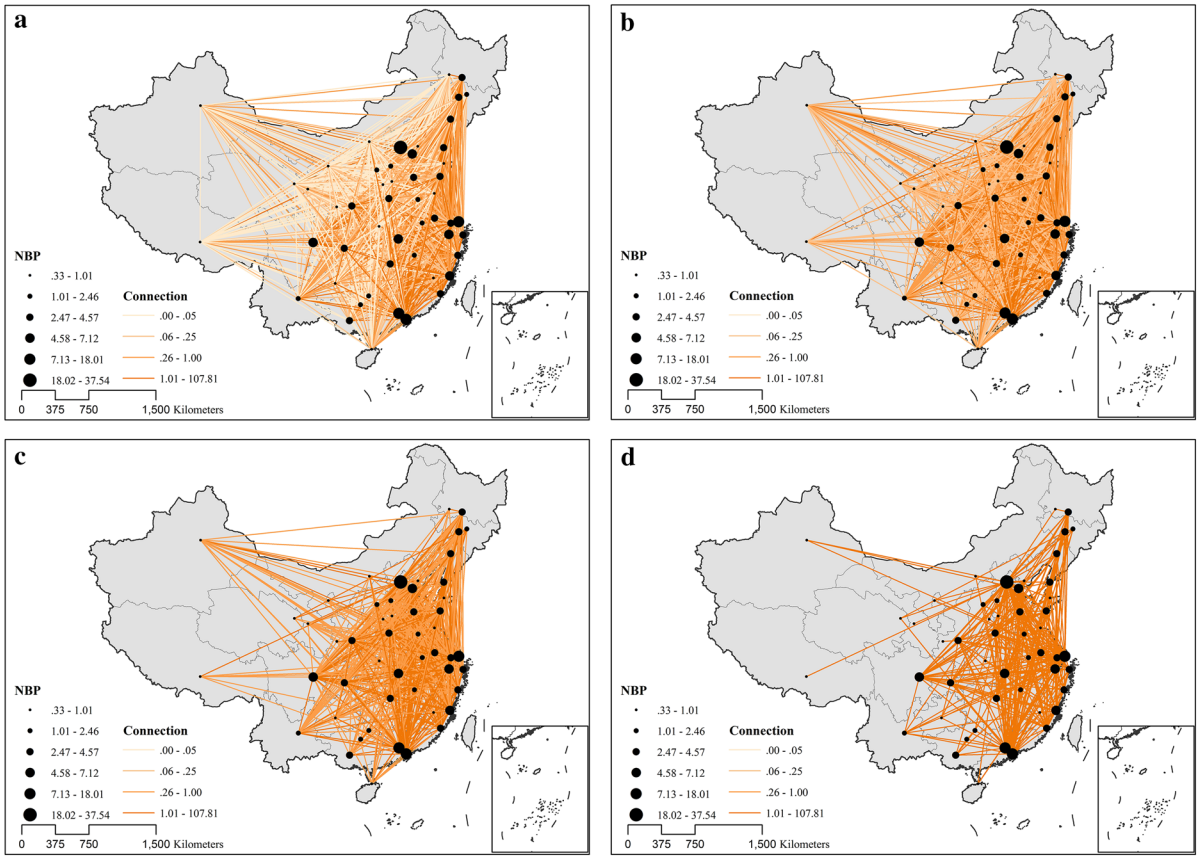

Fig. 3 China's city network based on Sina Weibo users' friend relationships (**a** city network including all connections, **b** city network including the top 75 % connections, **c** city network including the top 50 % connections, **d** city network including the top 25 % connections)

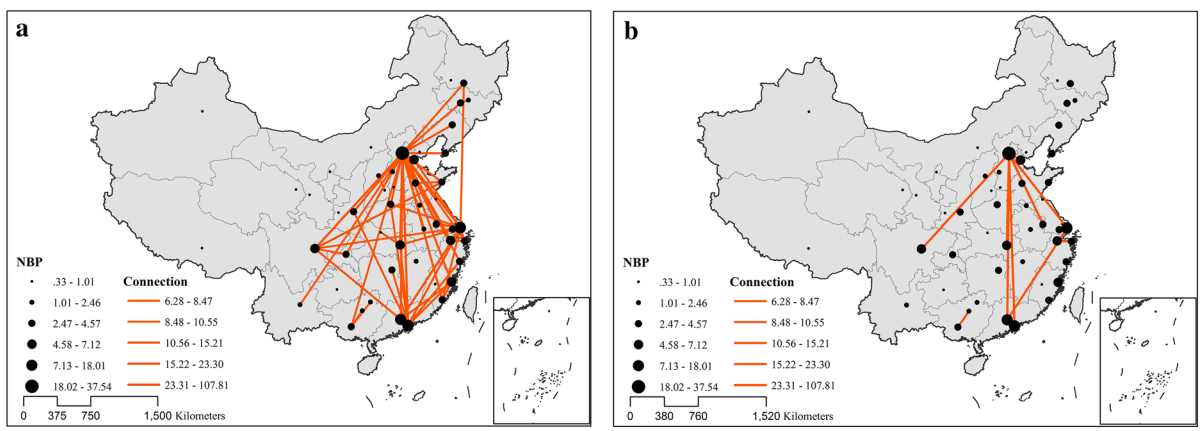

Fig. 4 China's core city network based on Sina Weibo users' friend relationships (**a** city network including the top 5 % connections, **b** city network including the top 1 % connections)

Table 3 Regression results on the power of a city in the city network

Dependent variable (NBP)	Model 1		Model 2	
	B	Beta	B	Beta
POP (in logarithmic form)	3.788	0.434***	1.476	0.169
PGDP (in logarithmic form)	4.691	0.326***	4.11	0.286**
POL (PC = ref.)				
PCC			0.729	0.058
VPC			1.738	0.133
MDCG			11.394	0.513***
Adjust R^2	0.359		0.495	
F-value	15.010***		10.799***	

** $p < 0.05$; *** $p < 0.01$

MDCG is drastically more powerful than PC. The NBP value of an MDCG is over 10 times of that of a PC. However, though the VPC and PCC have higher political status than PC, their NBP value are not higher in terms of statistical significance. This finding suggests that only MDCGs retain their importance in the city network. Thus, users in MDCGs are likely to be linked with users in other cities. A possible explanation is the popularity of Sina Weibo use among young generations, particularly among university students (China National Network Information Center 2011). These MDCGs are the education centers in China and have the most universities and university students in China. Another reason might be the appeal of users in MDCGs. These users tend to be exposed to many new ideas and interesting information because MDCGs also act as the media centers in China. Thus, these users in MDCGs are interesting and appealing for other users in the network.

Conclusions

The rapid development of ICT and its extensive penetration into the people's daily lives have contributed to the global popularity of online social network, such as Twitter and Facebook in Western countries and Wechat and Sina Weibo in China. This study endeavors to shed light on city network building through virtual connections by attempting to analyze China's city network based on users' friend relationships in Sina Weibo. A city network based on users' friend relationships was built by collecting online traces (e.g., user's followers, followings and their profiles) of 20 selected users located in 51 cities. Using Bonacich's approach, each city's NBP was calculated to indicate the power of each city in the city network. The connections among cities in the city network were also analyzed.

Using the Jenks natural breaks classification method, the (sub) national center, (sub) regional center, local center, and local node were identified. The identification implies that the an importance of cities in the real world has an influence on the power of cities in the virtual world. The regional centers in the city network identified in this study are similar to the findings based on traditional indicators of population, economy, and urbanization perspectives. In terms of connections, although microblog users tend to build friend relationships with users located almost everywhere, significant variations exist regarding the closeness of connections. A high percentage of the top connections are concentrated in a limited number of cities; this concentration indicates the leading role of these key cities play in the city network based on microblog user's friend relationships. In addition, these top connections are considerably related to cities located in Eastern China, thereby indicating the important role of this region in the entire city network. This study's regression model demonstrates that cities with higher PGDP are more powerful than other cities in the city network. MDCGs are also considerably more powerful than PCs in the city network.

A city network based on online social networking data was identified through this explorative research. However, several avenues for further research can be considered. First, additional cities can be included to build a considerably complicated city network and make the results substantially comprehensive. Second, including additional sample users in each selected city can make the samples highly representative. Third, explaining the mechanism of people's choice of friends in the virtual world may be useful in understanding the city

network. Therefore, an interview with typical microblog users can be conducted. These improvements are being considered for the future study.

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