Секция «Моделирование и прогнозирование глобального развития»

City wealth, shortest paths and geographical neighboring in the country-scale urban network

Макаров В.В.[1], *Горемыко М.В.*[2], *Кирсанов Д.В.*[3], *Boccaletti S.S.*[4], *Максименко В.А.*[5], *Храмов А.Е.*[6]

1 - , *E-mail: vladmak404@gmail.com*; 2 - , *E-mail: goremiko.mihail@yandex.ru*; 3 - , *E-mail: dankirsdot@gmail.com*; 4 - , *E-mail: stefboccaletti@gmail.com*; 5 - , *E-mail: maximenkovl@gmail.com*; 6 - , *E-mail: hramovae@gmail.com*

Every process flowing in different parts of urban system contribute to its economical and social outcome (Scott, 2015; Taylor, 2001). Lately, a lot of attention has been paid to the analysis of connectivity patterns of the networks describing various layers of urban complex (Leo, 2016). Recently, multiplex approach revealed itself very useful method to describe the interaction between various aspects of urban networks, including the social and cultural relationships, health, traffic flows and economics (Salonen, 2013; Strano, 2015). The fact remains that in the named works researches study urban networks limited by size of the specific city or agglomeration, while research on the scale of whole country is absent.

In this work, we study the interplay between the administrative structure of the country and the connections between cities, which arise from their geographical and population setup. We use the example of the Republic of Kazakhstan, considering dataset that covers 70 years of evolution of its urban network. The available data present itself the information gathered during population census in seven time slices from 1939 to 2006 year. Each census contains the geographic coordinates and the number of citizens of all cities and urban-type communities for the given year with their administrative submission. One of the main aspects of the majority of urban studies is the spatially-distributed nature of these systems (Makse, 1995). Our aim is to investigate how the characteristics of the spatially-distributed network of the cities can be directly affected by their hierarchical subordination. To do it, we measure several network characteristics of administrative and geo-population networks separately and while arranging them in the framework of multiplex network. We observe that multiplex interaction of named above networks leads to the actual exchange of eigenvector and betweenness centralities of the nodes belonging to the different layers. We have revealed two important effects which occur in the urban network of the country than we consider both administrative and geographical relations between its cities: (i) geo-populational network aggregates eigenvector centrality and impose its own ranking to the administrative (hierarchical) network, (ii) administrative network connects the structural hubs and redistrubutes the shortest paths between nodes in geo-population layer. We also have found the relation between the total values of centrality in each layer, and discover the sustainability of these values, that has been proved by numerical simulations. However, the comparison with the regular scale-free network reveals, that this effect is connected with spatially distriduted nature of the real urban networks. More specifically, the effect of redistribution of shortest paths refers to the absence of direct connections between main hubs in urban networks. To validate our results, we numerically produce and study spatially-distributed and spatially independent scale-free model networks.

What is practical implication of the revealed effects? For the first time, our study gives scientific ground and provides full understanding of two main phenomena (i) in a country-scale urban network and for each specific city, the geographical neighbouring with highly populated areas is more important than its political setting; (ii) the structure of political subordination is instead crucial for the wealth of transportation network and communication between populated regions of the country. First of all, the urban network of whole country demonstrates compex modular structure, where clusters are connected between each other by small number of nodes.

Obviously, this nodes are crucially important for the country, and their prosperity connected with the development of transportation network. On the over hand, the administrative network is responsible for the distribution of funds and innovations inside the country, in fact, their diffusion from the upper levels. That's why one of the presumptive ways to secure their foothold is to transfer them on the upper level of hierarhy.

There are much more global examples, that could be described by the multiplex interaction between spatially-distributed network, which is formed by some strong historical and geographical factors, and spatially-independent (not neccesary hierarchical) network, which makes a "wormholes" inside this structure. The most vivid and, somehow, topical example is the interplay between the geography of countries, which have their own historically conditioned culture and ideology, and WWW network, which can make connections between areas completely different in this sense. This in turn leads to the variety of reactions on the part of the geographical layer, from the active integration in the spatially-independent layer (Haythornthwaite, 2005), to the actual cutting off or filtering of inter-layer connections (Healy, 2007). There is no doubt, that further investigations of the interplay between spatially-distributed and spatially-independent networks will enable us to predict their interaction in real systems.

This work has been supported by the Russian Foundation for Basic Research (Grants No. 15-02-00624 and 16-32-00334).

Bibliography

Scott, A. J., Storper, M. The nature of cities: the scope and limits of urban theory // International Journal of Urban and Regional Research. 2015. V. 39. P. 1-15;

Taylor, P. J. Specification of the world city network // Geographical analysis. 2001. V. 33. № 2. P. 181-194;

Leo, Y., Fleury, E., Alvarez-Hamelin, J. I., Sarraute, C., Karsai, M. Socioeconomic correlations and stratification in social-communication networks // Journal of The Royal Society Interface. 2016. V. 13. № 125. P. 20160598;

Salonen, M., Toivonen, T. Modelling travel time in urban networks: comparable measures for private car and public transport // Journal of Transport Geography. 2013. V. 31. P. 143-153;

Strano, E., Shai, S., Dobson, S., Barthelemy, M. Multiplex networks in metropolitan areas: generic features and local effects // Journal of The Royal Society Interface. 2015. V. 12. № 111. P. 20150651;

Makse, H. A., Havlin, S., Stanley, H. E. Modelling urban growth patterns // Nature. 1995. V. 377.№ 6550. P. 608;

Haythornthwaite, C. Social networks and Internet connectivity effects // Information, Community & Society. 2005. V. 8. № 2. P. 125-147;

Healy, S. The great firewall of China // Social education. 2007. V. 71. № 3. P. 158-163.