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Online Social Networks from a geography perspective

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Distance dead or alive: online social networks from a geography perspective

Abstract

Triggered by the revolutionary development of internet technologies, a diminishing role of geography was claimed by the "death of distance" theorem more than a decade ago. Oppositely, empirical research demonstrated that online communities and internet infrastructure were bounded to physical, social, and cultural environment. This paper seeks to analyse the correspondence between offline geography and the settlement-level topography of iWiW, the largest Hungarian online social network (OSN). We find that the online network is spatially based; because inter-city reach measured by physical distance and by OSN edges are strongly related with a negative sign. In addition, a strong and spatially-based modularity is present in the network. The deterrence effect of distance still holds when controlling for modularity.

Keywords: online social network, intercity network, distance, modularity, regions

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1. Introduction

The role of geographical distance in Internet-based communication and in shaping Internet infrastructure itself has been a topic of debate in geography since the ‘90ies. On the one hand, strong claims have been developed stating that the deflating impact of distance is disappearing due to falling communication costs (Cairncross, 1997). On the other hand, empirical findings have repeatedly illustrated that this is not case; distance still plays an important role in forming Internet structure (Tranos and Nijkamp, 2012) and also online communities (Scellato et al, 2010) because establishing a hyperlink or a friendship might increase with distance.

The aim of the current paper is to provide a detailed picture of the offline geography of an online social network (OSN). We demonstrate that distance among settlements has had a major force on network topography. Our main motivation behind is that the spatial dimension of OSNs are under-researched and we still need a better understanding on cost-dependence of online activities. To put it simple, how does seemingly cost-less activities –like knowing someone in an OSN– scatter across space? Does gravity law stand in OSNs like in other telecommunication networks, in which communication costs are identifiable (Krings et al, 2009), or do we get a more complex picture from OSN data?

Our demonstration is based on iWiW, the largest Hungarian OSN counting for 40 per cent of the country’s population. A snapshot of the global network –in which profile-based individual data concerns the accumulated number of iWiW friends over the 2002-2013 period– is aggregated at the level of 2,562 settlements that constitutes the nodes. Edge weights are log-normalized values of the number of OSN friendship between two settlements. The findings suggest that the larger geographical distance between settlements the smaller number of online friendship. However, the large variation of edge weight at high distance values implies that no gravity-law applies to our case. We find spatially-based modules in the network. The deterrence role of distance still holds when controlling for these cohesive geographical regions.

A literature overview is provided in the next section regarding concepts and previous findings on offline space and OSNs. This is followed by the introduction of the data and methodology used. Analysis and results are summarized in the fourth section. A discussion on distance-related costs in OSNs concludes the paper.

2. Location and distance in online social networks

2.1 Location

The revolutionary development of Internet and other forms of digital communication ringed the alarm for geographers to reformulate major concepts and hypotheses in the '90ies. Cyberspace became central issue in understanding human behaviour in the virtual world, while the term cyberplace is used to depict spatially grounded online activities (Hayes 1997, Wellman 2001). These two concepts are natural starting points when addressing the issues of geographical location of online social network usage or interrelatedness between offline and online worlds.

Concerning its' character, cyberspace is a conceptional space of the flow of information and came to existence through elemental combination of infrastructure, softwares, telecommunication networks, and human mind (Devriendt et al. 2008). Cyberspace is a medium, in which complex convergence of computers, communication and people seems to come true (Dodge 2001). The space of flows – as Castells (1996) refers to cyberspace – is fluid and offers wide moving possibilities for everyone, which hereby may become independent of real physical space (Kitchin 1998). Cyberplace is central element of virtual geography and is defined as the projection of cyberspace on real space (Batty 1997). Cyberplace is something between physical and cyber space since on the one hand it is a composition of the internet infrastructure, fibre and satellite networks, and other technological elements of data communication, which are all embedded in real space (Tranos 2011).

Modern interpretations of geography determine cyberspace and cyberplace either similar or radically different from traditional geographical spaces. In certain compositions, the new digital and globalized world is similar to a pinhead, or at least to its' "sense" (Negroponte 1995) and geographical locations are not relevant for it. In contrast, with radical standpoints it is getting more accepted that although the internet and cyberspace have essential corrective effects on time-space relations, geographical aspects have important roles henceforward in many ways.

In this paper, we follow the latter argument: geographical location is still a major factor shaping the Internet layer of human life. For example, Brian Hayes (1997) argues that the internet cannot exist independently of conventional geography because no bit can proceed via the Net without passing through kilometres of wires and optical fibres or tons of computer hardware, which are all in physical space indeed. Furthermore, studies on online communities highlight that online communities are based on geographically bounded social relations and institutions (Benedikt 1991, Jones 1995, Fernback 2007). Thus, “glocalization” is a major phenomenon in internet-based communication; due to the internet, people interact stronger in their local area and extend some of their interactions to the global level (Wellman 2002).

Geolocation could be determined as a linkage with spatial units, cities, regions or by spatial delineation of material objects (e.g. fibre networks) with known geographical positions. All the formations that could be identified along these cross-sections are possible to be visualised in physical space (Haklay et al. 2008). For example, geolocation of activities in online social networks usually make use of IP addresses where users log-in from (Yardi and boyd 2010, Backstrom et al. 2011, Ugander et al. 2011). Another stream of analyses lean on OSN profiles and considers user location as self-reported data (Lengyel and Jakobi, 2013). The current paper uses self-reported data from the complete set of iWiW profiles and identifies settlement-level location.

2.2 Distance

Due to sintering communication costs a diminishing role of geography was envisaged in the “death of distance” theorem of Cairncross (1997). However, empirical evidence repeatedly showed that physical place and distance has a determining power on objects and activities located in physical place, despite the widening communication opportunities. For example, series of studies have found that the role of distance can be described by gravity models in the case of telecommunication flows (Krings et al 2009, Lambiotte et al 2008): the intensity of interaction between two communities are determined by their size and a deterrence function of distance between them. Although –to the best of our knowledge– no such deterrence function has been found regarding internet-based networks, the diminishing role of geographical distance on interaction has been reported on internet infrastructure (D’Ignazio and Giovanetti 2007, Tranos and Nijkamp 2012) and also on online social networks (Liben-Nowell et al, 2005, Scellato et al, 2010).

The influence of geographical distance on tie formation between two locations is described through the cost of establishing a tie (Borgatti et al 2009, Expert et al 2011). For example, Tranos and Nijkamp (2012) claim that despite Internet has lowered the costs of communication, establishing a hyperlink among webpages registered at distant places has higher costs than among proximate places.

However, online social networks are claimed to clearly differ from other web-based networks like Internet infrastructure. The latter are led by power-law tie-distribution: a small share of webpages accounts for an outstandingly high number of links (Barabási and Albert 1999). On the contrary, the tie-distribution of OSNs are very close to multi-scaling behaviour of real-life social networks (Ahn et al. 2007, Backstrom et al. 2011, Ugander et al. 2011). These services are supplemental forms of communication between people who have known each other primarily in real life and are used primarily to document offline friendships (Ellison et al. 2006, 2007, boyd and Ellison 2007). In other words, OSNs are “biased versions of real-life social networks“ (Backstrom et al. 2011, Ugander et al. 2011) and therefore costs of establishing ties in OSNs have to be differentiated from costs of establishing hyperlinks.

In spatial terms, the average degree of OSN users tend to be limited and the majority of links within online communities are bounded by geographical areas (Liben-Nowell et al, 2005, Ugander et al. 2011). Global online social networks, like Facebook, perform “small world characteristics” because users formulate strongly connected cliques with physically proximate other users and relatively few long distance ties make the whole network connected with a short average path between two random users (Backstrom et al. 2011). Certainly, the probability of online friendship decreases as distance grows due to travel-related costs (Onnela et al, 2011). However, this probability is influenced by various other factors like settlement functions (Tranos and Nijkamp, 2012), travel frequencies (Takhteyev et al. 2012), among others. We show in this paper that the online social network is strongly modular in spatial terms. Therefore, cohesive geographical units may also play a central role in shaping the network topography, which needs a detailed geographical insight when focusing on the effect of distance.

3. Data and dependent variable

The iWiW (International Who Is Who) was launched on the 14th of April, 2002 and shortly became the most known SNS in Hungary and even the most visited national website in 2006. 40 percent of the population had a registered profile in January 2013. We have a unique access to the anonymized version of those profile data that users left open for everyone to see when logged in: date of registration, date of last entry, sex, age etc. Plus we see all the connections within the OSN in a separate file and also know when the tie has been established. Location data of users is based on profile information, which is considered to be problematic in papers focusing on OSN user and social media content localization (Hecht *et al.* 2011). In iWiW, however, it is compulsory to choose location from a scroll-down menu when registering as user. This place of residence can be easily changed afterwards and certainly there is no eligibility check. Thus, one might consider our location indicator based on user profiles a biased and occasionally updated census-type data.

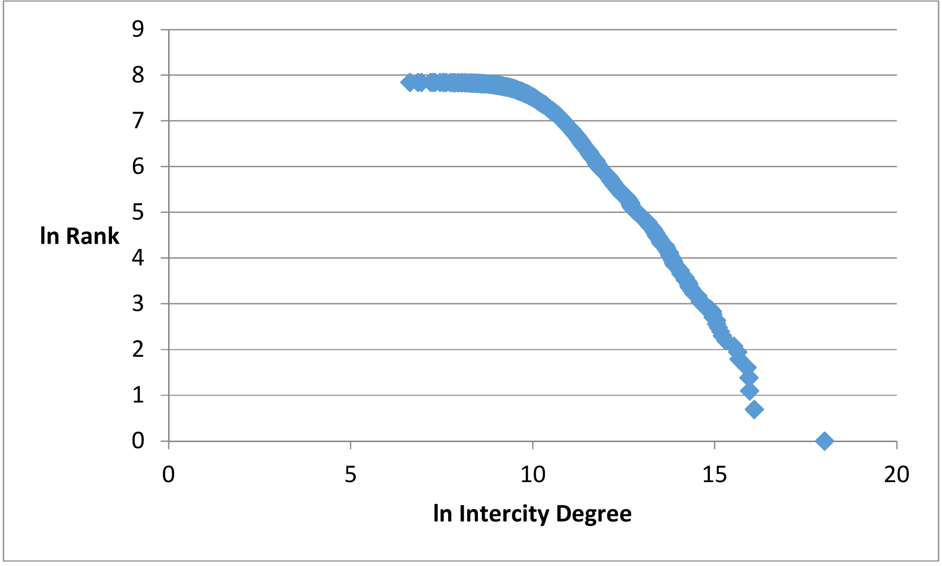
We used aggregated user-level data on settlement level in order to depict the spatial structure of the OSN and to analyse the role of distance in shaping network topography. Basic data description is represented in Table 1. Due to simplicity we use the word CITY instead of the word SETTLEMENT afterwards.

Table 1: Units of analysis in the iWiW network, 2013

	USER	CITY
Number of NODES	4,059,917	2,562
Number of TIES	786,046,834	1,372,540
Number of Intracity TIES (loops)	369,859,421	2,562
Number of Intercity TIES	415,789,222	1,369,978

The total OSN population (4,059,917 users) is located in 2,562 cities; there are 1,372,540 CITY–CITY pairs. There are 786,046,834 USER–USER ties in total, out of which 369,859,421 ties remain within city borders and 415,789,222 ties are established between users from two distinct cities. The raw number of CITY–CITY tie weights simply represents the number of friendship ties between the cities. There is a positive loop for every CITY.

Figure 1: Weighted degree distribution of intercity network



The degree distribution of the CITY-CITY network (Figure 1) illustrates that a significant share of (assumably smallest) cities are very similar in terms of sum of their CITY-CITY tie weights (or user level intercity degrees). However, the network of (assumably bigger) cities can be powerfully characterized by a power-law distribution, in which a small share of CITIES collects a very large share of tie weights.

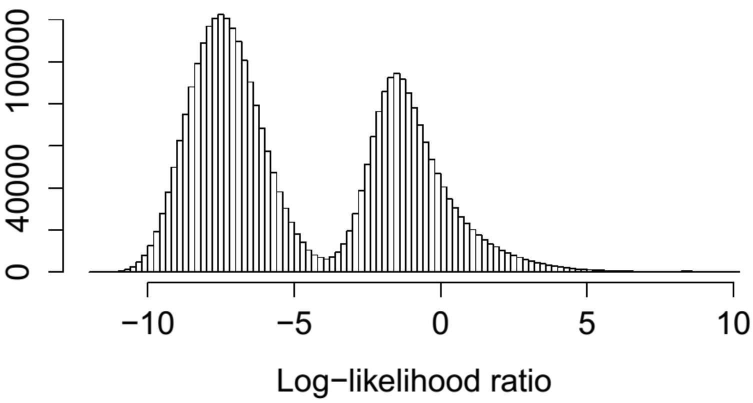
Inter-city tie weight

Log-likelihood ratios were calculated from the raw weight of CITY-CITY ties in order to control for size differences between cities. This measure is a basic statistical concept; in our case this is the logarithm of the ratio of observed and randomly expected CITY-CITY tie weights:

$$Log\left(w_{ij} / \frac{w_{i*} w_j}{\sum_{\substack{i=1\\ j=1}}^{n} w_{ij}} \right) \qquad (1);$$

in which w_i and w_j are the sum of tie weights of city i and j and w_{ij} is the raw weight of tie between city i and j. Log-likelihood ratios were calculated for all pairs of settlements including those whitout connection (structural zeros). In this latter case the observed weight was set to 0.001.

Figure 2: Log-normalized intercity edge weights, structural holes set to 0.001



The resulting tie weights (Figure 2) has a bimodal distribution with local maxima at - 7.267, and at -1.482. The first log-likelihood ratio approximately yields a ratio of 0.001, which means that the observed ties are only 0.1% of the randomly expected ones. The long tail of the distribution in the positive range of CITY-loop log-likelihood ratios, their average is 8.16. The peek closer to zero represents connections between settlements that are closer to each other than the average pairs. However, most of the log-likelihood ratios are under zero, thus observed weights are less than the expected weights. The reason behind this phenomenon is that expected frequencies were calculated from the total number of connections of cities, which also includes loops (intra-city ties) that are always higher than the randomly expected. This pushes the distribution to the negative range. The bimodal distribution suggests that the settlements are structured into distinctive regions (modules), in which the connections are intensive (the shorter "peek"), while the connections between them are rare compared to the randomly expected (the higher "peek" in the negative region).

4. Distance effect

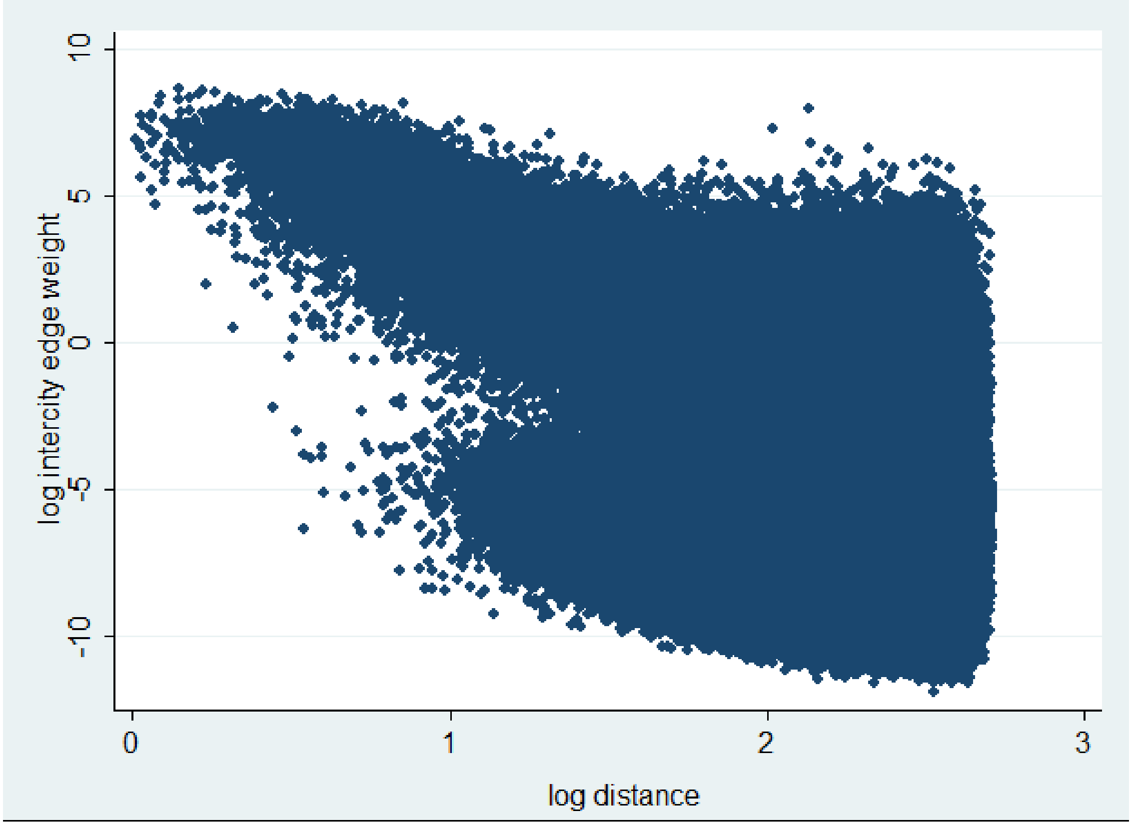
We find that intercity edges are negatively associated with geographical distance. The deterrence effect of distance holds even if the modularity of the network is under control.

4.1 Edge weight versus distance

All intercity values are depicted in figure 2: the zero line separate those ties that are above expectation (positive value) from the ones that are below (negative value). The highest positive log-normalized edge values are among cities that are in close geographical proximity. One can also observe a growing variation of intercity tie weights; however, maximum and minimum values decrease as distance grows until a certain threshold (log distance=1.5) after which intercity weights are completely independent from distance.

Those intercity ties that are extremely weak compared to the expected value seem to be affected by geographical distance as well. The minimum value of these edge weights decreases along distance. Structural holes (non-existing intercity ties) add another layer of complexity to the distribution, which is visible via the seemingly independent distribution in the negative range. However, the message of these non-existing links is the same: non-existing ties exist frequently at a much larger distance (log distance = 1) than existing ties.

Figure 3: Distance and intercity edge weights



Note: Loops are in the data, structural holes have been set to 0.001 before normalization.

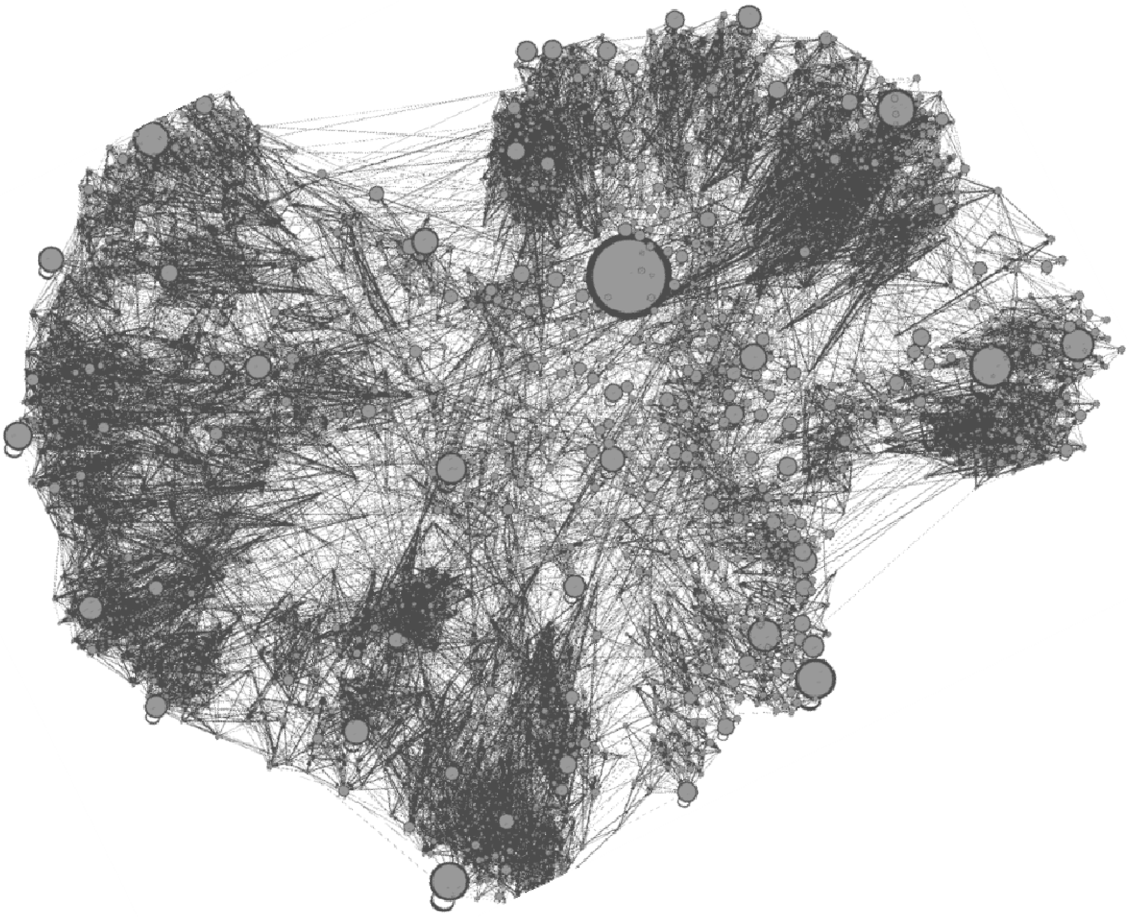
Our first findings clearly illustrate that distance matters and has a negative effect on the structure of an online social network. Led by thought-provoking gravity-model findings on telefon-call networks (Lambiotte et al, 2008, Krings et al, 2009) one might even expect that distance has a determining power on CITY-CITY links. This is certainly not the case in our iWiW sample. We will come back to this issue and the reasons behind it in the discussion.

4.2 Network structure

The visualization of the intercity network provides us with detailed insights. However, network structure is discussed only superficially in this paper and in-depth analysis is left for further papers. The strong modularity of the strongest 8% CITY-CITY ties in the network and sharp differences among geographical areas are strikingly evident. Although geographical coordinates have not been involved in the drawing algorithm, distance seems to be a crucial factor in shaping the network structure: those who are familiar with the geography of Hungary might realize a distorted map of the country in Figure 4.

Interestingly, the network is not organized around Budapest; despite the city was the origin of the network and itself counts for the vast majority of raw intercity connections, it loses from edge weights after controlling for node sizes in the normalization process (1). The same effect prevails in the case of other regional centres: although they are connected to almost all nodes, very few of their degrees are among the top 8%.

Figure 4: The intercity iWiW edges above expectation, 8%



Note: Due to the high complexity of the network, only those edges are used for visualization which outperform the expectation. The majority of the edges were filtered out after running Force Atlas 2 layout algorithm in Gephi. Node size represent CITY size (population in 2012) fitted by a concave splitting curve.

The network seemingly breaks into cohesive subgraphs. However, the modularity of the network differs across geographical units. Edges among little towns are depicted among the top 8% with a much higher frequency, which is observable by the dense dark areas in Figure 4 (in the peripheries of the network as well as the country). The geographical units these small villages are located in have a fragmented settlement structure. The network does not seem to be that modular in other parts of the country, like the Great Plain (cluster of nodes in the bottom-right of the network and South-East in the country). Settlements located here are relatively bigger in terms of population. These cities attract each other strongly and form closely-knit clusters in a seemingly similar manner as small settlements do in other areas.

Nevertheless, the major message that we take away from Figure 4 is that network is presumably modular.. In other words, CITY-CITY ties are relatively stronger within geographical units than across them, which might have an impact on the role of distance. We control for the modularity as it follows.

4.3 The effect of distance on intercity edge-weight

We develop simple linear regression models in the remaining part of the analysis. The dependent variable is the log-normalized CITY-CITY edge weight as described in section 3. The explanatory variable is Euclidean DISTANCE calculated from GPS coordinates of all the cities in the network. We run Ordinary Least Square (Model 1) and Variance-weighted Least Square (Model 4) regressions in order to check the robustness of the results. The results suggest a strongly negative and significant effect of distance on CITY-CITY edge weights.

Since we have observed a high probability of network modularity in the previous section, further model development shall control for the effect of geographical units. A Louvain Community Detection method for the whole graph (structural holes and below-expectation edges included) indicated 12 cohesive clusters within the graph with a modularity value of 0.341. The same algorithm for the strongest CITY-CITY ties (log-normalized weight > 5) indicate 114 clusters with a modularity value of 0.606. Since cohesive clusters are expected above the modularity value 0.3 and 0.6 is already indicating very high modularity; we have to be aware that the network is indeed constituted from spatially-based sub-graphs.

In order to control for cohesive geographical units, we use two levels of administrative regions that have comparable number with the number of clusters suggested by the Louvain method. There are 19 counties

(NUTS3 regions) in Hungary and 168 subregions (LAU1 regions)[2]. Two dummy variables SAMESUBREG and SAMECOUNTY have been created; the values of these variables are 1 if the two settlements are in the same administrative region and 0 otherwise.

Three further dummy variables are introduced to the models that control for settlement functions. The value of CENTER-CENTER_SUBREG is 1 if both settlements are administrative centres of their LAU1 regions; the value of CENTER-PERIPHERY_SUBREG is 1 if only one of the settlements is an administrative centre and PERIPHERY-PERIPHERY_SUBREG is 1 if none of the settlements is an administrative centre. The same logic applies at the NUTS3, county level. Control dummy variables on subregion and county levels are introduced into the models separately and all have significant effect on CITY-CITY edge weights with a varying sign. Their effect is not discussed in the paper since we only use them as control variables.

We find that the deterrence effect of distance still holds when controlling for possible geographical units of cohesive network subgraphs. This result is robust, because both types of linear regression models verify it. In sum, the higher geographical distance among settlements the less probability that people are friends in the network. Distance is not dead in OSN, it is still alive and kicking.

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[2] From 2007, there are 174 subregions in the country but for practical reasons, we refer to the 2003 regulation.

Table 2: Linear regression models, independent variable is log-normalized edge weight, structural holes set to 0.001

	Ordinary Least Squares			Variance-weighted Least Squares		
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
CONSTANT	4.996 ***	6.655 ***	5.937 ***	32.891 ***	77.221	39.401 ***
	(427.39)	(530.88)	(308.42)	.	(0.19)	.
DISTANCE	-4.424 ***	-4.157 ***	-3.291 ***	-16.477 ***	-38.938 ***	-16.805 ***
	(-833.63)	(-782.92)	(-547.79)	.	.	.
SAMESUBREG	NO	YES	NO	NO	YES	NO
CENTER-CENTER_SUBREG	NO	YES	NO	NO	YES	NO
CENTER-PERIPHERY_SUBREG	NO	YES	NO	NO	YES	NO
PERIPHERY-PERIPHERY_SUBREG	NO	YES	NO	NO	YES	NO
SAMECOUNTY	NO	NO	YES	NO	NO	YES
CENTER-CENTER_COUNTY	NO	NO	YES	NO	NO	YES
CENTER-PERIPHERY_COUNTY	NO	NO	YES	NO	NO	YES
PERIPHERY_PERIPHERY_COUNTY	NO	NO	YES	NO	NO	YES
N	3280990	3280990	3280990	1.6e+06	1.3e+06	1.6e+06
R2	0.175	0.25	0.222			
F	. ***	. ***	. ***			
Goodness of fit				4.9e+12 ***	2.5e+12 ***	4.8e+12 ***
Chi2				1.4e+12 ***	3.9e+12 ***	1.4e+12 ***

5. Conclusion

In this paper we analysed the global network of iWiW on an aggregate settlement level in order to demonstrate that geographical distance has a deflating power on the frequency of online friendship. The network is strongly modular in spatial terms and these cohesive subgraphs are based on geographical areas, which do not distort our findings.

Thus, the major conclusion of our exercise is that people establish distant online connections less probably than proximate ones. A plausible reasoning is that travel related costs are behind this deterrence effect. Since iWiW friendship ties predominantly mean that users have been involved in offline interaction aforehead, the interconnectedness of offline space and iWiW network might go without saying for many. However, the establishment of an iWiW tie was very easy (almost without cost); users even competed in collecting old and forgotten friends when the service was booming in the 2005-2008 period and might have collected many ties that were independent from actual location. Therefore, our disclaimer of cyber-space arguments for OSNs is a unique contribution and we demonstrate that cyberplace is a better anecdote for OSNs.

On the other hand, we do not find a gravity-law type of determining power of distance on online friendship. Gravity-type of spatial interaction was found in other telecommunication networks –like phone calls–, though communication-related costs have much clearer selection on tie formation (Krings et al, 2009). It is an interesting research agenda to investigate which online activities depend stronger on location and distance. For example, data on individual-level invitation to the service might perform better than mere friendship in this latter sense, because users could only invite a limited number of their offline friends to iWiW. This selection pressure can be interpreted as a cost factor; thus, distance might have an even more significant effect. The argument remains for a further paper.

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