

Spatial Patterns of Development of Mobile Technologies for 5G Networks

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Abstract. The paper deals with spatial (geographical) conditions for forthcoming 5G Mobile Technologies, especially their infrastructure at a global scale. The main assumption presents the idea that all networks, which evolved to converge together into one: internet and wireless computer networks, cellular mobile communication, radio and TV diffusion networks, constituting the infrastructure of information society are developing in the similar manner and depend on similar factors. Thus the spatial processes of these technologies should present alike spatial patterns of development, especially for expected IoT and wireless services, which are perceived as pillars of new networks usability. The main processes which let to interconnect them are related to convergence of the signal through the main gateways and interaction between users. The recognized spatial factors influencing on these processes are: the population potential, hierarchy of the cities (metropolitan urbanization) and geographical distance. These qualities are recognized and quantified in a set of models of spatial pattern development using the dedicated spatial (geographical) measures. The empirical approach involves the use of location quotients of infrastructure networks confronted with evaluated level of interaction between populated urban places applied to previous generation of mobile networks (estimated using geographical - population potential), verified by countries' mobile penetration statistics.

Keywords: Spatial patterns · Mobile communication · Fifth generation

1 Introduction

Mobile technologies intertwined with information and communication technologies (ICT) have determined the development of nowadays economy gradually replacing personal computers. They spread themselves sector by sector and countries. They are carriers of disruptive innovations: widespread wireless internet technologies and strengthen interaction between densely and sparsely populated places. The main determinants of spatial extent of development of infrastructure of mobile technologies are: spatial distribution of urban areas as well as areas along main transport routes between them. But since the last decade of XXth century the mobile technologies have changed themselves also, from the carrier of voice and short messages to completely new spatial emergent phenomenon involving wide areas of economy and social aspects

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of life, including way of life, entertainment and tourism. However, dealing with the significance of information and communication technologies (ICT) in social development, one can stress the implementation and ICT projects have huge positive potential, but often have also negative consequences, sometimes expected, sometimes not expected. This observation have found confirmation in opinion stating: "Over the last twenty years, rather than reducing poverty, ICTs have actually increased inequality, and if 'development' is seen as being about the relative differences between people and between communities, than it has had an overwhelming negative impact on development." [1]. The subsequent generations of technologies with different mobile devices are strictly converge with ICT, replacing the common use of PCs (personal computers) in everyday life of people. On the other side, each generation needed the advancement of infrastructure of base transceiver stations facilitating wireless communication between user devices and network. The differentiation of the infrastructure base of mobile technologies can help infer about the differentiation of the progress of development of ICT mobile technologies. The main hypothesis to verify in the presented research states that, emergent processes of development of internet and ICT take place, at the global scale, in most populated and urbanized areas leveraged and based on adoption of the disruptive innovation of mobile technologies. The approach uses the well known, modified, population potential model [2–5], and operate on the set of global statistical input data variables by countries and cities (with population over 250 thousands inhabitants), as well crowdsourcing data concerning the infrastructure of the base transceiver stations. The results of the modelling are verified comparing the accessible volume of mobile subscriptions by countries. The analysis presents the spatial evolution of mobile technologies diffusion since 1990, but the final verification concerns the data collected at the 2015–2018. This is slightly different approach from classic analysis of diffusion innovation process, which usually focused on time and number of different adopters, because in this research the main determinant is friction of space – geographical distance.

2 Methodology

Spatial development of mobile technology generations has been evaluated using available ITU statistics data of overall penetration (%) by countries since 1990 using anamorphic cartograms. Scaling of area of countries is proportional to range of penetration in different years. Next the recent state and dominant generations of mobile technologies has been presented using location quotients (according the data in 2017). Data for the number and type of BTSs have been acquired from voluntary (crowdsourcing) data base. Source of presented data is complete database acquired from opencellid.org (accessed Feb. 2019), which counted over 40 million records identifying base transceiver stations (BTS) and their generations of mobile technology. In fact BTS information is derived from voluntary crowdsourcing reports and later verified. OpenCellID is actively updated crowdsourcing database collecting GPS location data for cell identifiers. It had already been previously used in scientific research and its advantages and disadvantages are recognized [6]. But the volume of stored data since

2009 lets assume, that is close to real current situation at the global scale. Location quotients have been calculated for each country based on the formula (Eq. 1):

$$\mathrm{lq}_c = \frac{MG_c}{MG_w} / \frac{BTS_c}{BTS_w} \tag{1}$$

where: lq_c – location quotient of certain mobile generation technology in defined country, MG_c – number of base transceiver stations of certain generation in country, MG_w – number of base transceiver stations of certain generation in the world, BTS_c – total number of base transceiver stations in country, BTS_w – total number of base transceiver stations in the world.

It shows regional specialization within spatial unit (in above described case: country specific) related to global values. Location quotient determines in which countries occurs concentration ($\mathrm{lq} > 1$) or severance ($\mathrm{lq} < 1$) of certain mobile cellular technologies. Interpretation of the estimated location quotients show to what degree recently there is the domination of the certain generation of mobile technology in each country. The value greater than 1 means greater domination of certain mobile cellular generation, less than 1 lets infer that this generation is being withdrawn or, in case of newest generations, is starting. Value close to 1 lets assume, that the whole country reached the mature state of certain generation. The whole procedure were repeated for each mobile technology generations separately. Some authors claim that location quotients sometimes fulfil the function similar to standardization measures. But in this research they simply measure the over- or under-concentration of the mobile technology location.

Considering the problem of interactions between people needs to apply the proper method to evaluate the overall volume of potential contacts. There are set of models in scientific, geographical and mathematical literature. But for the recent study the modified formula of classic population potential model has been applied. It also has been previously used for similar study concerning the spatial simulation of initial stage of cellular phone network development in Poland [2].

On the other side there are 1860 cities of the world with inhabitants over 250K as the input data into the model. Variables used were the following: their geolocation (longitude, latitude), population data and calculated distances between them, i.e. between each pair potentially interacted masses (populated places). The only modification introduced into the model was Zipf's rule of the order and magnitude of cites, i.e. the rank of city. The model incorporates the absolute difference of the ranks of cities during calculation of potential interaction between them for each pair separately. The formula of the model is the following (Eq. 2):

$$V_i = \sum_{i=1}^{n} \sum_{j=1}^{n} \frac{P_i P_j}{d_{ij} h_{ij}} \tag{2}$$

where: i, j – cities, $\mathrm{P_i}, \mathrm{P_j}$ – population of cities i and j (2015), $\mathrm{d_{ij}}$ – calculated distance between cities i and j, $\mathrm{h_{ij}}$ – absolute value of difference of the ranks of the cities i and j, n – total number of the cities (1860).

The distance between the cities has been calculated using Haversine formula (in km). In case of evaluation of sole inner city interaction (with itself i.e. for i = j) the denominator of the formula takes value equal 1. "Population potential is treated as an appropriate measure of accessibility, and a tool for an assessment of the volume of interaction involving alternative locations. The general potential model assumes that interactions pertaining to a given location decline proportionally to the distance from the origin. The larger the population potential in the target location, the greater its ability to generate spatial interactions. The population potential model encompasses both the population size of places (numerator) and the distance (denominator) involved; the latter expresses the friction of space. The numerator represents the total number of people able to overcome the resistance of geographical space." [2]. The friction of space involves also the difference of ranks of the cities. The choice of this model has been preceded the evaluation of others, in forms – without ranks or including the values of location quotients of newest generations of mobile technology – but the final results of verification were statistically weaker and they were dropped. The main axiom for adoption such formula of population potential was that Euclidean metrics exist in real world space.

Finally the results of the modeling of interactions between cities have been aggregated (dissolved) and correlated with volumes of mobile subscriptions by countries, and discussed.

3 Development of Mobile Cellular Technologies

Wireless telephony and Wi-Fi (802.11) protocol have been pointed as disruptive innovations which imprinted on track on the technological consciousness of society, economy and business [7]. Android OS and iOS (Apple) together have gained over 97% share of the mobile devices used in the world since 2009, when Open Handset Alliance, supported inter alia by Google, decided to use Linux 2.6 kernel of the projected mobile platform (Fig. 1). This decision made a convergence between two loosely coupled technologies (up to this moment): internet and mobile phones (smartphones), replacing the competition of several other market strong players offering their operation systems (Nokia/Symbian, Microsoft/Windows Mobile, RIM BlackBerry and others). This new process, co-played with the diffusion of mobile phones and internet (separately since 1980), created the emergent phenomena which in turn accelerated the development both of the set of internet tools and allowed mobile applications for access to internet services. Thus, within 10 years, the number of users of smartphones significantly exceeded the users using computers accessing the internet (see Fig. 2). The mobile devices with Android OS (or Apple iOS) became the easiest and quickest way to access the internet for the overwhelming majority of users. So the research concerning dissemination of mobile technologies (smartphones) in fact is related to diffusion of Android or iOS (Apple) devices and cellular infrastructure network. This is new dimension and element which should be taken into account in the discussion of digital divides. Digital divides is defined "as the affordability of the hardware, software and services that make up information and communication technologies (ICTs)" [8].

Figure 2 presents common trends of growth of number of mobile subscriptions, Android & iOS users, compared to numbers of internet users, total and urban population as well as global domestic products and revenues of computer, communications and other services sector at the global scale since 2000.

Two of phenomena presented on Fig. 2 are similar to well known recognized diffusion process in form of logistic curve, i.e. number of world mobile subscriptions and (both) Android and iOS users of mobile devices. It is well known fact, that Android is the main operating system of ¾ of mobile devices - increased of market share worldwide from 4% in 2011 up to 75% in 2019 (source: gs.statcounter.com). If one take a look on mobile cellular evolution timeline (Fig. 3), nowadays, the forthcoming, perceived and predicted as disruptive innovation, fifth generation of mobile communication needs a huge investment into the infrastructure of future 5th mobile network, much more densely concentrated than previous ones (1st AMPS/TACS, NMT, 2nd - GSM/GPRS/, 3rd - UMTS, CDMA, 4th - LTE/LTE Advanced, WiMAX/. "5G will be smarter technology with no limits and to interconnect the whole world without limits. The upcoming life style will be different with uninterrupted access of information and interconnection" [9].

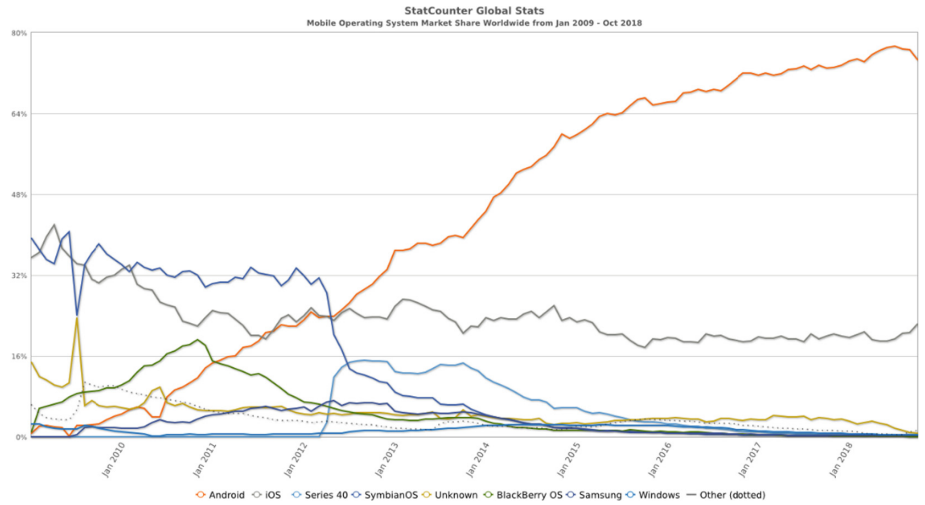

Fig. 1. Mobile operating system market share (source, http://gs.statcounter.com, access 11/21/18)

However, the spatial diffusion of mobile digital cellular generation was not so simple and in equal pace throughout the world (Fig. 4 a, b, c and d). The starting points of diffusion of cellular mobile telephony is pointed in USA (CDMA standard) and Finland (GSM standard). But in the last decade of XX century one can point also USA, Canada, Nordic (Scandinavian) countries in Europe, Australia and Japan. Initial differences in penetration have disappeared during the next 25 years, proving the

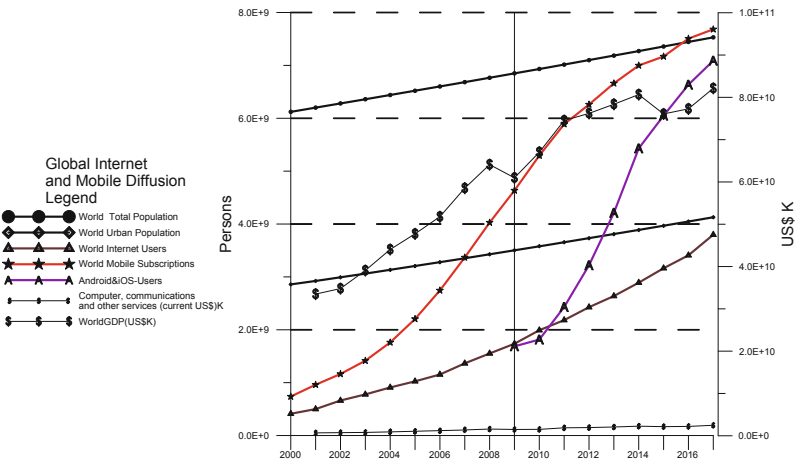

Fig. 2. Global internet and mobile diffusion (source, ITU, OECD, gs.statcounter.com, 2019)

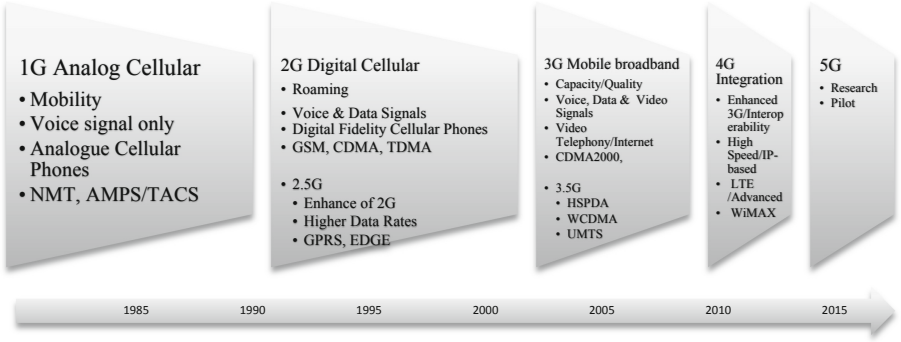

Fig. 3. Mobile cellular network evolution timeline [9]

significance of the masses of population as the target in marketing the use of mobile technologies. It took only twenty years to complete the dissemination of cellular phones since the introduction of second, digital GSM generation of mobile technologies.

On the other side, there are countries reached the high level of penetration but only with prevailed, certain generation of mobile technologies (Fig. 5 a, b, c and d).

LTE (Long Term Evolution) is recognized nowadays as the mature, modern, fast mobile technology and is dominating in most developed countries. But forecasts concerning forthcoming 5th generation anticipate evolution in multiplatform, heterogeneous technological eco-system. Future applications would might support geonavigation, tele-medicine, crisis management, education, tourism, travelling and others with immediate service availability and on-demand adaptability [9]. However it is questionable if this forthcoming intelligent technology is really capable of interconnecting

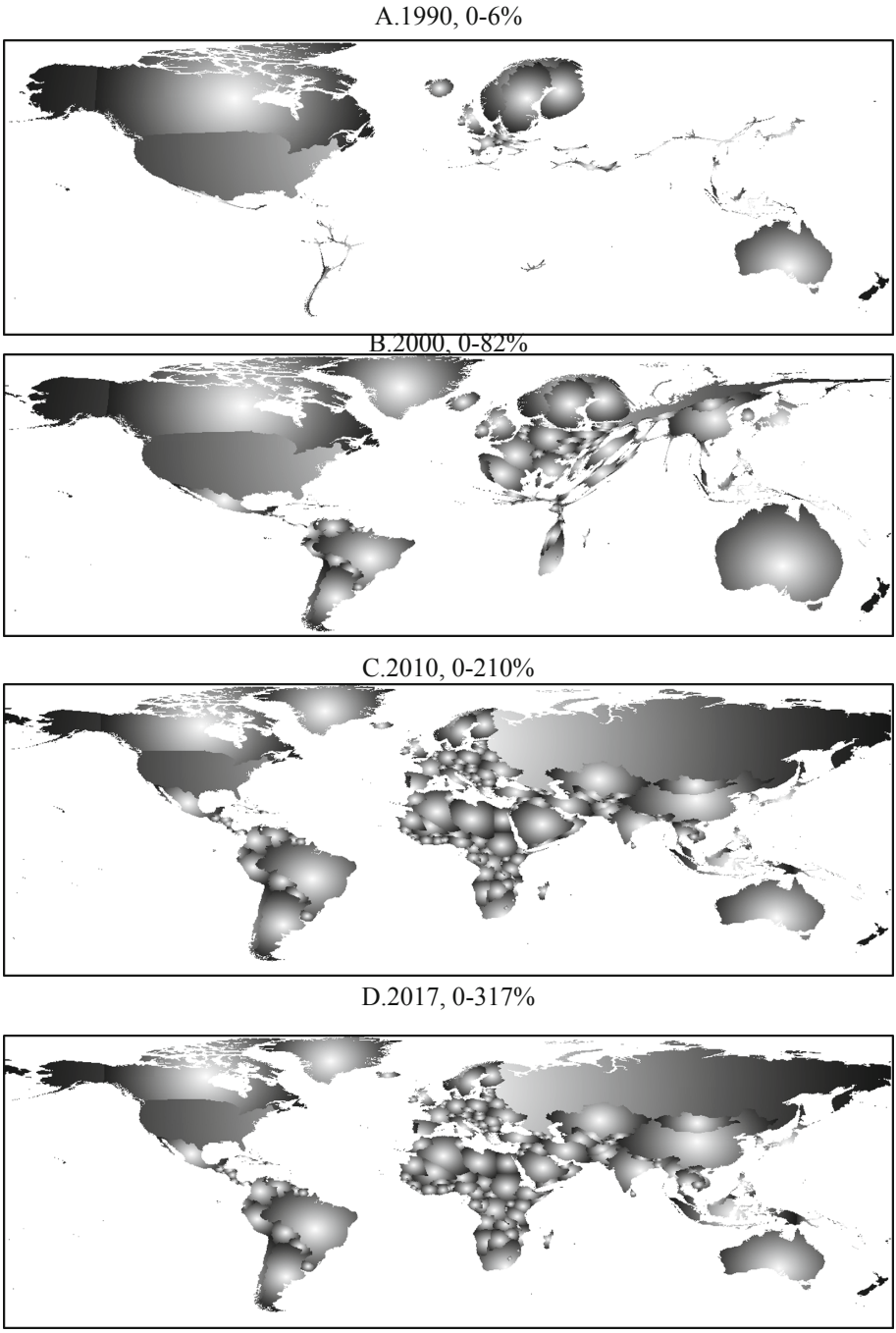

Fig. 4. Global mobile penetration/anamorphic cartograms/. A. 1990, scaling size of countries (%): 0–6%, B. Scaling: 0–82%, C. Scaling: 0–210%, D. Scaling: 0–317%.

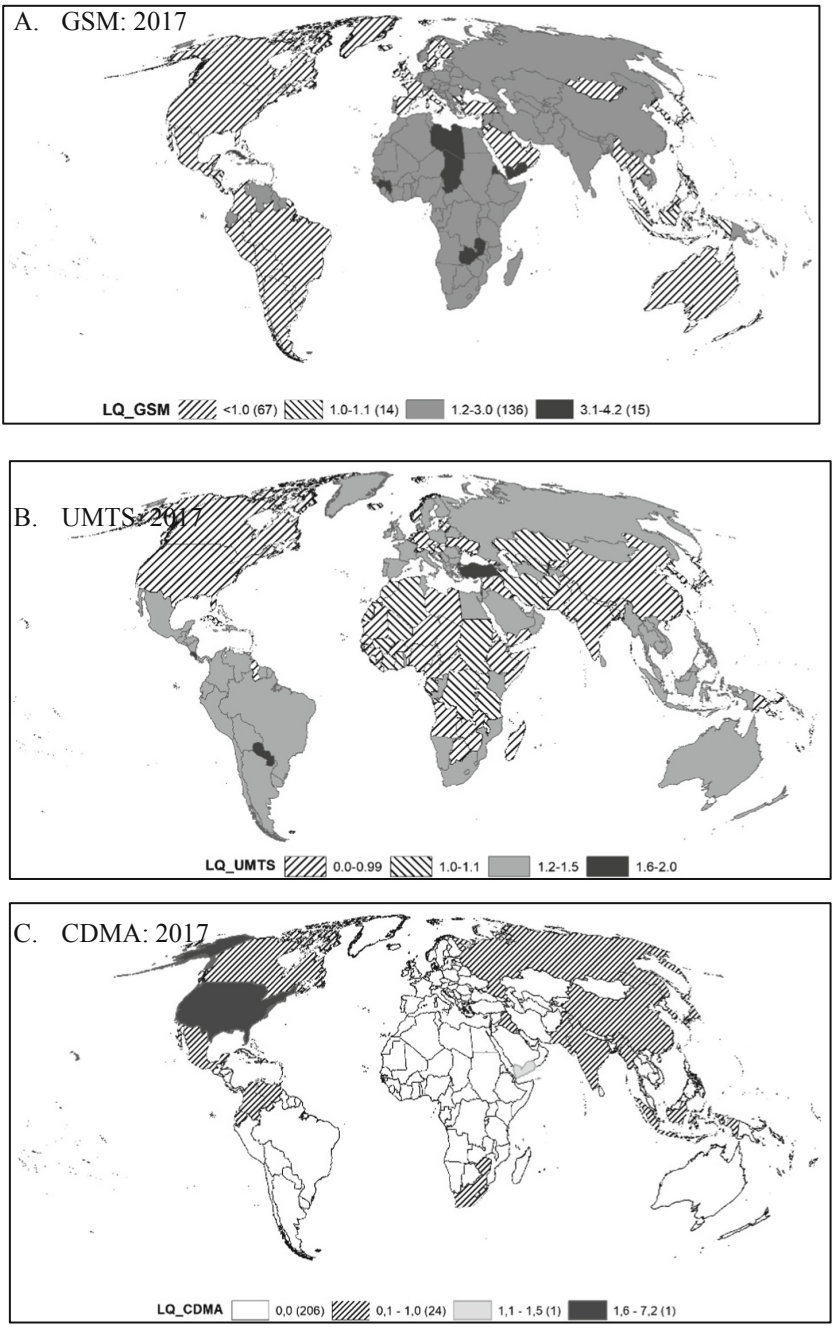

Fig. 5. Location quotients of mobile cellular BTSs by countries and technology (2017). A. GSM, B. CDMA, C. UMTS, D. LTE

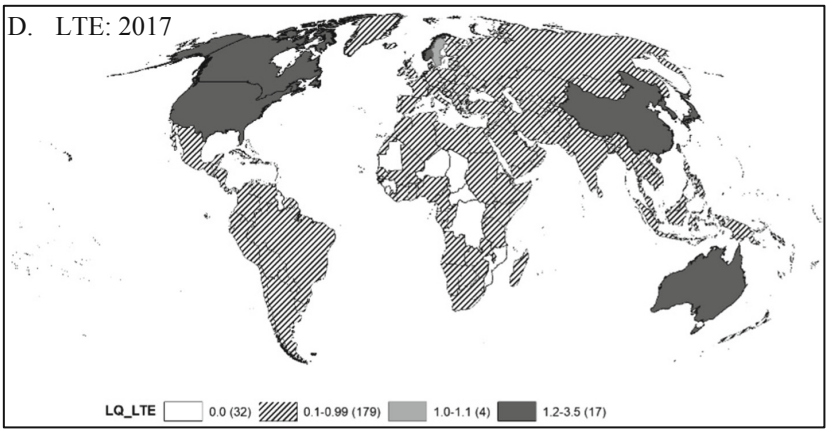

Fig. 5. (*continued*)

the entire world without limits. The vision of "World Wide Wireless Web" (WWWW) may gain the mature state in an undefined future time horizon, and most probably similarly to previous stages of mobile technologies spatial development. The disruptive innovation of smart phones seems the another version, manifestation of general purpose technology (GPT) emergent phenomena, which theory predicts that similar technological opportunities may not result in the same experience in all locations [10]. Some theories derived from past observation of internet diffusion and previous media may help to understand the factors of spatial development of the forthcoming changes in mobile technologies. There are inter alia: global village theory stating that adoption of such disruptive innovation may bring more benefits for sparsely populated places and smaller cities; urban density theory with advantages of complementary technology infrastructure, labor market and knowledge spillovers; industry composition theory with tendency to form advanced clusters, sharing local resources, labor and market. Last but not least GPT theory itself prove that urban areas improve co-habitation and co-invention lowering costs of implementation of innovation [ibid. 9]. All of them put on the forefront two factors: urbanization and people. The third, which is not explicitly listed and named is spatial dimension i.e. geographical distance. There have been proved that countries with a large percentage of their population living in urban areas are more likely to have higher penetration rates of ICT and internet [11].

Public relations specialists on the market adopted and named the emergent phenomena as Data Society (next to internet society) with main trends of hyper-connectivity involving more international connections, merge of real and digital worlds, huge consumption of info-data due to wide use fiber and wireless high bandwidth for 3D video on 4 K screens, cloud computing and software as a service (SaaS), augmented reality, smart city cameras monitoring, massive IoT (internet of things), industrial and commercial automation, mission critical broadband and self-driving (also electric) cars/vehicles.

4 Modeling the Global Interactions

The whole model of global interactions (Fig. 6) between global cities has been visualized as heat map with overlaid, scaled values of population potential of cities of logarithm at base 10. There revealed main global potential core areas of spatial diffusion of forthcoming 5th generation of mobile technology, which reflect the global distribution of world population.

The verification of main research hypothesis aimed correlation between aggregated values of modelled population potential by countries and available ITU data of volume of mobile subscriptions (Table 1). The procedure involved 150 countries of the world.

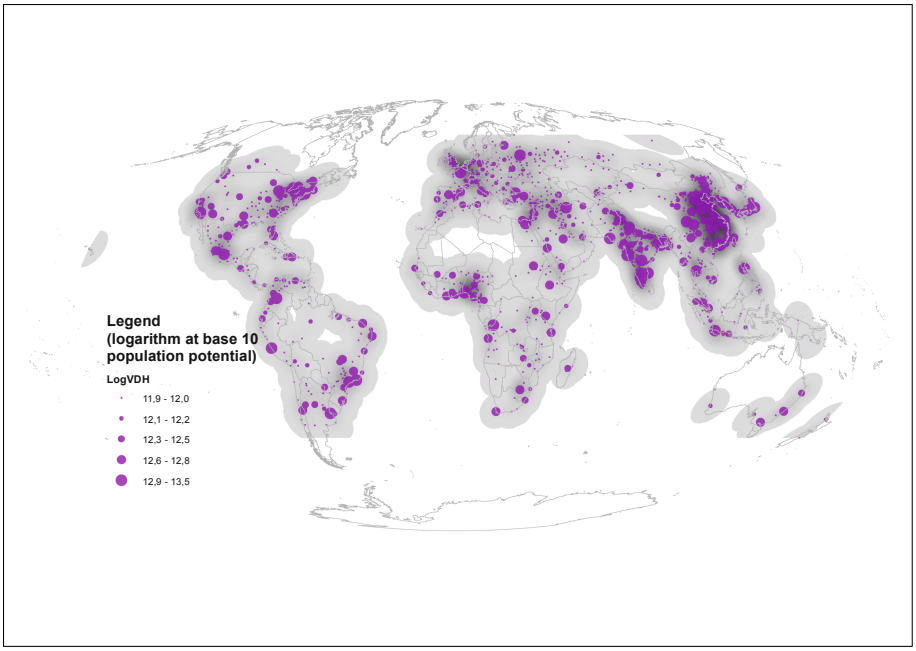

Fig. 6. Global volume of interactions – model of population potential of 1860 world cities overlaid on heat map (logarithm at base 10 values).

Table 1. Correlation and 2-tailed significance of coefficients between volumes of mobile subscriptions and global interactions (model of population potential) by countries: 2015, 2016, 2017.

** Correlation is significant at the 0.01 level (2-tailed)	Population potential/VDH/- Pearson correlation
Mobile subscription by countries (2015)	0.874**
Mobile subscription by countries (2016)	0.871**
Mobile subscription by countries (2017)	0.876**

5 Discussion

Classic approach to spatial accessibility and use of population potential model is often considered in scientific, transport literature and also to solve the problem concerning mobility of people: migrations or commuting to work. The classic potential model can be treated as the tool for evaluation of accessibility involving the function of attractiveness of the places measured with the population number related to function of spatial resistance (or decay) [12, 13].

Spatial accessibility is treated as multidimensional phenomenon and reflects the complexity of methods and techniques of research. In case of mobile technology – this approach finds a little bit another, easier explanation. The classic approach of population potential reflects the whole superset of (mathematical) 'handshake problem' – how many handshakes there will be altogether for certain number of people, or in case of handshake of dial-up modem computers network. The problem of spatial accessibility incorporated into the model (Eq. 2), despite of different infrastructural equipment, is measured using real world distance, as well as cumulative, personified, potential indicators [14–17]. It also includes non-Euclidean difference of ranks derived from well known, statistical Zipf's law – model applied to set of cities, reflecting the invisible friction of real world urban space [2].

The significant results verified using correlation coefficients with the volumes of mobile subscriptions, proved the viability and suitability of the potential model.

6 Conclusions

Modified model of (geographical) population potential seems the appropriate measure and tool to estimation global mobile technology interactions, especially modified, taking into account the ranks of the populated places. It is the tool ideally convenient to evaluate the level and volume of interactions between populated places and proved its value in case of development of mobile technology.

Affordability of smart phones and exponential rise of volume of data flows may also occur in case of interconnection into the world wide wireless web the quite new active elements: wearable devices and automatic intelligent sensors, which will operate independently without the initial human action. There is also another aspect of this emergent phenomenon: the limited bandwidths range resources for use of 5th generation WWWW network. Hope, this is only engineering problem. The presented pilot study aimed only the verification of the usefulness of modified (geographic) population potential in spatial studies of dissemination of new generation of mobile technology. The model itself proved its value, however the trial to include location quotients into the model was unsuccessful. The current strategic aim is still open – to gain the model which can simulate the spatial spillover of such technological innovation (part of ICT). It also need to choose the proper places and initial conditions to start this kind simulation, and it also hooks on quite new set of determinant factors: social, economic and political.

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