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Demographic Studies of Internet Routers

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We investigate the current state of Internet infrastructures by examining the position and the number of routers considering various demographic data. The scaling relation between the router and the population densities is studied in two different scales, one is a worldwide scale and the other is a country scale. We found the number of routers in each country to be proportional to its economic level, and a super-linear scaling relation to exist between the router density and the Internet user density on a worldwide level. From a district analysis of the country level, we found that the scaling exponents change according to economic conditions and the level of Internet development. As the Internet penetration rate increases, the scaling exponent tends to be close to 2/3, indicating that routers are distributed like public facilities.

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I. INTRODUCTION

These days, the Internet, which is one of the rapidly spreading technologies throughout the world, is very popular and deeply rooted in our daily lives. There is a brisk demand for better quality service – faster speed and more stable connection – as video streaming and mobile services are becoming popular [1–3]. For this reason, the scalability of Internet, which requires stable and extensible properties of Internet, is a big issue, because the current Internet was initially designed for communication between small groups of trusted professionals in 1960s without consideration of the range of the Internet these days, there exists an inefficient structural problem in which more routing steps are required to get information as the Internet structure becomes more complex. In this sense, it is important to consider the *scalability* at the design stage of the "future Internet" [4] because the Internet has not only virtual protocol layers but also physical backbones, which connect large cities and countries like branches of tree and courses of river. To design a scalable "future Internet", it is important to understand the distribution of the Internet facilities as the number of Internet users grows.

It is well-known fact that there exists scaling relations between many urban indicators, such as population size, characteristic rates of innovation, wealth creation, patterns of consumption, human behavior, and properties of urban infrastructure [5]. In particular, the exponents of the scaling relations between various facilities and the population densities depend on the characteristics of the facilities such as whether it is a profit-driven or a public purpose facility [6–8]. Gastner and Newman showed that the scaling relation between population and facility densities follows a simple power law by globally minimizing the travel distance between the population and the facilities [7]. Um *et al.* demonstrated that the scaling exponent of public facilities was different from that of commercial facilities by using an empirical analysis of real data and a model study [8]. Similar to these approaches, Lahkina *et al.* studied the relationship between router location and population density in US, Europe, and Japan [9]. Yook *et al.* also showed the scaling relation between the router and the population on five continents [10]. In this study, we examine the current status of Internet infrastructures by investigating the scaling relations between the densities of Internet routers and of the population with worldwide district data and compare

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the results to the works of Lahkina *et al.* and Yook *et al.* by using grid data. Then, we discuss how the spatial distribution changes as the Internet develops.

II. SCALING RELATIONS OF INTERNET ROUTERS

We investigate the scaling relation of Internet routers on two different scales – a worldwide scale and a district scale in each country. First, we investigate the relation between the number of routers and several demographic variables, such as gross domestic product (GDP), the number of Internet users, and the population, for 219 countries. Because there are more facilities in richer countries, we perform the analysis on two different scales. For each country, we investigate the number of routers at the level of administrative districts, such as county in the US and Canada, ward in Korea, municipality, district, and so on. For this detailed analysis, we examine 25 counties – Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, India, Ireland, Italy, Japan, Macedonia, Mexico, Netherlands, Portugal, Republic of Korea, Romania, Spain, Sweden, Switzerland, Taiwan, Turkey, United Kingdom, and United States.

One can obtain the position of the routers from the geo-location data of each router. MaxMind GeoIP® City Database [11] provides the number and the positions of routers in each country and administrative districts of 25 countries, which contain about 5,260,692 routers. Yahoo! PlaceFinder [12] is also used to transform locations based on the latitude and the longitude into normal addresses based on streets and city to distinguish which router belongs to which district. For the other data, population and area data from Internet World Stats [13], GDP data from World Economic Outlook of International Monetary Fund (IMF) [14], and the Internet penetration data from International Telecommunication Union [15] are used.

From the analysis for each country, one can see a strong correlation between the number of routers and the GDP in the top leftmost plot of Fig. 1 with a exponent of almost 1, which means the higher the GDP of a country becomes, the more routers there are in the country, which implies the economic level is an important factor in the development of Internet facilities. One may find a clearer scaling relation between the router density and the Internet user density than the population density in the last two plots of Fig. 1. Interestingly, the relation between the number of routers and the number of Internet users shows a sublinear relation ∼0.86, which means the exponent is less than 1, but the router density shows a superlinear relation to the Internet user density with exponent ∼1.25. We explain this by large counties having difficulty developing the Internet infrastructure compared to densely-populated, but small, countries such as Korea.

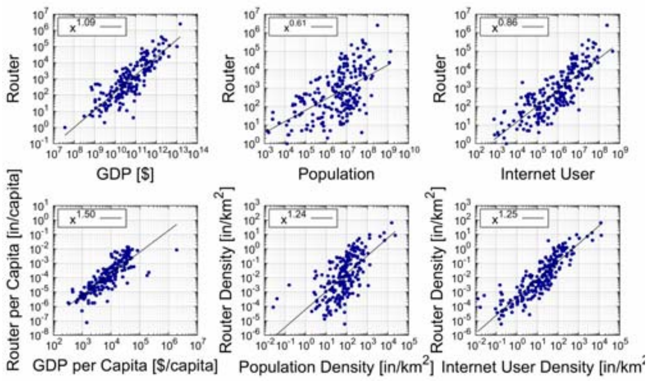

Fig. 1. (Color online) Relations between the number of routers and GDP, population, and the number of Internet users and plots with their densities. Each point indicates a country. The horizontal and the vertical axes meaning demographic variables are shown on a log-scale. The slope of each black line represents a scaling exponent. We omited several countries when the corresponding data were not available.

III. SCALING EXPONENTS FOR EACH COUNTRY

For the selected 25 countries, we examine the scaling relation between the router density and the population density at a district level. Although the Internet user data show better scaling relations than the population data, we should use the population data to find scaling relation because Internet user data at the district level are inaccessible. The scaling exponent of the relation between the population and the number of Internet users is approximately 0.9, which is nearly a simple proportional relation. Therefore, the results are not expected to charge very much where we use the population instead of the number of Internet users. Investigating the scaling relation for 25 countries, we measure the scaling exponent by using ordinary least-square fit as Figs. 2 and 3 show. All of the results and the Internet penetration rate are summarized in Table 1. One can classify 25 countries into two large categories; one has a scaling exponent close to 2/3, and the other has a scaling exponent close to 1.

Because the locations of routers are usually restricted within the land and the number of routers reflect the economic level of each district, the scaling relation between the routers and the population densities sometimes represents that level. For example, as Figs. 2 and 3 show, the scaling relations for Denmark and Italy show their local economic inequality: a difference between peninsula and island regions in Denmark, and a difference between northern and southern parts of Italy.

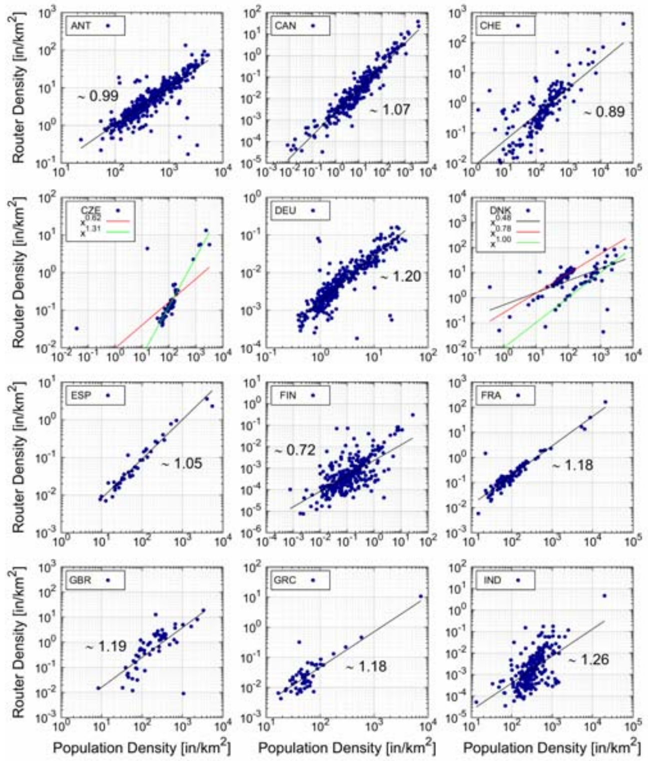

Fig. 2. (Color online) Scaling exponents of 12 countries in a district analysis: ANT (Netherlands), CAN (Canada), CHE (Switzerland), CZE (Czech Republic), DEU (Germany), DNK (Denmark), ESP (Spain), FIN (Finland), FRA (France), GBR (United Kingdom), GRC (Greece), and IND (India). Each point indicates a district. The horizontal axis shows the population density, and the vertical axis displays the router density. Both axes are log scaled. Each numeric label denotes a slope related to a scaling exponent. In particular, the red (green) line on the graph of CZE represents a slope related to all points (except the two leftmost outliers). The slope of the red (green) line on the plot of DNK means a scaling exponent related to peninsula (island) regions.

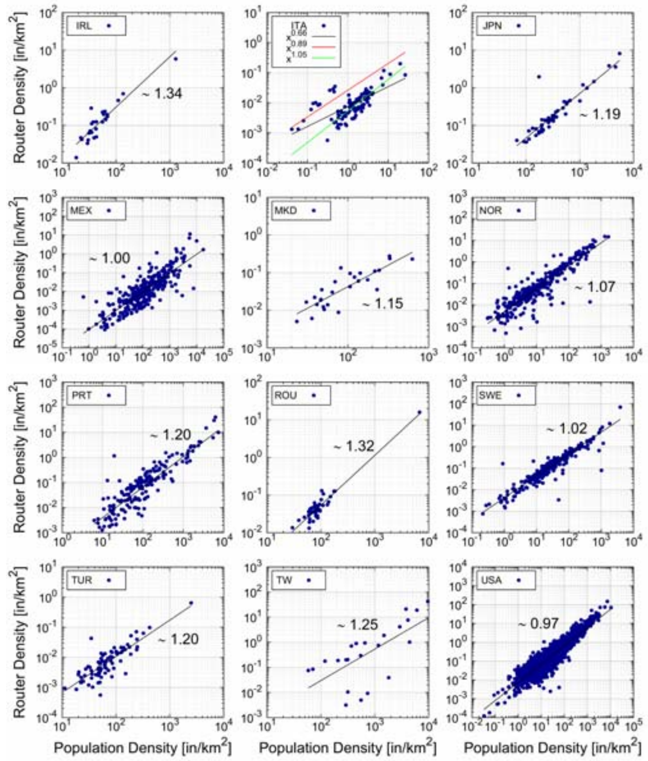

Fig. 3. (Color online) Scaling exponents of 12 countries in a district analysis: IRL (Ireland), ITA (Italy), JPN (Japan), MEX (Mexico), MKD (Macedonia), NOR (Norway), PRT (Portugal), ROU (Romania), SWE (Sweden), TUR (Turkey), TW (Taiwan), and USA (United States). Each point relates to a district. The horizontal and the vertical axes are log scaled. Each black label shows a scaling exponent. Especially, the red (green) line on the graph of ITA is associated with northern (southern) regions.

IV. DIFFERENCE BETWEEN WIRED AND WIRELESS ROUTERS IN KOREA

Among the countries whose scaling exponent is less than 1, we examined the case of the Republic of Korea more systematically because the Republic of Korea is the country having the highest bandwidth, the fastest Internet connection speed and a high Internet penetration rate. In this sense, we consider the Korean Internet infrastructure as the most developed one. The scaling relations of wired and wireless Internet are investigated for the data of Republic of Korea. Figure 4 shows the difference in the scaling relations between the population and the router densities for wired and wireless Internet. In the case of wired Internet, the scaling exponent is very close to 2/3, like public facilities [8]. However, the scaling exponent of wireless Internet such as NESPOT [16] and FON [17] is close to 1. Wireless Internet is usually installed for individual purposes and has a limiting traffic capacity. Therefore, one can expect the density of wireless Internet to be proportional to the population density (or Internet user density). Based on the results of previous research, although the number of routers per capita and router density in Republic of Korea is not so large, wired Internet service in Republic of Korea is provided as a public facility with high average connection speed and penetration rate.

V. SCALING EXPONENTS AND INTERNET PENETRATION RATE

The scaling exponents for 25 countries from district analyses are displayed with respect to the GDP per capita, Internet penetration rate, and Internet speed. As one can see in Fig. 5, the scaling exponent becomes smaller as the Internet penetration rate increases, which implies that the Internet service becomes more

Table 1. Scaling exponents of 25 countries in a district analysis.

Country Name	# considered districts[a]	Exponent	R^2	Penetration rate (%)
Denmark	98	0.48[b]	0.33	88.7
Czech Republic	75	0.62[c]	0.41	68.8
Italy	108	0.66[d]	0.48	53.6
Finland	326	0.72	0.44	86.9
Republic of Korea	195	0.76[e]	0.5	83.7
Switzerland	170	0.89	0.60	83.9
USA	3133	0.97	0.86	79.0
Netherlands	423	0.99	0.73	90.7
Mexico	676	1.00	0.70	31.0
Sweden	284	1.02	0.87	90.0
Spain	52	1.05	0.95	66.5
Norway	389	1.07	0.81	93.4
Canada	287	1.07	0.91	81.6
Macedonia	32	1.15	0.74	51.9
France	96	1.18	0.88	80.1
Greece	54	1.18	0.71	44.4
Japan	47	1.19	0.83	80.0
United Kingdom	91	1.19	0.65	85.0
Germany	415	1.20	0.77	81.9
Turkey	81	1.20	0.69	39.8
Portugal	270	1.21	0.78	51.1
Taiwan	23	1.25	0.45	71.5
India	385	1.26	0.39	7.5
Romania	42	1.32	0.90	39.9
Ireland	26	1.34	0.85	69.9

[a]Considered district means a region that has at least one router.
[b]0.78 (Peninsula region) and 1.00 (Island region)
[c]1.31 (Outliers are removed)
[d]0.89 (Northern region) and 1.05 (Southern region)
[e]0.89 (FON) and 1.02 (NESPOT)

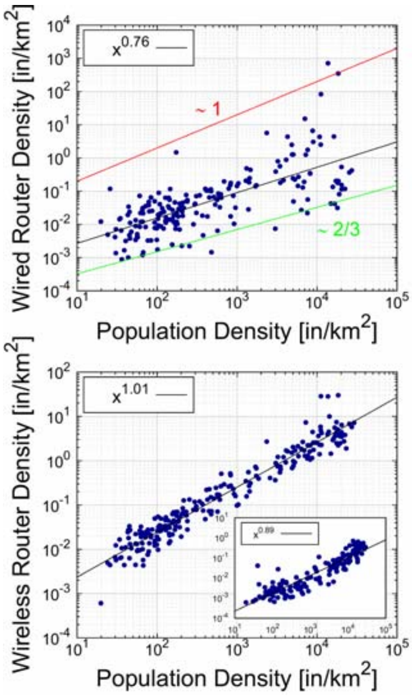

Fig. 4. (Color online) Comparison of scaling relations of wired (top) and wireless Internet – NESPOT (bottom) and FON (in the inset). Each point indicates a ward in the Republic of Korea. Each axis is log scaled. The red (green) line on the top is a base line.

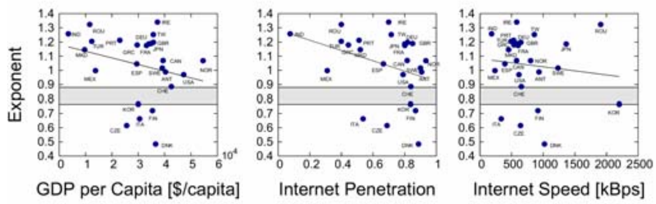

Fig. 5. (Color online) Scaling exponents of 25 countries in a district analysis versus GDP per capita, Internet penetration rate, and Internet speed. Each point means a scaling exponent of a country. The horizontal (vertical) axis is shown on a linear scale. The vertical gap between 0.8 and 0.9 indicates that a difference exists between scaling exponents following 2/3 and 1.

like a public service as it becomes more popular. We also checked the relations between the scaling exponents, economic condition and Internet speed, and they showed a weak correlation. For this analysis, the worldwide Internet speed data were obtained from ChartsBin [18].

VI. SUMMARY AND DISCUSSION

In this study, we have investigated the current state of Internet infrastructures by examining the position and the number of routers versus various demographic data. The scaling relation between the router density and the population density is studied in two different scales, a worldwide scale and district-in-country scale. We found the number of routers in each country to be almost linearly proportional to GDP of the country and a scaling relation to exist between the router density and the Internet user density, where the scaling exponent is larger than 1, superlinear, on a worldwide level. From a district analysis at the country level, we found that the scaling exponents could change according to the economic conditions and the level of Internet development. As the Internet penetration rate increases, the scaling exponent tends to be close to 2/3, which means routers are distributed like public facilities. Thus, as Internet becomes popular, the Internet service becomes necessary, and Internet facilities are placed like public facilities such as schools and fire departments. This result suggests that when we design the infrastructures of the future Internet, Internet facilities should be considered as public services not private ones. For future works, the inaccuracy of router data, errors coming from reverse geocoding, and the bias in selecting 25 nations should be more carefully reduced. The condition of the Internet line connection and the bandwidth between neighboring countries should be considered in the infrastructure design for the future Internet.

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