Expected Penetration Rate of 5G Mobile Users by 2020: A Case Study

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***Abstract*—The next 5th generation mobile network, or 5G key concepts, scenarios and requirements are actively debated in the research community. In this context, it is interesting to estimate a tentative 5G penetration rate, i.e., the mobile community of 5G users. In this paper, we focus on the initial 5G penetration, i.e., proportion of people who are willing to use the 5G networks, when the first 5G equipment is projected to be deployed, around the year 2020. The 5G penetration rate can be used as an input parameter for business viability, traffic estimation and network planning/dimensioning related to the 5G network infrastructure. The 5G penetration level will be country-specific; it may be different in different countries. We assume that the initial 5G penetration will depend on the penetration rate of the previous wave of the mobile wireless technology, which is called "fourth generation" (4G), or Long Term Evolution (LTE). Finland, currently, has the highest LTE penetration rate in Western Europe. As a case study, we estimate a number of potential users of the 5G network in Finland by 2020. In our approach we use relationships between mobile penetration rate, Gross Domestic Product (GDP) per capita, inequality of income distribution within population, and the Pareto law.**

Keywords-penetration rate; 5G; 4G; Pareto distribution; Logistic function; Lorenz curve; Gini coefficient; GDP per capita.

I. INTRODUCTION

So far, new technologies for mobile wireless networking have been deployed once in about ten years. The appearances of a new generation equipment on the market happened roughly in: 1981 (termed 1G, or first generation), 1991 (2G), 2001 (3G) and 2011 (4G). The fifth generation (5G) is expected to emerge around 2020-2021.

Even though the 5G mobile network is not defined yet in any official specification or standard, issues related to advanced 5G network infrastructure provoke intense interest in research community, e.g., within the framework of the Horizon 2020 European programme [19] for research and innovation. Please note that the exact time when the 5G technology will be introduced is still uncertain. We shall assume that it is the year 2020 in this paper.

The main factors/drivers towards 5G that should be taken into account are: (i) demand for services/applications from different groups of end-users in the 2020 time frame, i.e., competitive market impact; (ii) Gain/cost ratio related to new innovations/technologies/solutions/business models; (iii) existing limitations of frequency bands and spectral bandwidth; (iv) political factors that can impose some restrictions on innovative solutions.

The first 5G networks are projected to be deployed around the year 2020. For the first three factors, it can be useful to estimate the potential number of people that are ready to become 5G subscribers by that time. The 5G penetration rate will be different for each country. In this paper, we select Finland as a country for our case study. Finland has the highest LTE penetration level between countries of Western Europe in 2013 [1]. We estimate a potential number of 5G users in the country and the 5G density in its two largest urban areas by 2020. This is the main contribution of the short paper. To the best to our knowledge, there has been no prior work in literature showing how to estimate 5G penetration rate by 2020.

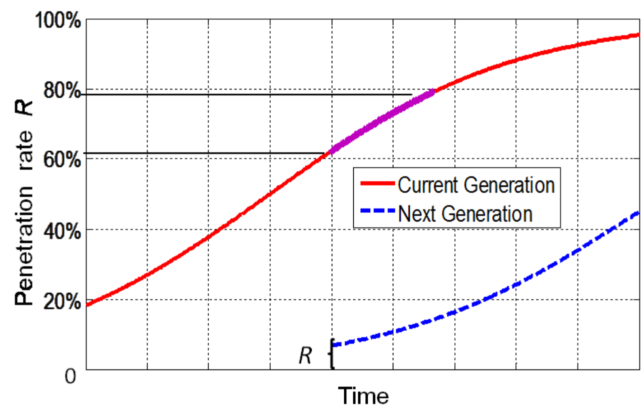

Figure 1. Penetration process *R* of current and next generation technology/service among the affluent part of the population. When 60 % to 80 % of the wealthy have "current generation" networking technology, it is time to introduce the "next generation." Then the whole group of affluent "current generation" users becomes the initial group of potential "next generation" users.

Our main premises are that first, the potential 5G subscribers initially come from the affluent subgroup of the population where the 4G penetration is much higher than the average. Second, the penetration of technology/service including telecommunication services follows the logistic function [2]-[4]. (Please note that qualitatively this function has three distinct phases: initial exponential growth up to 20%, almost linear growth up to 80%, and the final saturation stage [9].) We shall assume that when the new 5G technology is introduced, the penetration level of the previous, 4G technology among that wealthy (affluent)

 ISBN: 978-1-61208-366-7

subgroup will be between 60 % and 80 % that corresponds to the second part of the linear phase of the logistic curve (i.e., the greatest demand for the current technology/service [2] [10]). These assumptions are schematically illustrated in Fig. 1. The idea is that the wealthy (affluent) subgroup of people in the general population will be ready for the new 5G service when most of their wealthy peers have adopted the existing 4G technology.

We estimate the size R of that subgroup based on relationships between the Pareto law [5], Gross Domestic Product (GDP) per capita, inequality of income distribution within population, and the 4G penetration rate.

It is worthwhile also to note that methods similar to ours were applied to estimate a demand for telecommunication services in the past. For instance, the number of Integrated Services Digital Network (ISDN) users in several developed countries was estimated in [3][4]. Today, the results of these estimations seem quite plausible. In particular, very low demand for ISDN was predicted. It was estimated that the number of ISDN users even in developed countries had to be around 5-6% from the number of Public Switched Telephone Network (PSTN) users that corresponded with the real situation those years.

The rest of the paper is divided into three sections. The next section describes briefly the approach to evaluate the expected number of 5G users. Section III presents the case study related to estimating 5G penetration level in Finland by 2020. Finally, Section IV concludes the paper.

II. Approach for Estimating 5G Penetration Rate

In this section, we estimate the proportion of wealthy people in the population (potential 5G users) from the penetration level μ of 4G users and the Pareto parameter α. Then we show how α itself can be derived from μ.

It is argued in [2]-[4] that the demand for services depends on both GDP and its distribution within society and there is the relationship between a demand for telecommunication services, labour productivity, distribution of incomes between individuals, and GDP per capita. In particular, it is shown in [4] that the relationship between a telecommunication demand and income distribution is close to the Pareto law [5].

If X is a random variable with a Pareto (Type I) distribution, then the probability that X is greater than some number x is given by [5]

$$R(x) = \Pr(X > x) = x^{-\alpha}, \qquad 1 < \alpha < \infty, x \geq 1, \tag{1}$$

where $R(x)$ can be expressed as the proportion of individuals who have income more than x, and α is the distribution parameter, called the Pareto parameter or the tail index. (Please note that a range of small incomes has very small influence on statistical characteristics of income distribution [3]-[5].)

The income x in (1) is a normalized value that is equal to the ratio g/g_{min}, where g is one of income values, g_{min} is the minimum income value in a population.

The minimum income value may be expressed as $g_{min}(\alpha)=g_0/L(\alpha)$, where g_0 is the average value of personal annual income, that is GDP per capita, and $L(\alpha)=\alpha/(\alpha-1)$ is the average value of the normalized income. Thus, the expression (1) for estimating the number of individuals who have income more than $x = g/g_{min}$ takes the following form:

$$R(g/g_{\min}, \alpha) = \left(\frac{g\alpha}{g_0(\alpha-1)}\right)^{-\alpha}. \tag{2}$$

It is shown by Varakin [3] that the linear dependence takes place between the average amount of produced information generated by society per an individual in a country and its GDP per capita. Mobile telecommunications (as a part of society and economical infrastructure) impact on economic development [6]. Conversely, the economic development of a country determines its level of mobile telecommunications [7]. As a result, there is a relationship between a telecommunication/mobile penetration level and GDP per capita, that is generally assumed to be linear [3][4][6][7]. In our case, we also suppose that there is linear dependence between the penetration level of 4G users and GDP per capita g_0 (in the first approximation).

Mathematically, this relationship may be presented as

$$\mu = A \cdot g_0, \tag{3}$$

where $\mu = N_{4G}/100$ is the penetration level of 4G users, N_{4G} is the average number of users that have subscriptions for 4G per 100 individuals, and A is the normalizing dimension factor that is country-specific.

Since parameters μ and g_0 are the average values obtained by averaging many input data, in general case, it is also plausible that the penetration level T of 4G technology in the subgroup of the affluent individuals follows the relation $T = Ag_1$, where is g_1 is some income within the affluent group, and A is the same normalizing factor as in (3).

Thus, the ratio between the parameters is

$$k = \frac{T}{\mu} = \frac{g_1}{g_0}, k \geq 1, \tag{4}$$

where the coefficient k determines the excess of the penetration level of 4G subscribers in the affluent subgroup above the average value of the 4G penetration level in the total population.

As mentioned in Introduction, we assume that T is between 60 % and 80 % (i.e., k is between $0.6/\mu$ and $0.8/\mu$.) when 5G is introduced. Then, the whole group of affluent 4G users becomes the group of potential 5G users.

Based on equation (2) and the above assumption, the expression to determine the relative number of individuals who have the 4G penetration level more or equal than the parameter μ, or, in other words, the expression to estimate the relative number of the affluent 4G users or the potential 5G users (R) by the time when new generation is launched has the following form:

$$R\left(\frac{g_1}{g_0}, \alpha\right) = R(k, \alpha) = \left(\frac{k\alpha}{\alpha-1}\right)^{-\alpha}. \tag{5}$$

Recall that we assume that k is between $0.6/\mu$ and $0.8/\mu$ when the new, 5G technology is introduced. As a rule, forecasts of 4G penetration level μ in a region may be found in statistical literature. For instance, in the European Union report [1], the forecast related to the 4G penetration level in different Western European countries is presented up to 2020. But, to compute R according to equation (5), we also need to estimate somehow the Pareto parameter α at the time when the new, 5G technology is introduced.

In the rest of this section, we will show a way to estimate α from μ.

Generally, the parameter α depends on the inequality of income distribution between individuals. In our case, this parameter depends on the inequality of distribution of the number of 4G subscribers between individuals. The inequality of income distribution in a subgroup of individuals is described by the Lorenz curves [8]. In Fig. 2, the Lorenz curves show relationships between the current average income value in a subgroup of population Q and the number of individuals in the subgroup F for several values of α [18].

In particular, the set of the Lorenz curves illustrates that with increasing the parameter value α income in a subgroup is becoming more evenly distributed.

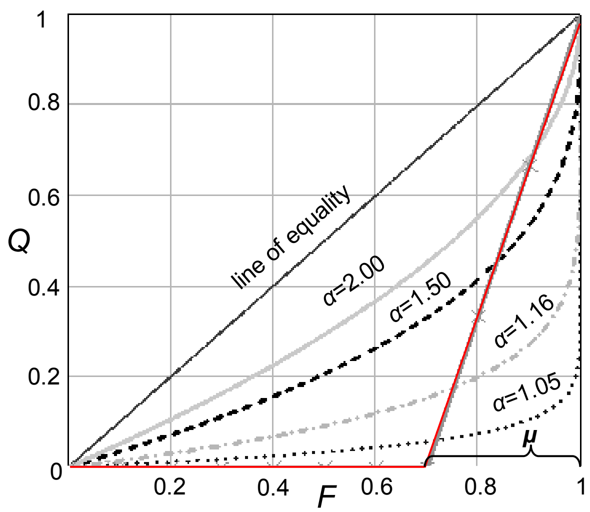

Figure 2. Set of Lorenz curves

The analytical function $Q(F)$ that allows assigning a set of the Lorenz curves has the following form [5]:

$$Q(\alpha, x) = 1 - (1 - F(x))^{\frac{\alpha-1}{\alpha}} \tag{6}$$

To estimate the Pareto parameter α for the expression (5), it is needed to approximate the function describing the broken line $Q(\mu,F)$ by the function (6) $Q(\alpha,F)$ corresponding to the Pareto distribution with the parameter α. It can be done by means of the Gini coefficient [8] W related to each of these functions. It is equal twice the area between the Lorenz curve and the line of equality, i.e., $W = 1 - \mu$ and $W = (2\alpha-1)^{-1}$ for $Q(\mu,F)$ and $Q(\alpha,F)$, respectively [18].

As a result of this approximation, the Pareto parameter α can be expressed as function of the penetration level μ:

$$\alpha \approx \frac{0.5(2-\mu)}{1-\mu}. \tag{7}$$

Then, the absolute value of the number of 5G potential users is estimated as

$$N_{5G} \approx R(k)N \tag{8}$$

where N is the population size in a region.

Thus, the expressions (4), (5), (7), and (8) give a basis to estimate the number of potential 5G users in a region.

III. Case Study

In this case study, we estimate a number of the potential subscribers of 5G networks in Finland by 2020 using the presented approach.

According to statistical information, 5.44 million people live in Finland (2013) [11]. The projection of the population growth in years 2010-2060 [12] predicts a number of inhabitants in the country by 2020 as 5.64 million (N).

Fig. 3 shows the forecast of LTE residential penetration of Western Europe up to 2020 presented in the EC report [1] (based on the Analysys Mason research [16]).

In accordance with it the penetration level of 4G (LTE) users in Finland (μ) is estimated as 32% by 2020. Then, applying the expressions (4), (5), (7), (8) we can evaluate the relative and absolute number of potential 5G users for Finland in 2020.

If T = 0.8 (conservative value), the relative number of potential 5G users in the country may be estimated as $R(k, \alpha) = R$ (2.5, 1.23) = 0.04. It means that just **4%** of people in Finland will be willing in 2020 to use the 5G network infrastructure to get their services. The absolute number of 5G subscribers in this case is around 0.22 million.

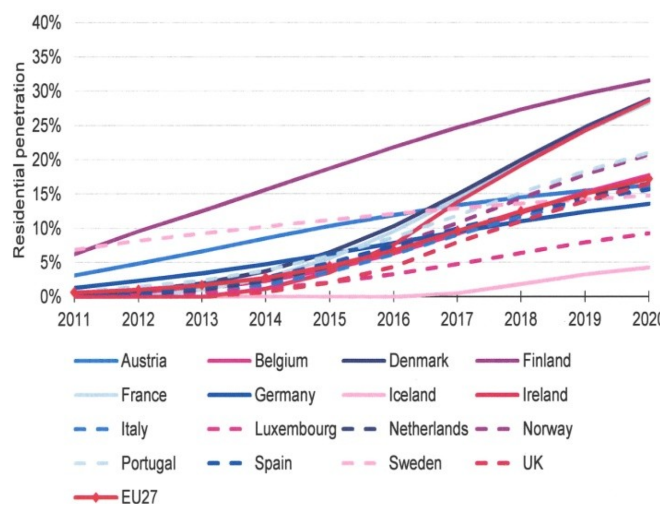

Figure 3. Residential penetration of LTE in Western Europe [Source: Analysys Mason]

If T = 0.6 (optimistic value), the relative number of tentative 5G users in Finland is equal to $R(k, \alpha) = R$ (1.9, 1.23) = 0.06. In this case, **6%** of Finish citizenships can be ready to become the 5G subscribers. It corresponds to 0.34 million people. Note that these values are initial numbers of potential 5G subscribers by 2020 and can be considered as lower limits.

It should be taken into account that population distribution in Finland throughout of the country is not uniform. People are mainly concentrated in the large urban areas. If we take the Helsinki metropolitan area (Helsinki, Vantaa, Espoo and Kauniainen) [13] and the Tampere urban area, the population of these two regions equals 1.4 million (1.1 and 0.3 million, correspondingly [14]). This is around 26% of the current 5.44 million Finland's population. The Gini coefficient value for Finland is very low (W is 25.9 [15]). It means more or less equal income distribution between country residents. Then, we can roughly assume that there is no big difference in income distribution level between these two regions and the rest of the country. Thus, we can suppose that 26% of all potential 5G users are concentrated in the Helsinki and Tampere urban regions.

As a rule, people in large cities have larger income and a share of 5G users for these two areas can be taken even a bit higher than 26%. But, we focus on a lower bound of the 5G penetration rate in this paper. In the absolute values, the number of potential 5G users in Helsinki and Tampere urban areas by 2020 is forecasted in accordance with the proposed approach to be between 60 thousand (conservative value) and 90 thousand (optimistic value). These two urban areas cover an area of about 1000 km^2 [13][14]. That is, the density of 5G users by 2020 in this territory is expected around **60~90 users/km^2**.

Definitely, only the future can confirm or disprove the estimations. However, it is interesting what happens if we would apply this approach to the past statistical information to estimate the number of 3G users based on 2G penetration level. On the one hand, the penetration level of 2G mobile phones in Finland in 2000 was 72% [17]. The first network equipment of UMTS (3G) was deployed in the beginning of 2000s. The initial penetration percent of mobile Internet phone (3G) in Finland was 22% [17]. On the other hand, if we use the presented methodology, then the relative number of 3G users had to be $R(k, \alpha) = R$ (1.11, 2.29) = 0.21 (T=0.8), i.e., around 21%, which is very close to the actual 3G penetration rate at the time.

Note that the 4G penetration forecast (Fig. 3) ends in 2020. If the 4G prediction would be known also for later years (for instance, up to 2025), then using the proposed methodology it may be possible to get the long-term dynamic forecast of 5G user growth.

IV. CONCLUSION

In this paper, we have presented an approach to estimate a tentative 5G penetration rate by 2020 when the first 5G network equipment is planned to be deployed. As a case study, we evaluated this parameter for Finland, but the approach can be applied also for other countries if corresponding statistical information is available. Though Finland is one of more promising countries in this context (it is predicted to have the highest LTE penetration in Western Europe), initial level of 5G penetration rate by 2020 is expected to be only around 4~6 % of the total number of inhabitants. The density of 5G users in two largest urban areas (Helsinki and Tampere) is also forecasted to be quite low, 60~90 users/km^2. These estimated values indicate a starting point of 5G penetration process.

To conclude, it is not worthwhile to expect an initial demand for 5G services at a level of 20-30% as it was when the first 3G network services became available. It is needed also to be cautious with regard to the density of 5G users per km^2 even in urban environment in the 2020 time frame. It is reasonable to support concentrating initial 5G deployment in "strategic" places like city centres and shopping malls.

The presented approach can help in issues related to traffic load estimations in 5G networks, network planning and network dimensioning aspects, in assessing the potential revenue from 5G subscriptions at the first stages of 5G network deployment.

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 ISBN: 978-1-61208-366-7