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How Does Improving the Existing DSL Infrastructure Influence the Expansion of Fiber Technology?

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Abstract**—**Experts, enterprises and operators expect that the bandwidth request will increase up to rates of 100 to 1,000 Mbps within several years. Therefore the most important question is which technology shall satisfy the future consumer broadband demands. Currently the consensus is, that the fiber technology has the best technical characteristics to achieve such the high bandwidth rates. But fiber technology is so far very cost-intensive and resource consuming. To avoid these investments, operators are concentrating to upgrade the existing copper and hybrid fiber coax infrastructures.

This work presents a comparison of the copper and fiber technologies including an overview about the current German broadband market. Both technologies are reviewed in the terms of demand, willingness to pay and economic efficiency in connection with the technical characteristics.

Keywords**—**Broadband customer demand, fiber development, G.fast, Vectoring, willingness to payfor broadband services

I. Introduction

NEW multimedia products and services, such as Cloud-Computing, streaming, voice over internet protocol (VOIP), Online-Gaming, video-conferences, E-Health, E-Government and E-Work, are responsible for the increased broadband bandwidth demands of companies and private customers [1]. For commercial and technical utilization of the new services, most company and private households will need to upgrade their access for a faster broadband access speeds over 50 Mbps in downlink (DL) and 5 Mbps in uplink (UL). Currently there is no country where the customers have an average broadband access over 50 Mbps [2]. A few countries have broadband access speed averaging over 10 Mbps [2]. At this juncture, the most important question is which technology should generate broadband access rates about 50, 100 or more Mbps in the future. Furthermore network operators have to ensure customer satisfaction with regards to broadband demand.

With regards to cable-bound infrastructures the following 3 technologies are taking the leading position of broadband access and satisfaction of customer broadband demand and needs: (a) the copper infrastructure with very high speed digital subscriber line (VDSL), Vectoring and G.fast, (b) the hybrid fiber coax (HFC) based on the TV broadband, and (c) the fiber technology. So far the utilization share of the copper infrastructure has declined in the number of broadband customers. From 2009 to 2014 there was a drop from two thirds to the half of the worldwide broadband customers [3], [4]. But in the consideration of the customers the worldwide broadband utilization increased from 466 million in 2009 to 673 million in 2013 and actual 711 million in 2014 [3]-[5]. Therefore the *absolute* number of the copper infrastructure users is rising. As a result the copper technology is still the most utilized technology in broadband access in the world.

In fact, the utilization of internet services and applications is likely to rise, so old infrastructures and capacities will not satisfy future consumer needs. In the opinions of experts only a fiber infrastructure can provide satisfactorily high bandwidth rates [1], [6].

This paper is organized as follows. In Section II we give a short review about the advantages and disadvantages of fiber technology plus VDSL with Vectoring and G.fast technology. Section III concentrates on the current broadband market overview in Germany. At this juncture we analyze the demand and willingness to pay of the private internet users. In Section IV we take an in-depth view of the improved copper infrastructures in relation to the development of fiber technology. Consequentially, it is important to figure out the current and future broadband development. Additionally, some examples of the current regulation and competition situation in the German broadband market complete this overview. The final remarks are given in Section V.

II. Technology Review

As mentioned above, there are 3 technologies, which take the leading position in the achievement of the customer broadband access. In this section we describe especially the fiber and copper infrastructures. VDSL copper technology uses bandwidths between 25 Mbps and 100 Mbps in DL. A high attenuation (10 to 17 dB per km) prevents higher bandwidth rates and broadband capacities. Furthermore strong interferences because of high frequencies in long ranges result in a high loss in bandwidth [7]-[12]. Therefore in general the copper bandwidth rates are limited and a DSL infrastructure can provide higher bandwidth rates in short ranges only. To improve the bandwidth it is necessary to eliminate interferences and to minimize the crosstalk [11], [12]. Accordingly operators are developing Vectoring and G.fast technology. Vectoring and G.fast coordinate and control the copper lines based on frequency optimization and crosstalk cancellation at the access point (AP) [11], [12]. At this juncture it is important, that only a simultaneous coordination can eliminate all interferences. So the lines should be managed

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and monitored as one unit [11], [12]. For this reason all copper cables, which are connected to the AP, are under supervision of *one* operator. The implementation of Vectoring ensures only copper-based bit rates up to 100 Mbps in DL and 40 Mbps in UL within a range of 500 meters from AP to the customer [8], [9], [12]. The G.fast technology guarantees 200 to 500 Mbps in DL and 110 Mbps in UL for short ranges up to 250 meters [9], [12], [13]. The boost of the DSL capacity is consequently limited. The advantage of this improvement appears to bring the technology physically closer to the customer [9], [12]. These advances enable the operators to extend their fiber-based access network from main distribution frame/point (DP) to AP and digital subscriber access line multiplexer (DSLAM) [12]. However, the Vectoring and G.fast technologies need a hardware update in the dynamic-spectrum-management (DSM) and customer premises equipment (CPE) [9], [11].

Compared with copper infrastructure, fiber technology works with optical signals [9], [14]. The optical transmission allows a high broadband bandwidth and a long broadband range together with an unknown capacity limit [9]. Based on these characteristics, the fiber technology could achieve bandwidth ranging from 100 up to 1,000 Mbps [7], [9], [15]. The characteristics of fiber technology are defined by a low attenuation (0.4 dB per km), low influence of resonances and electromagnetic signals, and a marginal loss by using high frequencies for transmission of signals [9], [15]-[18]. Furthermore, fiber infrastructure guarantees a high bit stream in connection with a low loss of bandwidth by the transport of information and signals [17], [18]. In contrast to copper cables, fiber lines are able to afford more users per one line. In addition, the fiber infrastructure can be used in two different ways. The one implementation is that all customers receive high bandwidth rates via private fiber lines as with DSL copper line. The other option is to use the fiber line as a shared medium, so that a number of customers can use the bandwidth of one fiber line and each customer gets a separated bandwidth [13], [16], [18].

III. Market Situation: Willingness to Pay and Demand

Section III will focus on broadband demand and will present specific examples from the German broadband market. Experts and operators expect that demand for higher bandwidth up to 100 Mbps, capacities and data rates will increase in the next years [1], [6], [18]. The aim for the future is an available bandwidth of 1 Gbps per single fiber line for each customer [4]. The planning horizon for development of broadband investment projects is very long [9]. In such a case, the future customer broadband demand is hardly quantifiable and predictable. If customers do not use high broadband access speeds, the carriers have to implicate new services and innovations to stimulate the broadband demand of the customers [4]. Innovations are essential to increasing bandwidth and broadband demand. Especially a high bandwidth is not the only key indicator for a high-speed internet access. Additionally, the following 3 factors of an internet access are very important for customers: (a) a simultaneous provision of different offers and broadband services, (b) the possibility to be always on and (c) a capable use of multiple services [4]. In general an internet access is depended on the access speed and the data throughput capacity [4].

As mentioned in Section I, the current copper infrastructure based on DSL and VDSL technology has a leading position on the broadband market. In the following, we describe the example of German broadband market to underline our statements. The German broadband market exhibits 29.4 million cable-connected broadband customers. The copper lines take the leading position, because of 23.5 million (80%) connected copper accesses [19], [20].

TABLE I
THE DISPERSION OF THE GERMAN DSL/FTTX USER FOR OVER 16 AND 50 MBPS [19], [20]

German DSL/FTTX User	> 16 Mbps	> 50 Mbps
2013	18.7%	1.3%
2014	24.3%	1.7%

However, the demand for more than 50 Mbps is in the current situation very low and is not economic efficient. The results indicate that most private households are satisfied with their current broadband access speed [1], [9], [21], [22]. This development is emphasized from a survey, which constitutes that 80% of the private customers in Germany are content with their current broadband access [23]. Table I presents the broadband utilization results of the German DSL and fiber to the X (FTTX) connections. As mentioned above, the German DSL and FTTX connections are in use by 23.5 million customers. Only a share of 1.7% customers uses broadband connections with a bandwidth over 50 Mbps. In fact, most of the copper and fiber infrastructure customers do not inquire high data rates over 50 Mbps [20]. It is very unlikely that the mass of the (German) customers demand broadband access over 100 Mbps in the next few years. As shown in Table I, in the current situation the shift rate from a bandwidth below 16 Mbps to a bandwidth over 16 Mbps is much higher than the shift rate from below 50 Mbps to higher 50 Mbps. The main reason for the slow adoption is constituted in consumer satisfaction with current broadband access. If DSL bandwidth achieves higher rates, consumer broadband demand will increase slowly. The consumer demand for VDSL/FTTX data rates over 50 Mbps increased only from 1.3% to 1.7% (out of 23.5 million) from 2013 to 2014 [19], [20]. Several customers do not might be having the option to get a 50 Mbps at the current situation. This result indicates that a demand cannot originate by the customers, because of the not existing infrastructure [22]. Another limiting factor is presented by the insufficient customer hard- and software. Because of the lacking technical preconditions and facilities, the customers cannot access and demand high broadband speed services, e.g. high definition television and cloud content. The customers and enterprises have to eliminate the technical problems and obstructions. After solving the problem, the customers can achieve high bandwidths and the new services. Services as

Emails, surf the Internet and Online-Shopping are added to the basic requirements of an internet access [22]. The new high broadband speed services can be assigned as additional services. There is a high probability, that the additional services will be basic requirements for a high speed internet access in the future [22].

Customer broadband demand is not only limited by the technical characteristics of the infrastructure. Furthermore the demand is limited economically by the customer willingness to pay. The customer willingness to pay determines the revenues of the net operators. The rise of the bandwidth rates results only a few effect on an increase of the customer willingness to pay [1], [22]. Consumers will remain price sensitive unless they recognize a substantial improvement in the quality and availability of broadband services [9], [22].

Looking at the German broadband market, customer revenues decreased from 36.55 euro per month per customer in 2009 to 32.96 euro per month per customer in 2013 [24], [25]. In future, the problem might come up that the operators receive declining revenues. As result the operators have insufficient funding for new investments in broadband and, especially, fiber infrastructure. This indicates that the operators cannot invest in high cost projects with low customer revenues.

From a world perspective with 140 countries, average broadband access per customer increased to 3.9 Mbps in 2014 [2]. Over the past year, the global broadband average rose with a value about 1.8% [2]. In contrast to the broadband average of the world in Germany the customer broadband access speed roses from 5.0 Mbps in 2011 to 7.4 Mbps in 2013 and actual 8.1 Mbps in 2014. Currently the average broadband access in Germany increases each year. This implicates that the German customer broadband demand develops to higher bandwidths. The average broadband access in Germany is above the global average. In contrast to this value, the rate of growth from 2013 to 2014 in Germany is with 19% below the most European and worldwide leading countries [2]. Most countries have broadband growth rates above 20% per year. For comparison the worldwide and European leading countries in broadband access speed, Rep. of Korea, Switzerland and the Netherlands have broadband access averaging 23.6 Mbps, 12.7 Mbps and 12.4 Mbps per customer [2]. In the world broadband access speed averages, Germany takes the 26th place [2]. This means that Germany is not among the top ten countries worldwide with regards to broadband access speed. These results indicate that Germany has fallen behind some other countries in the world in the broadband access speeds. At this juncture for Germany exists a high risk to lose the connection to fast implementers of high bandwidth data rates. The German broadband market risk being passed over by other countries. Furthermore Germany has the risk that companies will be less interested to invest in German economic projects, because of the lower bandwidth access speeds. For example the Rep. of Korean broadband market exhibits a 63% fiber penetration rate. On the other hand, the penetration rate for fiber in German households is under 1% [18], [19]. Of course, a comparison between other countries and Germany in the terms of broadband development is not that easy. The state of Germany has a larger rural area than countries like the Netherlands, Rep. of Korea and Switzerland. This point indicates that more fiber lines and cable ducts are needed for a comprehensive broadband access. Besides the area, the population density is also a very important point for a broadband development. The Netherlands and Rep. of Korea exhibit very urbanized and densely populated areas. If a new or improved infrastructure is expanded in a densely populated area, the operators can achieve a high number of potential customers. Furthermore the costs per customer will decline, if more customers demand such a broadband access. The probability rises in these countries because of a densely populated grade. In Germany there are few areas with a high dense population and a lot of areas with a low dense population. Because of the wide spread of populated areas the costs for a comprehensive broadband coverage is very high. As a result, the costs for fiber broadband access are higher in Germany than in smaller and urbanized countries. In general there is the question: Is this the real reason, why Germany is behind in terms of broadband access?

For a discussion of this question we analyze bandwidth development of 4 countries: Germany, Russia, Rep. of Korea, and Switzerland. The concentration of the German broadband market results, because Germany is the home country of our institution. The selection of Rep. of Korea based on the fact that Rep. of Korea has the leadership in broadband access speed development worldwide. Switzerland takes the leading position in the point of broadband access speed in Europe. Finally, comparing the Russian broadband market is very important given it larger land mass. Furthermore, we want to clarify, why Germany is in the terms of broadband access speeds less developed than other countries.

TABLE II
BANDWIDTH COMPARISON BETWEEN GERMANY, RUSSIA, REP. OF KOREA AND SWITZERLAND [2]

2014	Germany	Russia	Rep. of Korea	Switzerland
Bandwidth Average	8.1 Mbps	8.6 Mbps	23.6 Mbps	12.7 Mbps
Growth 2013-2014	19%	44%	145%	26%
Bandwidth Peak	35.4 Mbps	41.3 Mbps	68.5 Mbps	44.8 Mbps
Growth 2013-2014	13%	40%	52%	12%
Bandwidth > 4 Mbps	76%	77%	91%	94%
Growth 2013-2014	8%	27%	3%	25%
Bandwidth > 10 Mbps	21%	27%	77%	45%
Growth 2013-2014	61%	123%	146%	49%
Bandwidth > 15 Mbps	8%	11%	60%	23%
Growth 2013-2014	78%	225%	272%	85%

First we compare the bandwidth averages for the customer broadband accesses of the 4 named countries. As shown in Table II, the German broadband market exhibits the lowest bandwidth rates and the lowest percentage of customers for each range of bandwidth. The German customer bandwidth average of 8.1 Mbps is nearly 4 times lower than the 23.6 Mbps of Rep. of Korea. In the opposite the Swiss average (12.7 Mbps) is one and half times higher than the German average. The Russian bandwidth average (8.6 Mbps) exhibits nearly the same value. The rate of growth indicates that the countries, except Germany, have a bandwidth average growing over 20% from 2013 to 2014. The German growth rate of 19% from 2013 to 2014 is quite low [2]. This development is reflected by the bandwidth peaks too. The other 3 countries have bandwidth peaks about the 40 Mbps mark. The bandwidth peak of the Rep. of Korea is with 68.5 Mbps nearly double so high as the German bandwidth peak (35.4 Mbps). Russia (41.3 Mbps) and Switzerland (44.8 Mbps) exhibits a customer bandwidth peak a bit higher than the German mark [2]. The growing rates between 2013 and 2014 are lower as the rates from the whole bandwidth averages. The spread between the German and Rep. of Korean average is with nearly 40% quite lower than the value of nearly 125% of the bandwidth. In contrast, the growing rate of the Russian customer bandwidth peak is with 40% 3 times higher than the German average [2].

The following analysis focuses on customer adoption rate of bandwidths above 4 Mbps and 10 Mbps. Experts predict an increase in demand for broadband for broadband rates far above 50 Mbps [1], [2], [6], currently only 76% of the German broadband customers have access to a bandwidth above 4 Mbps [2]. Actually, 24% of the German broadband customer does not use a broadband access above 4 Mbps. As a consequence, it is very questionable, if the bandwidth demand will increase very fast. In comparison to Germany, the broadband markets of Switzerland and the Rep. of Korea exhibit more than 90% broadband customers access a bandwidth above 4 Mbps [2]. The Russian value is quite similar to German ones. The rate of growth is in contrast to previous explanations with values from 3% to 27% quite low [2]. Considering the bandwidth above 10 Mbps, the compared values between the 4 countries are differentiated. The Rep. of Korean market exhibits a high customer broadband adoption rate with 77% [2]. Not only do customers in the Rep. of Korea demand high bandwidths, there is also the access to it. The German and Russian broadband adoption rate is a bit higher than 20% [2]. This result symbolizes, that the most customers do not access a high bandwidth above 10 Mbps. Accordingly, the most German and Russian customer cannot demand and use the new broadband services. The Swiss adoption rate is far away from the Rep. of Korean value, but nearly double the German value [2]. The rates of growth are quite high and symbolize the operators, that the customers want change their current broadband access for an access with higher bandwidth.

At the last point in Table II, the analysis focuses on the broadband connections with a bandwidth above 15 Mbps. Reference [2] does not relate to the exact bandwidth of 15 Mbps. Instead they mentioned, that an access shall ready for “ultra-high definition television, cloud computing, big data and others”, named as 4K. In general, it is expected, that the future broadband access has to be capable to present a 4K content. At this juncture the question is: How many customers have a 4K (above 15 Mbps) broadband access? Reference [2] clarifies, it can be assumed, that the German broadband market has only 8% capable connections, which can deliver 4K content to the customer. The Swiss and Russian values are a slightly higher. The value of the Rep. of Korea is far away from the other countries. In comparison to Germany the value from Rep. of Korea is about 6 times higher. The whole rates of growth are extremely high. The spread is from 70% to over 200% [2]. The operators in the named countries try to upgrade their broadband accesses, so that the customers can get capable 4K connections.

As shown in Table II, the German broadband market is less developed than the other compared countries. The German operators and regulatory authorities cannot use the country’s large rural area as an excuse. Russia has a greater land area than Germany. Furthermore Russia is a sparsely populated country. In contrast to Russia, Germany exhibits a higher grade of population density. Nevertheless, the Russian bandwidth rates grow faster than the rates in the German market. The Russian rates of growth have achieved the German broadband penetration already.

However, in this case it is necessary to specify, how the broadband infrastructures are implemented by the national operators. In Russia and other countries (e.g. USA) the broadband infrastructures are mostly not embedded in the ground and can easily implement in the broadband network system. In comparison, in Germany it is tradition and law, that the broadband infrastructure is embedded in the ground by the operators.This approach leads to cost-intensive and resource consuming implementation of broadband infrastructure in Germany. The operators in the other countries exhibit low investment costs for the implementation of broadband infrastructures.

In the conclusion the German broadband market has a risk to falling behind in the terms of the broadband access speeds in an international comparison to the other countries. However, the German broadband is not the only broadband market, which has got problems in the terms of high access speeds. Beside Germany, the French and Italian markets also exhibit the same problems as in Germany. In general the most western European countries have customer bandwidth averages below the 10 Mbps mark. At 12.4/12.7 Mbps, only the Dutch and Swiss broadband market have higher average customer broadband rates than the other western European countries.

In general the broadband developments depend on the terms of regulation. The regulations between the western European countries, Russia and Rep. of Korea are quite different. The broadband development in Germany depends on the operator investments and the force of the competition. The regulatory authority assumes only the function of supervising the development and avoids the misuse of market power. In other countries the broadband development is led by the national authorities or an incumbent. In such case, a broadband development will be implemented completely differently as in environment of full competition. In such case, an implementation of the infrastructure will be done much quicker, easier and stricter than in the environment of competition.

IV. Influence of the Copper Infrastructure to the Competition

In the most countries of the world the copper infrastructure is embedded and the cables were brought into the ground years ago. For this reason the investment costs of the copper lines are almost depreciated. For an improvement of the copper infrastructure (hardware update, DSM and CPE) only few additional investments are necessary. In general, the copper infrastructures can provide higher bandwidth rates based on low investments. The improvement of the Vectoring technology needs a cash-out between 300 and 550 euro per access line. In contrast the fiber technology requires financial cash-outs between 1,500 and 4,300 euro [26]. This comparison demonstrates that the copper infrastructure together with the Vectoring and G.fast technology claims low investments and is 5 to 8 times cheaper than the fiber access. As mentioned in section II, the fiber technology can satisfy higher bandwidth ranging from 100 Mbps up to 1,000 Mbps. However, the roll-out of the fiber technology is extremely time and resource consuming [9], [11], [18]. Accordingly, the big network operators want to avoid inconveniences, expenses and high investments [12]. So the operators detain financial cash flows, avoid massive investments and extend the fiber access in the unknown future. This development ensures an advantage for the copper technology. In this case the Vectoring and G.fast technology prolongs the life expectancy of the copper infrastructure [9], [12], [27]. Furthermore, the customer does not use the full broadband speed capability of the existing copper wires/infrastructure. Consequently a fiber infrastructure is not needed from the position of customer demand.

The implementation of the Vectoring infrastructure is generally technical efficient, if *one* operator (normally the incumbent) in the most controls all connected copper lines [8]. If there would be some unbundled copper wires from competitors, the efficiency of Vectoring technology would decrease [8], [11]. Instead of a bandwidth rise from 25 to 100 Mbps the increase would only be from 25 to around 30 Mbps. If one operator controls all connected lines and uses the Vectoring technology, the competitors would be “pushed out” from the AP [8], [11], [27]. Consequently the utilization of Vectoring technology compromises the competition and the economic welfare of the broadband market [27].

In this case, we use the German broadband market as reference. Generally there is not an option to coordinate all copper lines from one operator due to the rule of unbundling. Competitors have the right to control and coordinate their own copper lines from the AP to the customer. Since 1998, the German telecommunication market has subjected to conditions of liberalization. In contrast to the market, the control and coordination of one operator symbolize a monopole structure [27]. A development of Vectoring and G.fast collide with the terms of law, regulation and liberal market [8], [27]. From the economic point of view, it could be possible, that one operator coordinate and control all copper wires and give the competitors the possibility of bit stream access [8], [11], [27]. The competitors can use the copper wires of the incumbent to offer own services and contents to the customers. Hereby, this implementation represents the best decision of economic efficiency. Generally the implementation of Vectoring and G.fast push out competitors and give the one big operator a nearly monopolistic position. For competitors, there exists the risk, that the one big operator uses his market share to control the whole market and do not allow the option of a bit stream access [8], [27]. This approach compromises the terms of the liberal German broadband market. In such case, the regulatory authority has the function to ensure the terms of a liberal competitive market [18], [27]. If the big operator allows the bit stream access, the regulatory authority has only the task to check the prices for competitors [8].

Additionally, there should be the option that also competitors can coordinate and control all copper wires on an AP and push out the incumbent, if they have the highest market share on an AP. In this case, the incumbent should get a bit stream access from the competitor. This, however, will also require governmental regulation [8].

Furthermore in the German broadband market, operators are looking for alternatives to substitute their usage of the incumbents cooper lines [1], [9], [28] e.g. Vodafone took over the big HFC network operator “Kabel Deutschland” and switched, as far as possible, from copper to hybrid wires. “Telefónica” focused on the mobile market and took over the mobile operator “E-Plus”. They stopped focusing on the fixed networks anymore and establish a bigger market share in the mobile phone and broadband market [9], [28].

From the perspective of cost and bandwidth demand the fiber technology is not necessary at the current situation. A fiber roll-out is too expensive just to improve the existent infrastructure and does not gain economic efficiency. A near change is not expected since the copper infrastructure gains too high benefits. If the operators do not use the profitable old infrastructure, they shed benefit and economic welfare.

On the other hand experts are quite sure that the data rates, the amount of data and the broadband volume will increase. In this case only the fiber infrastructure can satisfy the future broadband needs [1], [2], [6]. Copper infrastructure with the G.fast technology will only be able to reach bandwidths ranging from 1 to 2 Gbps around a 50 to 100 meters area from the AP [9]. It must be assumed that fiber roll-out will be indispensable, because the end of the copper infrastructure is conceivable. At this juncture an implementation of Vectoring and G.fast technology can be used as changeover from copper to fiber lines. The implementation conducts to a stepwise fiber roll-out in a migration from fiber to the curb (FTTC) to fiber to the building/home (FTTB/FTTH) [9], [18], [27]. As mentioned in section II, the active technology comes physically closer to the customers [9]. From the economic point of view the investments in a migration infrastructure from copper to fiber are not economic efficient. In fact, the

Vectoring and G.fast technology base upon a FTTC-system, where fiber lines will roll-out from DP to AP. The fiber lines from DP to AP can also be used for FTTB/FTTH-systems. However, the costs for the updates of the AP and DSLAM are sunk costs, because the fiber transmission from DP to the customers does not need an AP and DSLAM [29].

Fiber roll-out exhibits another problem. If the data rates and bandwidth increase the copper infrastructure cannot satisfy the customer broadband needs anymore. In this scenario an operator with a fiber access network will have a big advantage and a nearly monopolistic position. Similarity into the paragraphs above the regulatory authority will intervene due to the fact that a monopolistic structure of any kind is unacceptable [18]. As a consequence, the operator owning the fiber access network most likely will have to offer an unbundled access to the competitors. The option of unbundling constraints investors and they avoid investments in broadband and fiber architecture. An unbundling of the expensive fiber infrastructure by the regulatory authority would obliterate the high investment costs from the investors. Carrier will not invest in a new infrastructure in the context of uncertain regulatory rules and high probability for unbundling. The main task of the regulatory authority is, to ensure fair conditions and balance for all competitors in the market. Furthermore the regulatory authority will avoid high revenues from a monopolistic market structure. For the competition it is important, that the customers have not to pay high monopolistic price, because one operator has control the whole market [8].

In addition to the previous discussions the HFC infrastructure competes with the copper network and a (potential) fiber infrastructure [8], [9]. The HFC operators exhibit their own networks. Their infrastructure is laid in the ground and almost depreciated as well. Therefore the HFC operators exhibit low ongoing costs can proceed in a very price flexible and aggressive manner [18]. The HFC network can satisfy broadband needs up to 400 Mbps. From the capacity point of view the hybrid wires are more power efficient than the copper lines. The HFC network is the strongest competitor for a fiber roll-out [29].

Furthermore the HFC operators have got the big advantage that they do not have to unbundle their lines for competitors. This point indicates that within their own network, they have a monopolistic position. From the planning point of view the HFC network constitutes a strong competition for the copper and fiber lines in the next 15 years.

Finally, the copper and HFC infrastructures are the 2 broadband access networks in the German broadband market. Both infrastructures cannot achieve 100% customer utilization. Because of the existing mobile access network and a percentage of internet disclaimers a full utilization is not reachable [29].

With a fiber roll-out the operators would open a third access network in the German broadband market. The third network in the market avoids the full utilization of all existing networks [18]. From the economic point of view the implementation of fiber lines is not reasonable at the moment.

V. Conclusion

It can be assumed that the copper infrastructure (especially with DSL technology) has achieved the peak of utilization. Furthermore the DSL technology will achieve the peak of bandwidth and capacity in the next years. Experts expect that the utilization of the copper infrastructure will decline. The implementation of VDSL, Vectoring and G.fast impacts this outlook and slows the decline of the copper technology. The lifetime of the copper wires will be prolonged through these technical updates [8], [9], [12], [27].

Approx. 50% of the fixed lines in the world are taken by the copper infrastructure [4]. This indicates that the copper infrastructure takes the biggest market share in the worldwide broadband market. In contrast the FTTX-Infrastructure (including FTTC/VDSL-technology) has got a market share about 20% to 25% of the broadband market but is still steadily growing [4].

In general, the whole broadband market depends on the customer demand and the technical availability for a broadband access development. These factors are the key indicators for the operators and service provider [4]. In this case the willingness to pay of the customers will increase and the operators will gain more money for investments in infrastructure. Normally the infrastructure for higher bandwidth has to be implemented, to reach higher bandwidth levels. After this, new services can be offered by the service providers and the customer broadband demand can increase [22].

As mentioned in Section I and III, experts expect a rising of customer broadband demand, which is very probable. New contents as high definition television and cloud services push the broadband speed and increase the customer demand. This indicates that more customers will use the new services and the technical manufacturer will produce better and more powerful devices. Because of the rising requirements for broadband networks, the operators will upgrade their infrastructures. At least the operators will embed a more powerful infrastructure to satisfy the higher bandwidth requirements [22]. In general, the customers want receive an easy high speed internet access with a good and continual quality and provision.

Different regional and national broadband markets are subject to different dynamics and characteristics [4]. Each country exhibits variable circumstances for a further broadband development and fiber roll-out. As a reference, the German broadband market has determined by the hauling of the copper and HFC infrastructure long time ago. In this case the question would be: Should the German operators use the old infrastructures as long as possible? This point indicates, that the operators avoid investments in new infrastructures and try to get revenues until the technical end of the existing infrastructure. In contrast other countries did not have an existing infrastructure in the past. For them it is very easy to embed a new infrastructure, because they do not have to offset the investment cost to the sunk and opportunity costs. They roll-out the fiber infrastructure instantly without a competing infrastructure

The perception of the experts is that the fiber roll-out so far is developing slowly and delayed. The prediction of a faster growing fiber development by the experts, market and authorities cannot be combined with the terms of economic efficiency and the entrepreneurial approach of the telecommunication operators.

The broadband market will stagnate in the future on a several bandwidth level, if no operator invests funds in infrastructure and fiber roll-out. The regulatory and governmental authorities have the function to imply for the competition: (a) fair roll-out conditions, (b) an authentic and continual regulation and (c) enabling for promotion projects for the broadband development, particularly in rural areas. These factors shall supply the fiber roll-out and the implication in the national broadband markets. Furthermore the regulatory authority has to ensure the access to the last mile between DP or AP to the customer. As a general rule the incumbent has the control of the AP, because of the biggest market share and the most attached copper wires. In this case the incumbent have to guarantee an access for the whole competitors and enterprises. [6].

Considering the whole broadband market the mobile network takes with the mobile connections competitive position to the fixed broadband access connections too. The mobile connections have a big impact and influence to the customers because of a rising significance of the mobile phones and connections in the worldwide community. In contrast to the fixed broadband connections the mobile broadband network requires only few costs for a comprehensive implementation. Mobile communication networks can easily cover a large area in connection with few investments. In contrast to the fixed broadband connections the mobile broadband accesses cannot achieve the high bandwidth rates as the copper or fiber infrastructures.

Ultimately we conclude that the data capacity and the bandwidth rates are rising in the current situation. The whole world is developing into a “gigabit community”. Without Vectoring and G.fast technology, copper technology cannot reach high bandwidths over 50 Mbps. In this case the copper infrastructure is very limited and cannot satisfy the future customer broadband needs [27]. Vectoring and G.fast ensure the VDSL technology a higher bandwidth. This development is also comprehensible. If there are uncontrolled lines from competitors, the economic efficiency declines [11]. Furthermore it is comprehensible, that unbundling of competitors limits the efficiency of the improved copper infrastructures. From the economic point of view competitive lines reduce the improving bandwidth effect of Vectoring [8].

The incumbent provokes a pushing out of the competitors, if it controls and coordinates all copper lines on the relative AP. The regulatory authority do not aspire a monopolistic structure in the relative broadband market. If the incumbent ensures bit stream access for competitors, the regulatory authority will not intervene. Rather the authorities, the operators and enterprises consider in the Vectoring technology the option to perform a switchover from copper to fiber infrastructure [27]. The general aim for operators is to satisfy the future customer needs. If operators grade up their existing infrastructures and implement new infrastructure, the future customer needs can be satisfied. After this, the customer demand for broadband services will increase. In general the broadband market depends on a greater willingness to pay from the customers. If customers are willing to pay higher prices, the operators can gain more funds for further broadband investments.

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