Convergence of Mobile Communications and Broadcasting: A long term perspective

- Working Paper -

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Abstract - Terrestrial unidirectional broadcasting is currently being substituted by wired bidirectional IP-based services. In practical day-to-day use, user mobility for the 'last mile' is supported by wireless local area networks with massively growing data rates. Terrestrial bidirectional mobile communications, on the other hand, is currently moving into its fourth technological generation. With the new *UMTS Long Term Evolution* (LTE) standards, data rates required for television broadcasts can be achieved with mobile bidirectional IP-based services. To increase technological and economic efficiency, unidirectional terrestrial broadcasting will, in the long run, have to make room for bidirectional mobile communications. This has consequences for policy makers and technologist alike, as public broadcasting has to be integrated into these networks and hence the regulatory framework needs to be adjusted accordingly. From a technological viewpoint, a bidirectional network technology is needed which allows for efficient incorporation of broadcasting. From a regulatory point of view, policy makers need to revise regulatory thinking towards frequency allocation principles, too. A unified network approach can be more efficient, both technologically and economically. Technological aspects include higher spatial reuse factor of frequencies, lower infrastructure costs in sparsely populated rural areas due to lower frequencies and much higher supportable data rates: the current amount allocated to mobile communications in the VHF ranges would be more than doubled. Also, such a centralized approach will make it easier to integrate dynamic spectrum access methods currently under research. Economic efficiency is increased on the one hand by the possibility of eliminating redundant broadcasting infrastructure and by increasing social welfare from higher capacities available. Regulatory issues to be solved mainly concern the relationship between public broadcasting and private mobile communications corporations. As opposed to the situation of state monopolies in

wired communications at the end of the 20^{th} century, which moved towards supervised competition on a single infrastructure, mobile communications networks are largely run by private companies. In the long run, all these activities have to be integrated into one multidimensional infrastructure network system. A first step in this process was the reassignment of spectrum formerly allocated to terrestrial broadcasting during the digital switchover, also known as “Digital Dividend”. In most countries of the EU, and especially in Germany, this resulted in conflicts of interest between political entities responsible for public broadcasting and mobile communication companies. A second long-term Digital Dividend, beneficial to both broadcasting and mobile communications, will have to be based on a common infrastructure.

1. Introduction

Today, most European nations are covered by a dense network of wireless base stations, operated by a multitude of Mobile Network Operators (MNOs). This infrastructure provides high mobility data access at medium data rates, e.g., 7.2 MBit/s per cell user with currently deployed UMTS technology in Europe[1]. On the other hand, terrestrial broadcasting requires a completely redundant infrastructure in the same coverage area. With the technological progress in wireless cellular networks in mind, this research paper aims to answer the following research questions:

1. Is a unified broadcasting and cellular communications infrastructure technologically feasible? If yes, what are the potential benefits?
2. What are the regulatory obstacles that need to be overcome?

These questions are treated in light of the fact that, already today, MNOs are seeking to cut costs by sharing wireless infrastructure.

The remainder of the paper is structured as follows. Section 2 and 3 provide an overview of the current frequency assignment, deployed technologies and infrastructure characteristics for terrestrial broadcasting and cellular communications in Germany, respectively. Based on these facts, an analysis shows the potential gains which can be achieved by technological and regulatory convergence in Section 4. Section 5 highlights some of the key issues to be solved from a regulatory perspective, while Section 6 concludes.

The analysis focuses on Germany, but we believe that the technological progress in wireless communications will have to lead to similar long term changes between broadcasting and mobile communications in other countries.

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[1] See 3GPP (2009)

2. Terrestrial broadcasting infrastructure in Germany

2.1. Frequencies and standards for audio and television broadcast

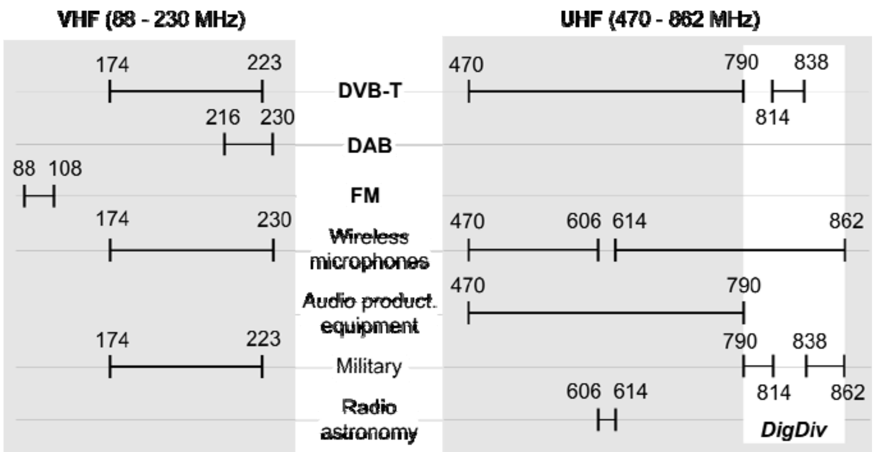

Figure 1: Spectrum assigned for terrestrial broadcasting and other services in the VHF and UHF bands in Germany[2]

The terrestrial broadcasting infrastructure provides audio and television broadcasts. Today, the most important services are offered in the VHF (30 MHz – 300 MHz) and UHF (300 – 3000 MHz) bands. Radio propagation characteristics in these bands are directional and, for a given transmitter, allow coverage of areas up to the radio horizon[3]. The implemented technologies and wireless standards are frequency modulated (FM) analog radio (20 MHz total), OFDM-modulated digital radio based on the DAB standard (14 MHz total) and OFDM-modulated digital video broadcast based on the DVB-T standard (393 MHz total). Figure 1 shows the current spectrum assigned for broadcasting purposes and its secondary use in Germany. The highlighted *Digital Dividend* (DigDiv) frequencies are currently undergoing a reassignment process and will likely be auctioned as MNO frequen-

2 See Bundesnetzagentur (2008), Frequenznutzungsplan and TKG §54
3 See Geng/Wiesbeck (1998)

cies to provide spectrum for the expected growing mobile data demand[4] and the UMTS Long Term Evolution (LTE) standard[5].

Public funding for Digital Radio based on the DAB standard has recently been cut in Germany, due to the fact that a reasonable user base could not be established in the period between 1998 and 2008. DAB will cease to exist in the near future and digitalization of radio broadcasting will have to take a different direction[6]. Analog FM radio will likely, due to its extensive user base and cheap/robust underlying technology, exist for decades to come. Potential for change, however , lies in the terrestrial television broadcasting infrastructure.

2.2. DVB-T infrastructure overview

Currently, there are 512 DVB-T broadcasting stations of varying transmit power active in Germany[7]. The total installed transmit power EIRP amounts to approximately 20 MW, the individual power varies from below 1 KW to 120 KW. Most common are broadcasting stations with a transmit power of 50 KW, meaning that the area covered is several dozen kilometers in diameter[8].

A major regulatory reason for introducing DVB-T to replace the analog television transmission was “efficient use of spectrum”. DVB-T is not only efficient due to the benefits of digital video compression - about one third to one sixths of the spectrum resources are needed per program if compared to analog broadcast [9] - but also allows for operation of Single Frequency Networks[10] (SFNs). SFNs provide for better reuse of frequencies in space by using the same center frequency to broadcast the same program with different, possibly lower power, transmitters. Unfortunately, this advantage of the underlying physical layer is not used to its full potential due to the federalist structure of broadcasting in Germany: Responsibility for broadcasting lies with the federal states. Programs are localized, and so a nation-wide SFN is not available.

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4 For estimates,see e.g. Cisco Systems (2009)

5 See Picot/Grove/Jondral/Elsner (2009), forthcoming

6 See KEF (2009)

7 TF-DVB-T (2009b)

8 TF-DVB-T (2009b)

9 See ETSI standard EN 300 744, Framing structure, channel coding and modulation for digital terrestrial television

10 See Kammeyer (2008), p. 632

3. Cellular communication infrastructure in Germany

3.1. Infrastructure overview – Deployment and Technologies

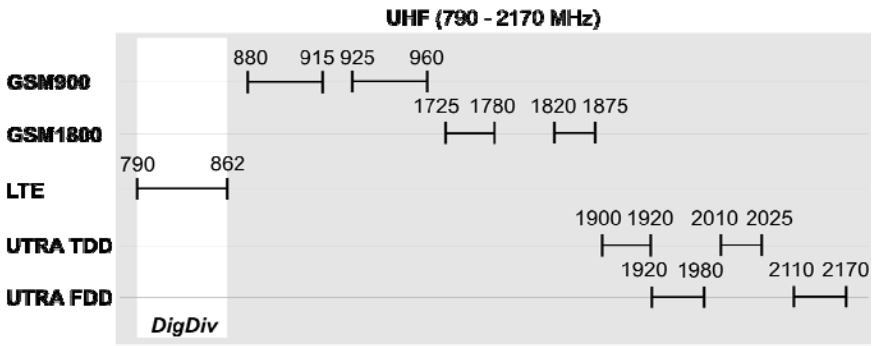

Figure 2: Spectrum assigned for mobile communications in the UHF bands in Germany, Global System for Mobile communications (GSM) and UMTS Terrestrial Radio Access (UTRA)[11]

Currently, there are two principally different mobile standards operating in three frequency ranges in Germany. The standards are GSM, a second generation mobile cellular communications system, and UMTS, a third generation cellular system optimized for data transfer and allowing for much higher data rates. GSM is operating at around 900 MHz (GSM900) and at around 1800 MHz (GSM1800), whereas UMTS operates in the 2 GHz range. UMTS supports two physical layers, based on *Frequency Division Duplex* (FDD, up- and downlink separated in frequency) and *Time Division Duplex* (TDD, up- and downlink separated in time).

11 See Bundesnetzagentur (2008), Frequenznutzungsplan and TKG §54

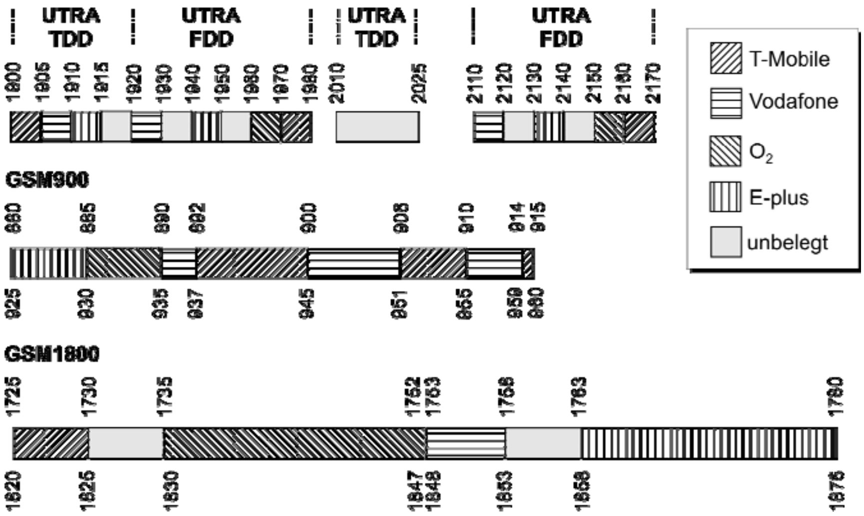

Figure 3: Spectrum allocation to MNOs

The assigned spectrum is distributed to the four commercial MNOs: T-Mobile, O2, Vodafone and E-Plus as shown in Figure 3[12]. All MNOs operate their own 2G and 3G infrastructure. It is worth noting that frequencies have been assigned during the auction process for UTRA FDD partially to companies which declared bankruptcy afterwards and hence never set up a network infrastructure. These frequencies, as well as the frequencies for UTRA TDD, are left unused.

GSM, UMTS and LTE – A quick comparison[13]

The *Global System for Mobile Communications* (GSM) was the first fully digital mobile cellular communication standard (second generation, 2G) and was introduced in Germany in 1992. Developed mainly to support mobile voice communications, several physical layer extensions, such as GPRS or EDGE, exist which allow to bundle channels and transmit data with up to 473 kbit/s.
The *Universal Mobile Telecommunications System* (UMTS) is a third generation mobile cellular communication standard, developed with mobile data communications in mind. The achievable data rate is 384 kbit/s, with the HSDPA extension up to 7.2 Mbit/s can be achieved.

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[12] See Bundesnetzagentur (2008). A separate frequency range is assigned to GSM-R, an adaptation of the GSM standard for railways. The network is operated by DB Systel GmbH. The service is not public and hence neglected here.

[13] For technological details and a description of abbreviations see 3GPP (2009) and Kammeyer (2008).

3GPP Long Term Evolution (LTE) is the designated successor of UMTS, developed with primarily mobile data access in mind. The declared goal is to allow high data rate applications, up to several dozen MBit/s at a scalable channel bandwidth of 5- 20 MHz. LTE is set to be the first standard, which provides higher bidirectional data rates than DVB-T provides in unidirectional broadcast.

4. Convergence of Mobile Communications and Terrestrial Broadcasting: A long term necessity

Looking at the current spectrum assignment and adding up all spectrum, an absolute of 335 MHz in total are assigned to MNOs and 441 MHz in total to broadcasting. Taking into account the reassignment of the Digital Dividend frequencies (72 MHz), a total of 407 MHz is available for MNOs, whereas 369 MHz are allocated to broadcasting. We predict that, in the long term, this ratio will have to change in favour of MNOs, allowing broadcasting and mobile communications on the same infrastructure. Three facts support this hypothesis: the rise of infrastructure sharing between MNOs, customer demand for high data rate bidirectional mobile communications unrestricted to a certain service, and the superior spectrum efficiency of wireless networks with small cell sizes.

4.1. Developments in cellular networks

Near Future: Infrastructure Sharing

According to a study by AT Kearney, Mobile Network Operators will face a significant decrease in their profit margins within the next years. Without countermeasures, for 2012 a negative margin of -7% is predicted[14]. As encompassing one-third of operational costs and 80% of capital expenditures, the physical Radio Access Network (RAN) hardware and sites, i.e. the physical access layers, are the major cost factor for MNOs. This indicates that cutting down these costs will have the largest effect on margin and profits[15].

Noticing, that MNOs “reached the limits of cost improvements” in their networks, the authors conclude that only *sharing* both active and passive infrastructure components *between MNOs* can bring further essential benefits. But this is possible only because the network itself “lost its former status as a crucial capabil-

14 See AT Kearney (2009)

15 See also Theron Business Consulting (2007), Salanave (2007)

ity” in the inter-MNO competition, at least in mature markets such as Europe and North America. I.e., the service level in different MNO networks is similar from a customers’ point of view, so that it will be no drawback for a MNO to indirectly support his competitor’s updates in network quality and features, as this competitor himself would invest in, e.g., new generation technologies at the same time.

To gain the full savings in cooperation, not only sharing sites and passive infrastructure (e.g. air conditioning, power supply), but also sharing of active components, i.e., sharing the actual radio equipment, is necessary. Of course, sharing comes at the expense of a higher level of coordination between MNOs. When aiming at a sharing contract, many aspects of all potential partners’ networks, such as geography and interoperability issues have to be considered. It has to be determined how costs will be shared and in which way each MNO’s existing network is integrated with the new site.

A major driver for infrastructure cooperation between MNOs will be the introduction of LTE[16]. This will be the third major investment in Germany for mobile phone providers after the first generation mobile network (C-Netz), GSM and UMTS; each investment lead to a decrease in coverage for the respective standard. Now, first operators did outsource their network operations (like E-Plus) to Infrastructure Operating companies. For LTE, again a massive investment is required, which will reduce coverage for each provider to a smaller area again, compared to UMTS. Hence, first negotiations started in the direction of joint investment and hence joint construction of LTE infrastructure between some or the entire MNOs active in the market. This would especially reduce the relative costs per provider outside of population dense areas, where parallel capacity from each provider is required by demand.

Looking at the current regulation practice concerning cellular networks, subsets of available frequency channels are allocated once by the regulating authority to different MNOs. But direct site sharing will only be possible if licenses are not hard-bound to a single MNO. The idea of giving away secondary licenses for money can also be applied to inter-operator trading of licenses. As for regulatory view, a comprehensive study for the European Commission on conditions and options in secondary spectrum trading in the European Union[17] gave the key recommendation that the European Commission "should seek to move ahead with both spectrum trading and liberalization through the use of appropriate binding measures on Member States." Furthermore, a recent Ofcom proposal for auctions in the 2.6 GHz band reveals the readiness to introduce high degree of liberalization and support of secondary spectrum trading[18].

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[16] See e.g. http://news.community36.net/redirect/?id=471 (cited 03/10/2009)

[17] Analysis Consulting Ltd, DotEcon Ltd, and Hogan&Hartson LLP (2004)

[18] Ofcom (2007)

Long Term: Online spectrum auctions

Auctions in general are an economic instrument for selling restricted goods, scarce either naturally or by regulated access. In contrast to a usual selling operation, the auction determines the price and the actual buyer out of the group of potential buyers simultaneously. By means of double auctions, multiple sellers can be brought together with multiple buyers at the same time, similar to stock exchanges. Regarding, e.g., frequency channels in a given GSM cell, MNOs facing a high traffic demand my bid for additional channels while other operators having a current low demand at the same time may offer parts of their allocated channels.

Inspired by works from Klöck (2005) and Grandblaise et al. (2005) based on one-to-one and one-to-many auctions between operators an clients, and in order to find a compromise between the contradicting goals of reliable allocation and short-term flexible adaptation, a hierarchic spectrum trading concept was proposed by Yamada (2008) and Burgkhardt (2008) et al. Operators trade resources by means of double auctions, where multiple sellers can be brought together with multiple buyers at the same time, similar to stock exchanges. As data traffic stochastically varies over time and the location, operators with temporarily and locally low traffic load offer unused resources to other operators who currently face high traffic load. Demand and supply of resources establish a market for the exchange of transmission resources between operators. Frequency resource goods are abstractly seen as a unit. Within one trading period, the trading goods are assumed to be fully interchangeable. After the trading period, only the number of goods each operator possesses is relevant. This enables transactions between arbitrary bidders and buyers by double auctions. To define elementary market places the spatial component of cells is introduced. The cell coverage of different operators is required to be equivalent to ensure the unproblematic exchange of resources between operators in a given location without causing interference. Together with the temporal partitioning into trading periods, these cells and the spectrum preallocated to the operator within this cell define a set of interchangeable goods for spectrum trading. Spectrum trading improves the network wide resource usage, and reduces the operator-centric probabilities of unsatisfied demand19. It is feasible especially on single shared infrastructure.

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19 See Burgkhardt (2008), Yamada (2008), Burgkhardt (2009)

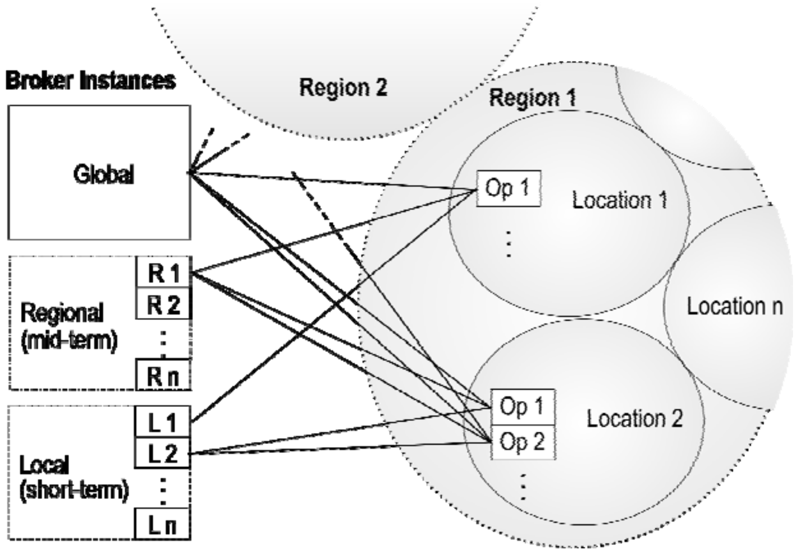

Figure 4: Diagram showing relation between operators and brokers. The instances of regional and local brokers are located in the respective area in a decentralized manner[20].

Figure 4 illustrates the instances of spectrum brokers, regarding, as an example, local-short-term, regional-mid-term and global-long-term hierarchy levels. The basic, most granular level represents the local trading of resources of one elementary trading period (or frame) within one cell. To meet best traffic estimation, the auctions for resources are conducted just before the actual transmissions. Now consider the concatenation of consecutive resources during one hour. Before trading for the elementary frames starts, an auction for the resources of the upcoming hour is performed. On the next level, assuming a similar number of resources per cell, also a group of neighboring cells with presumably similar traffic profiles can be grouped to form regional markets with trading periods of one day or similar. On each level, a trading good is the whole bunch of grouped transmission resources. For example, acquiring one good on the regional level is equivalent to acquiring one elementary good in each frame of each cell in that group. But after that trade the resource is split and each part will `enter'' the next more granular level of trading, respectively.

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20 Burgkhardt (2008)

4.2. Developments in broadcasting

Rising demand for bidirectional data transfer: new

The latest developments such as IPTV, WebTV or P2PTV are indicators for an ongoing transition process of traditional unidirectional broadcasting that we have been used to for more than 70 years. This process is in line with the ongoing convergence of IT, media and telecommunications. Especially the massively decreasing data traffic prices allow for a higher level of consumer choice, interaction and participation in multi-media activities. In the end, this development is leading away from unidirectional broadcast and towards individual content transmission, such as the diversified offerings of IPTV, Video-on-Demand offerings, *youtube* or other comparable services.

Latest developments such as social communities with user generated content or others proof even more the importance of these various transmission paths to and, concentrating at user generated content, from the customer to the internet. Especially upload rates are becoming more and more important, making hereby symmetrical bandwidth more and more necessary. This effect also drives global IP traffic, which will quintuple from 2008 to 2013. That equals a CAGR of 40 per cent per year according to latest predictions. Transferring this growth rate to mobile data usage, this puts massive pressure on the operators to satisfy this data demand in the near future[21].

In consequence, the demand for data transport capacity is increasing massively, as each customer requesting different content has to be served via a separate channel. And each of these channels requires capacity or bandwidth, respectively. This leads to the question of how much bandwidth is enough[22]. The question is even more important, as it arises all the time when it comes to network costs. Trying to find an answer, Nielsen (1998) introduced a relationship derived from Gilder's Law, known as the "Nielsen's Law", stating that network speed for home users will increase by 50 per cent per year. Therefore bandwidth doubles every 21 months[23]. This is a typical relationship where supply is driving demand, based on the fact that new innovative services require higher bandwidth in general. Examples in recent years are Internet Telephony, VoIP, and WebTV or InteractiveTV[24]. In the beginning, using VoIP caused massive problems due to physical bandwidth restrictions, capacity and latency problems. In 2008, VoIP is a commonly used

21 See Cisco (2009)
22 For the following argument, see Picot/Grove (2009)
23 See Nielsen (1998).
24 See Hess/Wilde (2005), p. 251f.

service and accounts for 1 per cent of Internet traffic on average only[25]. The next surge in data transfer was video-based services on the Internet, which cause a major share of Internet traffic today. First operators of Internet Video are offering High Resolution (HD) video, which has a higher resolution than DVB-T. And this is just the beginning: examples like “Cisco Telepresence” or prototypes of the three-dimensional TV with bandwidth demands of several GBit/s give a glimpse into the future of bandwidth requirements[26]. Tests could prove that Nielsen’s Law still holds and the bandwidth available will be used[27].

An important factor of success of new Internet-based services is the fact that they are offered on an application-layer level of the network. Traditional broadcast standards, however technologically efficient they may be, always confine

Picot/Jondral/Elsner/Grove (2009) could prove already for wireless broadband access based on the Digital Dividend only that it does not fulfill the actual requirements for city comparable broadband. And keeping ahead with the development of increasing individual data traffic for individual content delivery will also require additional spectrum and additional efficiency in spectrum allocation on order to fulfill the demands of today and the requirements of tomorrow.

4.3. Efficient use of spectrum: high infrastructure density leads to better spectral area efficiency

Regulation requires assuring efficient use of spectrum[28]. Defining “efficient” is not an easy task, as a multitude of social, economic and technological factors have to be taken into account. From a purely technological view point, however, it can be shown that frequencies are used (technologically) most efficiently if a high infrastructure density exists. This is especially the case for bidirectional communications.

The theoretically achievable data rate between a transmitter and a receiver ultimately depends on the available signal strength at the receiver and the available transmission bandwidth. These two parameters principally define the channel capacity, that physically limits the speed at which information can be exchanged[29]. The available signal strength at the receiver is given by the transmission power of the MNO base station or broadcasting tower, antenna characteristics, attenuation due to topology and, primarily, distance to the receiver. High available signal strength and a large bandwidth allow for high data rates. Assuming constant transmission power, high data rates are possible close to the transmitter, while the

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25 See Schulze/Mochalski (2009).

26 See Cisco Systems (2009a).

27 See Bogaert (2008), p. 24f.

28 See, e.g., *Telekommunikationsgesetz* (TKG) §52 (in German)

29 See Shannon (1949)

achievable rate declines rapidly with distance, at best (close to the transmitter) proportional to the square of the distance, more realistically and far away proportional to the cube to fifth power of the distance[30].

A given transmission standard such as defined by, e.g., UTRA FDD (bidirectional) or DVB-T (unidirectional), now offers a certain data rate for a fixed bandwidth and fixed signal strength. To achieve the necessary signal strength in the coverage area, either one high power transmitter can be used or several low power transmitters can be used. Assume a necessary signal strength P_C at the edge of a circular coverage area with radius r_0. For the power necessary to cover this area with one transmitter then

$$P_C \propto \frac{1}{r_0^\alpha} P_0$$

holds with the attenuation coefficient $\alpha \in [2,5]$. If the same coverage area is to be covered with n transmitters of lower power, the resulting power needed – assuming perfect spatial and frequency planning – is

$$P_N = n^{-\frac{\alpha}{2}+1} P_0 \leq P_0,$$

which is equal to or smaller than P_0. Each transmitter offers the possibility to transport a separate data stream, allowing spatial reuse of the same spectrum. Though frequency planning is a technologically difficult task, the rule-of-thumb “the smaller the cells, the better the spatial reuse and the higher the spectral area efficiency” holds. Hence, for bidirectional transmission, the capacity is increased n-fold, while the total power necessary for transmission is decreased by a factor of n (assuming a realistic $\alpha = 4$)[31].

Another aspect to be taken into account are the frequency dependent propagation characteristics of electromagnetic waves. Generally speaking, higher frequencies propagate worse in space for omnidirectional communication and suffer higher attenuation by physical objects[32]. Hence, for large cells low frequencies, e.g., frequencies in the UHF band, are better suited. On the other hand, higher frequencies allow a more focused or directed emission of radiation, making them ideal for use in areas with high user and hence cell density.

30 See Geng/Wiesbeck (1998), pp. 207
31 See also Wiesbeck/Jondral et al. (2008)
32 See Geng/Wiesbeck

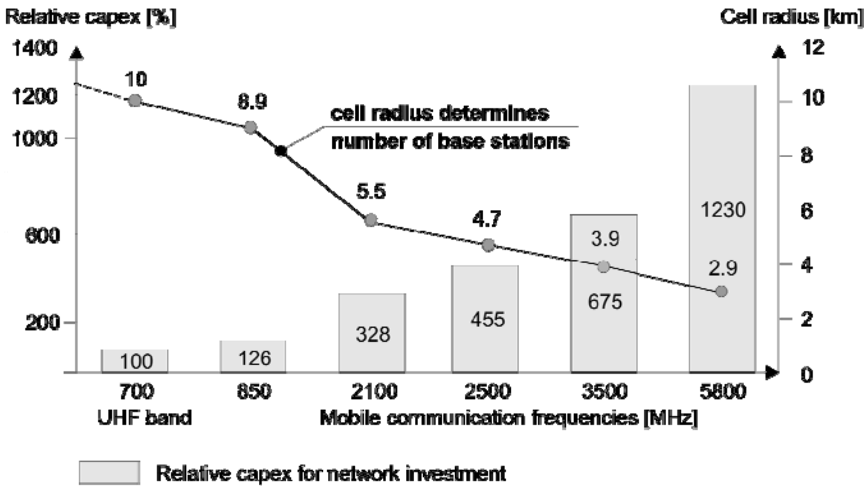

Figure 2: Relative capital expenditure (capex) and number of required base stations[33]

Figure 2 shows the number of base stations required for mobile operators to cover an area of 314 km², which can be achieved with a single cell of 10 km radius at 700 MHz. At 5.8 GHz, approximately 12 cells of 2.9 km radius are needed for the same coverage[34]. These cells are, however, able to support 12 times more users. From MNOs viewpoint, the Digital Dividend frequencies – and all other UHF frequencies allocated today to broadcasting - are hence especially suited for large cell sizes and at comparatively low user density.

Summing up, the frequencies blocked by relatively large television broadcasting cells could be used more efficiently by reducing the cell-size significantly and increasing the number of base stations / transmitters, resulting in a bidirectional wireless network. This would also have the great benefit of simplifying international frequency planning, as interference is reduced significantly.

Another driver for change: user preferences and economically efficient use of spectrum

Technological efficiency is only one dimension of “efficient use of spectrum”. Economical and sociopolitical efficiency are another aspect. Looking at penetration and user preferences might serve as an indicator of how accepted a certain means of transmission is or will be in the future.

33 According to Krämer (2009) and Forge/Blackman/Bohlin (2007), p. 9

34 See Forge/Blackman/Bohlin (2007), p. 8f.

Today, on average only 11 percent of all household in Germany use terrestrial broadcasting[35]. Outdoor coverage (DVB-T reception with a roof-top antenna) is possible in 90 percent of Germany, whereas only in 30 percent are covered with signals strength that allows indoor or portable reception. On the other hand, the market penetration of current wireless data services has reached 130 percent[36], corresponding to 107 million mobile customers at the end of 2008. Mobile coverage outdoor coverage is virtually universal for GSM; UMTS and in the future LTE will follow. Especially in population dense areas, indoor coverage is much easier to achieve by mobile networks due to the high infrastructure density.

Once MNOs are capable of carrying and distributing broadcasting programs, the regulatory body has to rethink if it is possible and more possibly more efficient to guarantee basic broadcasting services[37] (*Grundversorgung)* via broadband, wired or wireless, Internet access.

4.4. A Unified Infrastructure – Benefits

A unified broadcasting and communications infrastructure will be possible once high data rate cellular networks are implemented, LTE is a possible candidate. For MNOs, a single infrastructure brings benefits by decreasing redundant infrastructure (area coverage), while at the same time being able to optimize frequency planning in high customer density areas. A single network will allow for much better frequency planning in space and hence better spectral area efficiency. Major infrastructure investments are not lost anymore due to duplication of functionality. For broadcasters, gradually moving to IP-based services brings the benefit of eliminating the redundant broadcasting infrastructure while at the same time reaching more customers through a “virtual” terrestrial broadcast.

5. Regulatory issues

The proposed approach of one single, multidimensional wireless infrastructure requires the reallocation of formerly separately allocated frequencies for various uni- and bidirectional wireless application and services, including mobile network operator services like voice and data, as well as broadcasting such as TV and radio. This approach stands in contrast to actual spectrum allocation and regulation mechanisms. Existing law would have to be changed in order to create this single infrastructure with technology independent service delivery. This affects the cur-

[35] TF-DVB-T (2009a)

[36] See Bundesnetzagentur (2009), p. 78

[37] See Bundesverfassungsgericht (1986)

rent logic of spectrum assignment to competitive mobile phone operators as well as the current separation of spectrum blocked separately for telecommunications, radio and TV. Hence, the logic of infrastructure competition for wireless services has to be questioned as well as the matter of technology independence. Furthermore, effects to the federal state controlled media institutions, *Landesmedienanstalten*, as well as frequency allocation mechanisms have to be put into question.

Infrastructure Competition

Governmental market intervention is used in order to correct market distortions, which occur or are expected to occur due to monopolistic behavior[38]. Especially public goods are subject to regulation, as the private market output leads in general to market failure. This is the case especially for former state owned infrastructures, which have been transferred (partially) into free competition. Major examples are infrastructure for electricity, gas, post, public train transport or telecommunications.

As a monopolist is expected to take advantage of his single supplier position, he will optimize the price product combination towards maximum gains. This leads to an output quantity, where the marginal gains equal the marginal product costs. The limited output is hence sold at a higher price in addition. However, much higher welfare is created at the position, where marginal costs equal the average costs, leading to higher output quantities at much lower prices.

But this scenario will only occur if a sustainable level of competition is introduced to the market. Several approaches of transferring these former state monopolies into free market competition exist. A notable model is the Investment Ladder Approach of Cave/Vogelsang (2003). The former monopolist's infrastructure is opened to competitors initially on the service level for regulated low prices. After service competition is established into the market, these prices for services are increased by the regulatory authority in order to set incentives for the competitors to build up own infrastructure. After parallel infrastructure(s) have been set up, the former monopolist is not able to charge monopolistic prices anymore, due to alternatives available to the end customer. This ensures a long term sustainable level of competition.

The Investment Ladder Approach is of limited applicability and restricted to certain types of infrastructures, however. E.g., for the sector of public train transport, the underlying infrastructure is hard to duplicate, as is the case for gas pipelines and other infrastructure requiring major investments. This is the case due to the decreasing revenues under competition, as the market entry of another competitor will not only reduce the margins of the former monopolist, but also his own. Hence, the business case for investment in parallel infrastructure projects, where capacity limits can be neglected, is seldom positive. And the same is partially true for the sector of telecommunications. While the telecommunication market could produce a sustainable level of infrastructure competition for fixed

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[38] For the following argument see Picot (2009)

and mobile networks in population dense areas, high data rates are not available in rural areas with low population density.

Summing up, for the implementation of a multidimensional wireless infrastructure, the general approach of infrastructure competition has to be overcome in favor of a more efficient spectrum use. This requires a major rethinking in how and to whom spectrum is provided access to.

Spectrum and Functional Separation

For fixed networks infrastructure separation approaches isolate service and infrastructure from each other, allowing for service competition based on one (monopolistic) infrastructure, as it is the case e.g. for voice communication services. And the same approach could be used for the wireless spectrum. As the usage of electromagnetic frequencies excludes others from its use, emitting electromagnetically frequencies has to be restricted by governmental intervention. On the one hand, electromagnetic radiation is harmful to the human body above specific limits and must not be exceeded by the emitter at any circumstances. On the other, certain rules have to be addressed to the spectrum in order to make it utilizable in an economic and effective way. Therefore, the electromagnetic spectrum equals a common good resource, which is non-excludable (as everyone could transmit with the right equipment) but rivalrous in use (using one frequency blocks other users out).

Comparing the scarce, limited and excludable resource of spectrum to a public train system, can illustrate the parallels: It is not possible to operate two trains on one track at the same time. Hence, the access to this track has to be regulated, if more than one service provider wants to offer services on the same track. Duplicating a national public train system will not be economically efficient at all and lead, due to the high investment costs and the operation and maintenance of two parallel systems to higher end consumer prices. Comparing this scenario to the matter of frequencies, here it is physically not even possible to duplicate the electromagnetic spectrum. It follows that infrastructure competition for wireless communication is for a specific frequency range already limited to the number of users with their minimum requirements of spectrum for this service.

In general, spectrum can be seen as the transfer medium, which can either be used by many participants paying the price of coordination costs, inefficient spectrum use by each of the participants, transaction costs and furthermore different technologies and services used. For using spectrum as a general purpose technology, such a general access network would be required, which makes use of the entire spectrum, eliminating the former inefficiencies and costs between a multitude of participants. The existing law does not (yet) neither reflects, nor support such an approach.

Technology Neutrality

Interfering with this aspect is the postulation of technology neutrality. The concept of Technology neutrality is implemented in the European Regulatory Framework[39] in order to guarantee a forward looking approach, anticipating from future changes to applications, services and technologies. Specific markets are defined, in which hence the technology independent competition is driven by market demand and not regulated interference in specific technologies. That way, service, as well as infrastructure competition by investments of the different operators shall be ensured.

However technology neutrality comes to its limits, when it comes to new services or applications, including new infrastructures, which lay horizontal or vertical to existing markets. This is especially the case, if e.g. new platforms, including new infrastructure, are used to deliver "old" services[40]. An example is the IP network, which is used to deliver voice services, dedicated to the former Public Switched Telephone Network, PSTN, where different costs occur for delivery.

And the same is true for the creation of a multidimensional wireless infrastructure. Existing services based on existing networks would have to be integrated into one new, infrastructure out of entirely technically reasons. Our argument shows quite well, that major increases in efficiency and overall social welfare can be created by implementing this approach. However, this is based on a technical argument regarding frequency efficiency and it has to be admitted in that context, that technical progress might also solve one or the other problem, which appears to us currently as insurmountable.

Furthermore, the physical limitation of not being able to use one frequency by multiple users at the same time is already a matter of fact, which is put in a contrary position to technology neutrality. As soon as this, today physical restriction might hypothetical turn into a pure technical restriction solved by technical progress, the frequency allocation to individuals would become dispensable. As already Gilder suggested in 1994 exclusive rights to spectrum usage should not be given to anyone for the benefit of innovation. However, based on Gilder, McGartey and Medard (1994) come to the conclusion that a steady review is required for new technologies, which potentially leads to a better spectrum usage by reallocation[41]. However, we are not already technologically that far, that we can entirely follow Gilder, avoiding any kind of individual allocation[42].

But up to then, each possibility to make the most out of this resource would also go along in line with technology neutrality, if argued on the physical level only. Here, the multidimensional wireless infrastructure makes the most out of the spectrum available due to the physical restrictions in general. New technologies could overcome problems, which were seen as physical persistent in the past. In the end, emitting electromagnetic frequencies is always related to some specific technology. And if a major step has been done in technical progress, allowing a

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[39] EC Framework Directive 2002/21/EC
[40] See Alexiadis/Cole (2004), p. 79
[41] See McGartey/Medard (1994), p. 23
[42] See Gilder (1994), p. 112 and McGartey/Medard (1994), p. 29

more efficient use of this scarce resource. Then, within this defined usage pattern, technology neutrality can be applied again.

Federal State controlled Broadcast Content

Currently, the entire spectrum planning laws and mechanisms on European and national level are opposed to a multidimensional wireless infrastructure approach. An additional issue exists in Germany for frequency allocation regarding over the air broadcast TV and radio program. The frequency ranges for TV and radio contents are assigned on national level consistently. However, each *Landesmedienanstalt* controls the content of these frequency ranges in the federal states, allowing various independent broadcasters to use the spectrum. In the end, this lead to the presence of partially identical and different broadcasters in different federal states, even more on various frequencies. This is not only inefficient from an administrative point of view, it is moreover inefficient, when it comes to frequency usage. Before a multidimensional wireless infrastructure could be implemented at all, the inefficient mechanism of *Landesmedienanstalten* has to be eliminated, as already the primary reason for them – ensuring local media competency and cultural variety - has been made redundant due to the existence of all these contents on the Internet.

6. Summary and Conclusion

Two developments will lead to a long term convergence of terrestrial broadcasting and mobile communications: On the one hand, MNO infrastructures are converging implicitly through MNO outsourcing or explicitly through cooperation while at the same time extending the data transfer capacities massively by introducing LTE. On the other hand, the current terrestrial (television) broadcasting infrastructure results in less efficient spatial use of spectrum while having a very low market penetration. These developments will have to be reflected in future regulatory policies.

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