

Rheinberg, 22 October 2026

Can 5G technologies use-fully complement fibre-optic access networks?

An Economic Comparison of FTTH and 5G for Broadband Internet Access in Detached Housing Estates

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Chapter I

Management Summary

Management Summary

- ▶ The roll-out of FTTH networks continues to require significant investment in rural residential areas—100 % coverage can only be achieved with substantial public funding
- ▶ 5G internet connections are **easy to set up** and can be used either via a 5G standalone router or in combination with an external antenna
- ▶ In **Austria**, 52.0 % of private households and SME are served by 4G- and 5G-based mobile access solutions—**FWA solutions have played an important role for years**
- ▶ From a technical standpoint, **5G FWA can be a high-performance alternative to fiber-optic technology** that can be rapidly deployed in single-family housing developments on the outskirts of cities, in small towns, or in rural areas
- ▶ Overall, the investment required for a 5G broadband connection ranges from **108 € to 334 € per household** and is therefore significantly lower than for FTTH, at **1,600 € to 3,900 €**
- ▶ Since the installation of Starlink requires considerable space, an unobstructed view of the sky, and relatively high energy consumption, **Starlink will remain a niche application**
- ▶ All case studies show **significant economic advantages of 5G FWA access solutions over FTTH**—even without taking the faster roll-out into account
- ▶ 5G FWA solutions are not intended to compete with fibre-optic connections, but rather to serve as a **useful complement** in order to be able to offer high-performance broadband connections (a) **quickly** or (b) in **locations that are difficult to serve economically**

Chapter II

Broadband Coverage Situation in Germany

The roll-out of FTTH networks continues to require significant investment in rural residential areas—100 % coverage can only be achieved with substantial public funding

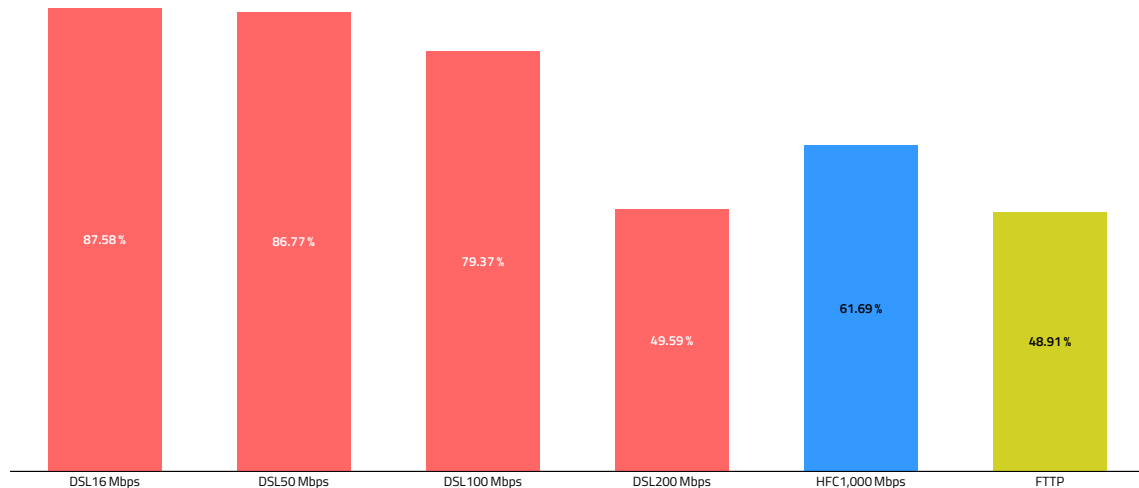
Fixed network broadband technologies and the coverage situation

Technology	Range	Bandwidth	Ownership
DSL digital subscriber line	Twisted-pair copper cables reach almost every home and permanent establishment	Despite the extensive roll-out of VDSL, speeds of 200 Mbps are only available on just under half of the connections	Almost 100 % DTAG
HFC hybrid fiber coax	HFC networks reach two third of all households—mostly in urban centres and some suburban detached housing estates	Speeds of up to 1 Gbps are possible almost everywhere—1.5–2.5 Gbps connections are as yet only available in a limited number of places	Ownership 90 % Vodafone, around 45 more regional carriers
FTTH fiber-to-the-home	New FTTH fibre-optic networks now reach 46 % of all households—mostly in detached housing estates and some urban centres	The currently prevalent XGPON technology limits bandwidths to 1–2.5 Gbps	Just under 50 % DTAG, Deutsche Glasfaser, OXG, Westconnect, around 40 more regional carriers

By the end of 2025, just under 50 % of German households and SME are reached by fibre-optic networks

Fixed networks coverage^a by technology

homes passed, at the end of 2025

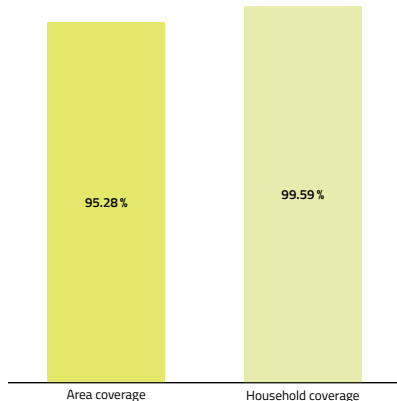


a) Based on 42.7 mn private households (HH).

Source: BNetzA 2025, Statistisches Bundesamt

5G coverage is already very good and can be used to replace slower DSL connections—in average only 16 households per community are not (yet) covered by this technology

Mobile networks 5G coverage by technology at the end of 2025



Not covered by 5G

$$(1 - 99.59\%) \times 42.7 \text{ mn HH} =$$

$$175,070 \text{ HH}$$

$$\frac{175,070 \text{ HH}}{10,747^a} =$$

16.3 HH per community without 5G

Additional Applications

- ▶ Long term evolution (LTE) and 5G can be used as a replacement for or in addition to a low-bitrate broadband connection
- ▶ Suitable plans and devices are available
- ▶ So far, 5G has been used only to a limited extent in Germany as a replacement for or supplement to landline service

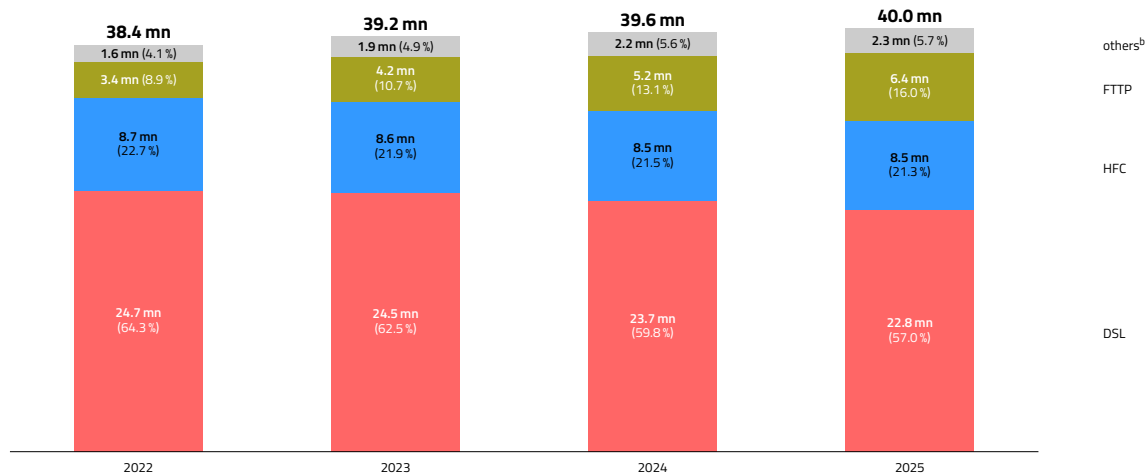
a) 10,747 communities in Germany.

Source: BNetzA 2025; Statistisches Bundesamt, Walter 2026a, p. 41

Of the nearly 40 mn active broadband connections, only 2.2 mn use various wireless technologies—growth is slow

Active broadband connections by technology^a

homes activated, at the end of each year



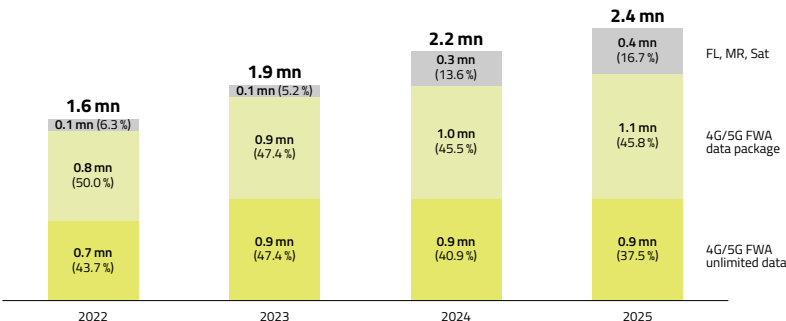
a) For further details, see p. 10.

b) Excluding connections for telephone only or broadcast television (TV) only.

Source: BNetzA 2026b, p. 11, Company information, Walter 2026a, p. 38

More than 80 % of wireless FWA broadband connections rely on fourth- and fifth-generation mobile networks—Starlink is growing significantly in the other technologies segment

Wireless active broadband connections by radio technology and contract type^a
homes activated, at the end of each year



Status fixed wireless access (FWA)

- ▶ Internet access via **LTE/5G** is by far the most widely used wireless technology
 - ▶ Mainly private customers
 - ▶ Mobile data plans with unlimited data and those with data packages are used equally
- ▶ Use of Internet access and data connections via **satellite** is growing rapidly thanks to Starlink
 - ▶ Low Earth orbit (LEO) internet access mainly private customers
 - ▶ An increase of 92,000 contracts within one year to 0.2 mn
 - ▶ Geostationary Earth orbit (GEO) Data connection exclusively for business purposes—roughly 25,000 connections
- ▶ Use of data connections via **microwave radio (MR)** and **fixed link (FL)**
 - ▶ Exclusively for business purposes
 - ▶ Shrinking market
 - ▶ A decrease of 39,000 connections within one year to 0.2 mn
- ▶ Potential future competition from space-based mobile communications solutions

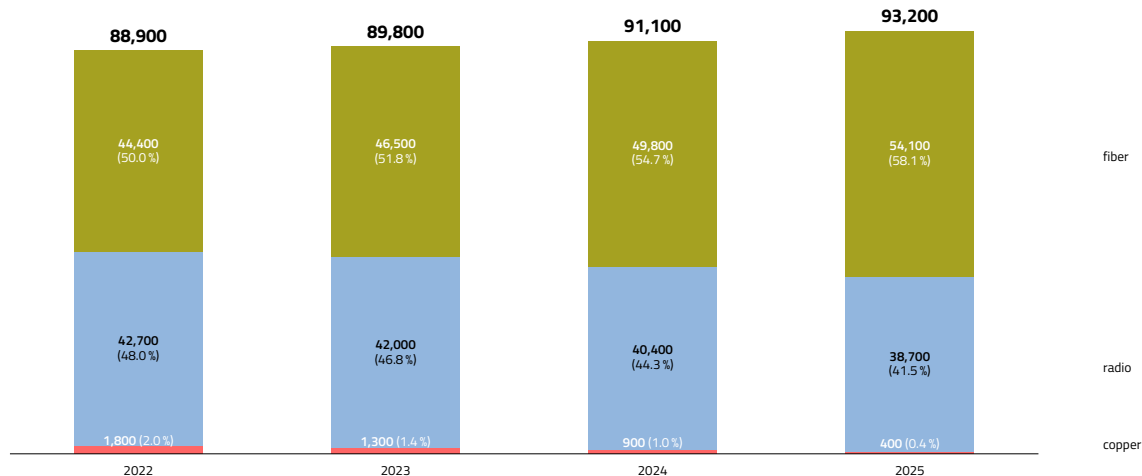
^{a)} Excluding connections for telephone or broadcast TV only.

Source: BNetzA 2026b, p. 11, Company information, Lenz 2026, Walter 2026a, p. 26, 38, Živadinović 2025

The number of mobile network sites is important for ensuring coverage of households as mobile networks are expanded—these are currently increasing by around 2,000 per year

Number of mobile phone masts by network connection

At the end of each year

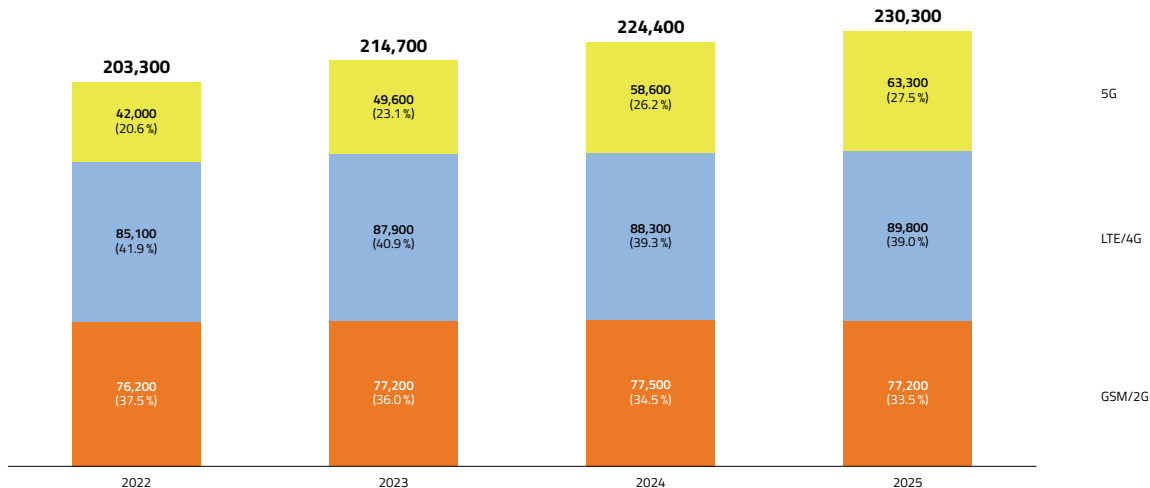


Source: BfNetzA 2026b, p. 30; Company information, Walter 2026a, p. 50

Mobile networks are being continuously expanded, and the number of base stations is growing, particularly in the 5G sector

Number of mobile networks base stations by technology

At the end of each year

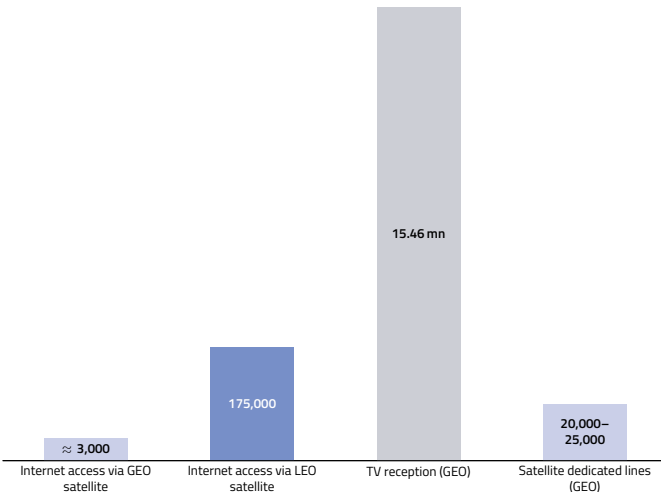


Source: BNetzA 2026b, p. 29–30; Company information, Walter 2026a, p. 49

The use of satellites for Internet access or data connections is a niche application in Germany for both households and businesses

Satellite usage

mid-2025



Satellite Status

- ▶ Satellite TV is one of the traditional methods of TV distribution
 - ▶ Its use is declining slightly due to internet protocol (IP)TV/Video-on-demand (VOD)
 - ▶ Technology does not support VOD
- ▶ Satellite internet via GEO
 - ▶ Declining market, barely relevant anymore
 - ▶ Private usage disrupted by LEO solutions
 - ▶ E. g. HughesNet, Viasat
- ▶ Satellite internet via LEO
 - ▶ Growing market
 - ▶ Main provider is Starlink, OneWeb, and others
- ▶ Satellite dedicated lines (GEO)
 - ▶ Corporate customers
 - ▶ Mostly backup/failover links
- ▶ Future technology: Direct-to-device (D2D) satellites (e. g. AST SpaceMobile, SpaceX)

Source: ITU 2026, Market Reports World 2026, Scheuer 2025

All network operators offer several FWA tariffs, and their marketing is becoming increasingly intensive¹⁴

FWA offers from German mobile network operators



- ▶ 5G zu Hause: 100/250/∞ GB, 500(40) Mbps



- ▶ MagentaMobil Speedbox Flex/S/M/L: 100/250/∞ GB, 500(40) Mbps
- ▶ Magenta Hybrid 5G: ∞ GB, 500(40) Mbps



- ▶ O₂ Data S/M/L/XL/XXL: 5/50/100/200/400 GB, 300(50) Mbps
- ▶ O₂ Home S/M: ∞ GB, 50(10)/100(40) Mbps



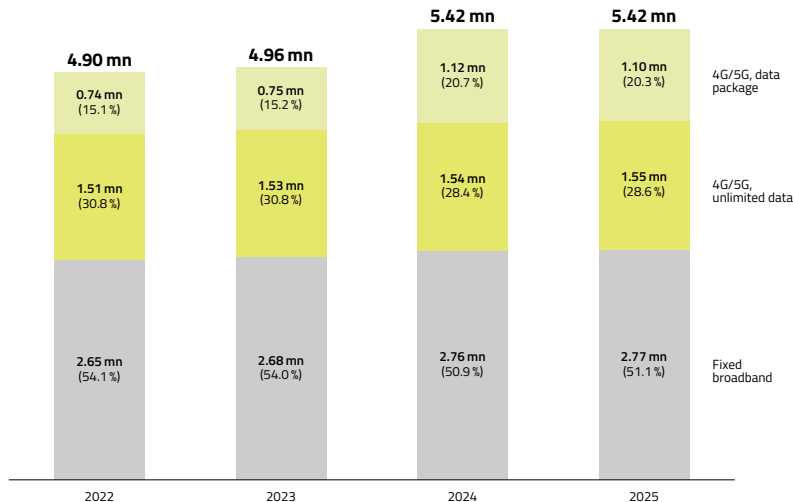
- ▶ Gigacube 100/200/Flex: 100/200/∞ GB, 300(50) Mbps

Source: Company information (as of 2026-05-20)

In Austria, 52.0 % of private households and SME are served by 4G- and 5G-based mobile access solutions—FWA solutions have played an important role for years

Broadband and FWA usage in Austria

homes activated, at the end of each year



FWA status Austria

- ▶ 5.10 mn target objectives
 - ▶ 4.17 mn private principal residence
 - ▶ 610,000 SME
 - ▶ 320,000 other flats
- ▶ 54.3 % use fixed broadband
- ▶ 1.55 mn (30.4 %) use specialised FWA solutions ('cubes') with unlimited data
- ▶ Some users combine fixed and mobile solutions
- ▶ Cubes are mainly used outside the state capitals

Source: Company information, RTR 2026, Statistik Austria

Conclusions: Given the large number of FTTH connections that are still lacking, 5G offer a fast and cost-effective solution

Broadband Coverage Situation in Germany

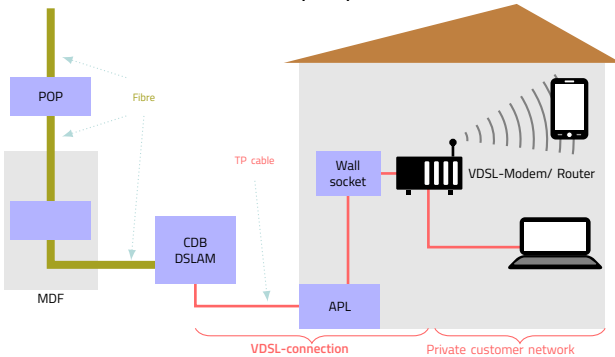
- ▶ **100 %** fiber coverage can only be achieved with **substantial public funding**
- ▶ The switch to **fibre-optic** is taking place at a **relatively slow** pace
- ▶ **5G mobile networks** have the potential to provide **high-performance** fixed-line connections
 - ▶ As a **temporary solution** pending the roll-out of FTTH
 - ▶ As a **long-term solution**, should the FTTH roll-out prove too uneconomical
- ▶ German mobile **network operators** are already **offering FWA** solutions
- ▶ A look at **Austria** shows that mobile networks can be **successfully** used to **replace fixed-line connections**

Chapter III

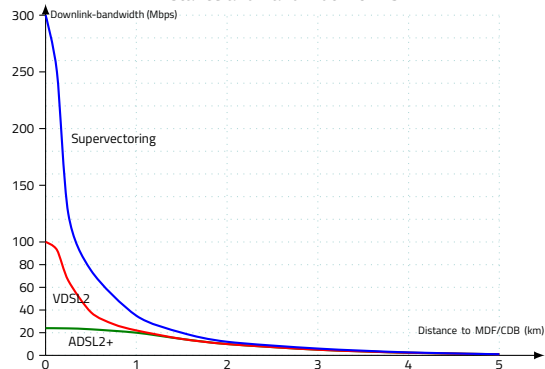
Technical Performance Parameters of Local Network Access Lines

Due to physical limitations, DSL technologies are not suitable for providing acceptable bandwidths in the outlying areas of built-up areas

VDSL principle



Distance and Bandwidth for DSL



- ▶ The bandwidth that can be transmitted is physically limited by the length of the twisted pair (TP) copper cable
- ▶ Shortening the length of the copper TP cable used in very high speed digital subscriber line (VDSL) roll-outs offers benefits only to households located near (< 500 m) the local distribution frames
- ▶ Vectoring and Supervectoring offer nothing but benefits for these short distances
- ▶ In detached housing estates in suburbs and villages, people are often limited to asymmetric digital subscriber line (ADSL)2+ and low bandwidth

1.9 mn (8.4 %) internet connections are still based on ADSL, whereas 20.9 mn households use VDSL with various bandwidths

DSL access networks (ADSL, VDSL, Vectoring)

- ▶ Almost all buildings in Germany have a TP copper connection by DTAG – subscribers use either DTAG's direct services or competitor's services via DTAG L2 wholesale
- ▶ Digital subscriber line (DSL) will remain an important connectivity technology in Germany until the late 2030s
- ▶ In rural areas, and particularly on the outskirts of towns, DSL is often the only option despite its limited bandwidth
- ▶ 1.9 mn (8.4 %) internet connections are still based on ADSL, whereas 20.9 mn households use VDSL

Technology used by DTAG	Distribution	Usage
ADSL2+	≈ 8 %	Rural areas, old
VDSL Vectoring profile 17a	≈ 65 %	Standard
VDSL Supervectoring profile 35b	≈ 27 %	Rapid growth in modernised areas

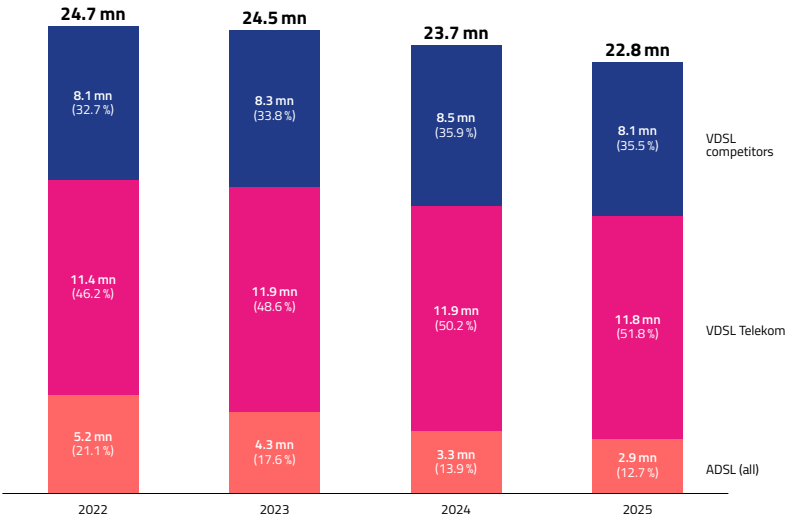
Tech	0–1 km	1–3 km	3–5 km	> 5 km
ADSL2+	24 Mbps	8–16 Mbps	1–8 Mbps	« 1 Mbps

Tech	0–300 m	300–800 m	0.8–1.5 km	> 1.5 km
Vectoring	100 Mbps	50–100 Mbps	15–50 Mbps	< 15 Mbps
Supervectoring	250 Mbps	100–250 Mbps	50–100 Mbps	< 50 Mbps

The decline in DSL connections is largely due to them being replaced by fiber-optic connections—although the decline averages just 2.8 % per year

DSL connections by technology and provider group

homes activated, at the end of each year



Roadmap DSL shutdown

- ▶ A proposal from the European Commission (EC) sets a timeframe for the phasing out of DSL by 2030—80 % of copper connections are to be phased out as early as 2028
- ▶ As the owner of the DSL networks, DTAG must apply to the BNetzA for the shutdown with at least one year's notice (§34 TKG)
- ▶ The WIK anticipates that copper network shut-off will begin in 2028 and that the phase-out of DSL technology will be completed between 2035 and 2040
- ▶ According to our own analysis, fiber-optic internet will not reach 100 % of German HH by 2040
- ▶ DSL shut down would reduce energy consumption for carriers by at least 50 %
- ▶ Telenor shut down its copper network on 2025-09-02 —Norway has 2.7 mn HH

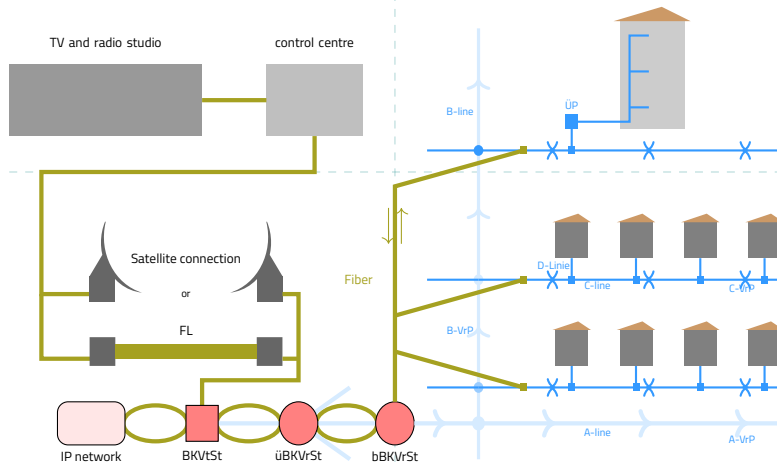
Source: BNetzA 2026b, p. 13, EC 2026, Mansmann/Steiner 2026, Pavel 2025, Weidner 2026, Company information

Although HFC networks are a shared medium, they are capable of delivering high bandwidths of over 1 Gbps

HFC principle

NL1: TV and radio studio

NL4: Inhouse distribution (NL5: Flat)



NL2: Cross-regional familiarisation

NL3: Regional distribution/Location

Anmerkungen

- ▶ The backbone networks are extended as far as the regional distribution networks via fibre-optic cables
- ▶ The remaining coaxial cables are used to connect between 20 and 150 homes in the connection areas
- ▶ All users within a service area must share the bandwidth
- ▶ If the fibre-optic cables are laid right up to the houses, these are fiber-to-the-building (FTTB) connections
- ▶ Inhouse coaxial distribution will continue to play an important role even in the age of fibre optics

Source: Walter 2026b

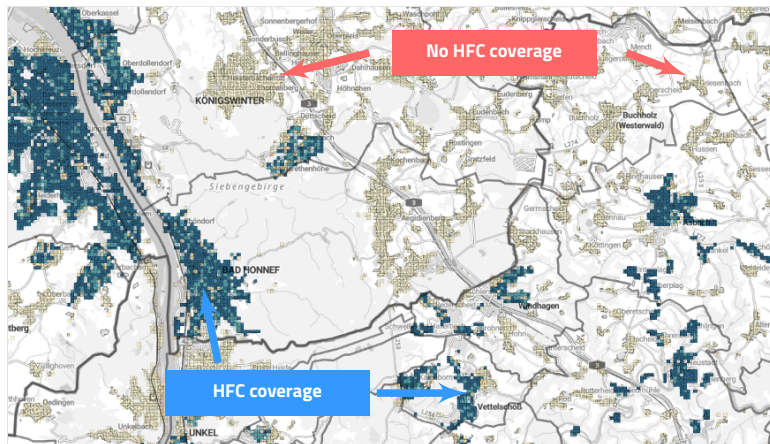
In large cities, all households are connected to HFC—smaller towns are only partially covered by HFC, and rural communities are often not covered at all

Coverage of the HFC access networks

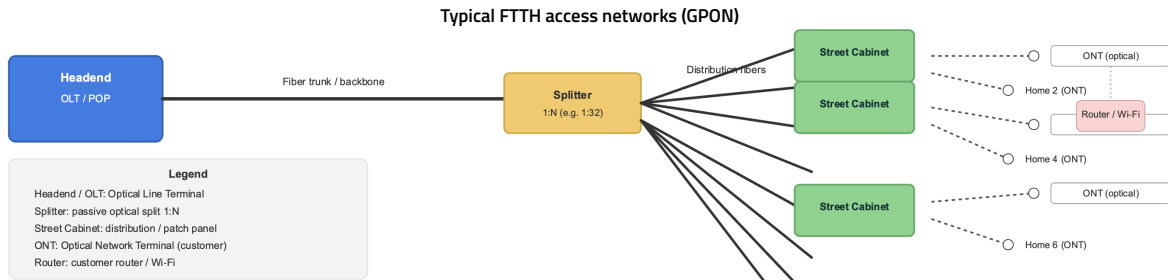
Reichweite und Nutzung

- ▶ 62.7 % of households are connected to hybrid fiber coax (HFC) networks
- ▶ 61.7 % of households are connected to gigabit-capable HFC connections with data over cable service interface specification (DOCSIS) 3.1
- ▶ The cable networks are currently being upgraded to 2.5 Gbps downlink speed
- ▶ Despite the widespread availability of HFC networks, these connections are used by only 22.5 % of all broadband households
- ▶ HFC will remain a key bridging technology well into the 2040s
- ▶ In rural areas, and particularly on the outskirts of towns, HFC is often not available

Source: BNetzA 2025



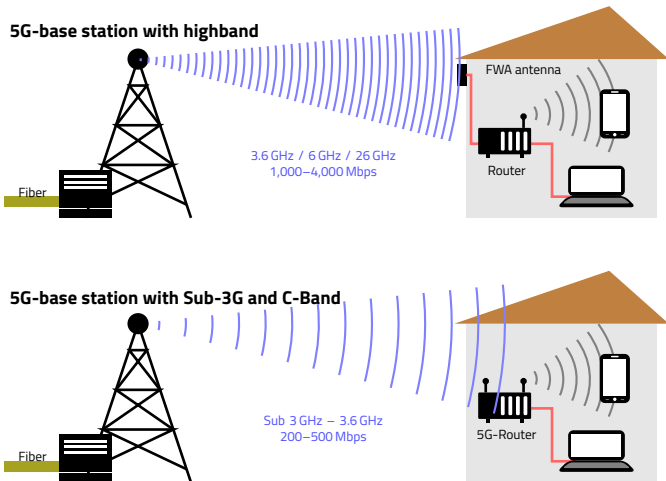
If fibre-optic broadband is available, it is the best access solution from a technical point of view



- ▶ The typical topology used in the construction of fiber-to-the-home (FTTH) networks is gigabit passive optical network (GPON) based on point-to-multipoint (PtMP)
- ▶ Including FTTB and FTTH
- ▶ These fibre-optic connection technologies enable today bandwidths of up to 2.5 Gbps (for FTTH)
- ▶ No bandwidth-based length restriction in local access networks (for FTTH)
- ▶ Significantly lower energy consumption compared to copper-based solutions for network operator
- ▶ Fibre-optic networks are the only fixed-line technology that offers promising long-term potential

5G internet connections are easy to set up can be used either via a 5G standalone router or in combination with an external FWA antenna

5G FWA schematic diagram



Comments

- ▶ Instead of a landline, a mobile network is used for the home internet connection
- ▶ Just like with a fixed-line router, the mobile internet connection can be used by several people and on different devices (e. g. laptops, smartphones)
- ▶ An outdoor receiver is optional, but should be used to
 - ▶ increase the available bandwidth or
 - ▶ receive very high bandwidths beyond 500 Mbps
- ▶ The installation effort is very minimal, particularly without an external antenna
- ▶ The 5G router can also be used for mobile applications (e. g. camper, holiday homes)

Source: Walter 2026b

C-band frequencies are currently used in around 50 % of coverage areas—Upper 6G frequencies have not yet been auctioned, and 26 GHz frequencies are available on application

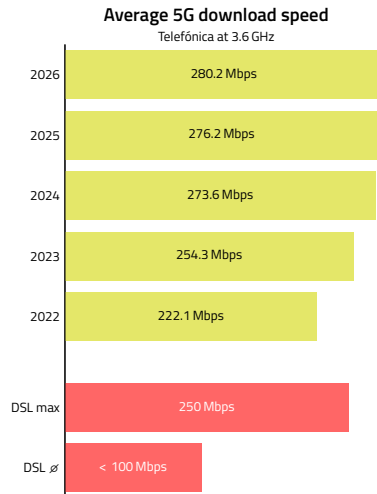
5G FWA networks access solutions—Frequencies and bandwidth

Band names	Frequencies	Bandwith	Availability for MNO	Basic services 50 Mbps	Advanced services 300 Mbps	Gigabit connectivity
C-Band	3.3–4.2 GHz	300 MHz	4	ideally suited	ideally suited	more or less suitable
Upper 6G	6.4–7.1 GHz	700 MHz	to be auctioned	ideally suited	ideally suited	well suited
Upper mid band	7–15 GHz	500 MHz	to be auctioned	well suited	ideally suited	well suited
mmWave	24–26 GHz	800 MHz	available on application	oversized	well suited	ideally suited

Source: BNetzA 2022, Ockenfels/Pfückebaum et al. 2024, p. 45

Mobile communications has already the potential to provide faster connections than DSL in rural and outlying areas quickly and can be upgraded with comparatively little investment

- ▶ Mobile networks already provide almost complete coverage of private households
- ▶ Average downlink bandwidth usage on German mobile networks has risen significantly since the launch of 5G
- ▶ Technological developments involving 5G standalone (5G SA) and 6G, new carrier frequencies, the phasing out of older 2G technologies and the continued densification of networks will further enhance the performance of mobile networks in terms of bandwidth, capacity and user density
- ▶ In the Austrian broadband market, data plans with no data limits ('Cubes') have been a key component of broadband provision for years and account for just over a third (52.0 %) of all broadband connections
- ▶ The average download speed on Telefónica's network has risen to over 280 Mbps—the figures for Telekom and Vodafone are similar
- ▶ Mobile network access offers additional benefits such as easy setup or use at recreational destinations (in Germany)
- ▶ Over all, mobile communications have the potential to provide faster connections than DSL in rural and outlying areas relatively quickly and can be upgraded with comparatively little investment



Source:

Chip Netztest 2022–2026, Mandau/Pauler 2025

The three strategies for 5G FWA are categorised according to whether, and to what extent, investment in mobile communications technology is required

Basic strategies for 5G FWA

Strategy	Quick Win	On-demand expansion	Precise investments
Network status	C-Band fully available	C-Band available $\approx$ 50 %	No C-Band available
Bandwidth	$\approx$ 500 Mbps	$\approx$ 350 Mbps	$\approx$ 250 Mbps
Capacity	very high	high	moderate
Settlement type	Outskirts of major cities	Small towns	Villages and rural areas
CPE	Indoor 5G router	Indoor 5G router	50 % Indoor 5G router and 50 % outdoor antenna
Investment	5G infrastructure can be used immediately to market FWA connections	In around 50 % of cases, 5G infrastructure is ready for the immediate roll-out of FWA connections—in the remaining cases, investment is required to utilise the C-band	The 5G infrastructure needs to be upgraded—either to C-band (50 % of cases) or to mmWave (50 % of cases)

Starlink's bandwidths are in the low three-digit range—however, high latency and the need for a clear view of the sky with 110° are limiting factors

Technical specifications and limitations of LEO satellite networks access solutions

- ▶ This study considers only access solutions using Starlink's LEO satellites for comparison, as this company has by far the most extensive network coverage
- ▶ Starlink's total capacity of actual 377 Tbps depends directly on the number of satellites (6,751 by end of 2024) and their individual capacity:
 - ▶ 200,000 possible customers in Germany with download speeds of 100 Mbps or
 - ▶ 20,000 possible customers with 1 Gbps
- ▶ Once fully rolled out, assuming the 42,000 satellites planned by Starlink, an optimistic estimate suggests
 - ▶ 13 mn possible customers in Germany with download speeds of 100 Mbps or
 - ▶ 1.3 mn possible customers with 1 Gbps
- ▶ The power consumption of the receiving antenna is very high, ranging from 75–100 W, due to the continuous tracking of passing satellites—as the heating system removes snow and ice on cold days, this further increases energy consumption
- ▶ The latency of Starlink internet access is between 40 and 50 ms
- ▶ Installing the receiving antenna is a complex process—Wall mounting (e. g. in apartment blocks) severely restricts reception
- ▶ The Starlink connection requires an unobstructed 110° view of the sky—Reception may also be affected by obstacles such as trees, masts, roofs as well as heavy rainfall

Source: Obermann 2025, Starlink company information 2026

Conclusions

Technical Performance Parameters of Local Network Access Lines

- ▶ Even though there is no longer any investment in **DSL**, usage is only **declining slowly**, most recently by 1 mn per year
- ▶ Although **HFC** offers gigabit bandwidth, not even **two-fifths** of the HH use it
- ▶ Even though **FTTH** is the optimal connection technology, **10–20 %** of households **cannot** be connected in a **cost-effective manner**
- ▶ The current C-band expansion would already enable high-performance FWA connections today (Strategy **Quick Win**)
- ▶ Further expansion of the C-band (Strategy **On-demand expansion**) and the future, demand-driven use of 6G and mmWave (Strategy **Precise investments**) will create significant bandwidth potential for high-performance FWA connections
- ▶ In order to use **satellite internet**, a more complex antenna installation requiring a considerable amount of **space is essential**

Chapter IV

Economic parameters of local access lines

The roll-out of FTTH connections takes place under a wide variety of conditions—consequently, the investments for completed connections range from 1,600 € to 3,900 € per connection

Investments^a for building FTTH access networks (Invest p. HH)

HP: Conduit systems running alongside the buildings

600–1,350 €

HC: Building service pipe and service connection

700–1,500 €

NE4^b: In-house cabling

300–1,050 €

Key drivers of investment HP

- ▶ Cable laying (50–200 € p. m)
- ▶ Laying techniques and complexity of civil engineering works (e. g. other infrastructure, explosive ordnance disposal service)
- ▶ Residential unit (RU) per building

Key drivers of investment HC

- ▶ Distance from the private building to the public road
- ▶ Complexity of civil engineering works
- ▶ Building construction method

Key drivers of investment NE4

- ▶ Number of flats in the building and size of the building
- ▶ FTTH solutions
- ▶ Set at 300 €^c

a) Survey of regional network operators (n = 79–110) conducted by the BREKO Association in early 2025. Question: 'What are your average costs for the various deployment stages per connection (Without public funding)?'

b) NE4 = Netzebene 4 = In-building cabling from the distribution point in the basement to the individual RU, including network termination and cabling infrastructure.

c) Since this study focuses primarily on the supply to single-family and two-family homes, this investment is set at a minimum of 300 €.

Source: Böcker 2025, p. 21, Jay/Neumann et al. 2013, Neumann/Schwarz-Schilling et al. 2026

An external antenna is required, particularly where high bandwidth is needed—however, experience in Austria shows that in many cases an 5G indoor router is sufficient

Building 5G FWA networks access solutions (customer premises)

Dimensions/variants

- ▶ Wall-mounted antennas are typically 15 cm × 20 cm in size
- ▶ Transparent antennas for window mounting are available

Assumptions

- ▶ Outdoor customer premises equipment (CPE): 40 € per household (incl. antenna, transmitter)
- ▶ HH connection: 20 €
- ▶ Wi-Fi-Router: 80 € per HH
- ▶ Router with 5G antenna: 120 € per HH
- ▶ **Costs without outdoor CPE: 108–132 € (= 120 € (±10 %))**
- ▶ **Costs with outdoor CPE: 126–154 € (= 40 € + 20 € + 80 € = 140 € (±10 %))**

Source: Fritz, Huawei, tp-link

The average CAPEX for upgrading a 5G base station is between 72 € and 180 € per user—These figures are significantly lower than those for FTTH connections

Investments for upgrading existing 5G base station (Invest p. user)

Basic upgrade to high band (C-Band)^a

72–100 €

Enhanced upgrade to VHC/mmWave^b

132–180 €

Router/Outdoor CPE

108–154 €

Key drivers

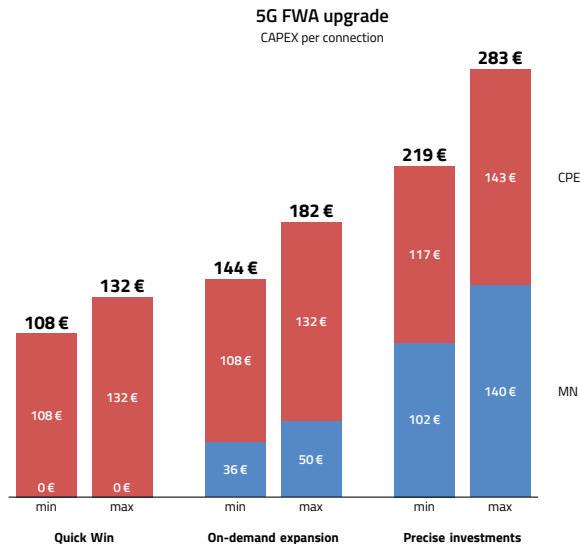
- ▶ The calculation is based on the assumption that a mobile communications site with a base station already exists, which simply needs to be upgraded to meet increased bandwidth requirements and, where necessary, increased capacity
- ▶ As the upgrade of the mobile base stations benefits all users, and would in some cases have been carried out as part of the regular expansion of mobile networks, the additional investment will be shared among all users (250 per cell)

a) The investment per base station is calculated as follows: $72 - 100 \text{ €} \times 250 = 18,000 - 25,000 \text{ €}$ for C-Band-Upgrade.

b) $132 - 180 \text{ €} \times 250 = 33,000 - 45,000 \text{ €}$ for mmWave-Upgrade.

Source: allpcb.com, Ericsson, Khatiwada/Dawadi et al. 2024, MPS, Nokia, Wisely 2019

Overall, the investment required for a 5G broadband connection—ranging from 108 € to 283 € per household—is significantly lower than that for FTTH



5G

- ▶ **Quick Win:** No upgrade needed
- ▶ **On-demand expansion:** Upgrade for using C-band in 50 %
- ▶ **Precise investments:** Major upgrade to enable use of mmWaves in 50 % and C-band upgrade for remaining 50 %
- ▶ 250 users per cell (FWA and mobile customers)

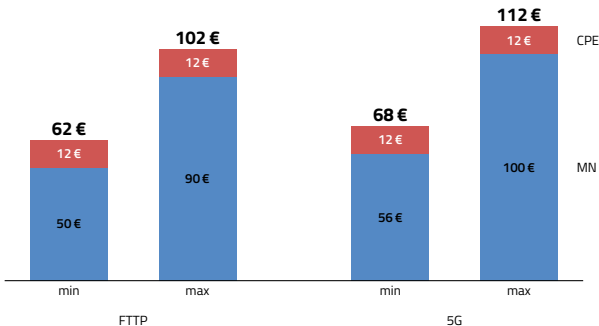
FTTH

- ▶ Minimum estimate of the FWA calculated by BREKO is 1,600 € per household
- ▶ Maximum estimate of the FWA calculated by BREKO is 3,900 € per household

Operating costs for mobile-based access solutions at the same level as those for fiber-optic-based solutions

Operating FTTH vs 5G FWA

OPEX per connection



FTTH

- ▶ No replacement investments, investment in expansion and depreciation
- ▶ 12 € customer side service costs (replacement of broken CPE)

5G FWA

- ▶ No replacement investments, investment in expansion and depreciation
- ▶ 12 € customer side service costs (replacement of broken CPE)
- ▶ 250 users per cell (FWA and mobile customers)

Upgrading existing 5G mobile networks requires moderate investments and can be implemented quickly

How to increase broadband coverage?

Technology	Bandwidth	Investments	Expansion rate	Operator
FTTH	+1,000 Mbps	very high	slow	regional, nationwide
5G FWA	200–1,000 Mbps	moderate	high	nationwide

FTTH	In the long term, FTTH will be the dominant connection technology in Germany reaching 80–90 % of the residential buildings Due to the high investment required for the expansion of FTTH and the significant time involved, FTTH will not become the most widely used connection technology until between 2030 and 2040
5G Mobile Upgrade	Only 'upgrade' needed: The infrastructure for 5G mobile networks is already in place Adjustments to capacity or maximum bandwidth can be made with relatively little effort Detached and semi-detached houses are the primary target and offer ideal conditions for the installation of 5G-based FWA solutions
Sat ^a	Development depends on satellite fleet operators ^b based in the US or China Satellite-based broadband connections will remain a niche application in very rural areas

a) This study does not include an analysis of the investment and operating costs involved in setting up satellite-based systems for internet access.

b) E.g. Geely, Leo, Starlink.

The Starlink installation requirements call for plenty of space and an unobstructed view of the sky—flats in apartment blocks are generally unsuitable

Installing satellite based access solutions^a

Antenna installation

- ▶ A location with a largely unobstructed view (110°) of the sky, free from branches, masts or roofs
- ▶ Satellite dish is a rectangular phased array antenna measuring 60 cm × 39 cm



Other installations

- ▶ Power supply for the antenna
- ▶ Data cable between Antenna and router
- ▶ Power supply for the router

^{a)} This study considers only access solutions using Starlink's LEO satellites for comparison, as this company has by far the most extensive network coverage.

Source: Starlink 05/2026

The total cost of using Starlink systems ranges from 600–1,200 € per year

Operating satellite based access solutions^a

Starlink pricing plan for residential customers

- ▶ *Lite*: 35 € pro Monat, Downlink 80–200 Mbps, uplink 15–35 Mbps, lower priority (old plan)
- ▶ *Privathaushalt 100 Mbps*: 29 € pro Monat, Downlink 100 Mbps, uplink 15–35 Mbps, lower priority
- ▶ *Privathaushalt 200 Mbps*: 49 € pro Monat, Downlink 200 Mbps, uplink 15–35 Mbps, lower priority
- ▶ *Privathaushalt Max*: 69 € pro Monat, Downlink 400 Mbps, uplink 20–40 Mbps, incl. 'Mini-Kit' for nomadic use, higher priority

All pricing plans include unlimited traffic, WLAN6 router, current bandwidth depends on network utilisation

Starlink energy consumption

- ▶ *Antenna*: power consumption 75–100 W → energy 657–876 kWh p. a. → Costs^b 204.98–273.31 € p. a.
- ▶ *Router*: power consumption 10–13 W → energy 88–114 kWh p. a. → Costs^b 27.46–35.57 € p. a.

Total costs

580.44–1,136.88 € p. a. (without energy required in sub-zero temperatures, consumer prices, incl. 19 % VAT)

a) This study considers only access solutions using Starlink's LEO satellites for comparison, as this company has by far the most extensive network coverage.

b) 31.2 €-Ct p. kWh average electricity price for existing private customers in March 2026 (stromanbieter.de).

Source: Pluto 2026, Starlink 05/2026

Conclusions

Economic parameters of local access lines

- ▶ The roll-out of FTTH connections takes place under a **wide variety of conditions**—consequently, the investments for completed connections range from **1,600 € to 3,900 €** per connection
- ▶ Overall, the investment required for a 5G broadband connection—ranging from **108 € to 283 €** per household—is **significantly lower** than that for FTTH
- ▶ **Upgrading** existing **5G mobile networks** requires **moderate investments** and can be implemented **quickly**
- ▶ The **Starlink** installation requirements call for plenty of space and an **unobstructed view of the sky**—flats in apartment blocks are generally unsuitable

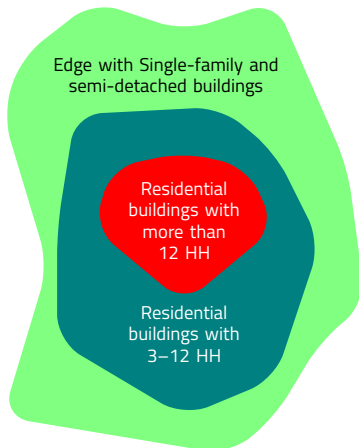
Chapter V

Case Studies

Even very large cities encompass significant areas with single-family or semi-detached buildings—these areas are the most suitable for the deployment of 5G FWA technologies

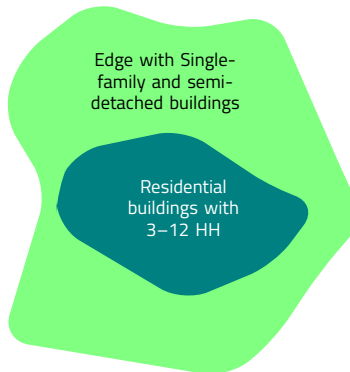
Settlement patterns in Germany by urbanization level

Big city



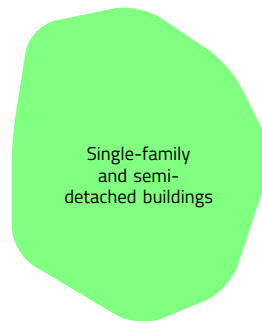
Leipzig-Südost
Saxony

Small Town



Burscheid
North Rhine-Westphalia

Village



Berg
Bavaria

Not all buildings on the outskirts of towns and in rural areas will be connected via fibre—5G^{4,2}, however, can provide high-performance alternatives in detached housing estates

Residential buildings and apartments^a

Residential area type	Villages	Small Towns	Big Cities	Broadband coverage	# Buildings	# HH
Edge with single-family and semi-detached buildings	mostly	living areas	detached housing estates	55 % FTTH 5 % HFC	15.9 mn	18.4 mn
With small multi-family buildings, 3–6 housing units per building	very few	living areas	living areas	30 % FTTH 10 % HFC	2.3 mn	9.4 mn
With medium size multi-family buildings, 7–12 housing units per building	—	city centres	residential centres	45 % FTTH 60 % HFC	1.0 mn	8.3 mn
With large multi-family building, > 12 housing units per building	—	—	city centres	60 % FTTH 100 % HFC	0.2 mn	5.5 mn

^{a)} Excluding 0.8 mn buildings classified as 'other types' by the Federal Statistical Office, which contain 2.2 mn dwellings.

Source: DC 2025, p. 9–11

 Target areas for 5G FWA

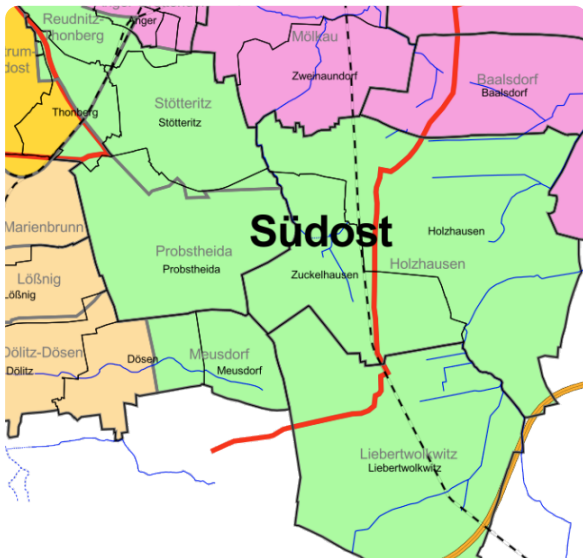
Whilst the technical infrastructure for 5G FWA in major cities and around 50 % of small towns allows for immediate roll-out, investment is required in the remaining small towns and villages

Basic strategies and settlement patterns

Strategy	Quick Win	On-demand expansion	Precise investments
Settlement type	Big Cities	Small Towns	Villages
Status C-Band expansion	installed everywhere	in about half of the towns	not available
Bandwidth	≈ 500 Mbps	≈ 350 Mbps	≈ 250 Mbps
Capacity	very high	high	moderate
Necessary investment for FWA	none	High-band investment in 50 % of the sites	High-Band and VHC/mmWave investment
FWA strategy	Quick launch of the 5G FWA marketing campaign	FWA services will be rolled out immediately where high-band coverage is available—in other areas, roll-out will only take place	Marketing after upgrading to VHC/mmWave

Around 10 % of Leipzig's residents live in the Südost district—the six local areas encompass both inner-city and rural settlement patterns

Case study 'Leipzig-Südost' in Saxony—Strategy Quick Win

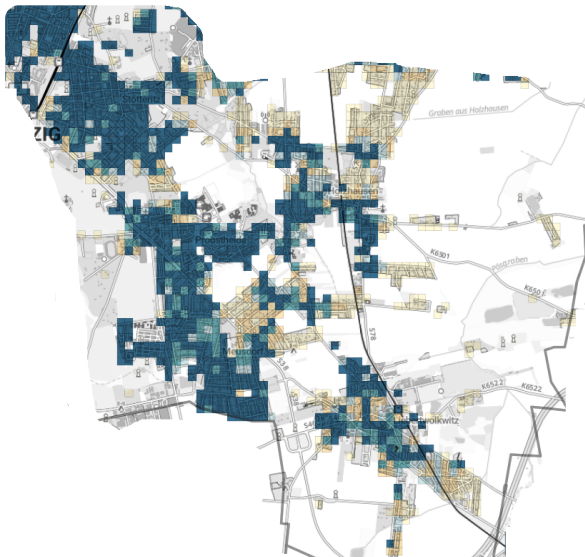


City district	Residents	Area (km ²)	PD (1/km ²)	HH
Reudnitz-Thonberg	23,955	2.03	11,800	14,688
Stötteritz	18,249	3.71	4,919	10,336
Meusdorf	3,896	1.95	1,998	1,919
Probstheida	7,168	4.85	1,478	3,735
Liebertwolkwitz	5,469	9.27	590	2,811
Holzhausen	6,728	12.91	521	3,351
Leipzig Südost	65,465	34.72	1,886	36,840

Source: Stadt Leipzig, Wikipedia

Of the six districts in Leipzig-Südost, coverage of 200 Mbps is below 50 % in Liebertwolkwitz and Holzhausen in particular and the deployment of 5G FWA should be particularly attractive

Case study 'Leipzig-Südost'—200 Mbps fixed line broadband coverage^a



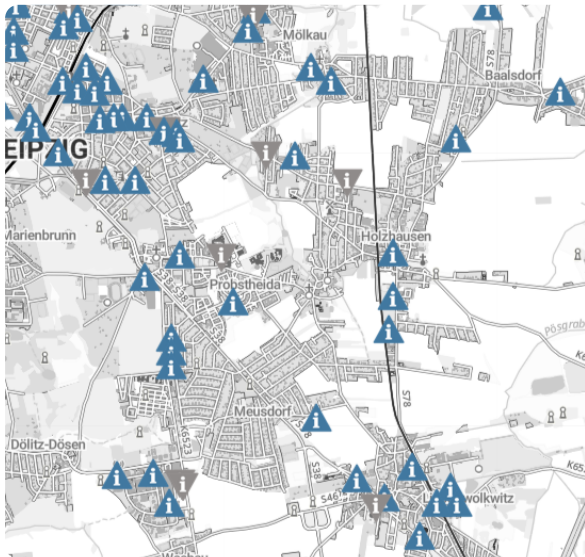
City district	DSL100	DSL200	HFC	FTTH
Reudnitz-Thonberg	95 %	78 %	86 %	36 %
Stötteritz	93 %	82 %	70 %	2 %
Meusdorf	88 %	51 %	73 %	8 %
Probstheida	85 %	50 %	75 %	8 %
Liebertwolkwitz	86 %	40 %	6 %	4 %
Holzhausen	79 %	42 %	4 %	3 %

^{a)} As the Breitbandatlas does not provide aggregated data for Leipzig's city districts or neighbourhoods, these were determined by analysing the cartographic information.

Source: BNetzA 2025

The city district Leipzig-Südost has comprehensive 5G SA coverage, and numerous mobile phone masts ensure good capacity

Case study 'Leipzig-Südost'—mobile base stations



Mobile coverage^a

- ▶ 5G SA: 100 %
- ▶ 5G network coverage is generally better in major cities than in rural areas, as there are a higher-than-average number of base stations in cities for capacity reasons

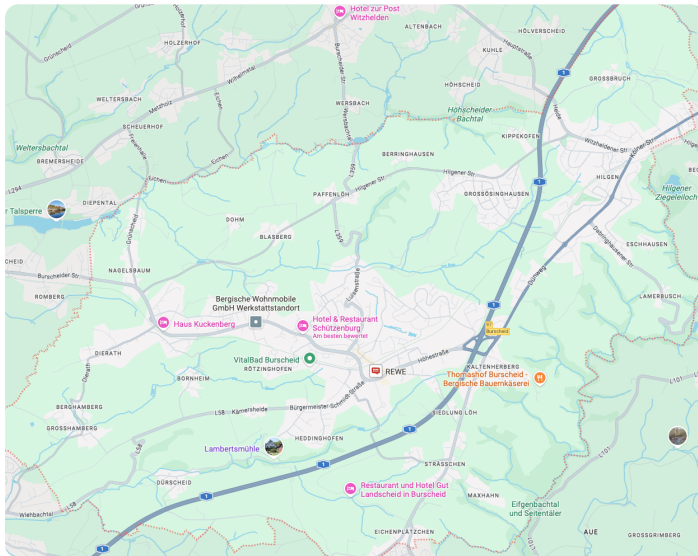
a) end of 2025.

Source: BNetzA 2026a

Burscheid is a small town in the Rheinisch-Bergisch district of North Rhine-Westphalia—the town is characterised by two main residential areas and many smaller hamlets

Case study 'Burscheid' in North Rhine-Westphalia—Strategy On-demand expansion

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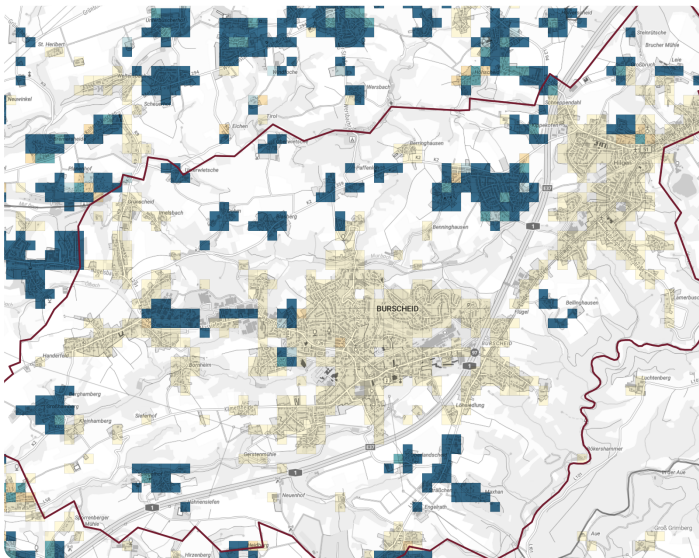
Demographic characteristics

- ▶ 2 main residential areas 'Burscheid Innenstadt' and 'Hilgen'
- ▶ 71 smaller villages
- ▶ 19,104 residents, 27.3 km²
- ▶ sparsely populated, 699 residents per km²
- ▶ 9,098 RUs
- ▶ 5,015 buildings with residential accommodation
- ▶ 4,862 detached, semi-detached and terraced houses (96.9%)
- ▶ 4,808 single or association of private owners (95.9%)

Source: Gemeinde Burscheid, Statistisches Bundesamt

Burscheid (NRW) is an example of a small town where the limitations of DSL technology prevent the widespread provision of higher bandwidths—FTTH is only used in outlying areas

Case study 'Burscheid'—200 Mbps broadband coverage



Fixed line coverage^a

DSL: 50, 100 and 200 Mbps → 88.4, 76.5 and 0.7 %—582 and 1,178 homes are not reached covered by 50 and 100 Mbps

HFC: 0.0 %

FTTH: 17.9 %—897 homes in some the smaller villages^b a covered by FTTH

- ▶ A total of 4,072 homes are unable to access a 200 Mbps broadband connection
- ▶ FTTH roll-out has already taken place in some villages to the north, west and south
- ▶ The target areas for 5G FWA deployment are the outskirts of the main built-up areas and villages not served by FTTH

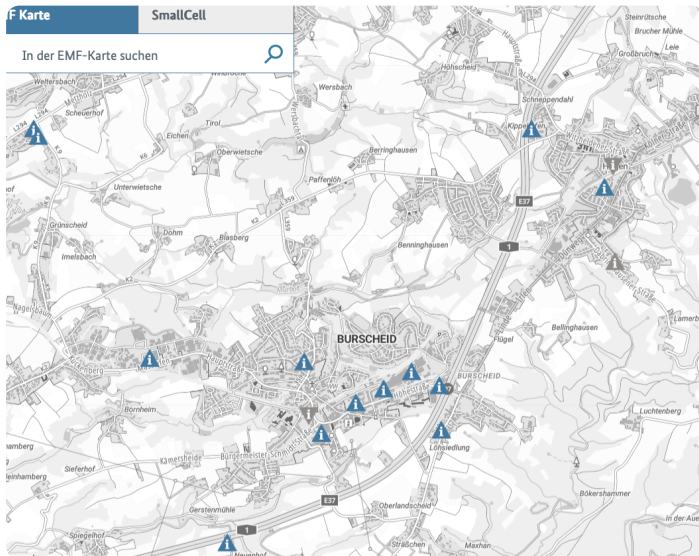
^a end of 2025.

^b Bellinghausen, Blasberg, Parts of Bornheim, Dohm, Dürscheid, Großbruch, Großshenberg, Kippelkofen, Kleinbruch, Oberlandscheid, Oberwietsche, Osinghausen, Pfaffenliß, Spornberger Mühle, Sträßchen, Unterwietsche.

Source: BNetzA 2025, Gemeinde Burscheid

5G SA mobile coverage is now 100%—12 mobile phone masts ensure good mobile phone coverage in the small town

Case study 'Burscheid'—mobile base stations



Mobile coverage^a

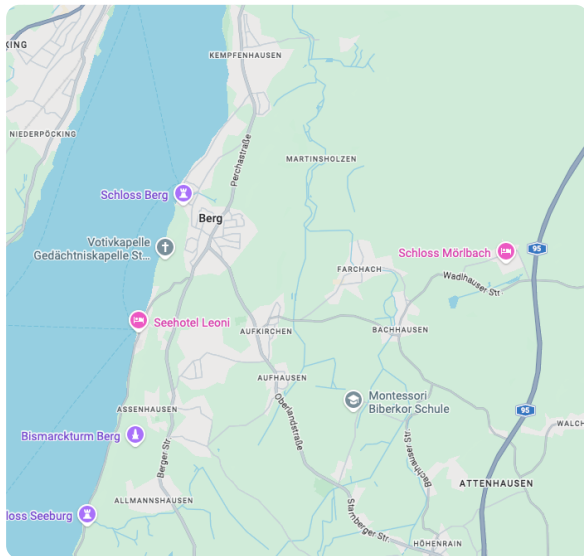
- ▶ 5G SA: 100%
- ▶ Mobile phone coverage is above average in the main residential areas, not least thanks to the A1 motorway, which runs along the main residential areas of the city
- ▶ The 12 mobile phone masts provide coverage, particularly in the central residential areas
- ▶ In some of the surrounding villages, the distance to the nearest mobile phone mast is quite considerable, meaning that the bandwidth available via 5G is likely to be rather low

^a end of 2025.

Source: BNetzA 2026a

Berg (Bavaria) is a tourist town in Bavaria, situated on Lake Starnberg, comprising 15 settlements of varying sizes

Case study 'Berg' in Bavaria—Strategy Precise investments



Demographic characteristics^a

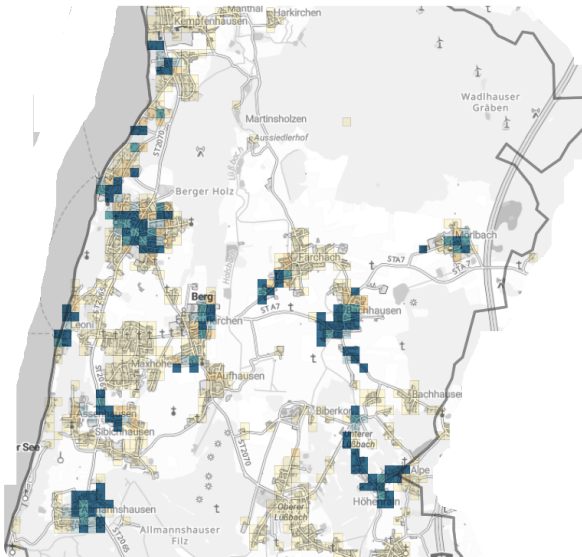
- ▶ 15 municipal districts
- ▶ 8,128 residents, 36.63 km²
- ▶ Moderately densely populated, 222 residents per km²
- ▶ 3,800 RU
- ▶ 2,435 buildings with residential accommodation
- ▶ 2,352 detached, semi-detached and terraced houses(96.6%)
- ▶ 2,341 single or association of private owners(96.1%)

^{a)} Status: 2022-05-15.

Source: Gemeinde Berg, Statistisches Bundesamt

Only a third of households in Berg (Bavaria) could access broadband speeds of 200 Mbps—HFC and FTTH reach fewer than 9 % of households

Case study 'Berg'—200 Mbps broadband coverage



Fixed line coverage^a

DSL: 50, 100 and 200 Mbps → 94.6, 84.4 and 33.4 %—coverage is below average—whilst 50 Mbps is available in 85 % of homes, only a third have access to 200 Mbps

HFC: 6.0 %—Cable networks only reach around 230 households in Kempfenhausen

FTTH: 2.8 %—The roll-out was carried out only very selectively and covers only around 100 homes^b

- ▶ Whilst broadband coverage reaches 200 Mbps in some villages, residents in other villages suffer from poor broadband coverage
- ▶ A total of 1,565 homes are unable to access a 200 Mbps broadband connection

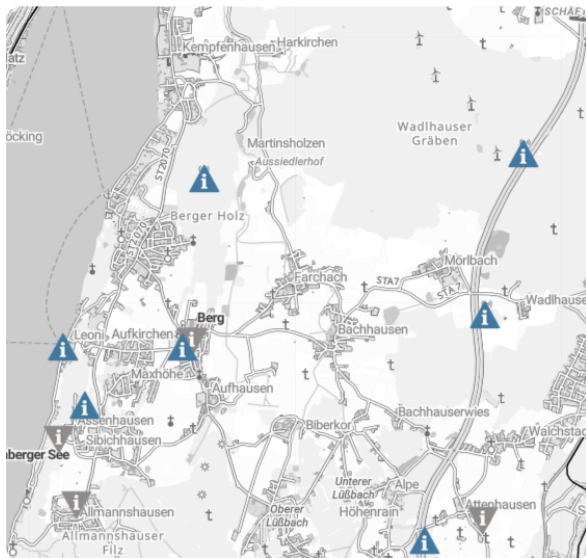
a) Status: 2022-05-15.

b) Möribach, Leoni, and a number of properties on the lakeshore.

Source: BNetzA 2025, Gemeinde Burscheid

Owing to its lakeside location, which attracts tourists, and the A95 motorway, there are numerous base stations within or near the municipal area

Case study 'Berg'—mobile base stations



Mobile networks coverage^a

- ▶ 5G SA: 99.0 %
- ▶ Mobile phone coverage is also driven by tourism and the nearby motorway
- ▶ The mobile phone masts are located, on the one hand, in the towns and villages near the lake and, on the other hand, along the motorway—in the villages in between, the distance to the nearest mobile phone mast is rather great

a) Status: 2022-05-15.

Source: BNetzA 2026a

The prices and demand distributions assumed in the model calculations are based on the values currently observed in the market

Consumer prices and demand

Bandwidth	Consumer price	Proportion
50 Mbps	29.99 €	27.0 %
100 Mbps	34.99 €	24.3 %
250 Mbps	39.99 €	19.6 %
300 Mbps	49.99 €	11.6 %
500 Mbps	69.99 €	9.9 %
1,000 Mbps	99.99 €	7.6 %

Source: Retail prices of 1&1 and Deutsche Glasfaser; BNetzA 2026b, p. 17, Walter 2026a, p. 25

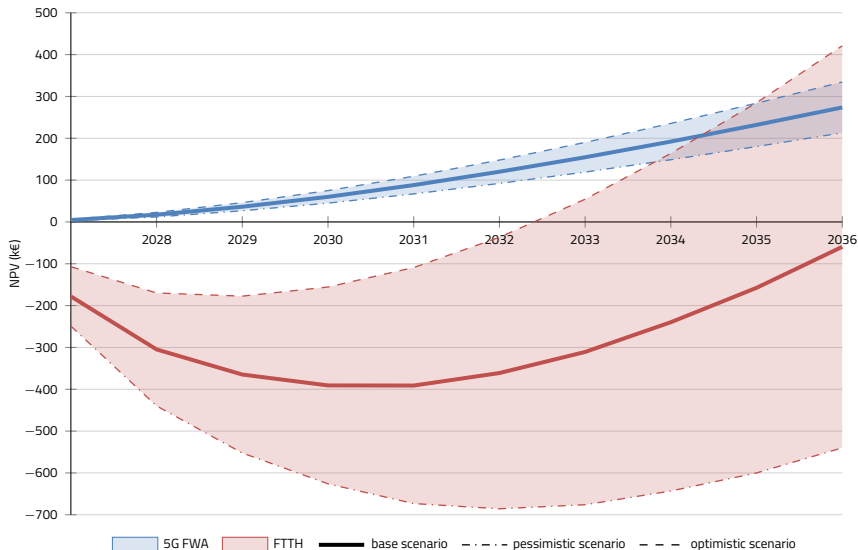
Key economic assumptions for calculating the case studies

- ▶ To market **additional broadband connections** in the target regions of the three case studies, calculations are performed for a **base scenario**, an **optimistic scenario**, and a **pessimistic scenario**
- ▶ The prices from the table on the left were used to **calculate the FTTH revenue**
- ▶ To calculate the 5G FWA revenue, the optimistic scenario used prices identical to those for FTTH, while the pessimistic scenario used prices that are 30 % lower—in the **base scenario prices are 15 % lower**
- ▶ **Demand for bandwidth** is increasing by 1 % per year in the two high-speed categories and decreasing by the same amount in the two low-speed categories—In the two mid-speed categories, demand remains unchanged
- ▶ In the 5G FWA category, only the 100, 250 and 300 Mbps models are available
- ▶ The investments and costs were estimated based on the information provided in chapter IV—the respective minimum and maximum values in the optimistic and pessimistic scenarios, and the **average values in the base scenario**—Investments in the roll-out of in-building fibre-optic networks are estimated at the minimum level, as these are less costly in detached and semi-detached houses
- ▶ In the **cash flow (CF)-based calculation**, revenue (= turnover) is included as cash inflows and costs and capital expenditure as cash outflows for each individual year, resulting in the CF for each year
- ▶ The CF calculated in this way are discounted at a **interest rate of 7.0%** depending on when they fall in the future, and are totalled up to the respective year as **net present value (NPV)**
- ▶ The **time series of the NPV values** for the three case studies can be found on pages 54–56 and provides a good indication of the amount of capital invested and the **payback** profile based on the revenues

Given the relatively good DSL coverage in Leipzig-Südost, the potential for 5G FWA is limited to Liebertwolkwitz and Holzhausen—yet these areas are economically attractive

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Case study 'Leipzig-Südost'—Strategy Quick Win



Trends in customer numbers

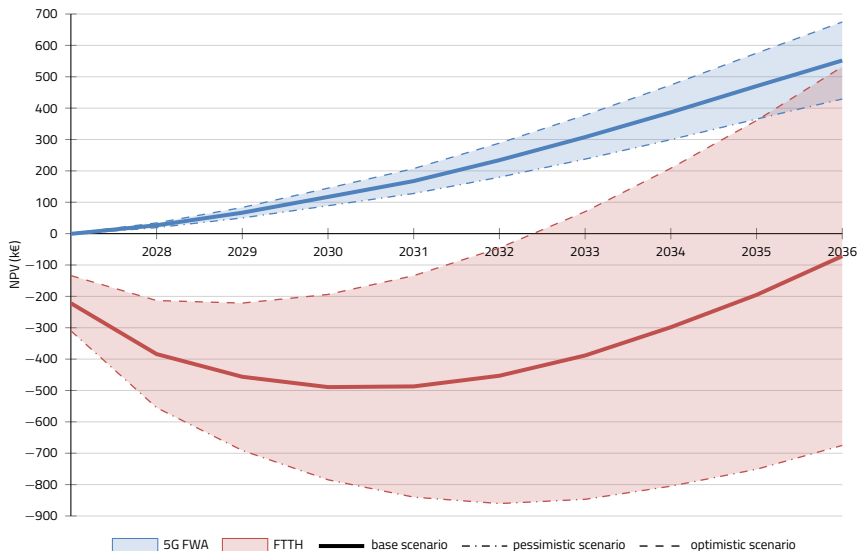
- ▶ 5G FWA customer growth from 30 in 2026 to 251 in 2035
- ▶ FTTH customer growth from 90 in 2026 to 762 in 2035

Results

- ▶ With 5G FWA access solutions, it is possible to rapidly roll out broadband connections—which are also economically viable—to a limited number of households in outlying areas of major cities that have below-average fixed-line broadband coverage but very good mobile network coverage
- ▶ As no investment in the network is required, the CF is already in the black in the first year, even with a relatively small customer base
- ▶ Even in the best-case scenario, and with three times the number of customers, FTTH access solutions only pay for themselves after over ten years
- ▶ The range of potential FTTH investments is wide
- ▶ In unfavourable circumstances, FTTH connections can only be made economically viable with public funding

In small towns such as Burscheid, where broadband coverage is under average, 5G FWA continues to offer advantages over FTTH for a limited number of customers

Case study 'Burscheid'—Strategy On-demand expansion



Trends in customer numbers

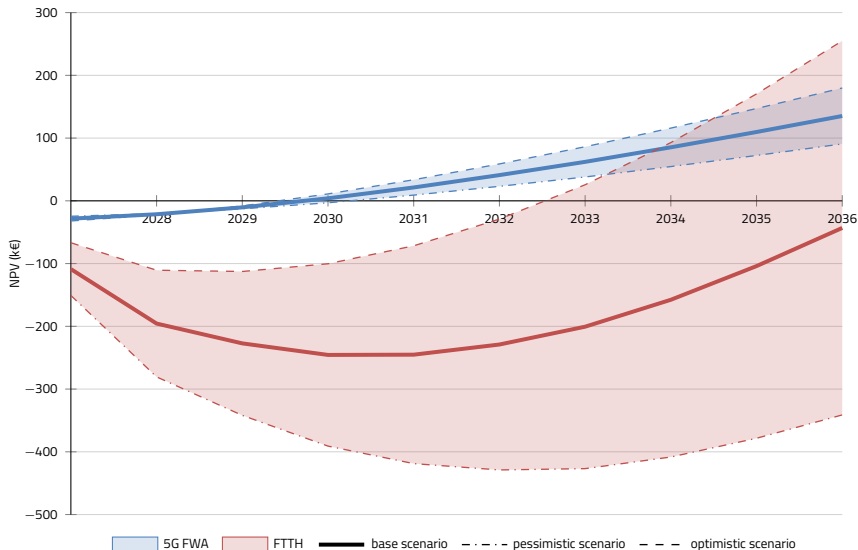
- ▶ 5G FWA customer growth from 62 in 2026 to 520 in 2035
- ▶ FTTH customer growth from 112 in 2026 to 957 in 2035

Results

- ▶ With 5G FWA access solutions, high-speed broadband connections can be rapidly rolled out to a limited number of households in small towns that have below-average fixed-line broadband coverage but good mobile network coverage; these connections are economically viable despite the relatively low level of investment required
- ▶ Investments in C-band technology at 50% of the base stations will be recouped through customer revenue in the very first year
- ▶ In the base scenario, with twice as many customers, the payback period for FTTH access solutions is still longer than for 5G FWA after ten years.
- ▶ The range of potential FTTH investments is wide

In smaller villages with only partial FTTH coverage and moderate DSL coverage, the advantages of 5G FWA over FTTH are admittedly smaller, but still significant

Case study 'Berg'—Strategy Precise investments



Trends in customer numbers

- ▶ 5G FWA customer growth from 20 in 2026 to 164 in 2035
- ▶ FTTH customer growth from 54 in 2026 to 473 in 2035

Results

- ▶ With 5G FWA access solutions, it is possible to rapidly roll out broadband connections—which are also economically viable—even where significant investment is required in mobile network technology, for a limited number of households in villages with below-average fixed-line broadband coverage and moderate mobile network coverage
- ▶ Investments in C-band and mmWave technology require significant capital expenditure, which, in a small community with relatively limited customer potential, will only pay for itself after 2 to 3 years
- ▶ With almost three times the number of customers, FTTH access solutions only pay for themselves after over 10 years
- ▶ The range of potential FTTH investments is wide—on average, the payback period extends well beyond 2026

Case Studies

- ▶ Residential areas with **detached and semi-detached houses** can be found in **villages** and on the **outskirts of small towns and even large cities**
- ▶ If such residential areas have **below-average broadband** coverage, they are the **primary target** for FWA services
- ▶ The **Leipzig-Südost** case study shows that FWA can be put to good use on the **outskirts of major cities**
- ▶ In **small towns** (case study: Buscheid) and **villages** (case study: Berg), the roll-out of **FWA alongside the ongoing expansion of FTTH** leads to **economically beneficial outcomes**

Chapter VI

Conclusions

The benefits of expanding mobile networks to 5G FWA as a complementary technology outweigh the risks

Risks for MNO

- ▶ Customers are **concerned** that a potential change in technology—and possibly also a change of provider—could lead to **problems or downtime^a**
- ▶ Growing acceptance of **satellite-based internet access** solutions

Risks for MNO without Telekom

- ▶ Telekom can step up the marketing of its **hybrid connections** (DSL + 5G)

a) Winzer/Ebert-Pappert 2026.

Opportunities for MNO

- ▶ **Mobile services are familiar** to large sections of the population
- ▶ Developments in **Austria** demonstrate the **widespread acceptance** of 5G FWA
- ▶ Fibre-optic roll-out and **take-up rates in Germany are low** by European standards
- ▶ **Trial offers** lasting 1–3 months can help convince new customers of the capabilities of 5G FWA
- ▶ **Investments** in the expansion of base stations **are very moderate**
- ▶ **All mobile phone users will benefit** from investment in new mobile technology, not just 5G FWA customers

Chapter VII

Appendix

Study design and author

The analysis is based in particular on an evaluation of the following sources:

- ▶ Company publications, financial reports and press releases
- ▶ Publicly available studies (e. g. the Federal Network Agency's annual report, FTTH-Council, etc.)
- ▶ Interviews with professionals of telecoms network operators and equipment manufacturers



Author of the study

Dipl.-Wirtsch.-Ing. Andreas Walter

- ▶ Managing Partner of the consultancy firm Dialog Consult GmbH
- ▶ 30 years' professional experience in strategic and regulatory economic issues within the telecommunications market
- ▶ Lectureship at Rhein-Main University of Applied Sciences

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List of abbreviations I

5G SA	5G standalone
ADSL	asymmetric digital subscriber line
ANGA	ANGA – Der Breitbandverband e. V.
APL	Abschlusspunkt Linientechnik
bBKVrSt	Benutzerseitige Breitbandkabel-Verstärkerstelle
BKVtSt	Breitbandkabel-Verteilstelle
BNetzA	Bundesnetzagentur für Elektrizität, Gas, Telekommunikation, Post und Eisenbahnen
BREKO	Bundesverband Breitbandkommunikation e. V.
CAPEX	capital expenditure
CDB	cable distribution box
CF	cash flow
CPE	customer premises equipment
D2D	direct-to-device
DC	Dialog Consult GmbH
Dipl.-Wirtsch.-Ing.	Diplom-Wirtschaftingenieur
DOCSIS	data over cable service interface specification
DSL	digital subscriber line
DSLAM	digital subscriber line access multiplexer
DTAG	Deutsche Telekom Aktiengesellschaft
e. g.	exempli gratia
EC	European Commission
EMF	Elektromagnetische Felder
etc.	et cetera
FL	fixed link
FTTB	fiber-to-the-building
FTTH	fiber-to-the-home
FTTP	fiber-to-the-premises

List of abbreviations II

FWA	fixed wireless access
GEO	geostationary Earth orbit
GmbH	Gesellschaft mit beschränkter Haftung
GPON	gigabit passive optical network
HA	homes activated
HC	homes connected
HFC	hybrid fiber coax
HH	household
HP	homes passed
incl.	including
IP	internet protocol
ITU	International Telecommunication Union
LEO	low Earth orbit
LTE	long term evolution
MDF	main distribution frame
MN	mobile network
MNO	mobile network operator
MR	microwave radio
NL	network layer
NPV	net present value
NRW	North Rhine-Westphalia
OPEX	operational expenditure
p.	page
p. a.	per annum
PD	podulation density
POP	point of presence
PtMP	point-to-multipoint

List of abbreviations III

RTR	Rundfunk und Telekom Regulierungs-GmbH
RU	residential unit
SME	small and medium-sized enterprises
TKG	Telekommunikationsgesetz
TP	twisted pair
TV	television
üBKVrSt	übergeordnete Breitbandkabel-Verstärkerstelle
ÜP	Übergabepunkt
US	United States
VAT	Verband Alternativer Telekom-Netzbetreiber
VATM	Verband der Anbieter im Digital- und Telekommunikationsmarkt e. V.
VDSL	very high speed digital subscriber line
VHC	very high capacity
VOD	video-on-demand
VrP	Verstärkerpunkt
Wi-Fi	wireless fidelity
WIK	Wissenschaftliches Institut für Infrastruktur und Kommunikationsdienste GmbH
WLAN	wireless local area network