

Techno-economic analysis of fibre-based broadband technologies in Stockholm FTTH vs. FTTB

An Acreo report on behalf of Stokab AB

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1 Summary

Consumers' use of capacity-intensive broadband services and the public sector's need to be able to deliver so-called societal services (e.g., home care), has in recent years increased exponentially. Meanwhile, a host of services designed to facilitate and streamline the operation and maintenance of properties have become available. These challenges and opportunities can be handled in different ways by property owners. This short report, in which we analyse and compare the options available, is meant as a support for real estate owners and managers in their choice of in-building broadband network installation.

Our recommendation is to choose fibre, preferably with four fibres per unit (apartment, business premises, service rooms etc).

An in-building network – the network between the fibre cables entering the building and each unit – is a prerequisite for both households to have access to the services offered and the public sector to be able to deliver so-called public services efficiently. The estate owner's choice affects the possibilities regarding:

- Choice and competition
- ability to tackle the growing demand for capacity
- environmental impact
- innovativeness in Stockholm
- ability to deliver public societal services
- ability to manage mobile network coverage
- ability to manage and operate properties in an efficient and environmentally smart way

1.1 Fibrefastighetsnät rekommenderas

Our analysis shows unequivocally that an in-building network (with at least two fibres) to each unit is what gives the best conditions to handle current and future communication needs. The analysis also describes how a property owner more concretely should act and the aspects that should be considered when selecting the network topology.

1.2 Acreo Swedish ICT och Stokab

The study was conducted by Marco Forzati and Crister Mattsson at Acreo Swedish ICT on behalf of Stokab, the city of Stockholm's IT infrastructure company. Acreo is co-owned by the Swedish government (60%) and by a consortium of hardware and software companies (40%). Stokab leases out only passive fibre connections, known as dark fibre, to all actors in Stockholm on equal terms. The company is owned by the City of Stockholm and has been commissioned to create competition, diversity and consumer freedom in the region. Approximately 90% of all households in the

municipality of Stockholm have the possibility to connect to the fibre network, which is the world's largest open fibre network.

2 Introduction and background

Acreo Swedish ICT has, on behalf of Stokab – the city of Stockholm's IT infrastructure company, analysed the various ways of connecting households by fibre in the municipality of Stockholm. The aim is to clarify the advantages and disadvantages of the various fibre-based topologies in Stockholm. The ambition is that, with the support of this report, property owners and developers who are about to invest in building a network in their properties will find it easier to choose the topology that, based on each property's potential, creates the best broadband-connectivity conditions for the consumers and businesses in the property. In addition, it aims to contribute to a better understanding of the broadband situation as well as how the market works in Stockholm.

2.1 The fibre network

The City of Stockholm has, through his company Stokab, deployed an operator-neutral fibre network in the region, starting in 1994. The network, which was built without tax financing, is a passive fibre network (no services offered) and is open to all on equal terms. The network has been expanded gradually. Between 2007 and 2012 a special effort was made to connect virtually all multi-family properties in the municipality. Currently, over 90% of all households, and almost 100% of all companies are connected to the fibre network.

The deployment to multi-family properties has been made with a fibre pair per unit (apartment or commercial other premises). The delivery point is in the property basement, which is current practice in Sweden to deliver other infrastructure like water, electricity, sewage, etc. Fibre cables from the properties are connected to a node (similar to a telecommunications exchange).

Provided that the property owner sees to it that an in-building fibre network installed, the model implies that each unit gets fibre access all the way to the node to which the property is associated. Each node connects approximately 40 properties with about 1,500 apartments. That, maintains Stokab, offers several opportunities:

- Each households can freely choose among the operators present in the node to which the property is connected, independently of their neighbours;

- Operators can streamline their networks in terms of both environmental impact and robustness;
- The introduction of societal services, such as ehealth, are facilitated;
- Operators can create new business models targeted to households and businesses.

The possibility of reaching individual households directly with fibre became possible in 2013, when the network deployment was completed, yet relatively few property owners and operators currently use the FTTH network structure. A joint communal communications solution (Internet access, TV and telephony) for the entire property is still the most common model (relying to FTTB+CAT5/6, as will be discussed below).

2.2 Object of the memo

This memo compares the two dominant solutions to deliver high-speed broadband to households: FTTH (Fibre-to-the-home) that is the fibre between the operator and each individual household, and FTTB (fibre-to-the building) combined with a copper in-building network (using CAT5/6 data communication cables) from the operator's active equipment in the basement to each individual household.

The objective of this memo is to analyse:

- The pros and cons of fibre in-building networks (between individual units and Stokab's fibre network in the property's cellar), including competition and consumer's freedom of choice, market development, service development, robustness and ability to deliver societal services (e.g. e-health);
- Investment cost of fibre in-building networks;
- Any alternative technical solutions and their advantages and disadvantages;
- Operational costs (OPEX);
- Energy consumption and climate impact;
- Data transfer capacity and quality.

2.3 Other technologies

In this analysis we do not go into xDSL, coax or mobile technologies available in Stockholm since all of them are subject to various limitations on access to capacity and choice.

2.4 About the authors and Acreo Swedish ICT

Acreo Swedish ICT is a research company that develops competence in electronics, optics and communication technology and has as a goal to turn research into commercially viable products and processes. Acreo is owned 60% by the Swedish government and 40% by the Swedish industry (hardware and software companies).

Acreo conducts several scientific socio-economic studies regarding fibre and broadband. One example is a study on the socio-economic impact of FTTH carried out on behalf of the Swedish government's Broadband Forum (*Bredbandsforum*). The study focuses particularly on fibre deployment impact on employment, the value of fibre for the individuals as well as the cost-savings made possible thanks to fibre. Recently, Acreo has written a *Guide to High-speed Broadband Investment* by appointment to the European Commission.

Marco Forzati holds a Laurea degree in Telecommunication Engineering from Politecnico di Milano, Italy, a M.Sc. and a Ph.D. degree in Electrical Engineering from Chalmers University of Technology, Gothenburg, Sweden, and a B.Sc. degree in Economics from Stockholm University. Dr. Forzati has held various R&D positions at Saab Ericsson Space and Ericsson, as well as visiting scientist positions at TRILabs, and France Telecom R&D. He has authored or co-authored more than 80 papers, conference contributions and book chapters, and 3 patent applications. He has been managing a number of projects at Acreo, and he has been involved in several European research projects in areas as diverse as long-haul transmission, access networks, techno-economics, business modelling and socio-economics.

Crister Mattsson is Senior Advisor at Acreo Swedish ICT. Mr. Mattsson specialises in open networks and strategies for municipal networks, including policies and business models, with focus on EU and Scandinavia. Prior to Acreo, Mr. Mattsson was Senior Advisor at Ericsson. Mr. Mattsson has also been Advisor to ERISA (the European Regions' Information Society Association), and Director of the Sweden Broadband Alliance, an industry organisation. Mr. Mattsson has written a large number of articles and participated in several Swedish and European research projects on subjects such as open networks, business-models and regulatory issues.

2.5 About Stokab

Stokab is owned by the City of Stockholm and has the task of deploying and maintaining a passive fibre optic network in the region. Its purpose is to provide good conditions for the IT development and a positive economic development in the region. This is done by leasing out unlit fibre, so-called dark fibre, with the aim to create competition, diversity and freedom of choice, while keeping street disruption to a minimum.

3 The situation in Stockholm today

Stockholm has 100% broadband coverage, both fixed and mobile. The fixed infrastructures deliver broadband via fibre, coax (cable TV) and telephone copper lines (xDSL). When it comes to fibre there are essentially two competing suppliers (Stokab and Telia Sonera's Skanova) . In most apartment blocks all these techniques exist next to each other. In addition there is 100% mobile coverage from four different operators (both 3G and 4G/LTE network). In Stokab's fibre network there are over 100 active operators.

3.1 Historical background

The historical background to the formation of Stokab was the deregulation of the telecom market in Sweden, among the first countries in the world, conducted in 1993. The City of Stockholm's politicians were all deeply concerned that the Swedish Government's decision to allow the former telecommunications monopoly (today's TeliaSonera) to both own the infrastructure and sell services. The city's politicians endorsed the need for a neutral player to provide the basic IT infrastructure to all on equal terms to create competition, diversity and freedom of choice in the ICT market. Against this background, the City Council decided in January 1994 to form Stokab.

3.2 Stokab's fibre deployment

The deployment of the fibre network began in the commercial district of central Stockholm and expanded rapidly to the major industrial areas. In the mid 1990s region's major medical facilities were connected. In the early 2000s, the network was expanded with a ring around lake Mälaren that linked metropolitan areas networks around the Mälardalen region. The fibre network was also deployed in the Stockholm archipelago where all major inhabited islands are now connected. In early 2005, almost all neighborhoods in central Stockholm were connected. In 2007 the deployment of fibre-to-the-home to apartment blocks began, an expansion that was completed at the turn of 2012/2013. In addition to continuously making the network more robust and more capillary, work is underway to connect properties in new urban development areas and the city's elderly homes. An expansion in the street environment is also planned for easier and more efficient development of the so-called "smart city".

The network is currently the world's largest open fibre network with a length corresponding to going more than 30 times around the world. The passive fibre network is open to all on equal terms. It offers several advantages for operators:

- Low barrier to enter the market when an operator can lease the fibre connections needed, instead of investing in an own network deployment
- Fibre lines leased by a neutral player rather than from a competitor that also sells own services
- Wide ability to design the network structure when the network is initially built for competition and robustness, unlike when lines are leased from an operator who designed the network based on their own business needs.

3.3 Operators

Over 100 operators and service providers operate on Stokab's network. Many of these offer services targeted towards households. That so many operators are active in a city is highly unusual internationally. Essentially there are two types of operators: on one hand the traditional operators which, using own fibre or fibre leased from another actor, deliver their services, and on the other hand the so-called network providers (NP), which mainly use the fibre network from other actors, to offer a portfolio of service from different service providers (SP). The largest NPs in Sweden today were however bought by traditional operators. There is also a debate about the NP role in connection to the trend of services migrating to OTT (over-the-top). In such a situation the SP takes a role that approaches NP role.

4 Different types of fibre network

In Stockholm there are two models to connect households to the fibre network:

- Fibre to the building (FTTB)
- Fibre to the home (FTTH) with two fibres, one of which is used to deliver services such as triple play (broadband, TV and telephony); this model could be described as FTTH-S (fibre-to-the-Home Standard).

We are also evaluating a third model, which would make even more of tomorrow's challenges:

- Fibre to the home with more fibre than two, for example four, to every household; Such a model could be described as FTTH-A (Fibre-to-the-Home Advanced).

In Stockholm there are currently two players that connect buildings with fibre, namely Stokab and Telia Sonera's Skanova. Skanova generally connects properties with a small number of fibre per property, while Stokab has chosen to connect the properties with twice as many fibres as there are units in a property, i.e. two fibres per unit. Stokab's network structure is based on a node system. Each node connects roughly 30 properties with about 1500 households. Provided that the property owner has built a fibre network from Stokab's incoming fibre cables in the basement up to each unit, an operator can reach every single household from the node to which the property is connected.

4.1 FTTB (Fibre till building)

FTTB requires a fibre pair to each building. This is the traditional way of connecting buildings with fibre. Skanova uses essentially this connection model. With the FTTH structure, deployed by Stokab between 2007 and 2012, an operator can reach the property via Stokab network with both FTTB to FTTH. In the municipality of Stockholm FTTB can thus be used both on Stokab's and Skanova's fibre network. With FTTB, the fibre pair to the property is then connected to a simple switch or router (active equipment) from which a network cable is drawn to each apartment. The in-building network is almost always a data-communication copper network (CAT5/6 cables). Such networks can theoretically deliver speeds of 1 Gbps over a maximum 100 m distance. This solution is the most widespread in Stockholm (FTTH is currently used in just over 25% of the households). Often the property owner signs a contract with an operator (sometimes with two operators: one for Internet access and one for TV) that delivers services to all of the property. Sometimes the operator installs the in-building network on behalf of the property owner. Over the in-building network sometimes TV is sometimes also distributed (while sometimes, an existing coax network

is used to distribute television). This technology works well for traditional triple-play services (broadband, TV and telephony). However, the model implies restrictions on the freedom of choice and the ability to deliver so-called societal services. This is because an operator delivers services to all in the property. If the property owner contracts an NP on the network instead of a traditional operator, freedom of choice for households is increased. However, households can only choose between SPs with which the NP has an agreement. Service providers are also obliged to choose the technological solution that communications operator has selected. Delivering public services is challenging with FTTB, although the NP solution allows the delivery of Layer 2 services.

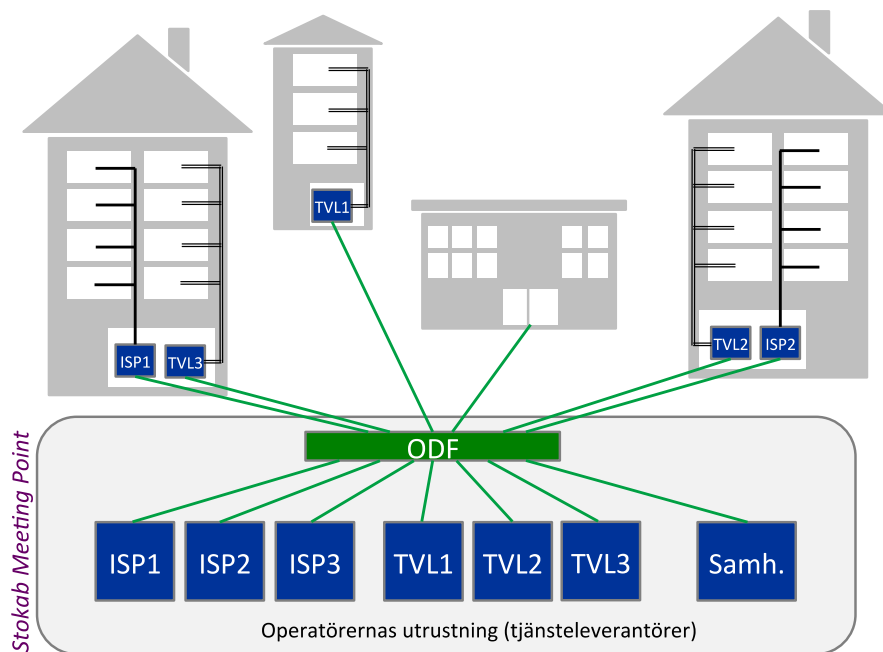


Figure 1 - FTTB model. *In green: fibre and other passive optical devices, in black: copper cables (- CAT5/6 = coax), in blue: electronic and opto-electric devices. ISP: Internet service provider (Internet Service Provider), TVL: TV provider, Samh.: societal services, ODF Optical Distribution Frame (where the fibres coming from outside are connected to the fibres inside a building).*

Pros and cons with FTTB

One advantage of the model is that households receive a regular computer network socket (RJ45) in the apartment that can be connected directly to a computer or wi-fi router (FTTH requires a powered media converter in the apartment, between the fibre and the household's devices). For an operator, the solution is attractive because it is possible to sell services to tens (sometimes hundreds) of subscribers, many times with a several-year contract. In addition, the operator needs to lease one or two fibres to reach an entire property (even if the cost of renting a fibre pair to the property in most cases is the same as for renting a fibre to every unit).

A major drawback of the model is limitations in capacity. In most cases speeds up to 100 Mbps are achievable without problem, but it may be

difficult in practice to achieve speeds of 1 Gbps, which in a few years will be important. Also, since the freedom of choice for households is limited, it leads to a less dynamic development of the broadband market.

4.2 FTTH-S (Fibre-to-the-Home Standard model)

In FTTH-S for each unit (apartment, business premises, etc.) two fibres (one fibre pair) are installed from the nearest node. In the node an operator places its active equipment (switches), and in each apartment a media converter (converting the optical signal in the fibre to the electronic signal for the data network socket, RJ45). A media converter is an active equipment, hence access to power outlets is needed.

The fibre itself allows virtually unlimited capacity. What defines capacity is the active equipment connected to the fibre cable. The equipment used for consumer use today allows speed of 1 Gbps, both down- and upstream. The day there is a need for even higher speeds, the equipment alone needs to be replaced, not the fibre.

The fibre delivery point is in the property basement, where there is no need for active equipment. In order to make use of FTTH, the property owner needs to build a fibre network between the fibre delivery point and each unit in the building.

For households, FTTH means that each can choose among the operators present in the nearest node. Furthermore, since only one of the two fibres are used by an operator to deliver services to the household, there is a second fibre unused. This fibre can be used for several different purposes:

1. For a competing operator;
2. For the property owner for the real-time measurement, control and monitoring (heating, power, water, doors, elevators, etc.)
3. For community services, such as e-health.

If purpose 1 is followed, two simultaneous operators can deliver services, and households can buy e.g. Internet access from a provider (through one fibre) and television from another provider (through the other fibre).

If purpose 2 or 3 are followed, each household can choose and buy services from only one of the SPs present in the nearest node (each household choose their own broadband provider and buy services from it: provisioning occurs by physically connecting the fibre to the SP's equipment in the Stokab node). Alternatively, if the owner allows an NP on the network, in place of a traditional operator, the competitive situation is the same as in the FTTB with NP.

If one wants to follow all three purposes, one can theoretically use WDM technology, whereby several different wavelengths ("colours") are used in the same fibre, one for each operator. However, the technology is complex and requires some interfacing and special equipment from the operators. Moreover, the cost of the WDM system for household very high. Freedom of

choice and high competition can be achieved more cost-effectively by making use of four fibres (FTTH-A) to each apartment, which we recommend and describe below.

Pros and cons

FTTH-S allows virtually unlimited bandwidth. In principle, in the future terabytes per second (millions of Mbps) can be transmitted over an optical fibre. There are a number of other advantages.

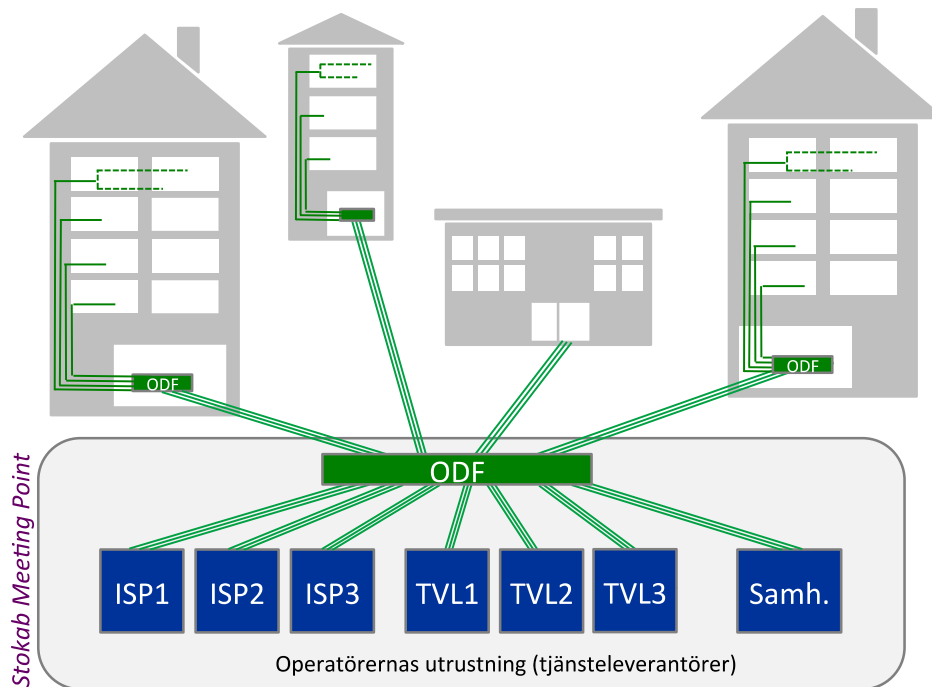
Unlike the FTTB model, where the operator needs to place the active equipment in a building's basement (the cost of this is virtually independent of how many customers the operator is in the property) in the FTTH model, the equipment may be used to reach customers in a variety of real properties. Concentrating the equipment in the node, instead of having equipment in each building where the operator has customers in, gives operators several advantages such as greater safety, increased equipment life and reduced energy consumption and operating noise. This is because the nodes have a controlled environment (temperature and humidity), backup capability, they are monitored continuously, allow physical access only to authorized persons, etc. In addition, managing all the equipment and all the customers in an area from one place reduces costs for equipment repair and maintenance (shorter lead times and optimization of travel). In addition, operators can more easily scale their business when more customers sign up: when several properties are accessed from one node, it becomes easier and economically possible to offer services to individual households in a property. Property owners have the advantage that they will not need to give the operator access to the property each time it needs to manage its equipment.

Increased freedom of choice for households is obviously positive, but it also means increased complexity for operators requiring individual, and over time, scattered fibre connections. On the other hand, it goes quite quickly to deal with this, when all switching between operators and customers takes place in the node and, unlike for FTTB, the operator does not need to access the property where the customer resides.

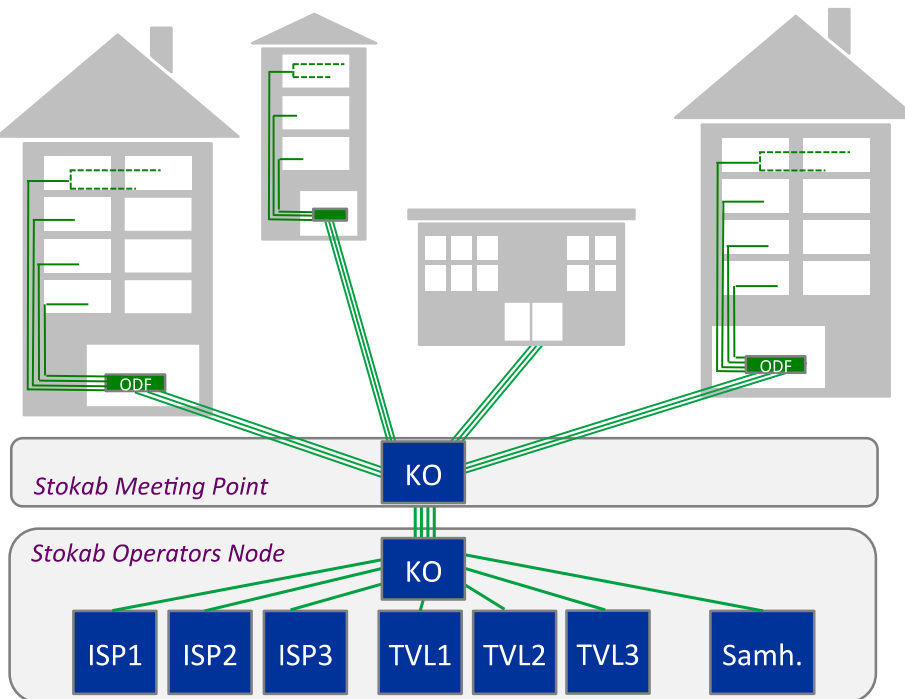
The ability to deliver public services is facilitated significantly in the FTTH model, when certain services that either require very high quality in terms of capacity and delay and/or are of a sensitive nature and therefore not suitable to be delivered in uncontrolled networks. Through FTTH-x, the actor (municipality, health authority, or other) who needs to deliver the societal service to a household, only needs to place its active equipment in the node and then reach the household via fibre (FTTH-x), regardless of which operator the property/households have chosen for commercial services. Thus a secure and controlled connection can be established quickly and at low cost.

The disadvantages of FTTH model are the need for power supply to the media converter in the apartment and the fact that the investment in an in-building fibre network in a property is currently slightly higher than a standard copper data-communication network (CAT5/6), used in FTTB

model. The time required for installation of fibre networks can also be slightly longer because the fibre is more sensitive to handle than copper cables.



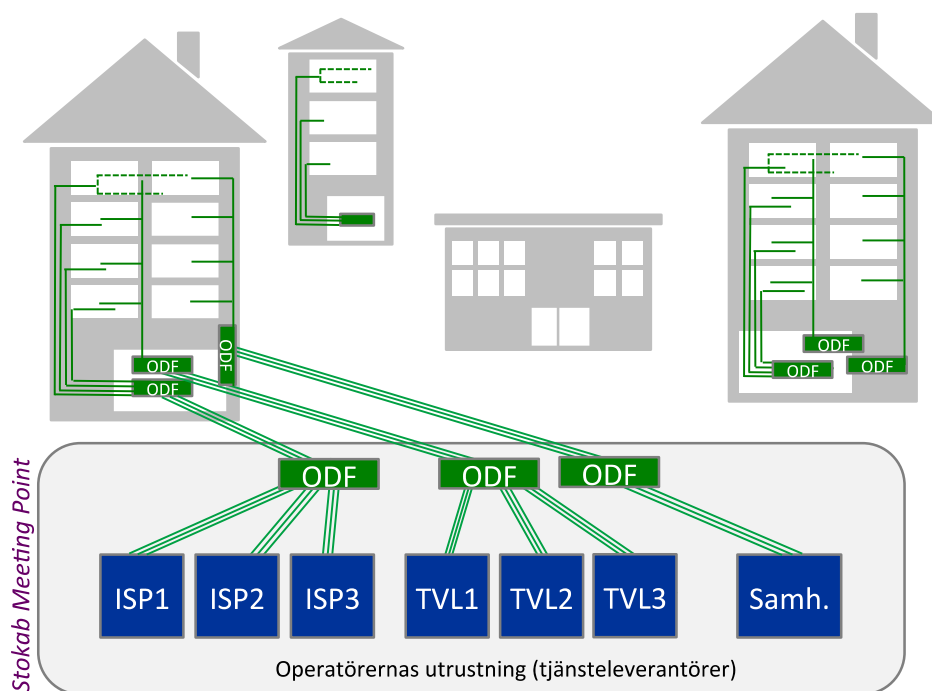
Figur 2 - FTTH model without NP. I grön: fibrer och annat passiv optisk utrustning, i blå: elektronisk och opto-elektrisk utrustning. För illustreringsenkelhet, är varje våning en lägenhet i figuren. ISP: Internet tjänsteleverantör (Internet Service Provider), TVL: TV leverantör, Samh.: Samhällstjänst, ODF: Optical Distribution Frame (där fibrer utifrån kopplas till fibrer inne i en byggnad, lokal, etc.)



Figur 3 - FTTH model with NP. In green: fibre and other passive optical devices, in black: copper cables (- CAT5/6 = coax), in blue: electronic and opto-electric devices. ISP: Internet service provider (Internet Service Provider), TVL: TV provider, Samh.: societal services, ODF Optical Distribution Frame (where the fibres coming from outside are connected to the fibres inside a building).

4.3 FTTH-A (Fibre to the Home – Advanced solution)

In the FTTH-A variant several fibres (e.g. four) are connected to each unit. The first fibre can then be used to deliver the Internet service, the second fibre to deliver television, the third to deliver societal services, and finally a spare fibre, for e.g. real estate services, or mobile signals or a combination thereof. All fibre to a unit could then be laid in the same duct. This provides the opportunity to deliver other services than the Internet in full competition, without the need for an NP role.



Figur 4 - FTTH model with several fibres per unit (three in this figure, in reality all fibres to a unit would be in one and the same cable). For simplicity we are showing only fibre connection to one building. *In green: fibre and other passive optical devices, in black: copper cables (- CAT5/6 = coax), in blue: electronic and opto-electric devices. ISP: Internet service provider (Internet Service Provider), TVL: TV provider, Samh.: societal services, ODF Optical Distribution Frame (where the fibres coming from outside are connected to the fibres inside a building).*

The key advantage of this model, compared to FTTH-S is an even wider freedom choice for end users.

FTTH-A solves several challenges compared to FTTH-S:

- Property owners have an obligation to ensure that all residents have access to TV.
- Property owners and/or energy suppliers will probably want to monitor, control and manage various things in real time in an unit, for example heating.
- The residents will also be interested to monitor, control and manage various things in their home (Internet of things).
- Even indoor coverage from mobile operators will need to be strengthened.

The ability to meet these challenges is increased if the in-building network is deployed with more than two fibres to each unit. For example, property owners are given good conditions, using one of the four fibres, to manage the operation, maintenance and monitoring of the buildings in an efficient and environmentally friendly way. Today there are many different systems and services for real estate-related services, but basically all services are connected individually. With a fibre-wired building, communication need is met

effectively while other capacity-demanding services are made possible. With an in-building fibre network, which the property owner controls, an intranet can for instance also easily be made available. Thus, property technicians and other staff have full access to the information and services available at the administrative office. A property owner can then purchase services without being dependent on any specific operator's own services. This is different from the situation in which an operator controls the fibre, in which the property owner runs the risk to depend on the operator's own services.

One drawback is that Stokab's so-called "in-building node", with the ODF (connection point) in the property's cellar is currently designed for in-building network with two fibres (FTTH-S). If a network with four fibres (FTTH A) is installed, a complementary ODF is required to be installed in the vicinity of the in-building node. This involves an extra cost.

5 Comparison between FTTB och FTTH solutions

5.1 Investment cost

To calculate the investment cost we must split it into network cost, installation cost and equipment cost. A FTTH solution requires the installation of fibre networks in the property. The difference in installation cost comes from the fact that the fibre cables must be handled somewhat more carefully. Ducting and material costs are comparable. Today, the difference in installation cost is not big between copper (FTTB) and fibre (FTTH) and is expected to be reduced further with time. On the other hand, if copper cabling (CAT5 or CAT6) is already present in the ducts, this can be replaced with fibre, by pulling out the copper cables and blowing in fibre cables. This operation is not very costly.

A FTTH solution with four fibres to each apartment would mean higher installation costs due to increased complexity, mainly in the form of an additional ODF in the basement. The complexity can be kept low with quad-wiring (ie a cable with four fibres for each apartment). The increased complexity in the management of fibres in ODFs can contribute to an increase in costs. The management of the four fibres in the apartment need not entail greater complexity when people are accustomed with various cables and ports for different services (TV, telephony and broadband).

5.2 Operational cost, energy consumption and footprint

In assessing the difference between FTTB and FTTH-x an analysis is also needed for the operational costs, energy consumption and footprint of each

model provides, ie how cost-effective and environmentally friendly each model. The cost per Mbps should also be considered in this context.

Here we have concentrated on only the cost relating to the Internet service. As we described earlier (and as shown in Figure 5) FTTB requires that at least one switch/router (the exact number depending on how many units there are in the building) is placed in the basement where the property is connected with fibre. This leads to an increased operational costs and energy consumption.

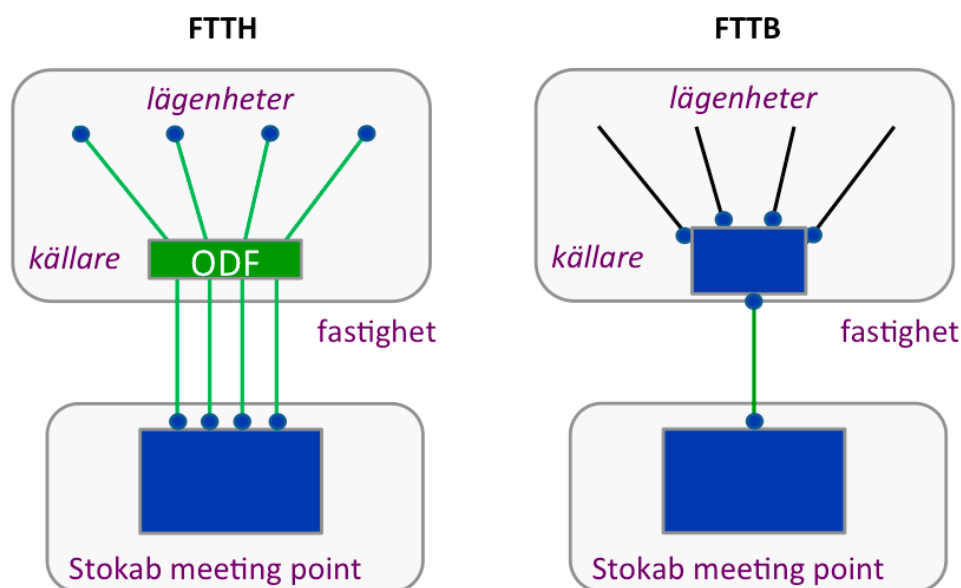
- Energy consumption in modern switches can be relatively low. A simple calculation based on figures from the OASE project¹ and figures from manufacturers² show that each end user increases the energy consumption of the switch with a couple of watts, probably a few tens kWh, or a few euros per year and active user.
- The extra switch also means purchasing and installation cost (a few tens of euros per end user, or anything under €10 per year and active user if it is amortised over 5 years).
- FTTB also leads to increased equipment maintenance costs, both because more of it is needed and because it is located in the basement of the property, making it time-consuming to access it; moreover the operating environment is basically never optimised for telecommunications. In the FTTH-x model all the equipment for a neighbourhood is in the same premises (in the node), so local operators can more easily reach it around the clock, all year round.
- On the other hand, the FTTH solution a media converters in the apartment is needed. This equipment is not needed in the FTTB solution. The cost of this is difficult to estimate because it depends on many factors (and it may be integrated with the router and WiFi in a home gateway), but probably a few tens of euros, so this would neutralise FTTB's higher cost due to the extra switches. As for energy consumption, media converters would probably use higher energy per user than the switch.

As for the footprint (space needed for equipment), there are two main differences:

- FTTH just needs an ODF in the property's cellar, which requires somewhat less space than a switch.
- Additional equipment may be required in the apartment for FTTH.

¹ IST-OASE project, Deliverable 4.2, *Technical Assessment and Comparison of Next-Generation Optical Access System Concepts*, 2013.

² www.cisco.com



Figur 5 – Comparison between FTTH when it comes to equipment needed in the node as well as the property. *In green: fibre and other passive optical devices, in black: copper cables (-CAT5/6 = coax), in blue: electronic and opto-electric devices. ISP: Internet service provider (Internet Service Provider), TVL: TV provider, Samh.: societal services, ODF Optical Distribution Frame (where the fibres coming from outside are connected to the fibres inside a building).*

5.3 Environmental impact

It is hard to resolve which model gives smaller environmental impact. In principle, the FTTH-x model is more environmentally friendly, because the switch/router connected to each apartment is placed in the nearest node (see the discussion on energy consumption above). The use of the switch can be optimised since it can be used to connect users in an entire neighbourhood. On the other hand, FTTH requires a media converter, which implies an energy consumption which is not needed with FTTB. In today's media converters, this may be higher than the energy savings from more efficient switches. However, one can expect that increased integration with other home equipment will eventually change this.

FTTH is more environmentally friendly in other aspects. Because the operating environment in the nodes is optimized for communications equipment (switches/routers) the life span of the equipment is expected to be longer. Moreover, the heat generated by the communications equipment may be recovered and used for other purposes. It is also expected that the operators' needs for physical transportation are reduced when multiple switches are combined in a specific location (the node) for an entire neighbourhood.

5.4 Performance, quality and freedom of choice

The different models also differ in terms of performance, quality and freedom of choice/competition.

- **Performance.** For newly installed FTTH networks, operators almost always use gigabit switches (1 Gbps in both down- and upstream). Older switches deliver 100 Mbps down- and upstream, but they can easily upgrade to 1 Gbps. FTTB relies on a copper network in the premises. Such networks (CAT5/6) is capable under favorable conditions to deliver 1 Gbps. Speed of 100 Mbps down- and upstream is no problem. Signal delay is slightly lower in FTTH networks, compared with FTTB. Looking a few years ahead, household needs of more than 100 Mbps will increase significantly. Therefore, in terms of performance, FTTH is clearly more future-proof than FTTB.
- **Quality.** FTTH is generally exposed to less downtime in the network (outage) and faster service for operators, since all necessary active equipment (switches/routers) is placed proper and accessible telecommunications facilities. Moreover, congestion in the network (contention) in the delivery of services in is less severe in FTTH than FTTB.
- **Freedom of choice/competition.** To sum up:
 - FTTB assumes that all of the property purchase services from the same provider, directly or indirectly through the rental fee / monthly fee to the property owner. Thus, the choice was. If a communications operator selected increases households' choice somewhat.
 - FTTH-S, with two fibres to every apartment, freedom choice for the households is broad. Partly because it is the second, unused the fibre, can be used by competing operator, and the coupler directly to the nearest node enables a marketplace so that each household can select the / operators that are in the node: one regardless of what other households in the property select.
 - FTTH-A, with four fibres to every apartment, freedom choice for the households is even broader, because TV and Internet services can be purchased from two different service providers. In addition, there is the ability to deliver societal services (e.g. e-health) in full flexibility, the possibility of environment optimisation in the apartments by monitoring, measuring and controlling in real time, the seamless delivery of must-carry TV channels, and the possibility to improve indoor coverage of mobile networks.

5.5 Societal services

When it comes to the possibility to deliver so-called societal services, such as e-health, the advantages and disadvantages are in principle the same as for the question of freedom of choice. Many societal services require a secure and stable connection with high capacity. For example, the fine-tuning of the medication for Parkinson's patients requires that the video communication is not disturbed or marred by delay/"hiccups".

- With FTTB the delivery of societal services becomes a challenge as these services would to be delivered as OTT service (over-the-top), or on layer 2. Thus, the provider of societal services must rely on the operator (or network provider) to prioritize its communication against the operator's own services.
- With FTTH-S, the second, unused fibre, may be used for societal services, irrespectively of whether the household and/or property subscribes to commercial services over the first fibre.
- FTTH-A, with four fibre to every apartment, allows easy delivery of societal services; the probability that one of the four fibres can be spared for societal service is quite high.

The ability to use societal services is essential to, among other things, meet the challenges the welfare is getting from an aging population. In a recently published study, we analysed current experiments with digital home-care services, and found that the socio-economic benefits generated are very large.

6 Conclusions and recommendations

It will be inevitable, sooner or later, to migrate to FTTH in order to meet the upcoming bandwidth capacity needs. FTTH increases freedom of choice and competition, the ability to deliver societal services, and to deal with other challenges such as environmental impact of buildings and mobile network coverage.

Based on a variety of aspects, we recommend FTTH with four fibre to each apartment (described in the report as FTTH-A). This model is possible to use in Stockholm, where Stokab, the City's IT infrastructure company, has connected almost all multi-dwelling properties with a multi-fibre solution, which enables FTTH-x, while properties that are connected with only a few fibre only can only deploy FTTB solutions.

We observe an increase in the use of so-called OTT services (over-the-top) such as Netflix, SVT-play, Spotify, Readly etc., while fewer consumers are watching so-called linear-TV (conventional TV). This leads to a greater need for broadband connectivity of high quality. If this process accelerates, and if the Internet goes from best-effort-based to being able to deliver certifiable Quality-of-Service, one can imagine a future where the Internet SP (the operator delivering the Internet service) will take over the role of network provider as the enabler of choice. This could affect the need for several fibres to every apartment. However, it is doubtful that the scenario will occur in the near future. Television habits change slowly, and QoS on the Internet protocol is a very complex topic that does not seem to be resolved in the near future. Having several fibres to each apartment, moreover, is critical to address other challenges like societal services, better indoor coverage of mobile networks and to optimise energy consumption.

A prerequisite to realise FTTH-x is that the property owner builds an in-building network, preferably with four fibres per apartment/room. Our recommendations to property owners in Stockholm are:

- Install an in-building network with four fibres to each unit.
- Set the requirement that the contracted operator place its active equipment in the node to which the property is connected.
- Set the requirement that the contracted operator uses FTTH-x and not FTTB.
- Allow only the first fibre to be used by the contracted operator so that the households have the opportunity to choose other suppliers via the other fibre(s).
- Install an in-building network that also allows for the efficient operation of the property, i.e. install the network even to the real estate key rooms and premises, such as garbage rooms, bicycle rooms, power distribution room, etc.