Worldwide development of FTTH

Martin Förster
Hochschule für Telekommunikation, Leipzig (FH)
Gustav-Freytag Str. 43-45, 04277 Leipzig
martin.foerster@hft-leipzig.de

Abstract: This article provides a general overview of current deployed FTTH systems worldwide. It presents the main network architectures and standards and briefly demonstrates some single company strategies in handling FTTH. Furthermore this article also shows possible FTTH solutions in future.

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1. Introduction

Today high speed Internet access and triple play services are mundane for many people around the world. But the hunger for speed is still growing and a much tougher competition between cable companies with their coax networks and telecommunication companies with their copper networks led to the cognition that the speed capacity of copper wires reached its limits and that only optical fibers can provide sufficient bandwidth for the future. So Fiber-to-the-Home (FTTH) became the major issue for broadband access networks.

2. Definitions and terms for Fiber-to-the-Home

Before looking at current Fiber-to-the-Home networks worldwide it is crucial to define the term FTTH. In general the designation for the utilization of optical fibers in the access network is Fiber-to-the-x (FTTx). The x refers to the location of the optical fiber endpoint next to the customer. This endpoint of the optical fiber is the optical-electrical interface and is located in some kind of transmission equipment, called Optical Network Unit (ONU) or Optical Network Termination (ONT). ONU and ONT are not exactly the same for ONU is used when the optical fiber terminates in a telecommunication cabinet next to several homes or businesses and ONT is used for the termination of the optical fiber within the customer premises [1]. So in terms of FTTH we talk about an ONT at the endpoint. The beginning point of the access network is located in a Central Office and is called Optical Line Termination (OLT).

Defining FTTH means defining the endpoint of the optical fiber. Besides FTTH there exist also the terms FTTB (Business [1] or Building [2]; in this article FTTB refers to Fiber-to-the-Building), FTTC (Curb), FTTCab (Cabinet), FTTN (Neighborhood), FTTO (Office), FTTP (Premises) and FTTR (Riser) [2]. The closest points to the customer are FTTH, FTTB, FTTP, FTTO and FTTR.

Fiber-to-the-Business and FTTO are the same term for providing an optical path to the premises of a business customer. The differentiation of FTTB and FTTR depends on the location of the ONT inside a building, but FTTR is a rarely used term and is to be neglected. And FTTP encompasses FTTB and FTTH. Finally, the line must be drawn between FTTB and FTTH. It is obvious that the part 'Home' in FTTH usually indicates the use of this term for the group of private customers with a huge number of access points. Therefore the focus of FTTH developments is the private customer and the mass deployment. The distinction between 'Building' and 'Home' is more complicated. For example an ONT located in a single family dwelling unit (SFU) can be classified as FTTB and FTTH. But is the ONT located somewhere inside an apartment building exclusive the apartments itself, only the term FTTB is the correct term. It should be observed that these definitions are individual decisions in some cases , thence one shouldn't rely on these terms to severely. Additionally, the term FTTP is a more general circumscription for both.

Finally the most important terms are FTTC, FTTO and FTTP inclusive of FTTB and FTTH.

3. Overview of FTTH subscribers worldwide

The worldwide situation of FTTH is very inhomogeneous on a larger scale and the status of the FTTH deployment and the utilization of standards in a country depends on the local telecommunication companies, regional distinctions, history of broadband Internet access in that country and individual technical issues. So every country and even every telecommunication company can be a different case. Fortunately, there are basic similarities in the utilization of standards and the progress of FTTH. So there can be identified three big FTTH markets: Asia-Pacific, Europe and North America.

According to the FTTH Council [3] there are 32 million FTTH connections worldwide. More

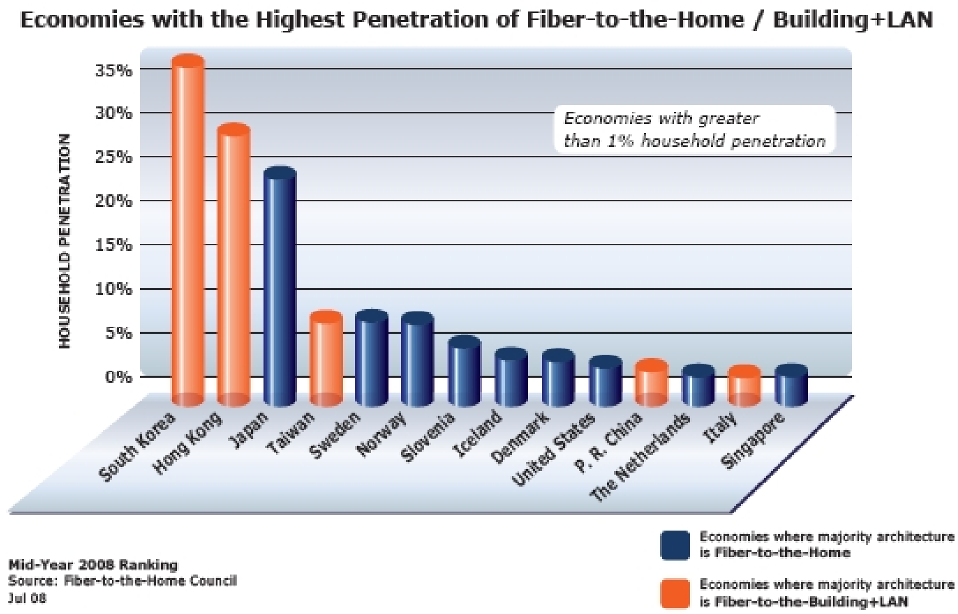

Fig. 1. Worldwide FTTH household penetration [3]

than 27 million connections are accounted by the Asian region. Figure 1 displays the household penetration for FTTB/H worldwide. The top four positions are occupied by the Asian countries South Korea, Hong Kong, Japan and Taiwan, although the majority architecture is only in Japan FTTH. In fact Japan is the country with the most FTTH connected households in the world (12.2 million [4]) followed by China with 7.5 million [3] households.
Secondly, the North American region reported more than 3.3 million FTTH connected households and the United States is with 3.3 million FTTH connected households third in the total rank after China. Additionally, the United States is the economy with the largest total growth of FTTH subscribers per year.
The European region reported 1.4 million FTTH connections with Scandinavian countries and Slovenia leading the penetration rate. The Netherlands and Italy are also listed in the chart with a penetration rate of 1.4 per cent. Big economies like Great Britain, France and Germany are not listed but are about the engage in FTTH connections [3].
So far the Asia-Pacific region and especially Japan are of the most interest.

4. BPON in Japan

Japan is the main impeller of the worldwide FTTH development and accounts for the most FTTH subscribers in the world. So the Japanese broadband market is the prime example for looking at the recent history, the current state and future perspectives of FTTH.
In Japan the Nippon Telegraph and Telephone Corporation (NTT) with its subsidiaries NTT East and NTT West can be considered as market leader [5] and technology pioneer [6]. NTT set in November 2004 the target to move 30 million customers to optical access by 2010. Furthermore, one third of NTT shares is owned by the Japanese Government.
NTT started to offer its first FTTH service with Cable TV (CATV) in 1997 and launched its high-throughput, flat-rate Internet access service in 2000. In 2002 NTT started with the roll out of the Broadband Passive Optical Network (BPON) for residential high-speed Internet services

and opened FTTH to many private users.
BPON is standardized by the G.983 series of ITU-T Recommendations and is a further development to the Asynchronous Transfer Mode based PON (APON). That means BPON uses ATM as the transport and signaling protocol but is able to transport any kind of traffic [1]. The decision for the ATM based FTTH infrastructure has three reasons: First, telecommunication service carriers used ATM extensively at this time. It was a proven technology. Second, ATM with its fixed-sized cells and asynchronous Time Division Multiplex offers a flexible and scalable traffic management especially for many users in the access network. Finally, ATM has tough Quality of Service (QoS) features, in particular Operation, Administration and Maintenance (OAM) features.
But lets first have a look at the architecture of BPON. Figure 2 shows the basic architecture of a BPON according to ITU-T G.983.3. It is consisting of an OLT for packet services such as data and VoIP with a WDM device (in reality they are one device), a single Single-mode fiber between the OLT and an optical 1-to-N splitter which splits the traffic to the ONTs in the customers buildings/homes. An optional video overlay can be implemented, too.

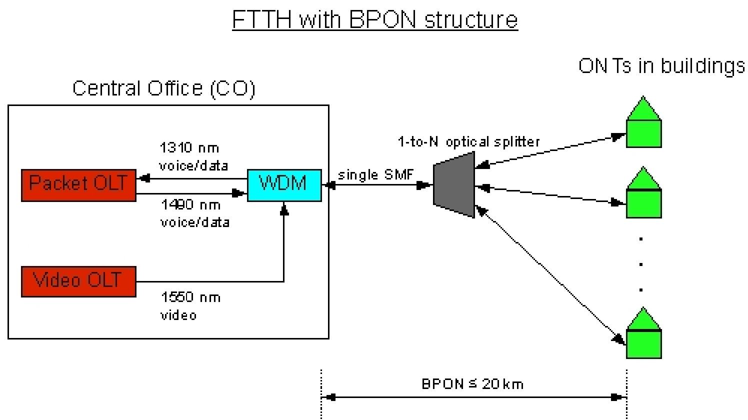

Fig. 2. BPON structure

The key-feature of BPON is the implementation of two different wavelengths for downstream (OLT to ONT) and upstream (ONT to OLT). G.983.3 specifies the final wavelength allocation with $1480\,nm$ to $1500\,nm$ in downstream and $1260\,nm$ to $1360\,nm$ in upstream. Additionally, it implements optional services (e.g. video distribution services) in the wavelength band of $1550\,nm$ to $1560\,nm$. G.983.1 declared slightly different wavelengths for downstream and upstream without optional services. In 2002 NTT chose to roll-out BPON according to G.983.1 for economical reasons [2]. Instead of implementing a separate video overlay as proposed in G.983.3 they introduced IP video services like Video on Demand (VoD).
However, the G.983-series offers a maximum bit rate of 1.2 Gbps downstream and 622 Mbps upstream depending on the quality of the components in OLT and ONT. NTT implemented its BPON with 622.08 Mbps in downstream and 155.52 Mbps in upstream. A typical OLT is able to manage 32 PONs simultaneously [1]. Combined with one 1:32-splitter next to the customers per PON this makes 1024 FTTH subscribers per OLT. Of course that means 32 users share 622.08 Mbps downstream and 155.52 Mbps upstream which results in the worst case to 19,44 Mbps / 4,86 Mbps downstream and upstream.
As mentioned above BPON utilizes ATM as transport and signaling protocol. ATM cells are 53

byte long (fixed-length) and are divided into a 5-byte control header and 48 bytes of information payload. Every kind of voice and data traffic is encapsulated in these 48 bytes. The fixed cell size of ATM is excellent for triple play traffic. Voice and video packets are normally small compared to data packets. If the two types of low-delay traffic and not time-sensitive traffic are mixed together by ordinary multiplex techniques, the low-delay traffic could suffer great delays. By using small sized fixed-length cells the packets of both traffic types are divided into equally ATM cells and neither of them suffers long delays [1]. So in ATM the prioritization between voice/video packets and data packets is covered automatically.

The traffic flows of a BPON are different for downstream and upstream. In the downstream direction the OLT sends informations in the form of ATM cells to all ONTs connected to the PON. Every ONT receives all downstream traffic. To ensure security the information in the ATM cells must be encrypted differently so that an ONT is only able to read the information addressed to it. A 622.08 Mbps downstream frame consists of 224 ATM cells each 53 bytes long. This frame format is designed for Time Division Multiplexing. The 224 ATM cells are divided into two types of cells: 216 data cells carry information, including user data, signaling information and OAM messages (operation, administration, management), and eight PLOAM (physical layer OAM) cells. The PLOAM cells contain information for synchronization, error control, security, maintenance and bandwidth allocation. They are inserted into the frame at the beginning and then every 27 time slots. One time frame has a length of $152.67\,\mu s$. Because of the eight PLOAM cells the effective downstream rate is 599.86 Mbps.

In the upstream direction a 155.52 Mbps time frame consists of 53 ATM cells each 56 bytes long. The additional 3 bytes are an overhead assigned to each cell and contain a minimum of 4 bits of guard time, a preamble and a delimiter field. The guard time provides an adequate distance in time between two cells to prevent collisions with cells coming from different ONTs. The preamble field is used by the OLT to determine the phase of the incoming cell relative to its local clock and can be used for bit synchronization. The delimiter field is a unique bit pattern indicating the beginning of the incoming cell and can be used for byte synchronization. The upstream traffic also contains PLOAM cells from each ONT. The PLOAM cell rate for each ONT is defined by the OLT. The minimum rate is one PLOAM cell every $100\,ms$.

There are now two basic issues left. The synchronization between the ONTs and the traffic control. For the synchronization the OLT measures the distance of each ONT. This is called ranging process. Once the OLT knows the distances, it assigns every ONT an optimal synchronized time slot. With that each ONT can send its data to the OLT without considering the other ONTs. The synchronization information from the OLT to each ONT is delivered with the PLOAM cells. Each PLOAM can be read by any ONT and has 27 grants for upstream time slots. In the BPON used in Japan there is an asymmetric transmission case (622 Mbps / 155 Mbps). The upstream time frame adheres only 53 cells. Therefore the last grant of the second PLOAM cell from the OLT is an idle grant and all grants in the PLOAM cells 3 through 8 are idle grants, too. So the ONT only has to look inside the first two PLOAM cells and check the data grant number with its own.

The traffic control in the downstream direction is done by the OLT depending on the downstream traffic of each ONT. In the upstream direction the ITU-T recommended 2001 in G.983.4 a dynamic bandwidth allocation algorithm (DBA) controlled by the ONT. The upstream grants are apportioned in traffic containers and categorized into the priority classes 'fixed', 'assured', 'non-assured' and 'best effort'. For calculating the necessary upstream bandwidth allocation there are two procedures possible. In the idle-cell monitoring method the ONT is sending idle-cells to the OLT if it has no upstream traffic. The OLT monitors the idle-cells and reassigns unused bandwidth to other ONTs. In the status reporting method each ONT sends status information of its traffic queue to the OLT. In order to keep the costs for the ONT low the idle-cell-

monitoring method is the better one.
The extensive deployment of BPONs in Japan by NTT until 2005 prepared the current success of Japan in terms of FTTH subscribers. PONs are cheap networks compared to active optical networks and can be upgraded to new standards just by replacing the OLTs and ONTs. Especially BPON offered already in 2002 high speed Internet and triple play services. In 2005 NTT had a market share of 77 per cent of all FTTH connections in Japan [5]. That correlates with approximately 3.5 million subscribers [4]. In 2005 NTT started with the implementation of a new PON standard [6]. Thereby BPON wasn't installed in new FTTH connections since 2006. Although BPON is not state of the art it is still the basis for the following standards and still running in Asia and North America.

5. GEPON in Japan

Alongside NTT many diverse players entered the FTTH market in Japan. Most of them installed BPON [6], but some of them also pioneered an alternative approach to FTTH with P2P Ethernet.
In 2005 other operators in Japan focused on Ethernet based FTTH connections. NTT clearly calls the deployment of Ethernet products by new market players and falling prices for technology and products of the LAN market the main reasons for focusing on Ethernet based FTTH connections [6]. The IEEE 802.3ah Task Force Ethernet in the First Mile (EFM) defined the Ethernet interface series [7] which was approved in June 2004 [1]. One part of it is the Ethernet PON (EPON). NTT started with the employment of EPON in 2005 [6] and so did other carriers in Japan [8]. EPON has a nominal bit rate of 1250 Mbps (after 8B10B coding). In Japan they call the EPON also GEPON (Gigabit Ethernet PON) although they appear to be the same. Due to the fact that the EFM task force used EPON as name this article refers to it as EPON, too.
However, the effective bit rate of EPON is 1 Gbps symmetrically split up to 32 homes which leads to a worst case bit rate of 31.25 Mbps per subscriber. The basic architecture of EPON is identical with the BPON architecture presented in figure 2. It also uses the wavelengths for downstream, upstream and video overlay as recommended in ITU-T G983.3. Instead of fixed-length ATM cells EPON is using variable-length IEEE 802.3 Ethernet MAC frames with a different use of the Preamble and the Start Frame Delimiter [1] as shown in figure 3.

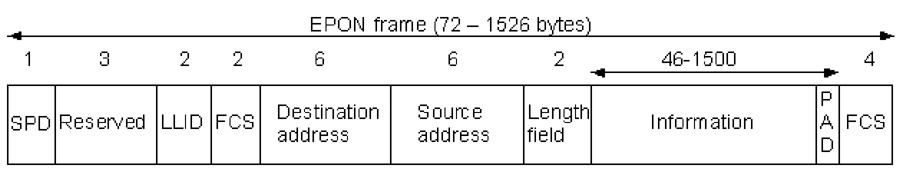

Fig. 3. EPON frame

The using of variable-length Ethernet frames instead of fixed-length ATM cells has several advantages: The reduction of the overhead compared to the information (ATM: 5 out of 53 bytes are overhead; Ethernet frame: 26 out of up to 1526 bytes are overhead), avoiding that a single corrupted or dropped ATM cell leads to retransmission of the entire IP packet and the widespread use of Ethernet technology. Today it makes no sense to split up IP packets into small ATM cells when Ethernet frames are the natural choice for such kind of traffic.
The really import parts of the frame displayed in picture 3 are the Start-of-Packet-Delimiter (SPD), the Logical Link Identifier (LLID) and the Destination Address (DA). The other parts have the same function as in normal Ethernet frames. The SPD has a length of 1 byte and

contains synchronization markers which are send every 2 ms to synchronize the ONTs with the OLT. The 2 byte LLID is used for the ONT identification. In downstream direction the OLT broadcasts all frames to all ONTs. But every frame is addressed to a single ONT through the LLID. ONTs on the other hand only accept frames with their own LLID and place their own LLID in frames they send to the OLT. The LLID provides a minimum of security but is not enough. The Information part of the frame needs to be protected by encryption unique for every ONT in a PON section. So every ONT is able to read the header with the MAC-address of the receiving ONT but is not able th read the information [9]. Theoretically it would be also possible to encrypt the entire frame so that malicious ONTs couldn't read anything of the frame (which protects the MAC addresses of other ONTs). But this kind of encryption would be implemented in the physical layer which is a connectionless layer. Implementing this kind of encryption would mean that the physical layer of the OLT would have to apply different keys for different ONTs [9]. It would also prevent the synchronization by the SPD. The first two bits of the DA have special functions. The first bit distinguishes between single user addresses and multicast addresses. The second bit indicates whether the address is a local or a global address. With the combination of LLID, information encryption and MAC address the broadcasting of the frames is secure.

The upstream direction needs a special procedure. In normal Ethernet CSMA/CD would be sufficient for coordinating several transmitters in a shared medium. But this is not possible for PONs. So the IEEE 802.3ah Task Group developed the Multipoint Control Protocol (MPCP) which is responsible for the discovery process, bandwidth assignment and transmission timing. The MPCP uses special types of 64-byte control messages: GATE and REQUEST messages for assigning and requesting bandwidth. REGISTER_REQUEST, REGISTER and REGISTER_ACK for auto-discovery, ONT registration and ranging process.

The OLT periodically broadcasts a discovery GATE message with a discovery LLID. When an ONT is turned on or resets it waits for such a discovery GATE message and answers at the assigned time slot. The registration process is carried out by all messages except of REPORT. In this process the ONT gets an unique LLID assigned.

The bandwidth assignment uses the DBA algorithm and the REPORT and GATE messages. The ONT indicates its bandwidth requirements with the REPORT message. The DBA algorithm inside the OLT calculates then the upstream transmission schedule of all ONTs and the OLT sends them with GATE messages to the ONTs. Each GATE message can contain up to four transmission grants.

NTT started also a video distribution system at the 1550 nm overlay. They use video broadcasting with RF formats (Radio Frequency) in conjunction with content providers. But they clearly see the combination of IP video and RF formats over the video overlay as an important key for triple play offerings [6]. Their video broadcasting system is extremely powerful. They developed an RF video delivery system named SCM-PON (Sub-Carrier Multiplexing PON) which can transmit 110 carriers with a bandwidth of 6 Mhz. By transmitting digital 64-QAM-TV format with 110 carriers they can transmit up to 500 standard TV programs [10].

6. South Korea and China

A brief look on South Korea and China reveals similar considerations as in Japan. Both countries have a higher concentration on FTTC and FTTB, but FTTH makes up for that.

In South Korea APON was evaluated in the late 90s and around 2001 BPON was considered for mass deployment. But the mass deployment for true FTTH showed up to expansive compared to ADSL and a BPON deployment in a FTTC structure would have vanished the advantages of PONs. So BPON wasn't deployed on a large scale [2]. Today the main architecture in South Korea is EPON. WDM-PONs are considered for deployments in the future and were success-

fully demonstrated in 2005 [2], [11].
China also started with the ATM based APON in 2001. But like in South Korea APON respectively its successor BPON have not been deployed on a larger scale due to its complexity and high equipment costs. Today, many vendors in China are focusing on EPON but also on Point-to-Point Ethernet (P2P Ethernet) and Gigabit-capable PON (GPON). EPON is deployed in areas with high population densities and GPON is mainly deployed for enterprises. P2P Ethernet is preferred to EPON for residential homes when they have an awkward disposition and it comes into consideration for business cases with higher bandwidth needs [2].

7. The United States

In the United States the competition between telecommunication operators and cable operators has been always strong. For a long time there have been more subscribers for cable-based Internet access than for xDSL-based Internet access. In 2006 it seemed that the growth of xDSL subscribers has been faster than the growth of cable subscribers [2]. In order to make the initiative and prepare for higher bandwidth Internet access and triple-play major telecommunication operators like SBC (now AT&T) and Verizon committed themselves to a large-scale deployment of FTTH access networks in their respective regions. In 2004 Verizon started with its large-scale deployment of fiber networks based on BPON (622 Mbps downstream, 155 Mbps upstream and a RF video overlay in compliance with ITU-T G.983.3). SBC started also with its BPON deployment in the last quarter of 2005 without a video overlay (instead of that they are focusing on IP based services like IP video). They installed FTTH in greenfield areas and FTTN + VDSL in brownfield areas. Verizon started deployment of GPON in 2007 [12] and SBC also plans to move to GPON soon [2].
GPON as recommended in the ITU-T G.984.x series has the same architecture like the PONs before. It is a direct advancement of BPON and pays credit to the widespread use of Ethernet. Therefore it uses DBA and OAM messages like in BPON. GPON is able to carry all service types. The downstream bit rate can be 1.2 Gbps or 2.4 Gbps and 155 Mbps, 622 Mbps, 1.2 Gbps or 2.4 Gbps in upstream direction. Verizon is using 2.4 Gbps downstream and 1.2 Gbps upstream [12]. The split ratio of GPON is recommended with 1:64 but can be up to 1:128 [13]. But Verizon prefers to use split ratios of 1:32 for single family FTTP deployment [12]. That makes in the 'worst-case' 75 Mbps downstream and 37.5 Mbps upstream. An real advancement in GPON is the encryption of the information part with the Advanced Encryption Standard (AES).
The general GPON frames for downstream and upstream are displayed in figure 4.

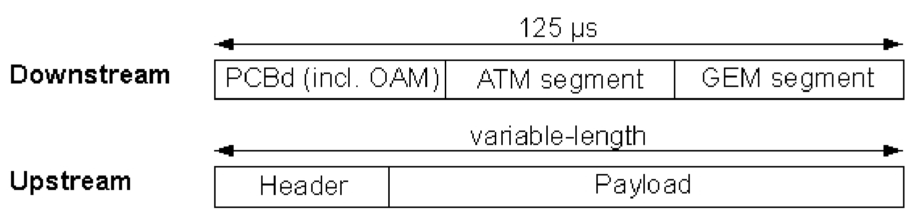

Fig. 4. GPON frame

The downstream frame has a fixed-length of $125\,\mu s$. The Physical Control Block for frames going downstream (PCBd) contains the information used to control and manage the network (including OAM). Behind that is the payload which can consist of optional ATM segments and a variable-length GPON encapsulation method (GEM) segment. The GEM segment can carry any kind of data and has a length of up to 1500 bytes. Larger data is fragmented as it is in

Ethernet. The encapsulation offers proper management for multiple service flows from different ONTs. The upstream frame has a variable length and consists of a header and a payload part. The header is less complex than in the downstream frame but is still enclosing information for control and management and carries OAM messages and the dynamic bandwidth report for the DBA algorithm inside the OLT as well. The payload also consists of a GEM segment and an optional ATM segment. In the upstream direction a guard time of 25.6 *ns* is inserted between every ONT packet due to higher bit rates and therefore smaller pulse widths [1].

8. FTTH in Sweden

As mentioned before Sweden is the European country with the most FTTH subscribers. The market there is highly competitive as it is in many other European countries [2]. Sweden is a good example for a different approach to FTTH. Asia and North America favor PONs as the key for a widespread FTTH deployment. But there is an alternative to PONs: P2P Ethernet or Active Ethernet. This version is largely deployed in Sweden and in many other European countries, too. The Active Ethernet is a concept also developed by the EFM task group and is specified in the ITU-T recommendation G.985. In fact the EFM task group proposed three physical specifications for an Ethernet based access network: EPON, Ethernet over Copper and Ethernet over fiber (which in general describers Active Ethernet). It uses the same wavelengths as BPONs but without an video overlay (as a result the downstream wavelength is 1480 *nm* to 1580 *nm*) [14] and it has the same data transportation specifications as EPON. ITU-T G.985 only describes a 100 Mbps P2P Ethernet based optical access system. Like in EPON it is also possible to use 1 Gbps by increasing the bit rates at the active equipment on both sides. But at the moment this is not necessary. The Active Ethernet uses point-to-point optical links between ONT and OLT. In most cases there is an active switch next to the customers premises. The switch is able to buffer data so all subscribers get a full 100 Mbps connection. This is enough bandwidth to offer a full triple play service [2]. Compared to a GPON with 1 Gbps shared amongst 64 customers Active Ethernet appears then very attractive. The disadvantage of Active Ethernet is the large number of optical fibers and active switches in the field. But therefore it providers higher guaranteed bit rates and better adjustments to customers needs and individual service wishes.

9. The future of FTTH

Future FTTH access systems are expected to have at least 100 Mbps per subscriber (asymmetric or symmetric) [1]. There is more than one possibility for achieving such bit rates depending on the starting basis.

Active Ethernet can be easily upgraded by upgrading or replacing the transceivers in ONT and OLT. 100 Mbps appears to be the most deployed bit rate but 1 Gbps has also been deployed [15]. So far Active Ethernet even meets bandwidth demands in the presence and near future. A comprehensive upgrade to 1 Gbps transceivers would satisfy the future demands for more bandwidth. A future installation of 10 Gbps is depending on the available transceivers (especially for the ONT) and the development of Ethernet itself. Additionally, 1 Gbps is still enough to challenge future PONs.

Future PONs are divided into TDM based Next Generation PONs (NG-PON) and WDM based WDM-PONs. Because of the sharing bandwidth nature of TDM based PONs they can only meet demands in the near future by using 10 Gbps as shared bit rate.

The WDM PON uses different wavelengths in order to manage the traffic of multiple ONTs. There are no proposed recommendations or tangible systems yet available. There are only some proposals. Thereby it is hard to determine a likely WDM-PON design. One design is to use separate wavelengths for different ONTs leading to TDM broadcast in downstream and WDMA in upstream [1]. Another idea is a vice versa design leading to WDM in downstream and TDMA in upstream which pays attention to the fact that private broadband traffic is asymmetric in most cases [2]. In this design there is also just a minimal upgrade or non upgrade at all required (depending on the existing photo diode) for the ONT which leads to cost reductions because the ONT represents e.g. 85 per cent of the equipment costs in a 1:32 PON [16]. A comprehensive design may include two unique wavelengths per subscriber or a design with less wavelengths than users (leading to e.g. WDM broadcast in downstream and WDMA with TDMA in upstream). However, there is no proposal for a frame structure yet. In theory there could be used Ethernet frames like in EPON, GEM frames like in GPON or even a new frame structure. But there are two problems to be solved in WDM PONs. First it is necessary to have affordable colorless ONTs. Otherwise each ONT would have a fixed transmission wavelength which would make the configuration and administration of the PON extremely complicated. Second there is a problem with the amount of available wavelengths. The Coarse WDM (CWDM) in the wavelength area between $1271\,nm$ and $1611\,nm$ with $20\,nm$ wavelength spacing [17] offers only 18 wavelengths which wouldn't be enough. Dense WDM (DWDM) would offer more wavelengths but requires a wavelength spacing of $0.1\,nm$ [18] which calls for temperature stabilized lasers. Anyway, the WDM-PON is favored by NTT to be the NG-PON in Japan [1].

A more feasible and most promising approach appears to be the 10 Gbps TDM based PONs / NG-PONs [19] because they allow a cost-effective and simple solution and they don't have such basic problems as the WDM based PONs have. The fundament for that is GPON and EPON. Both standardization groups, the ITU-T with FSAN and IEEE, are studying for NG-GPON and NG-EPON (asymmetric) but haven't released any recommendation until now [16]. NG-GPON has a considered specification of 9.95 Gbps downstream and 1.24 Gbps / 2.49 Gbps upstream and NG-EPON is considered with 10.31 Gbps downstream and 1.25 Gbps upstream. Apart from that a 10G-EPON was already demonstrated with more than 9.9 Gbps downstream and more than 9 Gbps upstream by increasing the burst length for the upstream transmission [19]. Both standardization considerations exclude a symmetric bit rate because the access services have asymmetric characteristics. The current main research problems are the transceivers for the ONTs and the feasibility of different approaches to these architectures. For instance the first cost-effective transceiver module as ONT was presented in 2008 with the above considerations [16].

Finally, the future of FTTH is on its way but still needs more research for the mass deployment. Especially cost reductions are at focus to assure feasibility. A combination of WDM PONs and NG-PONs might dominate the remote future. Meanwhile EPON dominates the Asia region, GPON is about to dominate in North America and Europe remains a diverse market with focus on Active Ethernet.

10. Conclusion

This article defined the term FTTH and provided a brief overview over the three main markets of Asia-Pacific, North America and Europe with focus and Japan, the United States and Sweden. Thereby the main optical access architectures of BPON, EPON, GPON and Active Ethernet concerning their functionality, feasibility, standardization and characteristics have been investigated. In the end this article investigated future FTTH solutions with the result that there is still much to research and that there are different possible solutions for the future.