The design and performance of the hybrid access network for FTTH bottleneck areas

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Abstract—It is the development trend of the current carriers to enhance the rate of broadband services. The FTTx+VDSL2 access network is one of the best choices for the broadband access network, and migrating to the FTTH access network. It may be difficult to build the fiber into/in the house for some situation, such like the ful-filled line pipe and the decoration issues. The carriers have to introduce new methods or technologies for higher rate to form a hybrid access network in the FTTH bottleneck areas. In this paper, we had investigated the various technologies and architectures that could provide high speed access network and enlarge the coverage of the broadband service, including VDSL2 bonding, vectoring, G.fast, G.hn. Furthermore, we also proposed the test technologies and results to verify these technologies.

Keywords- VDSL2, Bonding, Vectoring, G.Fast, G.hn, FTTH

I. INTRODUCTION

With the rapid growth of global broadband services, and consumer demand for broadband services growing, global carriers build actively broadband networks to meet user demand for network bandwidth and high-quality broadband services. As the rapidly growing number of FTTH (Fiber-to-the-home) users in recent years, it is more important to telecom carries about network technology and deployment, especially GPON (Gigabit-capable Passive Optical Networks). However, the permeability of the fiber is limited due to that the client site is not yet completely universal, and some problems for deployment issues, for example, the line pipe is filled, or the issues of house decoration, to cause the fiber can’t get into the home (called “FTTH bottleneck areas”, shown in Figure 1). It is still based on DSL (Digital Subscriber Line) technology for wired access network now, especially VDSL2 (Very-high Digital Subscriber Line 2) technology for more highly rate. Therefore, the FTTx (FTTN/B, Fiber To The Node/Building) + VDSL access network with GPON technology is the one of the best choices for the broadband access network.

Because there is the crosstalk interference from other VDSL2 circuits within the same cable, the transmission rate will degrade when the transmission distance is increasing. Currently ITU-T (International Telegraph Union - Telecommunication Standardization Sector) had drawn up many standards for VDSL2 technology to enhance the rate, including G.993.2, G.998.2 (G.bond) and G.993.5 (G.vector). It also had established the home networking standard of G.9960 (G.hn), and will development the new technology standard G.9700 (G.fast) for high-speed data rate.

![Figure 1. The FTTH bottleneck areas architecture](image)

It would be expected that these techniques can be helpful to solve the high-speed requirement in FTTH bottleneck areas for carriers. This paper introduced these new techniques, and analyzed what problems may encounter when these techniques deployed in broadband networks. We also proposed the test technologies and the test results to ensure these techniques work well.

The remaining of this paper is organized as follows: in Section II, we illustrated the advanced technologies, and their application architectures. The problems, which the operator shall overcome, also be analyzed briefly. The technologies test methodologies were proposed and proved by experimental test results in Section III. It also pointed out the issues to consider when performing technical tests. Finally, the conclusions were made in Section IV.

II. THE ADVANCED METHOD OF TECHNOLOGIES

ITU-T G.998.2 Ethernet-based standard was developed for bundling multiple DSL coppers circuit to a logical channel in order to provide higher bandwidth for use. The vectoring technology specified in the ITU-T G.993.5 standard is one if the technologies to eliminate crosstalk interference resulted from other VDSL2 circuits in the same bundle cables. By the vectoring technology, the rate of the VDSL2 link would be almost the same as that without crosstalk. In order to deliver the 1Gbps broadband service, the G.fast and the G.hn technologies were developed and specified in ITU-T G.9700 and G.9960 standards, respectively. Hereinafter, we described these techniques.
A. Bonding (G.998.2)

Bonding technology applications is target from the extending the distance to gradual moving towards the upgrade rate. Bonding technology is mainly in between TPS-TC layer (Transmission Protocol Specific TC Layer) of the VDSL domain and the Ethernet domain to add Rate Matching and PME Aggregation (Physical Media Entity Aggregation) management functions and through bundle protocol. It controls the operation of the bonding group. It based on the state of each line of the bonding group, automatically determine whether the line into service. It works without interrupting the service to be added line to the bonding group or remove line. Therefore, carriers will increase the transmission rate using bonding technology, management issues should also consider thinking deeply.

Now VDSL2 devices mainly use 2-pair of wire bundle with 17a profile technology. The architecture includes two ports of CO (Central Office) and bonded CPE (Customer Premises Equipment) through two telephone lines, as shown in Figure 2.

![Figure 2. Bonding application architecture](image)

B. Vectoring (G.993.5)

To achieve higher rate for copper network, self-FEXT (Far-End crosstalk) would play a key bottleneck, but vectoring technology could reduce the crosstalk level. Vectoring mechanism works as described in Figure 3; Vector Control Entity (VCE) can analysis and cancel the crosstalk among a vectoring group that is composed of multi-line (CO and CPE) in same cable. For upstream direction, the signal from the receivers of CO-side would be analysis and the crosstalk could be cancelled through post-coding. As for downstream direction, the receivers of CPE-side would report the related message, and VCE estimates the crosstalk and uses pre-coding to mitigate the FEXT.

![Figure 3. Vectoring working mechanism](image)

C. G.fast (G.9700)

G.fast technology will increase the use of the bandplan to 106MHz, even to 212MHz, and changed the modulation schemes from VDSL2 taken by the FDD (Frequency Division Duplex) technology to G.fast taken by the TDD (Time Division Duplex) technology. Therefore, it is expected to provide 1Gbps broadband services. Due to the high frequency signal transmission, signal attenuation and interference will be faced issues. The main places for installation equipment are for a short distance, and with GPON network to provide the FTTdp architecture. According to the current standard-setting G.fast direction, if the rate will more than 500Mbps, the distance will less than 100 meters, but must be considered by vectoring technology to eliminate crosstalk interference.

Figure 4 is BroadBand Forum (BBF) proposed a FTTdp architecture [1], which DPU (Distribution Point Unit) equipment includes the GPON ONU (Optical Network Unit) interface, as well as to the G.fast interface of the client side. Therefore, the location of DPU may in a basement, the wiring box of each floor of the building, or on the pole-top.

![Figure 4. FTTdp architecture](image)

For the telecom network management and maintenance, the GPON and VDSL2 networks take the form of a network managed separately. In the FTTdp architecture, there will be a consolidation and a trend that OMCI (ONT Management Control Interface) as a management function of FTTdp GPON and VDSL2. In addition, as the fiber is very close to the client, the copper distance is relatively short, and there has the power issue of DPU. Use of remote power supply to provide the DPU power is one of solutions. For DPU power supply scheme, we propose the following points:

- **Single port**: This power supply is decided by a single user, and therefore relatively simple. It must be considered that VDSL2 included vectoring used extra module to cancel the cross-talk from other lines.
- **Multi port**: Because multiple users provide the power to DPU, it will maybe produce the unfairness situation when someone turns off the power feeding deliberately. We suggest that the normal reverse powering model
with considerations for at least one customer to provide the reverse power to DPU, and it should not be shut down by manually. The power loading sharing with many customers concurrently to provide the power of DPU should be considered.

D. G.hn (G.9960)

G.hn applied to the in-house field for home network. G.hn technology can use home wires include the power line, coaxial cable and phone line. If we use G.hn technology over phone line to extends to out of home areas that including the building floor or MDU (Multi-dwelling unit) field as shown in Figure 5, G.hn becomes a non-standard application. G.hn access application will face practical issues. It includes interference problems, the line stability, and OAM (Operation and Maintenance) management issues. Major impact is multi-line vertical cable interference problems, similar to vectoring technology. The development of this G.hn standard does not cover this problem. G.hn technology over phone line can use MIMO (multiple-input and multiple-output) technology as two pairs bonding to provide a higher rate. In addition, G.hn could not currently support the SRA (Seamless Rate Adaptation) mechanism like VDSL rate adjustment features such as online reconfiguration. It can change in real time to maintain line stability while the environmental noise happens. This issue shall be assessed deeply when the carriers want to be deployed.

According to the discussions, we compare and organize the keypoints shown in Table I.

### Table I. Comparison of the advanced technologies

<table>
<thead>
<tr>
<th>Item</th>
<th>G.hn</th>
<th>VDSL2</th>
<th>VDSL1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. Frequency</td>
<td>1000 MHz</td>
<td>2125 MHz</td>
<td>1000 MHz</td>
</tr>
<tr>
<td>Max. Agg. Rate</td>
<td>500 Mbps</td>
<td>500 Mbps</td>
<td>500 Mbps</td>
</tr>
<tr>
<td>Modulation</td>
<td>TDD</td>
<td>TDD</td>
<td>TDD</td>
</tr>
<tr>
<td>Distance</td>
<td>&lt;1km</td>
<td>&lt;200m</td>
<td>&lt;200m</td>
</tr>
<tr>
<td>VDSL2 Compatible</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Vectoring</td>
<td>ITU-T G9962</td>
<td>ITU-T G9963</td>
<td>ITU-T G9963</td>
</tr>
<tr>
<td>Remote power feeding</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
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Figure 5. G.hn for MDU/DPU architecture

The test architecture of G.hn over phoneline was shown in Figure 8. We fixed upstream rate to verify the downstream performance due to G.hn half duplex characteristic. We also adopted TR-069 protocol for G.hn interface of DPU parameter setting.

The efficiency of vectoring, self-FEXT cancellation, was evaluated through real cables, and the test architecture was shown in Figure 7. Compared to single-line rate and FEXT rate, the loss and gain of vectoring rate were used as the efficiency index, respectively. To verify the performance of vectoring, test cases should include two conditions: collocated CPEs (same cable distance) and non-collocated CPEs (different cable distance). The CPEs were featured with vectoring, vectoring friendly and non-vectoring, respectively, for each condition. Combining the bonding technology, the 2-pair vectoring link would provide almost twice rate further.

Figure 7. Vectoring test architecture

Figure 9 was the FTTdp test architecture. The DPU to connect with OLT via GPON ODN interface, and used the VDSL2 interface to connect with CPE through Loop Simulator / Real Cable (24AWG phoneline). The DPU was powering from Remote Power Supply at CPE side. In this architecture, we consider that the loop only has background.
noise, and the impact of remote powering on the data rate. The parameters of DPU were setup by the OMCI protocol.

Figure 9. FTTdp use single port VDSL2 test architecture

A. FTTN/FTTB

In the FTTN/FTTB architecture, because the distance of copper wire was not short, the carrier could use three kinds of VDSL2 technologies to deploy the high-speed service, which are bonding, vectoring, and both bonding and vectoring concurrently. Figure 10 and Figure 11 showed the test results of these techniques. Owing to limitation of under test equipments, Ethernet rates were almost the same at short loop for the same technologies. According to the test results, the 100Mbps downstream rate could be achieved up to 1900 feet when both bonding and vectoring were adopted concurrently. Moreover, the distances could also be achieved up to 1500 feet and 800 feet for using bonding and vectoring, respectively.

Figure 10. FTTN/FTTB Downstream Ethernet rate test result

Figure 11. FTTN/FTTB Upstream Ethernet rate test result

B. FTTdp

In the FTTdp architecture, the single-port of the VDSL2 featured with 30a profile, and the single-port of the G.hn technology were used to deploy the high-speed service for short loop, which ignored self-crosstalk noise. Figure 12 and Figure 13 showed the test results of these techniques. According to the test results, it would be able to provide symmetrical 100Mbps service up to 300 feet. The maximum rate could be up to 300Mbps/100Mbps for downstream/upstream by using G.hn technology. For the VDSL2 featured with 30a profile, the 200Mbps/100Mbps (downstream/upstream) could also be achieved and up to 400 feet.

Figure 12. FTTdp Downstream Ethernet rate test result

Figure 13. FTTdp Upstream Ethernet rate test result

IV. CONCLUSIONS

How to provide at least 100Mbps high speed Internet and 100Mbps expand coverage to meet the new demands of multiple broadband services are future trends for carriers. VDSL2 vectoring, bonding and FTTdp technologies were introduced to raise the speed, while for these new technologies to establish rigorous testing and validation methods and platforms. It will be the need to carefully think about for the VDSL2 equipment specifications and network building maintenance and operation.

In this paper, we proposed new technologies for the FTTH bottleneck areas. Not only VDSL2 technology, but also added a reference to the G.hn home networking technology in the access network. We also verify the potential reach and rate of these new technologies. These analysis can provide a reference to telcom carrier to meet consumer demand for new high speed broadband services. It also was helpful to keep the market in response to tough competition and challenges.

REFERENCES