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Wavelength Division Multiplexing-Passive Optical Network Based FTTH Field Trial Test

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In this paper, we have presented the results of Wavelength Division Multiplexing-Passive Optical Network (WDM-PON) based fiber-to-the-home (FTTH) field trial test which was held in the city of Gwangju. We have implemented an injection locked Fabry-Perot Laser Diode (FP-LD) based WDM-PON system and reliably delivered Internet Protocol TV (IP-TV), Networked Personal Video Recorder (N-PVR), High-Definition Video on Demand (HD-VoD), Education on Demand (EoD) and Internet service as FTTH service through the system during the field trial test. We have also verified that the WDM-PON system worked well to provide quality of service (QoS) guaranteed 100Mbps bandwidth per subscriber. Furthermore, we have presented network designing issues in Outside Plant (OSP) and Customer Premises Network (CPN) that should be overcome to efficiently deploy FTTH service. Finally, based on the field trial test results, we proposed FTTH service deployment strategies.

OCIS codes : 060.4250, 060.2330, 060.2330

I. INTRODUCTION

In Korea, once a leading country in broadband internet deployment, the increasing ratio of new subscribers per year has been decreasing for the last few years. This was mainly caused by fierce competition among carriers. The competition also raised users' expectations for internet bandwidth. From the point of view of the incumbent carrier, the situation has been getting worse due to internet market penetration by Multiple System Operator (MSO) that already provided triple play service. So, the broadband internet market was not being considered as a profitable business model any more. As a result, the carriers are searching for a new business model to leverage the Average Revenue Per Unit (ARPU). Today, high quality IP-media service is considered as the new business model that increases revenue. For example, High definition IP-TV, VoD, and Video phone service could be the main services delivered by a new access network that guaranteed the required QoS of each service. To make this a reality, the access network system must meet functions, performance and price criteria. FTTH based on PON is currently viewed as the best solution for the new access network topology that meets these requirements. But in order to deploy FTTH service, we need to consider not only the access network system but also the fiber installation issues in OSP and CPN.

In this paper, we have presented the results of FTTH field trial test held in the city of Gwangju. We have implemented injection locked FP-LD based WDM-PON system, and reliably delivered IP-TV, N-PVR, HD-VoD, EoD and Internet service as FTTH service through the system during the field trial test. WDM technique has long been considered as an expensive solution usually suitable for back haul transmission. With injection locked FP-LD scheme [1,2,3], the optical components cost has been lowered. That allows the possibility of commercializing WDM-PON system solution in the access network.

In the next section, we will look through the issues that should be solved in order to successfully deploy FTTH service.

II. FTTH SERVICE DEPLOYMENT ISSUES [4,5,6]

One of the biggest challenges in a network service provider that must be solved prior to mass market deployment is to select the most suitable technology for FTTH. PON technology has been considered to be a solution due to its low Operating Expenditure (OPEX). PON technology can be divided into Time Division

Multiplexing (TDM)-based PON [7,8] and Wavelength Division Multiplexing (WDM)-based PON. We have selected WDM-PON technology, because it has provided high bandwidth regardless of the number of connected Optical Node Terminals (ONT) and stringent QoS function to guarantee service quality. We have confirmed feasibility of FTTH service delivery through the system during field trial tests. The WDM-PON was employing broadband light source injected FP-LD method to lower the high cost of WDM light source that is the weakness of typical WDM-PON. With the feature of "colorlessness" of the WDM-PON in Optical Node Unit (ONU) side [1,4], the wavelength of each subscriber was automatically determined by the wavelength of injected light that was spectrally sliced at Arrayed Waveguide Grating (AWG). This prominent feature makes an easy service deployment and decreases the system operation cost. Despite sharing feed optical fiber, physically WDM-PON is a point-to-point network topology based on AWG due to allocating different wavelength for each subscriber. On the other hand, logically the system seems to be a multi-connected Ethernet switch topology. Since WDM-PON system does not have PON Media Access Control (MAC) as that of TDM-PON, it can provide simplicity in terms of Operation, Administration and Maintenance (OAM) and provisioning of QoS parameter for specific service. Furthermore, the system operators can easily manage the system without any confusion by adopting PON-MAC, because many system operators in CO have been accustomed to legacy Layer-2 and Layer-3 Ethernet switching system for a long time.

Another challenge in deploying FTTH service is the OSP and Customer Premise Network design considerations, especially fiber installation in CPN, in-door wiring in the subscriber's home, and optical power and reflection management. The installed fiber topology in KT access network is a mixed topology of ring and star. The trunk fiber network was in a ring type, a few fibers that branched at the trunk fiber were distributed to CPN in a reduced or unreduced star topology. Sometimes some fibers branched at the star topology network were passively divided into multiple fiber at the Remote Node (RN) where the optical splitter or AWG was installed, and have gone to Customer Premise Equipment (CPE).

Major carriers in Korea use the underground ducts for distributing optical fiber core from Central Office (CO) to CPN. Enough room for placing the fiber core has to be left in the ducts. Furthermore, the location of RN, in which the passive optical mux/demux or AWG are installed, should also be carefully selected in order to provide the connectivity for future subscribers.

Speaking in detail, we can divide CPN into two cases, Multi Dwelling Unit (MDU) and detached house. For MDU, we have to select what fiber installation method is convenient, not time-consuming, future-proof, cost-effective, and reducing labor costs. Maybe, Air Blown Fiber (ABF) is seen as its key enabler. ABF method claim to offer reduced cost, increased network design flexibility and other advantages that cannot be matched by conventional optical fiber cables. The environment of a detached house is worse than that of MDU. Plastic or metal duct in which optical cable can run does not exist en route to CPE from the pole. Therefore we must use the drop cable in the detached house environment. Drop cable installation from the RN to the optical termination box inside the house is not an easy process and will invoke some issues. This job is tedious and time-consuming, because the majority of the jobs such as installation of cabinet, fiber splicing, connectorization, connector cleaning, and optical power measurement, have to be done upon the pole instead of the ground. The CPN has many different environments so that it is difficult to forecast the exact optical power loss. Therefore optical power loss and reflection should be carefully measured and monitored for designing the service offering cell zone.

The last hurdle is the service operation and management to guarantee service availability. From the customer's point of view, the most important thing is not network but service, especially service quality and reliability. It is required that service fault locations be found fast, service opening be fast and service failure calls be solved fast to guarantee the service availability.

With those considerations, FTTH field trial test in Gwangju city has been processed. Some of the results are presented in the next section.

III. FTTH FIELD TRIAL

The 3-month field trial test has been done for two kinds of CPN, apartment and residential area with 100

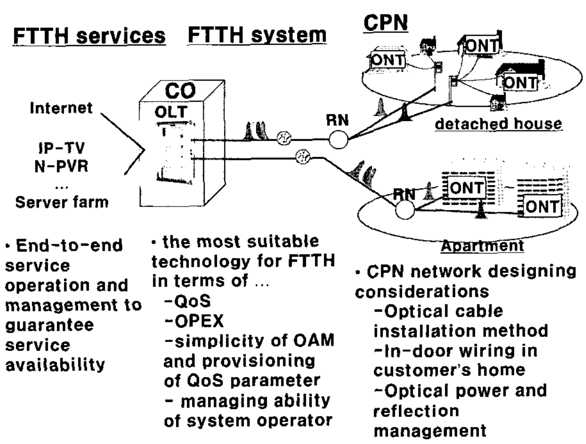

FIG. 1. FTTH service deployment issues.

subscribers. Fig. 2 shows the field trial test network configuration which was installed in the city of Gwangju. It seems to be grouped at Head -End (HE), WDM-PON system, and CPN. The HE, a kind of server farm, consists of MPEG-2 encoder, N-PVR server, EoD server, Web server and HD VoD server. We have selected injection locked FP-LD based WDM-PON technology as that of a FTTH access network due to its low source cost. WDM-PON system consists of an Optical Line Terminal (OLT) which is placed at the CO, Optical Node Terminal (ONT) which is placed at customer house, and RN which is placed at CPN. The service HE and OLT was located at the same CO. The server farm was directly connected to WDM-PON OLT where the internet connection is also made through backbone router. In subscriber side, Internet Protocol Set-top-box (IP-STB) and PC was connected to ONT.

The real time IP-TV streams have been stored at the N-PVR server by joining multicasting group from the encoder.

According to the subscriber's service request, the streams were sent to the requested STB by unicasting from the N-PVR server. The web server has controlled the subscriber's authentication, logged the subscriber's access and stored raw data for usage of each service. Based on the data in web server, we are able to analyze the subscriber's view pattern, frequency in use of service, and hit ratio of VoD contents.

To make use of all delivered service, firstly STB must be logically connected to the web server, and some information for authentication had to be properly downloaded to the STB as cookies. All authentication process has been done on the web-base by comparing the STB MAC address and service authentication ID with the stored information in a database of authentication server. Public dynamic ip address and public fixed ip address were assigned to STB and PC, respectively.

The traffic flow for IP-TV service is as follows: The satellite STBs have decoded broadcast TV channels that are received from the satellite into each audio/video (A/V) format. The decoded signals were re-encoded into MPEG-2 and encapsulated into IP packet format with multicasting IP address in the Encoder, then transmitted to the OLT. One channel was encoded into 20 Mbps bandwidth HD; the others were into 4 Mbps SD. The IGMP multicasting protocol was used to deliver IP-TV streams from the Encoder to the IP-STB through the WDM-PON system. IP-STB in the subscriber's home used also IGMP to change channels, by leaving and joining multicast groups representing the channels. The Digital Right Management (DRM) for protecting the real time IP-TV contents was not applied at this field trial test. Otherwise, VoD contents were protected by the DRM.

We have observed that compressing the digitized video signal deteriorates the video image quality, which is even more severe for SD-level channel contents which do not fit well with the size ratio of HDTV. Also the performance of satellite STB influences the video quality. For IP-TV service, A/V display time after joining the multicast group that representing the channel appeared to be quite long about 1.5 sec. The delay includes both the delay of network and decoding time. The average network delay was measured about 20 msec for the join time and 37 msec for the zapping time. The maximum decoding delay was 1.3 sec. We are able to infer that major factor of the long A/V display time delay could be induced from the decoding delay of the IP-STB. Therefore, In order to provide a fast channel changing, we have to reduce the decoding delay of IP-STB by reducing buffering time of the IP-STB. On the other hand, too short buffering time of IP-STB will increase the sensitivity of video quality to network jitter. Therefore we have to find optimum

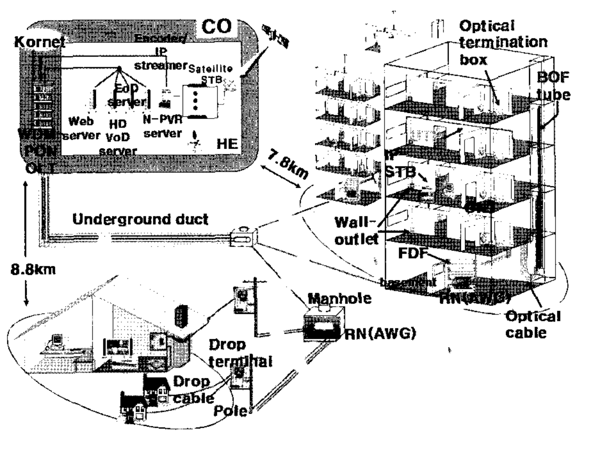

FIG. 2. FTTH field trial test network configuration.

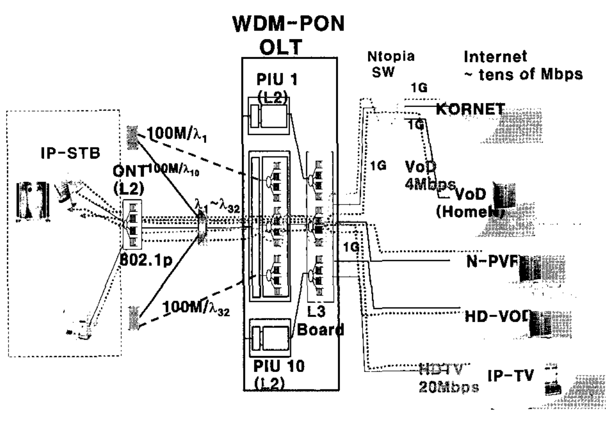

FIG. 3. WDM-PON system QoS configuration for field test.

point balancing decoding delay and video quality.

We have also observed that the denial of service attack or malicious traffic, not an issue for traditional TV, could be a threat to IP-STB.

Speaking about the WDM-PON system in detail, the WDM-PON System was designed to assure reliable transmission performance for coverage of 10 km radius with BER 10^{-10}. One rack has 4 OLT shelves. One OLT shelf consists of 10 PON Interface Units (PIU) and each PIU connects to 32 ONTs through the AWG which is installed in the CPN. The maximum capacity of one OLT rack is 1280 subscribers. Each ONT is connected to OLT through one wavelength for downstream and upstream, guaranteeing 100 Mbps at minimum. Above the optic termination layer, Ethernet interface and layer 2/layer 3 switching technique is used for aggregating the user's packets and forwarding them to the appropriate destinations. QoS is supported for both layers using the 4-queues based congestion management capabilities. So this system is best suited for IP-based mixed QoS environment.

The internet and service head-end is connected to the L3 switch unit, which acts as an interface to the uplink network for the OLT. Subscriber connections are made through PON interface unit. Each subscriber is connected using private wavelength for up and downstream with guaranteed link rate of 100 Mbps symmetric. QoS functions based on multi-field packet classification are applied for assuring each service requirements. For IP-TV service and HD VoD, the classification was based on multicast IP range and server's source IP, respectively. For N-PVR service, it was based on server source IP and port number. The fig. 3 describes the system configuration for handling QoS services.

Consequently, The QoS function worked well, guaranteeing safe bandwidth delivering 20 Mbps MPEG-2 streaming contents, which were both multicast and unicast traffic. WDM-PON MAC worked transparently and showed reliability with no tuning and provisioning in the PON MAC layer.

On the other hand, many issues have been observed in the CPE related fault management. The systems did not distinguish the ONT link failure alarm from that caused by the subscriber's intentional ONT power off or systematic error such as optical power failure or optical cable fault. This makes it difficult to solve the problem and makes service recovery time longer when subscribers complain about the service failure. Another issue is related with subscriber management function in the system. When a subscriber made a service call, we didn't know which PIU is connected to the subscriber. This also makes maintenance and repair time longer.

CPN is divided into apartment and detached house environments. The average distance of Optical Distribution Network (ODN) of the cases was 7.8 km and 8.8 km, respectively. Optical fibers coming out from the Fiber Distribution Frame (FDF) at the CO were installed to CPN using underground ducts. The optical connection is described in the next figures. For each environment, there were more than 7 optical adaptors, both SC/PC and SC/APC mixed. The difference in reflection power between SC/PC and SC/APC were about 30 dB. More loss has been observed for SC/PC than SC/APC type. But the overall performance in the transmission quality was merely affected in this trial environment.

For the case of APT, we used both Air Blown Fiber (ABF) installation method and conventional bare optical fiber (optical patch cord) to install the optical fiber from the FDF placed at the basement to the optical fiber termination box that was placed at the subscriber's house. Average optical power loss of ODN, from OLT at CO to optical termination box in subscriber's home, was measured about 6.3 dB including all connector loss and splicing loss. Though the distance from RN to optical termination box in each subscriber's home was less than 100 m in maximum , the optical loss power including optical adaptors was distributed by a range from 0.7 dB to 4.3 dB. This is caused mainly by impurities on the surface of the optical connector, optical fiber bending, and wrong management for the optical connector during the installation period. Fig. 6 shows the optical loss distribution that was measured per subscriber in APT environment. The graph shows that ABF installation has optical loss less than conventional optical fiber installation by about 1 dB. This loss difference was mainly caused by the different optical fiber installation method. For ABF cabling, optical fiber was blown into the tube, then the fiber was not nearly as damaged by the job process. On the other

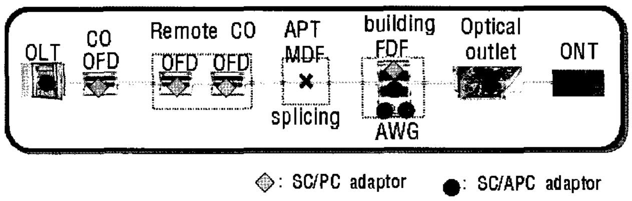

FIG. 4. Description of the optical connection: Apartment.

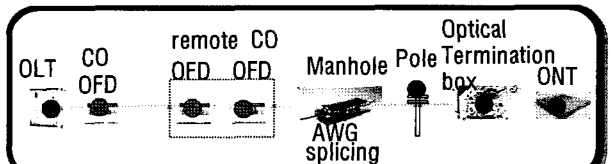

FIG. 5. Description of the optical connection: Detached house.

hand, the other case of conventional optical fiber installation, optical fiber was installed by pulling the optical fiber; stretching and bending for the optical fiber would induce optical loss.

Average input power of ONT was -10.9 dBm. This was measured during the opening of the service. But after that, as the ONT was located at the user home, the measuring of the optical power loss was very inconvenient.

In the other case of the detached house, AWG was installed at joint closure in a manhole. Several optical fiber cores were distributed to the drop terminal on the pole through underground duct. Two types drop cable with diameter 250 um and 900 um were overhead dropped from the drop terminal on the pole to the optical fiber termination box in the subscriber's house. Underground duct from manhole to the subscriber's home for optical cable in a detached house environment does not exist, causing tedious and time consuming laboring. Each drop cable was joined by mechanical splicing or fusion splicing method to compare technical issues. The subscriber connection was made not at FDF on the ground like APT, but at pole top drop terminal. This process increased installation time and cost, also increased difficulty in measurement of optical power and reflection by using OTDR when fiber fault occurred. In both cases of optical fiber installation, we should pay more attention to clear the dusts lying in the optical connector's surface, because the main optical power loss has occurred at that point in CPN.

We have observed that continuous optical loss power and reflection power monitoring are needed after the OSP deployment. The optical connector with APC type should be used to reduce reflection in OSP, because the WDM-PON system performance was severely influenced by reflection of the optical link. Furthermore, we should design the network topology to minimize the number of reflection points.

The biggest barrier associated with deploying the FTTH may not be due to the technical or cost constraints but due to customer demand. Though the infrastructure and transmission equipment is developed and cost optimized, deploying FTTH will not be commercially viable unless sufficient customers want the services that it can deliver. Most customers are interested only in the service to which they have access and not in the network over which it is provided. Therefore we will need to develop an attractive service so that a customer is willing to pay for this.

The delivered services through the WDM-PON system could be classified into 4-classes, including IP-TV, HD VoD, VoIP and Internet. The N-PVR is an attractive service model that could only be provided through QoS-guaranteed high bandwidth network. The N-PVR service consisted of two functions, time-shift broadcasting and schedule recording. In this field trial test, the former was only given to subscribers. The time-shift function gives a user access to controls for pausing, fast-forwarding, rewinding real-time broadcast channels regardless of time as it is delivered to their own TV. In N-PVR model, all storage and manipulation technologies reside in the provider's server at CO, rather than in STB at the customer's home. So, there was no recording channel limitation and no hardware failure of STB in the home.

We have observed that the Quality of Experience (QoE) that describes how well a service satisfies a subscriber expectation is determined by the following three factors: Channel zapping which describes how quickly a user can change the channels, video quality and convenience of service. In particular, in order to provide QoE, we should satisfy user expectation about the channel zapping time and video quality as providing equal or better than today's TV services, cable

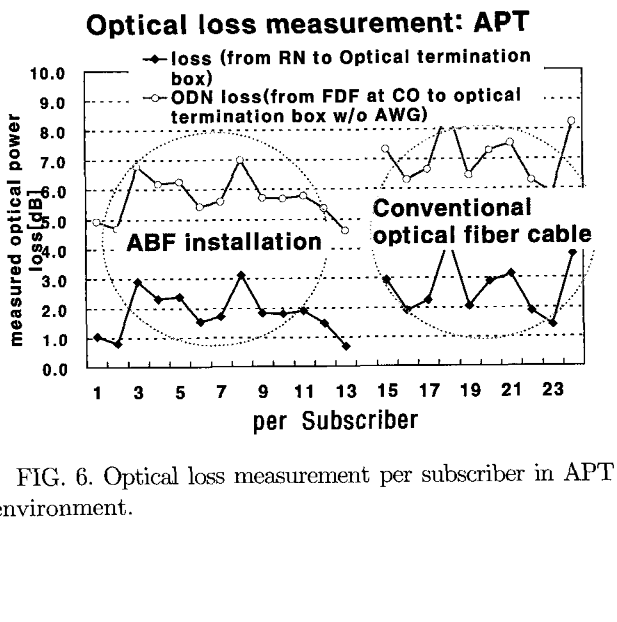

FIG. 6. Optical loss measurement per subscriber in APT environment.

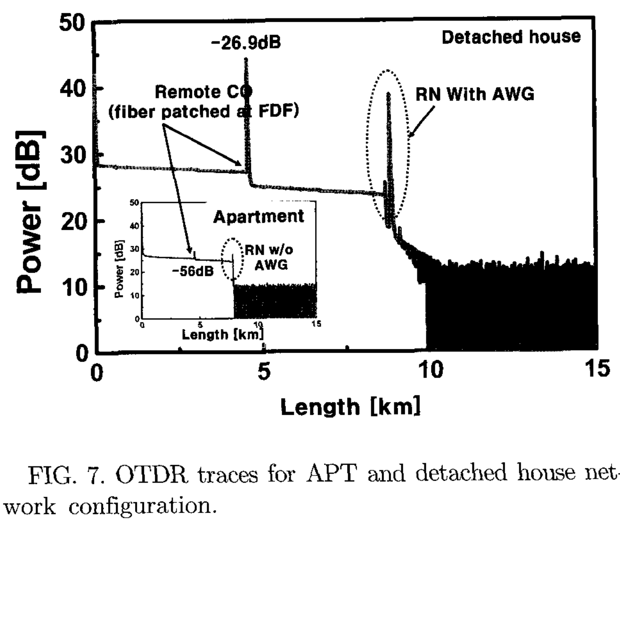

FIG. 7. OTDR traces for APT and detached house network configuration.

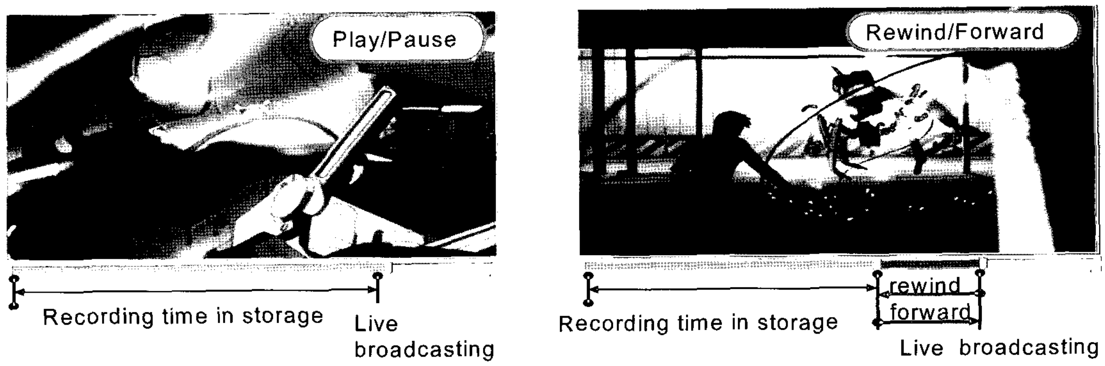

FIG. 8. N-PVR with time shift function.

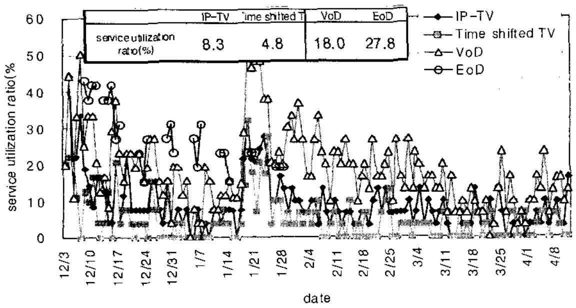

FIG. 9. Service utilization ratio for FTTH services.

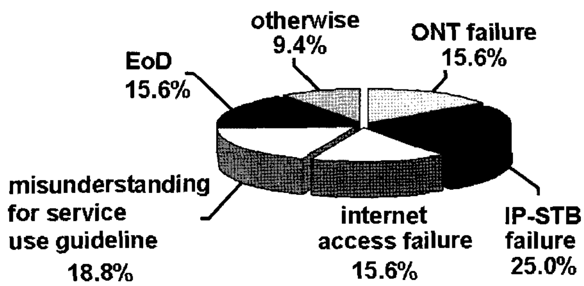

FIG. 10. Classification of service call during the field trial.

or satellite.

The service convenience from the user perspective is dominantly determined by usability of the remote control. Two remote controls have been used to utilize the delivered services in this field trial test: one is the remote control for conventional TV and the other is for IP-STB. A lot of subscriber's complaints for delivered service were coming from inconvenience of the remote control. So we have to integrate all remote control into one box. Other factors for deteriorating QoE are heat, fan-noise of IP-STB and ONT, and not locating the ONT in the proper place. Also, we have observed that diversity of A/V environment and complexity of wiring between many devices in the home would cause long service opening time and difficulty in repairing service failure. The depth of remote control to access service has also caused inconvenience of service use.

Fig. 9 shows interesting results of user's opinion investigation about degree of service utilization. The reason for lower usage of IP-TV and N-PVR service was mainly caused by deficiency of attractive contents, for example lack of terrestrial TV channels, the most favorite channels in Koreans. The most loved service was EoD service. In Korea, education is one of the critical social issues. So all subscribers are interested in education service.

We have classified service calls invoked during the field trial as seen in Fig. 10. With only a few exceptions, more than 80% of the service calls have are relatedto CPE and misunderstanding of service use guidelines, not with the FTTH system. Therefore we are able to conclude that WDM-PON systems can deliver the TPS with enough reliability and availability.

During the initial deployment stage, every FTTH subscriber was visited personally to insure that the services were properly installed and to check service status. After each service repair call, a trained person has to visit the customer house to verify the performance of each segment of the system, for example, to check whether the cable is cut or not, to check if optical power into ONT is the proper level, to check if IP-STB is working, to check if IP assignment into IP-STB was done, to check degradation of video quality, to check whether the authentication process is properly passed. All these processes have to been done in the subscriber's home. On the other hand, to visit a customer's house is one of the most difficult things that confronted us during the field trial test. Therefore, we need to develop the service operation management system for monitoring the end to end service quality, which can help to identify and locate a service failure in advance before it occurs, as well as to take a measure that would reduce the time needed to correct the service failure.

IV. CONCLUSION

We have made a field trial test to confirm the feasibility of the FTTH service in Gwangju city. We have verified that WDM-PON system is suitable for delivering triple play service. Also we have verified the technical maturity of the HD IP-TV service along with other services. Based on field trial test results, we attempt to raise some of the most important and interesting issues related to FTTH service deployment. The difficulties for fiber installation in CPN and in-door wiring in home must be overcome for an efficient and economic deployment of FTTH services. Furthermore, we have to carefully choose the most convenient and future-proofing fiber installation method, and make a standard fiber installation and maintenance engineering guide in CPN. Also, In order to provide the best QoE to subscriber, we need to develop end to end service management system for monitoring each segment of service delivery path, which include fiber fault management, service fault management generated by ONT or STB, optical loss power monitoring in CPE, and service headend monitoring.

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