Proposal of RF/IP Adaptive Video Distribution Scheme over Cable Television Access Networks

A Technical Paper prepared for SCTE•ISBE by

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1. Introduction

UHD video streaming services have been launched worldwide. In Japan, 4K/8K broadcasting services has been promoting by "All Japan," which are organized by the government, broadcasters, telecommunicators, and TV manufacturers since 2014. Figure 1 is "4K/8K roadmap" advocated by the Ministry of Internal Affairs and Communication (MIC) and satellite, cable TV, and IP TV are picked up as the access networks for 4K/8K broadcasting services in the roadmap. According to this roadmap, cable industry in Japan has been started 4K community channel service organized by themselves, named by "Cable 4K", since 2015.

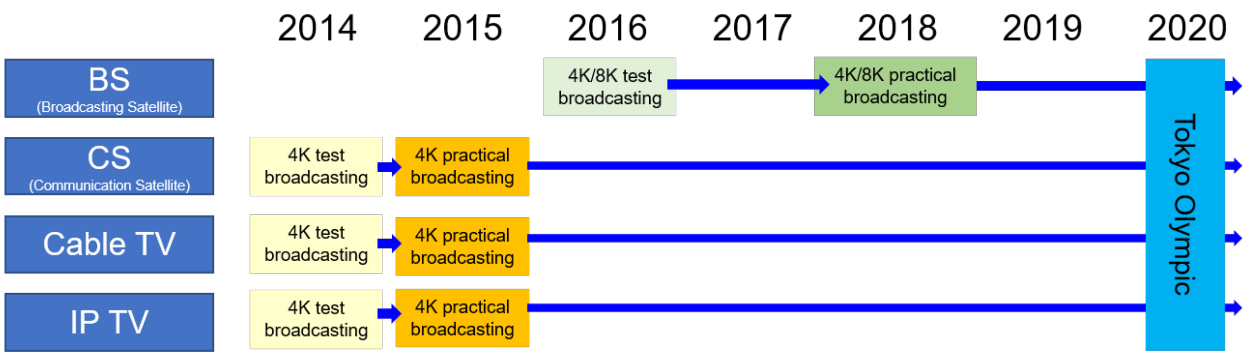

Figure 1 - 4K/8K roadmap based on an interim report from the study group for 4K/8K broadcasting at the Ministry of Internal Affairs and Communication (MIC)

2. Problem statement

Demand for 4K/8K video is increasing toward the Tokyo Olympic games, cable industry seeks to increase 4K video channels to respond the demand from customers. The final goal of Japanese cable industry is to convert over the 100 community channels with SD/HD resolution into 4K. The transmission capacity of HFC access networks is, however, limited by the existing TV services and Internet services, and the network band cannot be expanded due to the retransmission of satellite broadcasting (1~3GHz). Figure 2 shows the typical utilization of HFC network band in Japan. Cable operators needs to manage to deliver the over 100 broadcasting services and Internet services in the limited network band.

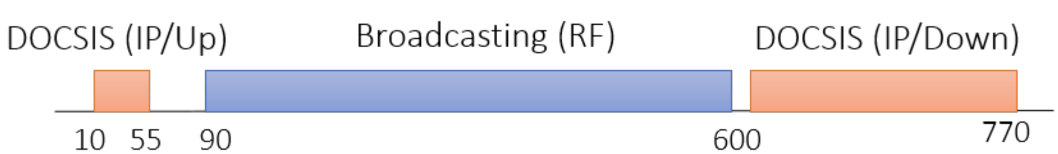

Figure 2 - Typical utilization of HFC network band

Furthermore, cable operators cannot easily replace HFC by FTTH because of the high installation cost of FTTH. Figure 3shows the portion of access network types of Japanese cable subscribers in 2017 and indicate the fact that HFC is still dominant. Because of this, the cable operators cannot easily enhance the network infrastructure to increase the 4K channels.

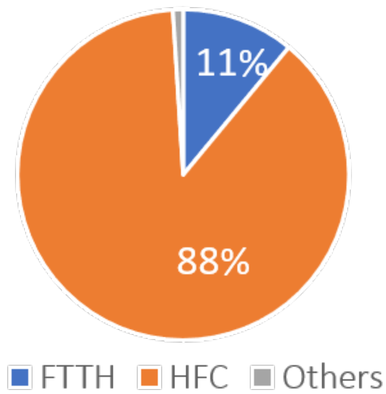

Figure 3 - The portion of access network types of Japanese cable subscribers in 2017.

Figure 4 shows the conventional scheme of video distribution over HFC access network. In Japanese, the most of the cable operators deliver the all broadcasting services on RF-network band as shown in Figure 4. This is because that the RF distribution scheme is consider to be more reliable than IP distribution scheme, that is IP multicast scheme. The detail is as follows. In general, with RF-distribution scheme, the received video quality is stable since the video is transmitted at a fixed coding bitrate over quality-guaranteed network where are fixed transmission band is reserved for each video channels. The utilization efficiency of video of the network band resource is, however, low since they occupied by the videos regardless audience ratings, In contrast, with the IP distribution scheme, the received video quality is unstable since the video is transmitted at a variable or adaptive coding bitrate over best-effort network where the bandwidth is not reserved for reserved for each video channels. The utilization efficiency of network band resources, is however, high since they are used for the transmission of not only video but also Internet data. Whichever method is used, therefore, it is difficult to realize 4K conversion of all existing video channels aimed at by the cable industry, and a novel approach is required.

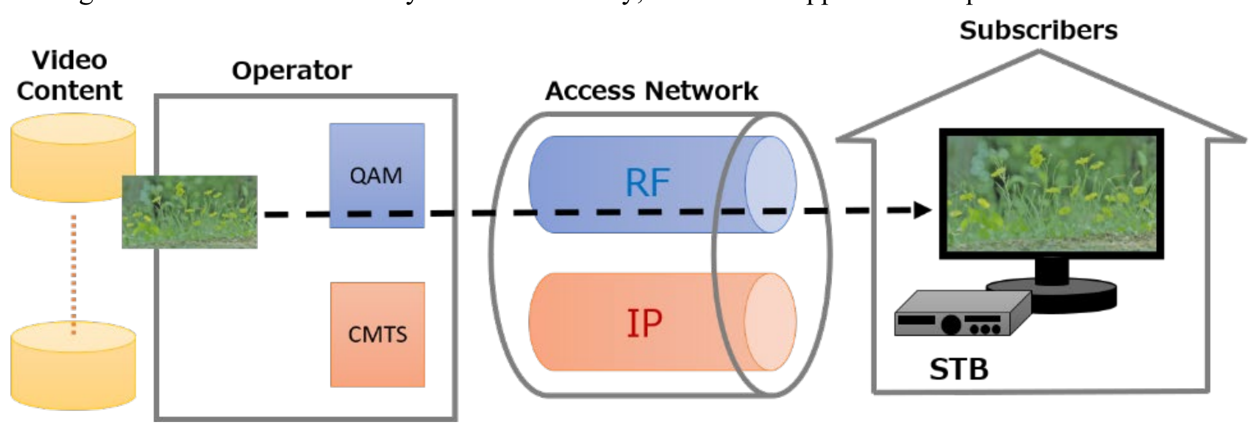

Figure 4 - Conventional scheme of video distribution over HFC access network.

3. Proposed method

3.1. Basic Concept

As the solution of the problem described in section 2, RF/IP adaptive distribution scheme is proposed. The strategy of proposed method is to create the environment where almost all the subscribers can watch 4K videos. According the strategy, the following two key ideas are proposed. The first idea is sharing of the RF/IP network band resources. The second idea is adaptive control of video qualities and distribution scheme according to the following three parameters; attribute of video content (e.g., emergency degree), available network bandwidth, and audience rating of content. Figure 5 shows the priority rule of video regarding the second idea. In this rule, the scheme quality, that is video resolution and bitrate we defined, is controlled according to audience ratings and emergency degrees. By preferentially distributing video channels with a high audience rating in 4K resolution and high bitrate, it is possible to realize an environment in which almost all subscribers can watch 4K channels. The reason why RF distribution scheme is higher priority than IP distribution scheme is that RF distribution scheme is more stable than that of IP described section 2.

Audience Rating Emergency Degree	High	←			→	Low
Scheme-Quality	RF-4K	IP-4K	RF-HD	IP-HD	RF-SD	IP-SD
Bitrate (bps)	20M	15M	10M	7M	5M	3M

Figure 5 - Priority rule of controlling video qualities and distribution schemes.

Figure 6 shows the proposed RF/IP adaptive distribution scheme. The basic principle is as follows: First, the optimizer collects the audience ratings, available network bandwidth, and attribute of video content. Second, the optimizer calculates the switching indicator and determines the necessity of switching the video distribution scheme for each video channel. Third, the optimizer signals a switching order to the switcher for each video channel which the optimizer determined that the switching is required. Forth, the switcher change the video distribution scheme according to the switching order from the optimizer.

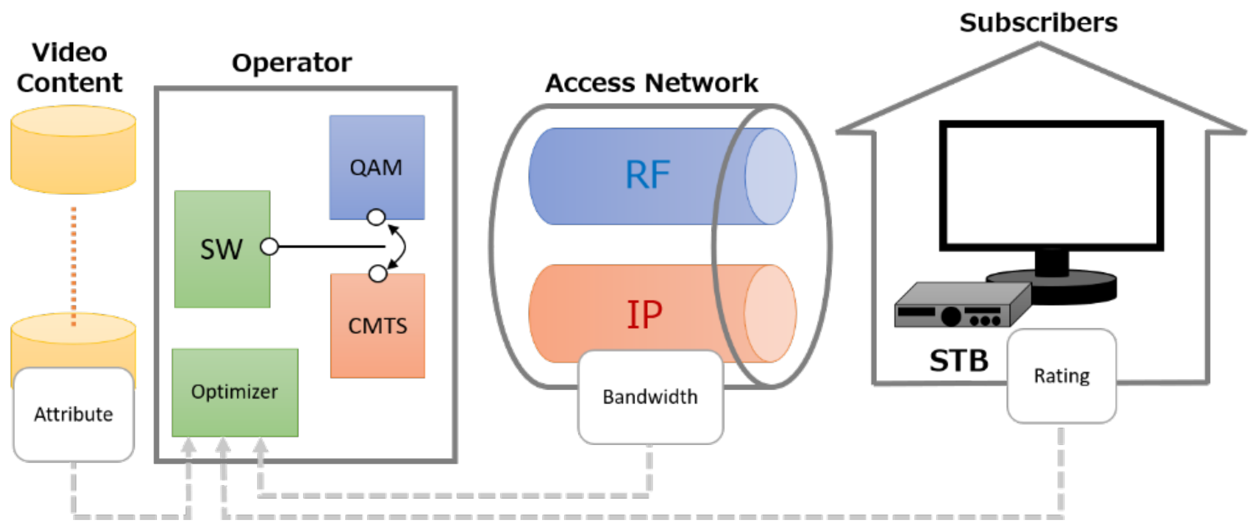

Figure 6 - RF/IP adaptive distribution scheme

3.1. System architecutre, Technolgoy

In this section, a system architecture and key technologies of key components are described. Figure 7 indicate a system architecture to realize the proposed RF/IP adaptive distribution scheme. Data collector in addition to optimizer and switcher is also key component. The role and technology for each key component is described separately in the following section.

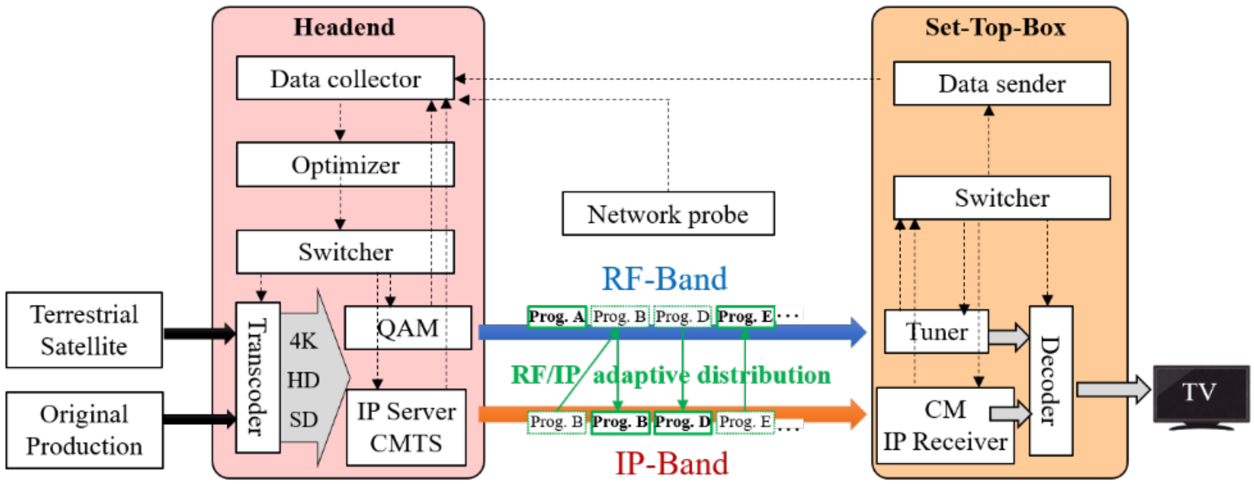

Figure 7 - A system architecture to realize the proposed scheme.

3.1.1. *Optimizer / Switching Indicator*

The switching indicator is designed as like QoE with the following formula. We call it audience satisfaction degree (ASD). The definition of this is the ratio of A and B as shown in the formula. A is a measured score calculated with sum of products based on the actual audience rating and the score corresponding to the bitrate of the actually used video distribution scheme. B is an ideal score calculated with sum of products based on the actual audience rating and maximum score which is corresponding to the bitrate of RF/4K video distribution scheme.

$$ASD(t) = \frac{A}{B} = \frac{\sum_{i=1}^{n} R_{t,i} \times S_i}{\sum_{i=1}^{n} R_{t,i} \times S_{max}} \times 100$$

It is noted that *R, S, i, n,* and *t* indicate audience rating, score based on video bitrates, indicator of programme, total number of programmes, and distribution time, respectively.

3.1.2. *Optimizer / Switching Algorithm*

The switching algorithm is designed to keep always the highest score of ASD even when the audience ratings and available network bandwidth, and attribute of video content vary. It is realized by recursively checking and assignment based on the priority rules. The overall processing order is as follows:

1. Collect the latest ratings, bandwidth, attribute
2. Sort programmes by ratings
3. Assign programmes with high ratings to the RF-band at a high bitrate preferentially.
4. Lower the rank of the scheme and quality if bandwidth becomes insufficient
5. Recurse No.3 and No.4 processes until all programmes are completely assigned.
6. Calculate difference of new/old ASD based on the new/old assignments
7. Switch scheme and quality if the difference is greater than threshold

Some simulation experiments for validation of the switching algorithm are conducted and those are described in section X.

3.1.3. Data collector, etc. / Real-Time and Large-Scale Data Collection

Real-time and large-scale data collection in data collector, network probe, and CPE devices is essential to guarantee the accuracy of the switching scheme. To realized that, lightness and ease to implementation, will be required. From our preliminary study, MQTT (Message Queuing Telemetry Transport) is the best protocol in terms of the requirements.

3.1.1. Switcher /Seamless Switching

Seamless switching is essential to avoid subjective side-effect from the switching shock. These are the requirement:

1. How to transmit the switching timing from HE to STB
2. How to remove the switching shock (e.g., stop playback, skip frame, etc.)
3. How to solve the difference in video format (e.g., resolution, frame rate, codec)

Feasibility study of seamless RF/IP switching is conducted thorough the prototype development of switching demo system, which is described in section X.

4. Simulation Experiment

4.1. Simulation System

To validate the proposed switching algorithm, simulation system is developed with two web application servers. Utilized CPU and software are as follows:

- CPU: 1vCPU, Memory: 2GB, OS: CentOS
- Software: Apache Tomcat, mysql, openssl, Echarts

A simulation engine where switching runs is implemented from scratch. Figure 8 shows the simulation system configuration. Time-varying audience ratings and IP network bandwidths are input as scenario files. Other basic parameters are set with GUI before the simulation.

Time transition of ASD (= switching indicator) is plotted as a result of simulation execution.

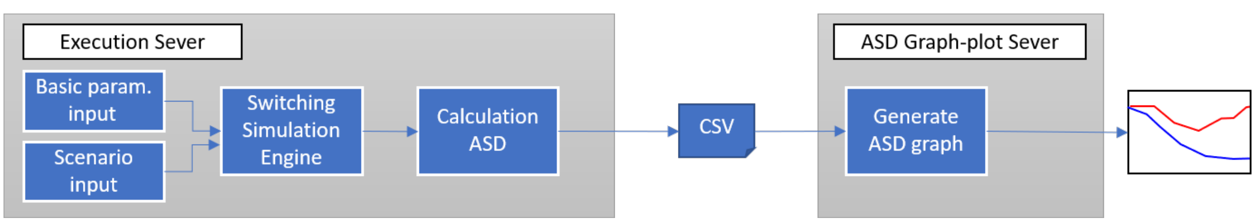

Figure 8 - Simulation system configuration

4.2. Simulation Condition

Utilized basic parameters and time-vary parameters are shown as follows:

- Number of video channel: 50ch, 75ch, 100ch
- Network capacity: Utilize 8 patterns of infrastructure referred to Japanese operators
- Video coding bitrate:

- RF-4K: 25Mbps, RF-HD: 15Mbps, RF-SD:6Mbps, IP-SD: 4Mbps

- Number of STB: 10,000
- Emulation Time: 24 hours
- Switching Cycle: 5 min
- Switching Threshold: 0
- Time-varying parameters
- Audience rating: Utilize real data from Video Research Ltd.
- Internet traffic (affect the capacity of IP-bandwidth): Utilize statistical data of time transition of Internet data from MIC

4.3. Simulation Result

4.3.1. Validation from Time Transition

Figure 9 shows the difference of audience satisfaction degree (ASD) between with the proposed method (w/ switching) and without the proposed method (w/o switching) where the number of video channels are 100 and network capacity is set as follows:

- Total of RF-network bandwidth: 900Mbps
- Total of IP-network bandwidth: 320Mbps

The red line an black line indicate the ASD with the proposed method and the ASD without the proposed method, respectively. From this result, it is confirmed that the proposed method has the effect to maintain high ASD value in all hours.

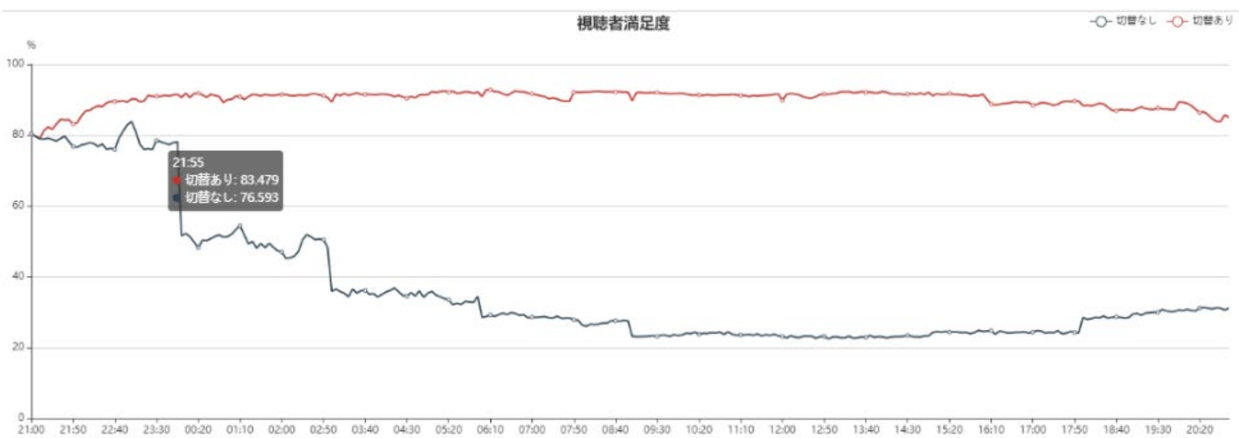

Figure 9 - The difference of audience satisfaction degree between with the proposed method (switching) and without the proposed method (no switching).

4.3.2. Validation for Various Condition

The simulation of various condition regarding infrastructure type and the number of video channels are conducted. Figure 10 shows the comparison table of that. In total, 8 patterns of infrastructure types and 3 patterns of the number of video channels are tested as described in Figure 10. From this table, it is observed that ASD with switching is over doble score of that without switching as the maximum effect of the proposed method under certain conditions (described as red square frame in Figure 10). This means that the proposed method has the effect to doubles the utilization efficiency of bandwidth or the number of 4K content compared to without this scheme.

Number of video channel (ch) → ↓ Infrastructure pattern (bps)		50ch = 1250M (if all channels are 4K)	75ch = 1875M (if all channels are 4K)	100ch = 2500M (if all channels are 4K)
1	RF-band: 2070M IP-band : 160M	N/A (Because all channel can be transmitted as 4K)	N/A (Because all channel can be transmitted as 4K)	w/o Switching: 83.7 **w/ Switching: 99.0**
2	RF-band: 1770M IP-band : 160M	N/A (Because all channel can be transmitted as 4K)	w/o Switching: 95.4 **w/ Switching: 99.9**	w/o Switching: 72.3 **w/ Switching: 97.6**
3	RF-band: 1320M IP-band : 160M	N/A (Because all channel can be transmitted as 4K)	w/o Switching: 73.7 **w/ Switching: 97.7**	w/o Switching: 52.7 **w/ Switching: 94.3**
4	RF-band: 1020M IP-band : 160M	w/o Switching: 82.5 **w/ Switching: 98.9**	w/o Switching: 58.6 **w/ Switching: 95.3**	w/o Switching: 40.2 **w/ Switching: 90.5**
5	RF-band: 1950M IP-band : 320M	N/A (Because all channel can be transmitted as 4K)	N/A (Because all channel can be transmitted as 4K)	w/o Switching: 80.2 **w/ Switching: 98.6**
6	RF-band: 1650M IP-band : 320M	N/A (Because all channel can be transmitted as 4K)	w/o Switching: 90.6 **w/ Switching: 99.5**	w/o Switching: 69.7 **w/ Switching: 96.9**
7	RF-band: 1200M IP-band : 320M	w/o Switching: 96.6 **w/ Switching: 99.9**	w/o Switching: 69.9 **w/ Switching: 96.9**	w/o Switching: 49.6 **w/ Switching: 93.4**
8	RF-band: 900M IP-band : 320M	w/o Switching: 78.5 **w/ Switching: 98.2**	w/o Switching: 54.4 **w/ Switching: 94.7**	w/o Switching: 36.5 **w/ Switching: 90.3**

Figure 10 – Comparison of ASD in different types of cable infrastructure

5. Prototype Development of Switching Demo System

To study the feasibility of seamless RF/IP switching, PC-based demo system is developed. Figure 11 and Figure 12 show the configuration and overview of switching demo system, respectively. We confirmed that the switching has been completed within 1 second from the switching order of the server PC (HE-PC) to switching video quality of client PC (STB-PC). It is noted that we used the 4K video test materials of ITE in the verification test.

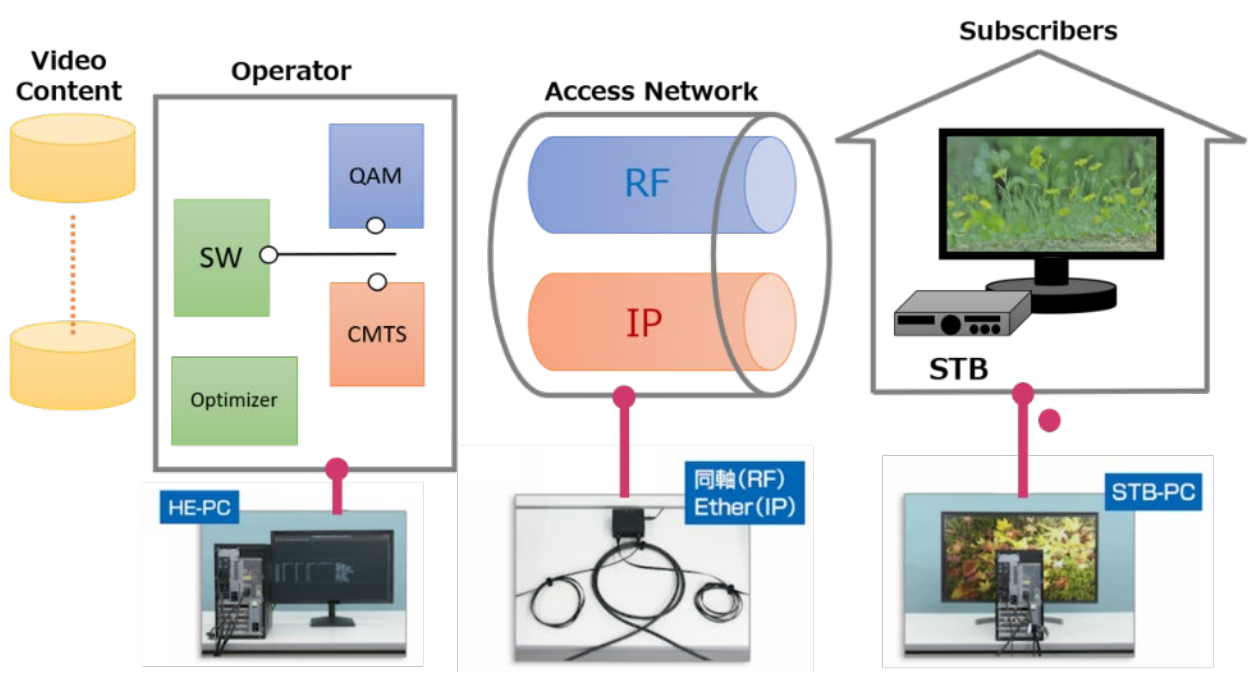

Figure 11 – Configuration of switching demo system

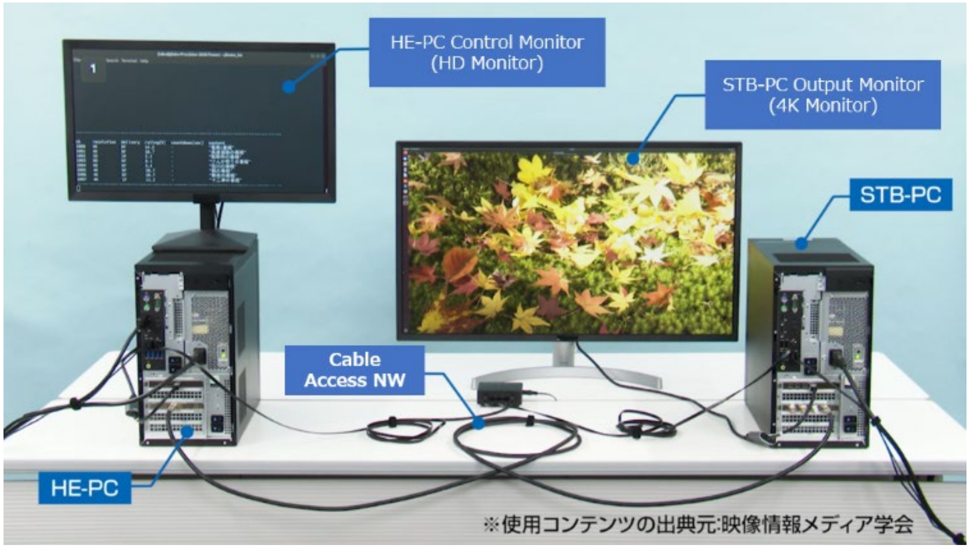

Figure 12 - Overview of switching demo system

6. Conclusion

Highly-efficient video distribution scheme over the existing HFC network was proposed. Basic concepts are sharing the RF/IP resources and switching RF/IP distribution scheme according to audience ratings, network bandwidth, attribute of video content. From the simulation results and the prototype development of demo system, it was revealed that theoretical effectiveness and feasibility of the proposed scheme. Especially, experiment results show that proposed scheme doubles the utilization efficiency of bandwidth or the number of 4K content compared to without this scheme. The switching demo system show the evidence of feasibility for seamless RF/IP switching. A total feasibility study by implementing optimizer and data collector on the demo system, and international standardization are future works.

Abbreviations

bps	bits per second
CMTS	cable modem termination system
CPE	customer premises equipment
CPU	computer processing unit
DOCSIS	Data Over Cable Service Interface Specification
FEC	forward error correction
FTTH	Fiber to the home
GB	giga byte
GUI	graphical user interface
HE	headend
HFC	hybrid fiber-coax
HD	high definition
Hz	hertz
ITE	The Institute of Image Information and Television Engineers
PC	personal computer
IP	internet protocol

QAM	quadrature amplitude modulation
QoE	quality of experience
RF	radio frequency
STB	set-top-box
SD	standard definition
TV	television
UHD	ultra-high definition

References

ITE 4K Test Materials (https://www.ite.or.jp/content/test-materials/)