Resource control of access networks responding to a dynamic change in application requirements

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***Abstract*— Access network systems are studied to accommodate a variety of services and applications using next-generation communication systems, e.g., 5th Generation Mobile Communication System (5G) and Beyond5G. These communication systems have architectures and mechanisms designed to ensure communication quality other than mere traffic capacity, i.e., high reliability and low latency. However, in terms of the usage of network systems for various applications, it is necessary to consider a wide range of usage conditions, such as time and location of network connection. In this case, the important network requirements are establishing control methods that span different networks and control schemes that can respond to dynamic changes in the usage requirements.**

Authors' previous research focused on controlling optical access networks that can be controlled in common for different networks, generating traffic models focused on 5G, and studying resource control schemes for optical access networks designed to carry 5G traffic.

In this study, authors take on the challenge of responding to the dynamic requirements changes at the service and application level. In particular, the authors propose a new resource control method and a system configuration that enables integrated control of wireless and wired networks. One of purposes of the proposal is achievement of network resource allocation function that can follow traffic fluctuations caused by the movement of mobile entity carrying terminals. The authors evaluate the effect of adding terminal mobility information to the resource control of the optical access network to improve the responsiveness to the traffic fluctuations.

Keywords*— *Network resource control, traffic monitor, heterogeneous networks, QoS, 5G, Beyond 5G

I. INTRODUCTION

In high-speed mobile communication systems (5G / Beyond5G) [1], small cells are expected to be introduced to realize high-speed, high-capacity service provision. To efficiently accommodate a large number of small cells, Passive Optical Network (PON) technology [2] can be applied and is considered in international standardization activities [3].

5G is said to be capable of accommodating multiple applications with different requirements in the same network using slicing technology. However, to achieve the accommodation with slicing technology, QoS control must be performed in each domain that constitute the end-to-end communication path. In addition, in terms of the usage of networks for a variety of purposes, it is necessary to consider a wide range of usage conditions, and the situation where users with different usage requirements. In such a case, it is essential to have a control method that can be applied different networks in common and respond to dynamic changes in requirements.

The first issue of the common control over different networks is solved by the application of network virtualization technology. The authors have conducted research on resource abstraction and the management of abstracted resources in optical access networks, and have presented a method to realize end-to-end resource control, including for access network systems. Therefore, the issue to be addressed in this paper is the second one, which includes proposal and verification of a method to perform resource control accurately and efficiently in situations where the requirements change dynamically. The authors have also studied dynamic resource control technologies for access networks that carry traffic for 5G and other systems. One of them is Bandwidth Control based on Online Monitoring (BCOM) [4,5], a lightweight bandwidth allocation method that uses linear regression analysis and extrapolation based on input traffic measurements.

In this study, based on the above BCOM method, authors investigated the issues and proposals for bandwidth control schemes focused on optical access networks, and the specific conditions under which the proposed control schemes will be effective. The proposed control scheme is verified by simulation.

II. RELATED WORK

This section describes prior work on transmission of wireless traffic such as 5G and dynamic resource allocation control in optical access networks.

In prior research for allocating network resources such as bandwidth assuming 5G traffic, a method to calculate resource allocation, including edge computing based on the parameters of delay and packet loss rate assuming different 5G applications, is proposed [6]. The proposed method allocates resources in multiple domains based on common requirements parameters. Research that worked on a scheme for bandwidth allocation control using AI [7] is also an example.

As an essential technology related to the above issues, many studies have been conducted on dynamic bandwidth allocation of network resources, and recently, some studies on allocation control combined with the latest information processing technologies have been published. For example, these include a study proposing a learning-based dynamic bandwidth allocation scheme [8], a study on a dynamic slice resource allocation scheme based on traffic prediction [9], and a study on a self-adaptive resource allocation scheme combining traffic prediction and user satisfaction [10]. A study [11] used a linear value function approximation for dynamic virtual resource allocation in a RAN, and a study [12] described a case in which a learning-based algorithm is effective. A study [13] proposed improving the ITU-T compliant Dynamic Bandwidth Allocation (DBA) algorithm for bandwidth allocation in optical access networks.

These studies have identified methods to realize dynamic resource allocation control of access networks to accommodate traffic for different 5G applications. However, consideration of allocation response characteristics in response to changes in application status and requirements, and realization of allocation control schemes common to multiple physical resources such as wavelengths and time slots are issues to be addressed.

III. OVERVIEW OF DYNAMIC RESOURCE CONTROL IN PON SYSTEMS

Since mobile communication systems, such as 5G, employ cellular-based communication techniques, their cell size decreases as the transmission rate increases, and the total number of cells increases. Therefore, as a network that can efficiently realize traffic multiplexing from such mobile systems, a PON with high-speed transmission performance and efficient use of station-side equipment and optical fiber resources is suitable [2].

This section describes the basic mechanisms related to PON and issues of DBA.

A. *Basic Mechanism of PON*

PON is an economic access network in which multiple subscriber-side devices share a single optical fiber resource and station-side device. It has been standardized by the ITU-T [14] and the IEEE [15].

Main conventional multiplexing scheme of PON is Time Division Multiplexing (TDM), and most of the systems currently standardized and commercially deployed are based on this scheme [1]. On the other hand, non-TDM schemes such as Wavelength Division Multiplexing (WDM) are also being considered due to the trend toward high-speed, high-capacity systems [16].

The primary mechanism of bandwidth allocation on PON uplink is shown in Figure 1. In the PON for FTTH, downlink bandwidth is essential. However, in the case of usage for a variety of services and applications, uplink bandwidth is also a major issue since many kinds of devices are connected. Regarding bandwidth allocation control, the TDM method is based on bandwidth sharing within an Optical Distribution Network (ODN), while the non-TDM method is based on bandwidth sharing. As shown in the figure, the OLT is generally configured to combine multiple ODN interfaces (PON interfaces) and to connect them to the upper-level equipment. It is assumed that bandwidth control over multiple ODN interfaces may be required in some cases.

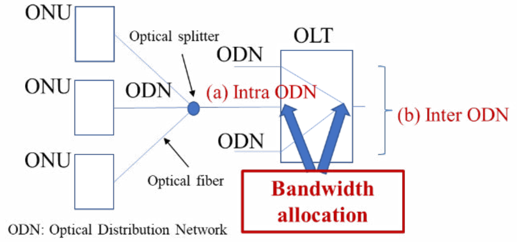

Figure 1 PON bandwidth allocation mechanism

B. *DBA Problems*

DBA in PONs is an excellent method for efficiently controlling bandwidth allocation according to user usage in a TDM scheme [1,17]. However, as mentioned in the previous section, DBA cannot be applied in a non-TDM scheme because each ONU occupies multiplexed channel bandwidth, such as wavelengths within the ODN interface. Furthermore, in a configuration where the OLT combines multiple ODN interfaces, it is necessary to apply a method other than DBA for bandwidth control across multiple ODN interfaces.

The above problems are expected to become apparent when accommodating a variety of applications with different communication requirements, as envisioned for 5G, and when dealing with users who expect to be connected over a wide geographic area, which is precisely the problem setting that defines the objective of this study.

The level of dynamism that should be addressed here is not a change within the defined service requirements as in the so-called DBA of the PON system but should be assumed in a situation where the usage requirements themselves change across multiple systems. Therefore, it is not exclusive to the DBA of the PON but is a level where issues are solved by working together. For example, the control cycle order of DBA is several hundred □s ~ several ms, but the dynamic changes in requirements, which are the subject of this study, occur in seconds, minutes, and hours. Therefore, while DBAs are necessary, functions that operate outside of DBAs should be considered.

IV. PROPOSAL OF BANDWIDTH ALLOCATION METHODS USING TRAFFIC MONITORING AND INFORMATION OF MOBILITY

To solve the DBA and other problems described above, the authors have been working on Bandwidth Control based on Online Monitoring (BCOM) [4, 5], a lightweight bandwidth allocation method using linear regression analysis and extrapolation based on input traffic measurements, to achieve rapid and efficient bandwidth control in response to dynamic changes in 5G traffic in optical access systems connected to wireless communication systems, such as 5G.

A. *Overview of BCOM*

Figure 2 shows the functional configuration of a 5G-RAN and PON access network with BCOM. Traffic with characteristics such as massive Machine Type Communications (mMTC), enhanced Mobile BroadBand (eMBB) and Ultra-Reliable and Low Latency Communications (URLLC) from 5G cells is input to each ONU via a DU. First, the traffic on the demarcation point between the DU and ONU is monitored <Step 1>. Next, bandwidth calculation is performed at the multiplexing point based on the results of each monitoring process <Step2>. Finally, the OLT performs bandwidth allocation control and bandwidth update processing <Step3>.

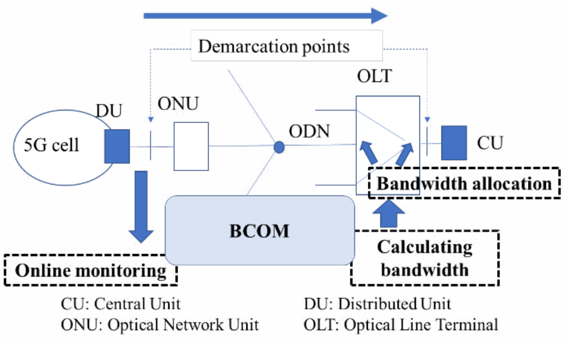

Figure 2 Schematic functional diagram of BCOM

The amount of bandwidth to be allocated is calculated by a prediction process that extrapolates the bandwidth one second later from the regression line obtained in the linear regression analysis. BCOM has as a parameter of reference time (the number of samples used in the regression analysis). If the reference time is short (few data points used in the regression analysis), the forecasts follow traffic fluctuations rapidly; if the reference time is long (many data points used in the regression analysis), the forecasts can be produced at moderate speed. The detailed algorism for the process is described in [4].

B. *BCOM Issues and Measures*

Figure 3 shows an example of the traffic from a mobile entity accommodated in the BCOM via the ONU. For the actual traffic shown by the black line, the prediction results are shown in orange when the reference time is 3 seconds, and the results are shown in blue when the reference time is 20 seconds. In general, longer reference time makes stable performance of bandwidth allocation and achieves high utilization efficiency. However, in case that input traffic changes very rapidly as shown in the figure, the longer the reference time, the slower the rise of the prediction when burst traffic occurs. The slower the rise of the prediction, the higher the frame loss rate sent out by the mobile. Therefore, the prediction tracking needs to be improved.

C. *Proposal Method*

To solve the above problem, authors developed BCOM+, which increases the allocated bandwidth when a mobile entity passes through the cell and reduces the bandwidth at other times, utilizing information of the time when a mobile entity is in the cell where each DU/ONU is located.

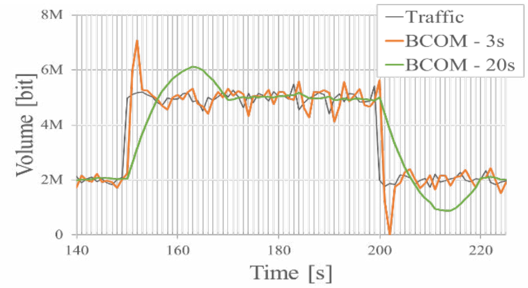

Figure 3 An example of bandwidth allocation.

In BCOM+, the bandwidth calculated on a BCOM basis is increased when a mobile entity passes through the connecting cell of a RU/DU connected to one ONU, and at other times, the portion of the bandwidth provided is reliably allocated to the other ONUs through which the mobile entity passes.

If α [bit] is increased for the allocated bandwidth calculated by BCOM when a mobile entity passes, β [bit] is reduced when the mobile entity is not observed. At this time, β is calculated as in Equation (1).

$$\beta = \frac{\alpha}{\min\left(2, the\ number\ of\ ONUs\right)} \qquad (1)$$

Figure 4 shows an example of BCOM+ operation when a mobile entity passes through a cell connected to ONU3. As shown in the figure, the system aims to provide sufficient bandwidth to accommodate the increase in mobile traffic due to the passage of the mobile and to reduce the frame loss rate of the mobile traffic. The increased bandwidth in the time when mobile entity pass through an ONU is divided among and subtracted at the other ONUs that it does not pass, thereby distributing the impact.

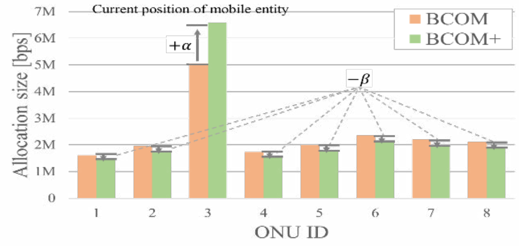

Figure 4 An example of BCOM+ operation

V. EVALUATION OF EFFICIENCY IN THE DYNAMIC BANDWIDTH ALLOCATION FUNCTION

This section compares the bandwidth allocation control schemes (BCOM and BCOM+) for situations where traffic sources move beyond communication coverage boundaries such as 5G cells due to terminal movement. Then it clarifies their respective assumptions and defines verification models and traffic models. Additionally, the simulation environment is explained, and the main simulation results are presented. Finally, the cases in which the proposed method is effective are discussed.

As a specific example of an application with dynamically changing requirements, authors assumed a case in which a group of terminals that are part of a service target move as a group as the mobile entity moves in an area where a local information service is provided. In particular, the authors considered a situation in which the mobile entity has a predetermined route and operation plan, such as a train or bus, and the movement of the moving group of terminals can generally be predicted.

A. Methods of Evaluation Target

In assumption of application shown in Figure 5, where mobile traffic sources move through multiple 5G cells connected to a PON system one after another, a comparative evaluation of different bandwidth allocation control schemes in the PON system is performed. It is assumed that the time for the mobile traffic to pass through each cell is known in advance.

(a) BCOM: traffic monitor-based dynamic bandwidth allocation

As described in the BCOM overview, perform near-term traffic predicting based on the results of traffic monitoring at the input stage of each ONU, calculate the required bandwidth, and perform the allocation process

(b) BCOM+: Coordination of traffic monitoring and planning allocation

Based on the bandwidth for BCOM, increasing process is performed when the mobile entity passes through, and decreasing process is performed for the other times.

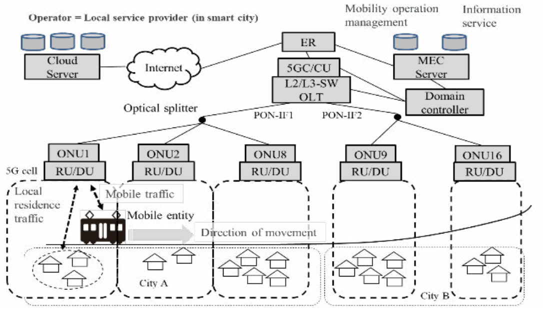

Figure 5 Example of an application where dynamic requirement changes occur

B. Models for Evaluation

1) Verification model

The system configuration of the target verification model is as follows: the number of ONUs in each PON-IF of the OLT is 8, and a total of 16 ONUs are connected to the upper L2SW via two PON-IFs. Mobile traffic generated from terminals on mobile entity is preferentially accommodated and forwarded to the upper network, distinguishing it from traffic generated from the homes of residents in the vicinity. The traffics are monitored at each ONU and used for bandwidth calculation in OLT. In addition, mobility schedule information from Mobility operation management is also used for the calculation.

2) Specification of a typical traffic model for a 5G system

A traffic model is specified to consider the traffic characteristics of URLLC/mMTC/eMBB in 5G systems.

First, because URLLC/mMTC is an ultra-low latency and multi-connected communication system, it is assumed to be less bursty than eMBB. Therefore, traffic multiplexed with these types of traffics can be modeled by an exponential distribution.

Next, the traffic model for eMBB is specified. eMBB is very bursty traffic due to its ultra-high speed and high capacity, i.e., the coefficient of variation between occurrences exceeds 1. This situation can be represented by multiplexing the ON-OFF model. It can be approximated by a second-order super-exponential distribution represented by a single distribution.

3) Verification conditions

The conditions for the simulation evaluation are shown in Table 1. A significant value derived from the above parameters is that the time for a mobile to be in the cell connected to each ONU is 50s at a speed of 36 km/h and 25s at 72 km/h.

Table 1 Simulation conditions

Items	Specifications
Communication coverage range per ONU	500m
Mobile traffic rate (average)	300Mbps
Local residence traffic rate (average)	50 Mbps/ONU
Moving object speed	36 km/h or 72 km/h
Reference time	variable
BCOM+ bandwidth increase rate	10, 30, 50, 80, 100 %
Time resolution	1s

4) Simulation environment

The environmental conditions are shown in Table 2.

Table 2 Simulation environment conditions

Items	Specifications
Size of CPU	48 cores
Clock frequency	3.8 GHz (Max)
Cache	L1d:768KiB, L1i:768KiB, L2:12MiB, L3:128MiB
Memory size	62GB

* L1d/L1i: L1 data/instruction cache

C. Verification

1) Overall operation

Figure 6 illustrates the overall operation, showing the time evolution of the bandwidth allocated by BCOM and BCOM+ for the generated traffic based on the traffic model. The figure also shows the mobile entity is passing through a 5G cell connected to ONU1 in a period between 70s and 120s. The movement speed is 36 km/h and the allocation ratio in BCOM+ is 30%.

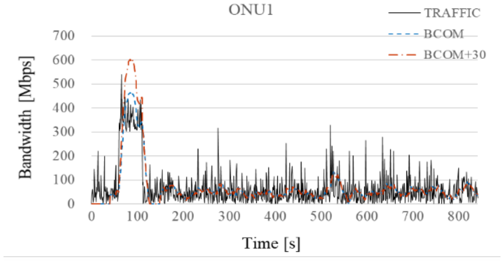

Figure 6 Overall operation diagram (ONU1)

2) Reference Time

Figure 7 shows the bandwidth control response characteristics with BCOM+ (rate increase of 30%) of an ONU when a mobile passes by, depending on the reference time. The speed of the mobile entity is 36 km/h. The cases of 10%, 50%, 80%, and 100% increase rate of BCOM+ were also verified, and it was found that the overshoot to the rise of real traffic was suppressed when the reference time was 40 s or longer in all cases. In addition, authors quantitatively measured the degree of safety (bandwidth surplus: potential margin against traffic fluctuations) and the degree of risk (bandwidth shortage: potential risk of shortage against traffic fluctuations) of allocated bandwidth concerning actual traffic and found that the characteristics were better when the reference time was 40s. The results are shown in Figures 8 and 9. Therefore, a reference time of 40s is recommended for a mobile speed of 36 km/h. The unit of the vertical axis of the safety and risk graphs is the difference between the allocated bandwidth and the actual traffic, integrated with the time direction, divided by the total time value of the actual traffic.

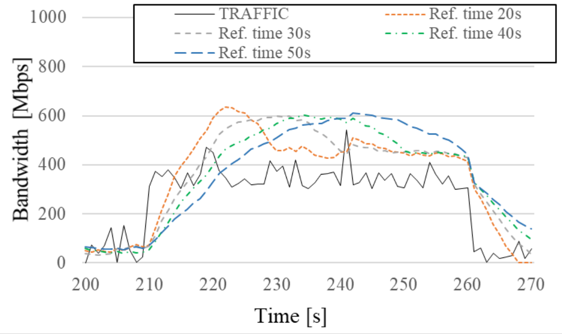

Figure 7 Allocation characteristics vs. reference time (BCOM+ (rate of increase 30%))

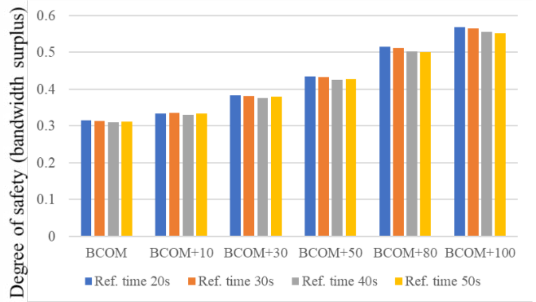

Figure 8 Potential margin of allocated bandwidth

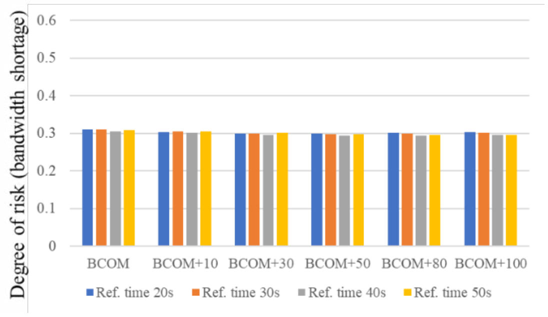

Figure 9 Potential risk of allocated bandwidth

3) Mobile traffic-oriented allocation characteristics

Figures 10 and 11 show the degree of safety and risk of bandwidth allocation for each method for actual traffic passing through a mobile. The results indicate that BCOM+ has a clear advantage when the rate of increase is 30% or more. However, since these safety and risk factors conflict regarding the accuracy of bandwidth allocation, an inadvertent increase is undesirable from the standpoint of overall network resource efficiency.

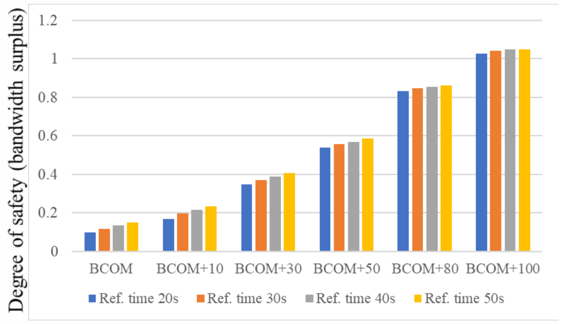

Figure 10 Potential margin of allocated bandwidth (when passing through a mobile)

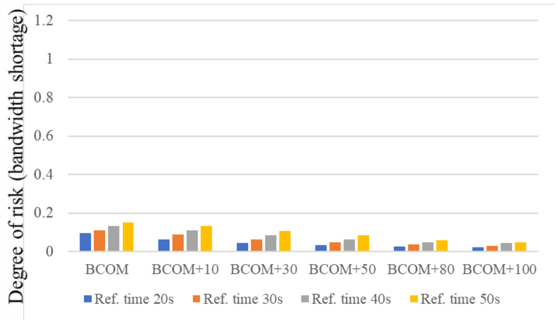

Figure 11 Potential risk of allocated bandwidth (when passing through a mobile)

4) Method for comparison (BCOM and BCOM+)

Based on the above preliminary verification, it was concluded that a reference time of 40 s (20 s for 72 km/h) at a mobile entity speed of 36 km/h and a BCOM+ bandwidth rate of increase of approximately 30% are suitable as critical parameters.

In the following, authors will proceed with verifying the characteristics when the movement of the moving object deviates from the plan, which is assumed to be a benefit of BCOM+ under the above primary parameter settings.

Figure 12 shows the actual traffic and bandwidth allocation characteristics when a mobile entity passes through each cell is delayed from the scheduled time. For example, in the case of traffic in Japan, minute-by-minute changes are always known, so it was assumed that deviations of less than 60 seconds would occur outside the control range as delay orders. Here, the characteristics are shown for a delay of 20s.

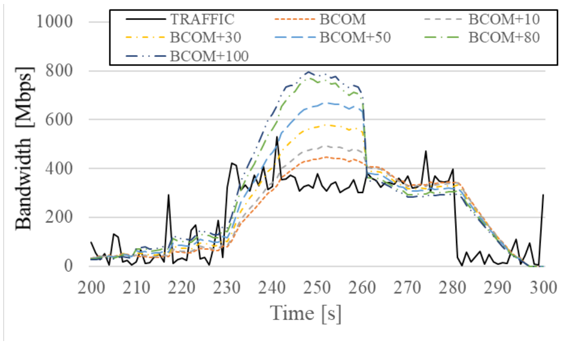

Figure 12 Allocation characteristics when mobile delay (of 20s) occurs

Under the above conditions, a comparison of bandwidth allocation margins and shortages during mobile transit was performed in the same way as described in 3) above. The results are shown in Figures 13 and 14. BCOM+ (here assuming a rate of increase of 30% based on the results of 3) above) is superior to BCOM when the delay time of the mobile is 20s and 30s but is comparable for 40s and inferior for 50s. This result is considered to be due to the fact that the increasing process cannot be performed at the mobile's transit time, which is a feature of BCOM+, and the time ratio of the decreasing process increases.

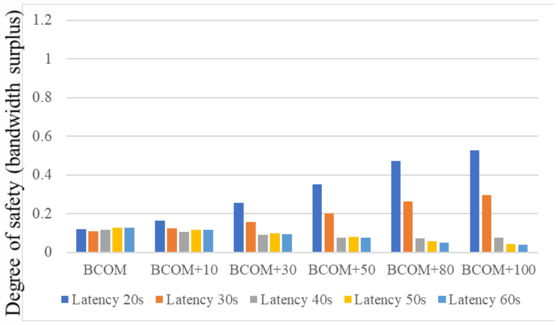

Figure 13 Potential margin of allocated bandwidth (when mobile delay occurs)

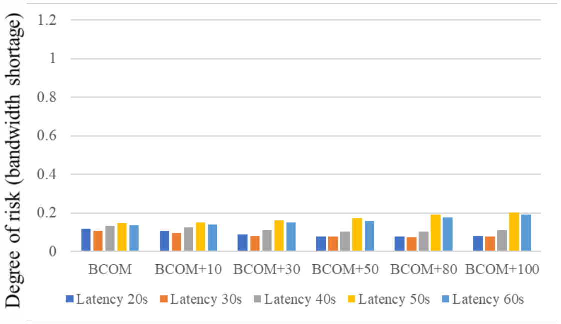

Figure 14 Potential risk of allocated bandwidth (when mobile delay occurs)

VI. CONCLUSIONS

The authors studied bandwidth control schemes for optical access networks that dynamically implement end-to-end resource control by connecting to wireless communication systems that accommodate various applications such as 5G and support diverse usage patterns. In particular, as a case where the user requirements change dynamically, authors studied, proposed, and verified a quick and stable bandwidth allocation scheme for a system that provides a variety of information to both mobile passengers, e.g., on trains and buses, and local residents. The simulation results showed that the proposed method is superior to the conventional method in terms of both safety and risk of bandwidth allocation, regardless of the delay times of the trains and other entities from the scheduled time, as long as the delay time of the entity is approximately half of the time the entity remains in each cell. In the future, authors plan to expand further the conditions under which significance can be demonstrated and to conduct an evaluation that considers the efficiency of network resource utilization.

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