Combining Multicast ABR and Information-Centric Networking

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Abstract— **Live video streaming through the Internet is being widely used in the content distribution of popular concerts and bid sport events. There are several technologies to realize it, and among them, the multicast Adaptive BitRate (mABR) provides efficient network utilization accommodating a large number of clients. Actually, it is adopted by some network operators. It realizes the efficient content data transfer using IP multicast. However, mABR uses a unicast data transfer for the retransmissions of corrupted content data. This mechanism may introduce a situation that a large number of clients request the same content data at the same time. On the other hand, the Information-Centric Networking (ICN) is another technology to realize a multicast type content delivery by the content name data identification and the network caching. ICN is a pull-based architecture and some efforts are required to adapt it for the live video streaming. This paper proposes a new approach to combine the mABR and ICN architectures to realize efficient content delivery. Content data are delivered by use of mABR and corrupted data are retransmitted by use of ICN. The results of performance evaluation show that our proposal reduces the retransmitted data largely comparing with the original mABR.**

Keywords-Adaptive BitRae; Multicast ABR; Information-Centric Network; IP Multicast.

I. INTRODUCTION

Live video streaming through the Internet is being widely used for distributing various contents such as popular concerts and big sport events. There are several technologies to realize it. Most popular one is the MPEG-DASH (Moving Picture Experts Group-Dynamic Adaptive Streaming over HTTP) [1]. In MPEG-DASH, the content distribution is performed as a style of Web server access via a point-to-point connection. It allows clients to watch TV broadcasting using their web browsers, but the congestion in servers or networks may occur when a large number of clients request the same content. Actually, the FIFA World Cup Qatar 2022 was broadcasted with the MPEG-DASH technology by ABEMA in Japan, but some clients did not access the server by its congestion [2].

A way to provide efficient live video streaming is to introduce the multicast scheme. One approach is IPTV (Internet Protocol Television) [3], which introduces the IP multicast between client-side set-top boxes and headends, and requires that networks should be managed with QoS guarantees. The problems of IPTV are that it requires multicast support in access networks and that clients are not HTTP-based.

Another approach is the Information-Centric Networking (ICN). It is a new network architecture suited for a large scale content retrieval, and the Named-Data Networking (NDN) [4] is one of the representative studies. In NDN, content is identified by its name, not by the address of the host containing it. A consumer, a client, requesting a content sends an Interest packet containing the content name. A producer, a server providing the corresponding content data returns a Data packet to the consumer backward through the path that the Interest path traversed. Intermediate NDN routers transferring the Data packet cache the packet for future redistribution. However, NDN is a pull-based architecture, where a consumer requests an individual content segment explicitly, and so it does not fit a push-based data transfer in the real-time content delivery in live video streaming. There are some studies to adapt NDN to live streaming [5][6]. Both of them eliminate the one-to-one correspondent between Interest and Data packets, and introduce a long-lived Interest packet called a Symbolic Interest or a Persistent Interest. But in the current situation, ICN or NDN itself is still in the research stage.

The most realistic technology is the multicast Adaptive BitRate (mABR) [7], which extends MPEG-DASH by adopting an IP multicast in the delivery network. In mABR, the multicast server and the multicast gateway are introduced inside the network and they delivery content data using IP multicast. The communication between clients playbacking contents and the multicast gateways as well as that between the multicast servers and the content hosts are HTTP-based unicast and pull interactions. It can be said that mABR provides the standard HTTP ABR streaming and avoids the congestions in servers and networks. Actually, several network operators, such as Orange S.A. and Telecom Italy, offer live video delivery services using mABR [8][9]. In mMBR, however, corrupted content segments are retransmitted by unicast via the Unicast repair service, and so it may be possible that if data are corrupted in some link close to the multicast server, a lot of retransmission requests are sent to the unicast repair service and a lot of retransmitted data rush to the delivery network.

In order to resolve this problem, this paper proposes a new network architecture combining the mABR-based content delivery and the ICN-based content efficient segment retransmission.

The rest of this paper is organized as follows. Section 2 gives some background information including the overviews of mABR and ICN. Section 3 proposes our new network architecture combining mABR and ICN. Section 4 provides the results of performance evaluation focusing on the retransmission of corrupted content segments. In the end, Section 5 concludes this paper.

ISBN: 978-1-68558-392-7

II. Backgrounds on mABR and NDN

A. mABR

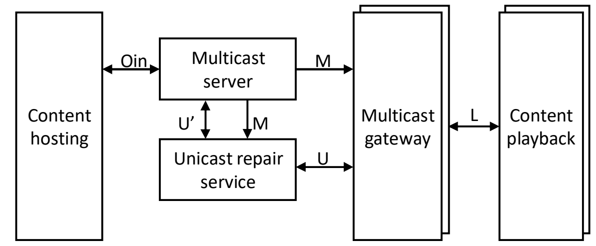
1) Overview

Figure 1 shows the overall architecture and the interfaces between modules in mABR. Video contents are stored in the *Content hosting* module, and the *Multicast server* requests and delivers them to the *Multicast gateway* and *Unicast repair service* modules. The *Content playback* module, which corresponds to a user terminal device, requests the delivered contents to the corresponding Multicast gateway storing the contents in the cache called *Asset storage*.

The interface between the Content playback and the Multicast gateway, *L*, is the HTTP-based unicast interaction, and so the conventional MPEG-DASH terminals can be uses as they are. On the other hand, the interface between the Multicast server and the Multicast gateways, *M*, is the IP multicast-based interaction. When some Content playback modules request a specific content or the delivery of the content is scheduled, the corresponding Multicast gateway requests its delivery by IGMP (Internet Group Management Protocol) or MLD (Multicast Listener Discovery). Then, the multicast delivery tree is established between the Multicast server and the Multicast gateway by use of the multicast routing protocol. The interface between the Content hosting module and the Multicast server, *Oin*, is again a pull-based unicast interaction, which is functionally identical to interface *L*. The push-type interaction, such as HTTP push method may be used in this interface.

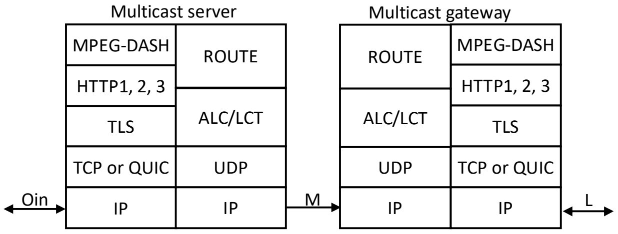
The Unicast repair service module offers the payload repair function. Normally, the Unicast repair service module listens to multicast content transmissions over interface *M*, and caches the packets locally. When a Multicast gateway detects a loss or a corruption of some content segment, then it requests the retransmission of the segment to the Unicast repair service module through interface *U*. If the Unicast repair service module itself detects a corruption, then it requests the corrupted packet to the Multicast server through interface *U'*.

2) Application Layer for Multicast Delivery



M: Multicast IP content transmission
L: Unicast HTTP interaction
Oin: Ingest of content by Multicast server, implemented as a pull interface
U: Unicast interaction between Multicast gateway and Unicast repair service
U': Unicast interaction between Multicast server and Unicast repair service

Figure 1. Overall architecture of mABR.



ROUTE: Real-time Object Delivery over Unidirectional Transport
ALC: Asynchronous Layered Coding
LCT: Layered Coding Transport

Figure 2. Protocol stack in Multicast server and Multicast gateway.

Figure 2 shows the protocol stack in the Multicast server and Multicast gateway modules. Both of them have a dual protocol stack structure, one stack for HTTP-based MPEG-DASH interactions and another for IP multicast-based content delivery. The HTTP-based protocol stack includes MPEG-DASH over HTTP stack, which uses HTTP/1, 2, or 3. For the case of HTTP/1 and 2, TCP is used as a transport layer, and for HTTP/3, QUIC and UDP are used as a transport.

For the side of multicast-based content delivery, mABR defines two protocols; File Delivery over Unidirectional Transport (FLUTE) [10] and Real-time Object Delivery over Unidirectional Transport (ROUTE) [11]. FLUTE handles an individual content segment as a separate file, and is well suited for non-real time delivery over lossy links. On the other hand, ROUTE is designed for the real-time media object delivery, particularly for broadcast/TV environments. Therefore, this paper uses ROUTE for the application layer in the delivery network.

As shown in Figure 2, the ROUTE protocol stack includes Asynchronous Layered Coding (ALC) [12] and Layered Coding Transport (LCT) [13]. ALC is a massively scalable reliable content delivery protocol for multiple rate congestion controlled content delivery, which is specifically designed for IP multicast as the underlying network service. It uses LCT as a header format of a ROUTE packet, which includes Transport Session Identifier (TSI) and Transport Object Identifier (TOI). TSI uniquely identifies a session among all sessions from a particular sender. TOI identifies a specific DASH segment.

It should be noted that the ROUTE protocol divides a content segment handled in the MPEG-DASH protocol into multiple ROUTE packets, whose size is smaller than MTU size used by the delivery network. So, the IP fragmentation does not happen during the IP multicast transmission. To identify a ROUTE packet explicitly, ROUTE packet header includes Payload ID, which shows the start_offsset specifying the number of the first octet in the contest segment carried in this packet.

It should be also noted that the URL used in the MPEG-DASH/HTTP protocol stack is not specified explicitly in the ROUTE protocol stack. The URL information is mapped to the TSI and TOI values in the LCT header.

The following is an example of relationship between the URL information and the TSI/TOI values. A Multicast gateway or a Multicast server module requests a specific content segment by its URL, in the form of

`http://netoperatorA.net/live/channel1/3000k/segment_1000.m4s`.
In this case, `chanel1` corresponds to the multicast channel supported by this network operator and so the TSI value is assigned to a value of `0x1001`. The sequence number assigned to the segment, a value of `1000`, identifies the DASH segment, and so the TOI value also becomes `1000`.

3) Unicast Repairng

On the other hand, the retransmission of lost or corrupted segments is performed by the unicast HTTP-based interactions between Multicast gateway and the Unicast repair service, or between the Unicast repair service and Multicast server. For example, when the Multicast gateway detects a packet loss, then it sends a `HTTP GET` request with `Range` request header specifying the lost data. An example is as follows supposing that data corresponding to byte `500` through `1900` are lost in segment `segment_1000.m4s`.

```
HTTP GET /live/channel1/3000k/segment
         _1000.m4s
Range: bytes=500-1900
Host: netoperatorA.net
```

B. NDN and its Application to Live Streaming

NDN nodes (consumers, NDN routers, and producers) maintain the following major data structures [4].

- Forwarding Information Base (FIB): used to forward Interest packets toward producers of matching Data.
- Pending Interest Table (PIT): keeps track of forwarded Interest packets for returning Data packets.
- Content Store (CS): caches received Data packets.

When an Interest packet arrives on some face, the content name in the Interest is looked up. If there is a copy of the corresponding Data packet in CS, it is sent out to the face the Interest packet arrived on and the Interest packet is discarded. Otherwise, if there is a PIT entry exactly matching to the received content name, the Interest's arrival face is added to the PIT entry and the Interest packet is discarded. Otherwise, if there is a matching FIB entry, then the Interest packet is sent to the face specified in the FIB entry.

By the help of these data structures, NDN provides a multicast-type content delivery. As described in Section 1, however, NDN is based on the pull-type communication, requires an Interest packet transfer for each content segment.

Two references [5][6] proposed a similar way to avoid the overhead of frequent Interest packets. In [5], a new type of Interest, Symbolic Interest, is proposed. A Symbolic Interest includes the content name and the duration, but does not require the sequence number specific to individual segment to be specified. When an NDN router receives a Symbolic Interest, it expands the life time of PIT entry for the specified duration, and keeps the corresponding Data packets to be delivered during the duration.

III. COMBINATION OF MABR AND ICN

A. Overviews

We adopted the following design principles to coordinate mABR and ICN.

(1) Use NDN as a tool to retransmit a lost or corrupted content segment instead the unicast repair mechanism in the current mABR. The multicast-based content delivery within the delivery network is used as it is.

(2) Some NDN nodes called NDN proxies are implemented within the delivery network. They work as IP multicast receivers similarly with the Multicast gateway nodes. They handle received ROUTE packets as NDN Data packets and store in its Content Store. The Multicast server also works as an NDN producer, and the Multicast gateways work as NDN consumers. This means that NDN Interest/Data packet exchanges are not performed in the initial delivery of content segments. Instead, the IP multicast is used in the initial delivery.

(3) When a Multicast gateway detects the loss or the corruption of a ROUTE packet, it requests this packet via the NDN interaction. That is, the Multicast gateway sends an Interest packet requesting the ROUTE packet to the corresponding NDN proxy. If the NDN proxy has the ROUTE packet in its CS, it returns the corresponding Data packet. If not, the NDN proxy consults its PIT for this Interest, and sends the Interest packet to the upstream NDN proxy or the Multicast server (the producer), if the PIT does not maintain the entry corresponding to the Interest packet.

(4) The content name specifying a ROUTE packet is composed using the corresponding TSI, TOI, and Payload ID values of the ROUTE packet.

(5) The NDN level network is constructed with the help of NDN routing protocol, such as NLSR [14]. Interest and Data packets are transferred using TCP for the reliable transfer [15].

B. Network Configuration and Protocol Stack

Figure 3 illustrates the proposed network configuration. The delivery network consists of IP routers supporting IP multicast. The Multicast server / NDN producer and the Multicast gateways / NDN consumers are connected to the delivery network. Multiple NDN proxies are installed within the delivery network. They are connected with a nearby IP router.

A multicast tree is constructed with the Multicast server being the root of the tree. The Multicast gateways and the NDN proxies work as the leaves of the tree. The relationship of NDN producer, routers, and consumers are established among the Multicast server, NDN proxies, and Multicast gateways, as shown in the figure.

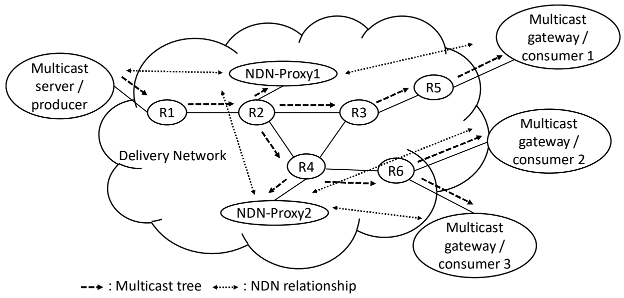


Figure 3. Proposed network configuration.

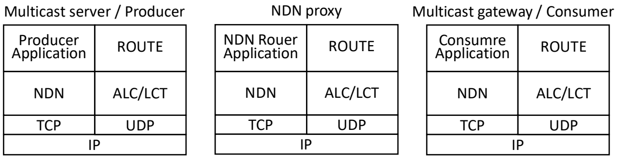


Figure 4. Protocol stack used in delivery network.

Figure 4 shows the protocol stack of the nodes used in the delivery network. All of them include the protocol stacks for the ROUTE multicast content delivery and the NDN content delivery. As mentioned above, ROUTE uses UDP and in this paper NDN uses TCP as a transport protocol.

C. *Mapping among DASH URL, ROUTE Packet Header, and NDN Content Name*

As described in the previous section, the content to be delivered is identified by some URL which identifies an MPEG content segment. It takes a style of

http://<domain-name-of-multicast-server>/<service-name>/<segment-identifier>.

In the example given above. <domain-name-of-multicast-server> is `netoperatorA.net`, <service-name> is `live/channel1/3000k`, and <segment-identifier> is `segment_1000.m4s`. This URL information can be constructed from the information stored in the MPD (Media Presentation Description) file of the content.

The parameter values of ROUTE packet header, TSI, TOI, and Payload ID, are derived from the URL information. The value of TSI identifying the session corresponds to the part of <service-name> in the URL. The value of TOI specifying a specific object in the session corresponds to the part of <segment-identifier> in the URL. In the previous example, the value of TSI is set to `0x1001`, and the value of TOI is set to `1000` by number part of the segment ID `segment_1000.m4s`. In the ROUTE protocol, the segment is fragmented into ROUTE packets in the application layer. Each packet is identified by Payload ID specifying the offset of the first octet contained in the packet. The Payload ID of the first ROUTE packet carrying a content segment will be `1`, and that of the second ROUTE packet will be `1401`, when the MTU size is 1,400 bytes.

The IP multicast address used in the delivery network is defined according to the policy of the network operator managing the delivery network. The multicast address needs to be unique within the delivery network, and does not need to be unique globally. So, a possibility is to use the source-specific multicast range (232.0.0.0/8). The multicast address for a specific Multicast server and for a specific live content can be determined according to the policy of the delivery network.

In the proposed method, the NDN system in the delivery network handles ROUTE packets as individual content segments. Therefore, the content name in our proposal will be specified by the combination of the Multicast server ID, the multicast flow ID (TSI), the object ID specifying the segment conveyed in the flow (TOI), and the ID of the fragmentation of the fragment conveyed in the ROUTE packet. So, the content name specifying a ROUTE packet can be a style of

/<domain-name-of-multicast-server>/<TSI>/<TOI >/<start_offset>.

The example will be

`/netoperatorA.net/0x0001/1000/1`.

D. *Sequence Example of Retransmission*

Figure 5 shows an example of communication sequence in our proposal. In the beginning, the Multicast server requests a content segment whose URL is `http://A/live/seg1000`. When the Content hosting returns the data of this segment, the Multicast server starts the delivery. In this figure, we suppose that the content segment is divided into ten ROUTE packets each of which has 1,400-byte data. They are delivered by IP multicast to NDN proxy and Multicast gateway. In the NDN proxy, individual ROUTE packets are stored as Data packet in its content cache. In the Multicast gateway, the content segment is reconstructed and stored in its Asset storage. The Content playback will request this segment via HTTP interaction.

In the delivery of the second content segment, the figure shows two cases of transmission error and its recovery. In the first case, the ROUTE packet containing bytes 1401:2800 is lost before the Multicast gateway receives it. Then the gateway sends an NDN Interest packet with content name `/A/0x1000/1001/1401`. Since the corresponding data is cached in the NDN proxy, the proxy returns the corresponding Data packet immediately.

In the second case, the sixth ROUTE packet containing bytes `7001:8400` is lost and none of the NDN proxy nor the gateway receive it. In this case, the gateway sends an Interest packet with content name `/A/0x1000/1001/7001`. Since the NDN proxy does not have the corresponding data, it relays the Interest packet to the Multicast server / producer. The producer returns the corresponding Data packet to the proxy, and the proxy relays the Data packet to the Multicast gateway.

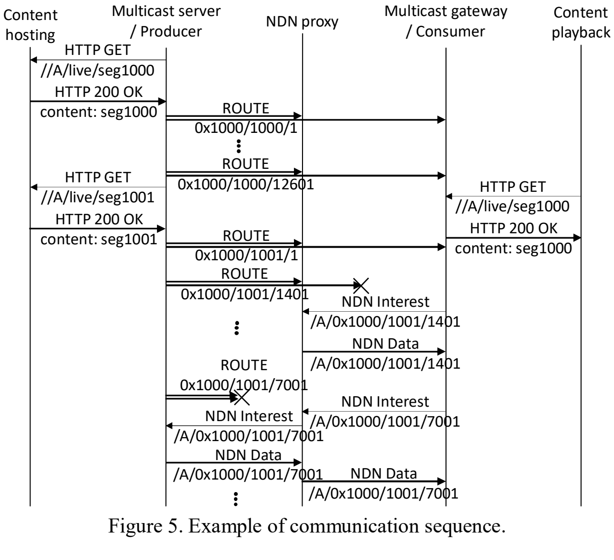


Figure 5. Example of communication sequence.

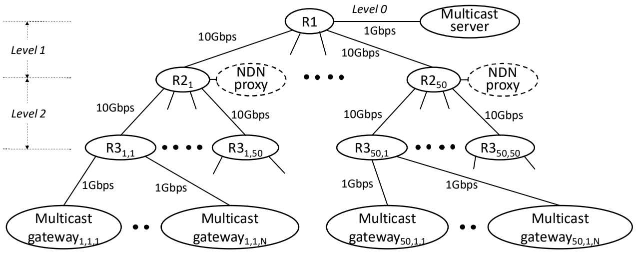


Figure 6. Network structure for evaluation.

It should be noted that, even if there are multiple Multicast gateway, only one Interest packet will be relayed to the Multicast server, because the Interest is specified in the PIT or the received Data packet is cached in the proxy.

IV. PERFORMANCE EVALUATION

A. Conditions for Evaluation

Figure 6 shows the network structure used for the performance evaluation. This configuration is a hierarchical style which is designed by supposing the network in Japan. Router $R1$ is the root router to which the Multicast server is connected. Routers $R2_1$ through $R2_{50}$ are intermediate routers, which are installed in the prefecture level. Routers $R3_{i,1}$ through $R3_{i,50}$ are access routers located below router $R2_i$ (i=1 to 50). Under access routers, N Multicast gateways are accommodated. The transmission rate of individual links is specified in the figure. In the proposed method, the NDN proxies are connected to the intermediate routers. We suppose that the one-way delays between the Multicast server and individual Multicast gateways take random values between 10 msec and 50 msec.

As a content delivered over this network, we assume the full HD video, whose bitrate is 5 Mbps. The ROUTE packet size is 1,400 bytes, and so the packet rate is 0.446 K packets per sec (pps).

We assume the packet losses in links of individual levels; level 0 through level 2 as depicted in the figure. The packet loss rate is denoted by p, which contains the losses in the link and the router. We approximate those losses as random errors.

In the original mABR, when a packet loss occurs, the Multicast gateways request the lost packet to the Unicast repair service module installed in the Multicast server. This request is done by the HTTP communication, and so the Multicast gateway establishes a TCP connection with the Multicast server in the beginning. After that, the individual Multicast gateway sends an HTTP GET command, as described in Subsection 2.A.3), to request the content data corresponding to the lost ROUTE packet. Since the ROUTE packets are delivered to all the requesting Multicast gateways, the retransmission requests are performed by multiple gateways in a short time frame. That is, the TCP SYN packets and the HTTP GET commands rush into the Multicast server. These communication sequences will provide the Multicast server with two types of heavy loads. One is a traffic congestion like a TCP SYN floods DDoS attack. Another is a heavy traffic load of the HTTP GET responses conveying the lost data sent by the Multicast server. We evaluate these two traffic loads as for the original mABR.

In the proposed method, when a packet loss occurs, the Multicast gateways send an Interest packet for the lost packet to the corresponding NDN proxies. If the NDN proxy sores the lost packet in its Content Store, it returns the lost packet by the NDN Data packet, else the Interest packet is forwarded to the Multicast server when it is the first request. In those cases, a TCP connection is established to the NDN proxy or to the Multicast server. So, we evaluate the following two aspects: the TCP SYN congestion at Multicast server and at NDN proxy and the traffic load of Data packets sent by the NDN proxies and the Multicast server.

B. Evaluation of TCP SYN Congestion

The TCP SYN congestion is evaluated by focusing on one ROUTE packet loss. When a ROUTE packet is lost in the level 0 link, all of the Multicast gateways do not receive the packet, and try to request the retransmission. In the original mABR, all of the Multicast gateways establish TCP connections to the Multicast server. The number of the transmitted TCP SYN segments is $N \times 50 \times 50 = 2500 \cdot N$. Since the round-trip delay between the Multicast server and the individual Multicast gateway takes a value between 20 msec and 100 msec, these SYN segments rush to the Multicast server during 80 msec. So, the rate of SYN segments is $2500 \cdot N / 0.08 = 31250 \cdot N$ pps.

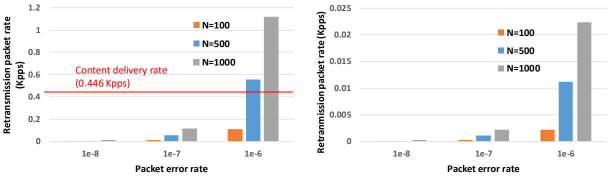
In the proposed method, a Multicast gateway establishes a TCP connection to the corresponding NDN proxy in order to send an Interest packet. The number of the SYN segments transmitted to one NDN proxy is $N \times 50 = 50 \cdot N$. The rate of SYN segments is $625 \cdot N$ pps. Each NDN proxy establishes a TCP connection to the Multicast server, and so the number of TCP SYN segments is 50 and the rate is 625 pps.

We use 100, 500, and 1,000 as the value of N. It is reported that the number of access to the FIFA World Cup Qatar 2022 content delivery exceeded 23 million [16], which is the result of access throughout one football match. The case of N = 1,000 corresponds to 2.5 million simultaneous access, which may be comparable with the 23 million access in one content.

Table I shows the TCP SYN segment rate caused by one ROUTE packet loss. In the original mABR, the case of N = 1,000 provides 31.25 Mpps SYN segments. This is almost a level of SYN flood DDoS attack. A DDoS attack example Google server suffered in 2020 is reported as 167 Mpps [17]. Moreover, if the SYN segment size is 50 bytes, the total SYN traffic in the case of N = 1,000 becomes 12.5 Gbps. This traffic cannot be transferred through the 1 Gbps link between $R0$ and the Multicast server. This also says that the SYN rate

TABLE I. TCP SYN SEGMENT RATE FOR ONE ROUTE PACKET LOSS

		N=100	N=500	N=1000
original mABR	to Multicast server	3.125 Mpps	15.625 Mpps	31.25 Mpps
proposed	to NDN proxy	62.5 Kpps	312.5 Kpps	625 Kpps
	to Multicast server	625 pps	625 pps	625 pps



(a) Retransmission from Multicast server in original mABR

(b) Retransmission from an NDN proxy in proposed method

Figure 7. Retransmission packet rate.

in the original mABR is extremely heavy. On the other hand, the proposed method can lighten the SYN segment congestion as shown in the table.

C. *Evaluation of Retransmitted Traffic Load*

The next evaluation point is the traffic load of retransmitted packets from the Multicast server or the NDN proxies. As mentioned above, we assume the packet loss rate is p for individual links. For the packet losses in the Level 0 link, the expected value of retransmission packet rate in the original mABR will be *the multicast packet rate* $\times p \times 2500 \times N$. When packet losses occur at some link in the Level 1, the expected value in the original mABR will be *the multicast packet rate* $\times 50 \times p \times 50 \times N$. This is the same result as the case in the packet losses in the Level 0. Therefore, we assume that packet losses occur at the link between *R0* and Multicast server in Figure 6.

We assume that the coding rate of the content is 5 Mbps, that is 0.446 Kpps when a ROUTE packet includes 1,400-byte content data. So, in the original mABR, the retransmission packet rate from the Multicast server is $0.446 \times 2500 \times p \times N = 1115 \cdot p \cdot N$ (Kpps). On the other hand, in the proposed method, the retransmission packet rate from the individual NDN proxy is $0.446 \times 50 \times p \times N = 22.3 \cdot p \cdot N$ (Kpps), and the retransmission packet rate from the Multicast server to the individual NDN proxy is $0.446 \times 50 \times p = 22.3 \cdot p$ (Kpps).

Figure 7 shows the results for $p = 10^{-8}$, 10^{-7} and 10^{-6}, and $N = 100$, 500 and 1,000. In the original mABR, the retransmission packet rate from the Multicast server is relatively large. Especially when the packet loss rate is 10^{-6}, the retransmission packet rate is larger than the content delivery rate in the cases of $N = 500$ and $N = 1{,}000$. In contrast, the retransmission packet rate from one NDN proxy is much smaller than the result in the original mABR. This shows the effectiveness of our proposal.

V. CONCLUSION AND FUTURE WORK

In this paper, we proposed a scheme to combine the multicast ABR and the information-centric networking, specifically the named data networking. mABR is actually adopted by some network operators and is used for the efficient live content delivery by making Multicast server transfer content packets via IP multicast. However, when some multicast packets are lost or corrupted, the retransmission of those packets are performed by the unicast repair communication. This mechanism may introduce a heavy congestion when a large number of clients, Multicast gateways, request retransmissions for a specific content packet. This paper proposed an approach that the retransmission is performed by the NDN scheme. Several NDN proxies are introduced in the delivery network, and they behave as a multicast client in ordinary times receiving content packets and storing them in their content stores. When some Multicast gateways detect packet losses, they request the lost packets to the corresponding NDN proxies. The results of the performance evaluation confirmed that the proposed method provide an efficiency in terms of the TCP SYN sending and the retransmitted traffic load. As a future work, we will design the similar scheme using HTTP proxy.

ACKNOWLEDGMENT

This work was supported by JSPS KAKENHI Grant Number JP25K15075.

REFERENCES

[1] ISO/IEC, " Information technology - Dynamic adaptive streaming over HTTP (DASH) - Part 1: Media presentation description and segment formats," ISO/IEC 23009-1:2022, Aug. 2022.

[2] Black Box, "Internet broadcaster Abema scores World Cup livestreaming win," Dec. 2022, available at https://www.blackboxjp.com/news/internet-broadcaster-abema-scores-world-cup-livestreaming-win, accessed Feb. 2026.

[3] ITU-T, "Requirements for the support of IPTV services," Recommendation ITU-T Y.1901, Jan. 2009.

[4] V. Jacobson, et al., "Networking Named Content," In Proc. CoNEXT '09, pp. 1-12, Dec. 2009.

[5] K. Matsuzono and H. Asaeda, "NTRS: Content Name-based Real-time Streaming," In Proc. 13th IEEE CCNC, pp. 1-7, Jan. 2016.

[6] P. Moll, S. Theuermann, and H. Hellwagner, "Persistent Interests in Named Data Networking," in Proc. IEEE 87th VTC Spring, pp. 1-5, Jun. 2018.

[7] DVB, "Adaptive media streaming over IP multicast," DVB Document A176 Rev.7, Mar. 2025.

[8] Euronext Markets, "Broadpeak's Multicast ABR offer chosen by Orange in Spain," Sep. 2013, available at https://live.euronext.com /en/products/equities/company-news/2023-09-27-broadpeaks-multicast-abr-offer-chosen-orange-spain, accessed Feb. 2026.

[9] Broadpeak, "Broadpeak Multicast ABR Solution Optimizes Live Sports OTT Delivery in Italy, Jan. 2022, available at https://broadpeak.tv/newsroom/broadpeak-mabr-live-sports-tim, accessed Feb. 2026.

[10] T. Paila, R. Walsh, M. Luby, V. Roca, and R. Lehtonen, "FLUTE - File Delivery over Unidirectional Transport," IETF RFC 6726, Nov. 2012.

[11] The Broadcast Standards Association, "ATSC Standard: Signaling, Delivery, Synchronization, and Error Protection," A/331, Oct. 2025.

[12] M. Luby, M. Watson, and L. Vicisano, "Asynchronous Layered Coding (ALC) Protocol Instantiation," IETF RFC 5775, Apr. 2010.

[13] M. Luby, M. Watson, and L. Vicisano, "Layered Coding Transport (LCT) Building Block," IETF RFC 5651, Oct. 2009.

[14] A. Hoque, et al., "NLSR: named-data link state routing protocol," in Proc. ACM SIGCOMM workshop on Information-centric networking, pp. 15-20, Aug. 2013.

[15] T. Kato, R. Yamamoto, and S. Ohzahata, "NDN over TCP with Multi-Level Congestion Control," in Proc. IEEE ICCC 2023, pp. 592-596, Dec. 2023.

[16] NHK, "ABEMA, the video streaming service, recorded its highest-ever viewership during the Qatar World Cup (in Japanese)," The NHK Monthly Report on Broadcast Research, Feb. 2023.

[17] S. Batool, el al., "Lightweight Statistical Approach towards TCP SYN Flood DDoS Attack Detection and Mitigation in SDN Environment," Security and Communication Networks, vol. 2022, iss. 1, pp. 1-14, Jan. 2022.