IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

SPECIAL SECTION ON SMART CACHING, COMMUNICATIONS, COMPUTING AND CYBERSECURITY FOR INFORMATION-CENTRIC INTERNET OF THINGS

Received May 30, 2019, accepted June 17, 2019, date of publication July 1, 2019, date of current version July 18, 2019.

Digital Object Identifier 10.1109/ACCESS.2019.2925885

Design and Performance Evaluation of Content-Oriented Communication System for IoT Network: A Case Study of Named Node Networking for Real-Time Video Streaming System

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This work was supported in part by the Establishment and Demonstration of Common IoT Platform Technologies, Ministry of Internal Affairs and Communication (MIC), Japan, in part by the Japan Society for the Promotion of Science (JSPS) Grants-in-Aid for Scientific Research (KAKENHI) under Grant JP18K18044, and in part by the National Natural Science Foundation of China under Grant 51807106.

ABSTRACT Information-Centric Networking (ICN) was born in an era that more and more users are shifting their interests to the content itself rather than the location where contents are stored. This paradigm shift in the usage patterns of the Internet, along with the urgent needs for content naming, pervasive caching, better security, and mobility support, has prompted researchers to consider a radical change to the Internet architecture. However, ICN is still in its infancy and development stage, and many issues still exist and need to be addressed. The common ICN architecture is lacking the host-centric communication ability and difficult to provide seamless mobility in current solutions. To solve this problem, our team had proposed the Named-Node Networking (3N) concept, which not only naming the content but also naming the node and it proved to have better performance of providing seamless mobility in the simulation. However, the previous contributions were limited in the 3N namespace for seamless mobility support in both producer and consumer. In this paper, we have proposed a 3N system which includes 3N naming, data delivery, mobility support, and data security. Moreover, we have created a 3N-based real-time video streaming system to evaluate data delivery performance and mobility handoff performance. The evaluation result proofs that our system performs better than TCP video streaming in a multi-client situation and a WiFi-based handoff was demonstrated.

INDEX TERMS ICN, CCN, 3N, Internet of Things (IoT).

I. INTRODUCTION

In recent years, people are shifting their interests in the content itself rather than the location where the content stored. This leads to the birth of ICN architecture [1], which is designed to win the content delivery contest. There are many use cases in the ICN area [2], like vehicle network, smart grid, and IoT network. Especially in IoT network [3], ICN architecture helps to deliver content regardless of the physical location of the content provider. There are many ICN projects

The associate editor coordinating the review of this manuscript and approving it for publication was Jun Wu.

among the world, Content-Centric Networking (CCN) [1], Named Data Networking (NDN) [4] and Named-Node Networking (3N) [5], [6]. However, common ICN network lacks better mobility support and some host-centric scenario support. The 3N project, brought up by Waseda, aims to support seamless mobility in the ICN world. We will evaluate and demonstrate the 3N practical implementation in this paper.

3N implementation is a severe exercise towards the development of a robust, completely safe but less complex future network. After understanding the current TCP/IP network's limitations, it was vital to work on creating a solution that can overcome the current as well as future challenges in the existing networking solution [7]. This leads to the extensive studies of the current alternative solutions and to the work around them to realize an integrated solution to overcome the challenges of the existing network.

To do that for TCP/IP, there is an alternative network design called the Recursive Internetwork Architecture (RINA) network. To overcome the challenges related to the content request, in the future, ICN can play an important role. The RINA is a computer network combination with mixed computing and telecommunications. RINA's central attitude is that Inter-Process Communication (IPC) is the key to computer networking. RINA rebuilds the general construction of the Internet, creating a prototypical single recapping layer, the Distributed IPC Facility (DIF), which is the negligible set of machinery essential to allow application processes having distributed IPC among them. The principle on which ICN works is to make the network more content-centric rather than host centric. Again, safety is always the primary concern of any type of networking, and RINA is capable of providing safety. However, to make the network more secure and truly robust, 3N mobility may be the best additional security layer.

The contributions of this paper are listed as follows.

a)We created a recursive internetwork based 3N network system design and its implementation.

b)The 3N system has full support for content-oriented data delivery mechanism and mobility support.

c)We created 3N real-time video streaming function and the evaluation shows improvement in multiple subscribers scenario and mobility scenario.

The remaining of this paper is organized as follows. Section 2 presents our previous studies includes 3N concept, network stack RINA and IoT network. In section 3, we have proposed our 3N system, which includes node name routing and mobility support. Moreover, in section 4, we have designed and evaluated a multi-subscriber video streaming experiment and a seamless mobile client handoff experiment. In the end, we have concluded our proposal with some scope of future work.

II. PRELIMINARIES

A. ICN

As one of the well-known ICN solutions, CCN [1] is designed by Palo Alto Research Center. It relies on the concept of publish/subscribe paradigm as an alternative way to the commonly used send/receive paradigm. Interest and data, as two different types of CCN packets, are widely used in CCN. A subscriber sends an interest message which she/he is interested in. This interest message is only identified by the content name and routed based on the content name toward the publisher. Once the interest arrives, a data message by a publisher is returned back to the subscriber as a response from which the interest came and store the copy of data in each crossed router. Hence, other subscribers can get this data according to the content name from the nearest router which has stored the copy, instead of from the publisher again. Thus, ICN has proposed a radical revision of the Internet architecture from named hosts to one named data. Furthermore, ICN has provided basic mechanisms for content integrity and authentication verification. During the whole process of message transmission, the data are addressable, routable, and authenticated, irrespective of its physical.

B. 3N

3N [5] is designed to improve the packet loss and delay performance of ICN for the two ends of the network, procedure, and consumer. 3N architecture applies to all its nodes and supports mobility [6] beyond normal ICN. 3N nodes have 3 differences from common ICN nodes.

1. "3N Node Name Namespace & PoA Namespace." There are 2 new namespaces, 3N Node Name namespace which manages 3N node names, and Point of Attachment (PoA) namespace which handles PoA names.

2. "Node Name Signature Table (NNST) & Node Name Pair Table (NNPT)." There are 2 new tables to handle the two new namespaces, which are Node Name Signature Table (NNST) and Node Name Pair Table (NNPT).

3. "Mechanism PDUs & Transmission PDU." There are 2 sets of new Protocol Data Units (PDUs), mechanism PDUs and data transmission PDUs, are promoted to leverage the new namespaces.

1) 3N NODE NAME NAMESPACE & PoA NAMESPACE

There are two new namespaces introduced in the 3N architecture. They are 3N Node Name namespace and Point of Attachment (PoA) namespace. The namespace mapping in 3N can be viewed in figure 1.

The 3N Node Name namespace [8] is an independent namespace that adds labels to the nodes. The names in this namespace are 3N names. This namespace is a topological space and contains multi-level structure fitting all 3N names. The names follow the naming rules strictly in the previous subsection and they help the network to maintain the namespace highly regulated.

The other new namespace, PoA namespace, is an independent namespace adds labels to the nodes' PoA in the network. This PoA namespace uses the names, called PoA names that are typically identifying physical transmission interfaces. PoA names are unique to the endpoints of the communication medium.

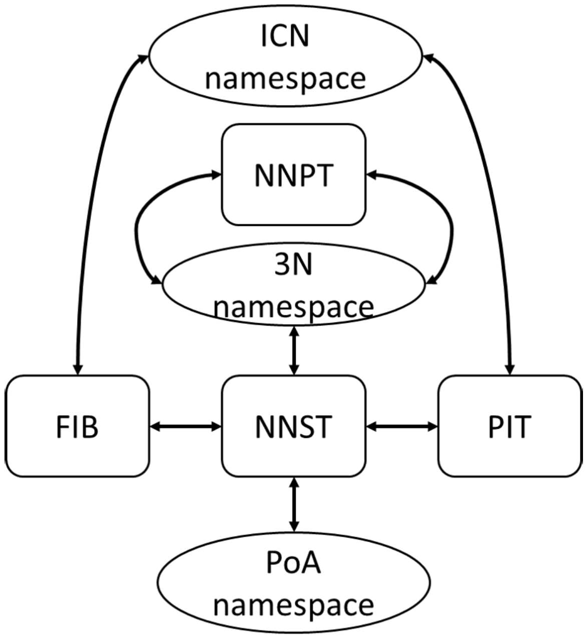

FIGURE 1. 3N namespace and mapping.

TABLE 1. PDUs table.

PDU Name	Description
Mechanism PDUs	
EN	Enroll a node into a sector with a node name
OEN	Offers a name to an enrolling node
AEN	Acknowledges the enrollment
REN	Re-enrolls a node into a new sector, while the node's node name is still valid
INF	Informs sectors about the node obtaining a new node name
Transmission PDUs	
SO	Includes Source node's name only
DO	Includes Destination node's name only
DU	Includes Source and Destination nodes' names

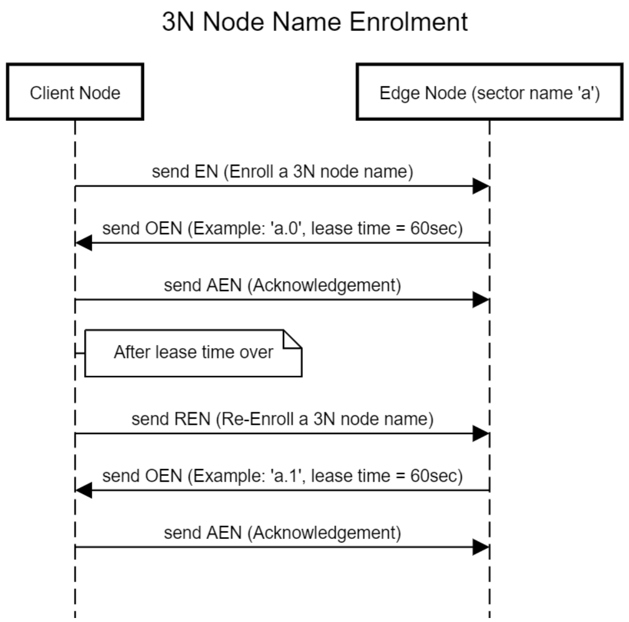

FIGURE 2. 3-way handshake procedure.

The second independent namespace adds labels to a node's Point of Attachments (PoAs) to the network. This namespace is called the PoA namespace and consists of the names typically used to identify interfaces on a physical transmission medium. Names belonging to this namespace are called PoA names. PoA names must only be unique among the endpoints of a shared communication medium.

2) NODE NAME SIGNATURE TABLE (NNST) & NODE NAME PAIR TABLE (NNPT)

The NNST and NNPT are additional table structures to the common ICN network architecture. NNST keeps track of the mapping between PoA names and 3N node names. This mapping information is to make physical communication among nodes possible.

The other table, NNPT, is used to maintain the newly obtained and previous owned 3N node name mapping. This mapping table checks whether a node with a 3N name had been updated due to the change in the PoA namespace. In most cases, this type of reattachment makes the node use a different 3N name to maintain the properties of the names in the 3N namespace.

3) MECHANISM PDUS & TRANSMISSION PDU

There are two new kinds of PDUs introduced in 3N architecture, mechanism PDUs, and transmission PDUs. The two types of PDUs are summarized in table 1.

Mechanism PDUs use signaling to modify NNST and NNPT structures. Mechanism PDUs are used to Enroll (EN) and Re-Enroll (REN) nodes with their nodes into the network and update related information to other nodes in the network. The NNST is modified when a node enrolls into the network and obtains a node name with the EN, offer Enroll Name (OEN) and Acknowledgment Enroll Name (AEN) PDUs, or a node re-enrolls into a new network and obtains a new node name with REN, OEN and AEN PDUs. The NNPT is modified when a node re-enrolls into a new network and get a new node name, updates the new 3N node name mapping using the Informing (INF) PDU. The simplified enroll and re-enroll procedures are shown in figure 2.

Transmission PDUs are used with 3N names in the forwarding strategies. These PDUs include 3N name information in its fields and package ICN PDUs. The packaging method allows the operation to works with other ICN implementations. The definition of transmission PDUs is in table 1. Source Only (SO) PDUs are used to carry Interest information from the content subscriber, in search of the content server. SO PDUs contain only the source node's name to let the contents find the subscriber. Destination Only (DO) PDUs and Duo Unit (DU) PDUs are used to carry the content back to the subscriber, but they are different from each other. A DO PDU has only the destination node's name, to trace the subscriber. A DU PDU has both the source and destination nodes' names in it, to trace both the subscriber and server.

C. RINA

The Internet needs to move beyond TCP/IP to live in the long run, RINA thinks TCP/IP has outlived its usefulness. The RINA is a new network architecture that thinks networking is only IPC. This internetwork architecture was proposed in need of emerging applications and networks.

RINA reorganizes the structure of the Internet, forging a model that comprises the DIF, a single repeating layer which should be the minimal set of parts needed to allow distributed IPC in application processes. To allow RINA DIF to operate over a legacy protocol with as small as possible veneer, the concept of shim DIF was introduced [9]. A shim DIF only provides the capability of the legacy layer to minimize the impact of the transition of RINA DIF. RINA supports mobility, multi-homing, and Quality of Service provides a secure and configurable environment, motivates for a more competitive marketplace and allows for a seamless adoption.

D. IOT

IoT is the networking of physical objects that contain electronics embedded within their architecture in order to communicate and sense interactions among each other or with respect to the external environment.

In the previous studies [10], we have used x86 compute platform [11], powered by Intel compute stick [12], as the IoT platform to perform experiments in Low-Power Wide-Area (LPWA) network [13], and it proofed that 3N architecture can improve the disaster network's reliability [14]. In the analysis of this paper, we consider the content server nodes are IoT nodes which have the ability to generate content.

Moreover, many related works have been proposed. In [15], it described a Fog-Computing-based Content-Aware Filtering for Security Services in ICN Networks. He had also introduced a kind of management method for big data analysis-based secure cluster to optimize the control plane in Software-Defined Networks (SDN) [16]. Furthermore, a new lifetime extension scheme for safety-critical cyber-physical systems using SDN and Network Function Virtualization (NFV) [17] has been proposed. [18] introduced a service popularity-based smart resources partitioning for fog computing-enabled industrial IoT. In the energy efficiency field, Mr. Zhou had described a task assignment and route planning method in mobile crowd sensing in Unmanned Aerial Vehicles (UAVs) [19]. A machine-to-machine (M2M) based access control and resource allocation automation were introduced back then [20].

III. PROPOSED SYSTEM DESIGN

In this section, we first introduce the 3N implementation architecture and its objective. Then the naming part will be introduced in detail, which contains two different groups of names, content name and node name. Thirdly, we explain how the information is delivered in 3N. This part includes the typical Forwarding Information Base (FIB), Pending Interest. Table (PIT), Content Store (CS) and our new 3N header, and the interest & content processing. This part also includes how 3N works as an overlay on RINA architecture. Fourthly, the mobility, handoff, support along with enrolment 3-way handshake mechanism. The last but not the least is the security in this system.

A. OBJECTIVE

The objective of this paper is to describe the design and implementation of 3N. The common ICN method of sending the request data back through the breadcrumbs of the interest route is challenging for the mobile node, because moving from one wireless connection to another may happen before the request is satisfied. To address this issue, and to provide seamless mobility access as the objective, we consider assigning names to the nodes in an additional namespace beyond naming only the content.

The Named Node Networking system development is mainly focusing on the implementation of the 3N architecture based on a RINA. The application should have basic ICN functions and 3N PDUs and node names. The purpose of this document is to provide the information necessary for the user to effectively use a 3N-RINA-ICN integrated application. This well-designed architecture of the 3N system introduces ICN properties to RINA with seamless 3N mobility ensures the system is distributed to a wide audience, maximizing the impact of the proposal. This paper will be helpful for any extension or future development from the developer point of view.

B. SYSTEM ARCHITECTURE

We have implemented 3N architecture in the practical network with RINA as the copilot, which alternate to TCP/IP structure. By merging 3N and RINA, we are able to achieve various layered network architecture, which in general is a layered network stack shown in figure 3. 3N application registers with DIF, and subsequently it registers with bottom level shim DIF of nodes then while 3-way handshake finishes logically, there will be a Distributed Application Facility (DAF) formation. The DAF works as the communication bridge between 3N layer and RINA layer. The RINA underlay manages the namespace which includes service names, node names, and PoA names. The 3N overlay keeps track of the content name namespace for content delivery. The 3N mobile's 3N node name namespace in the 3N overlay works with RINA underlay to provide smooth mobility support.

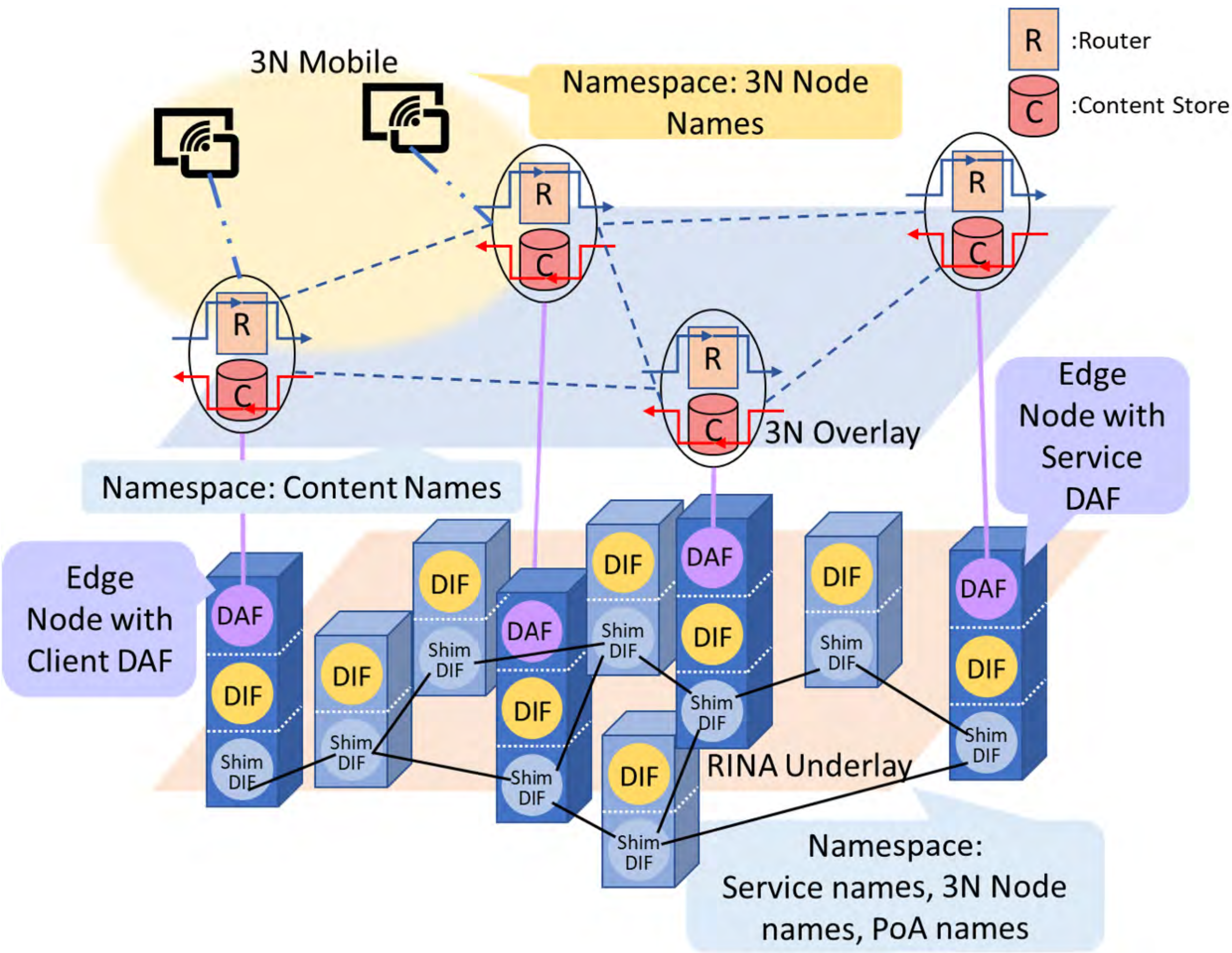

FIGURE 3. 3N system conceptual layers.

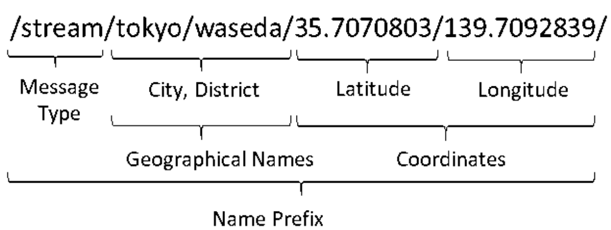

FIGURE 4. Content name example.

C. NAMING

There are two kinds of names involved in 3N architecture, one is common ICN content name, and the other is 3N node name.

1) CONTENT NAME

In 3N system, like common ICN platforms, a content name is structured as a hierarchical format, using "/" characters to separate different components. For example in figure 4, the content name prefix is format in geographical structure, which improves content delivering performance in IoT and disaster network [13]. The first and second part of the content name provides global routing information and organizational routing information for packet routing. The last part of the name contains the segmentation functionality and the versioning, basing on the principle, one content can be fragmented into multiple segments and still be addressable.

2) 3N NODE NAME

On the other hand, for the nodes, a 3N name is composed of labels, ranging from 1 character to the whole 16 characters permitted by the name. Figure 5 shows some 3N node name examples. A name can have as many labels as required, separated by a dot ("."); if the total number of characters used in a name does not exceed 16 hexadecimal characters. This gives us variable sized names that range from half an octet to a maximum of 8 octets. When a label is defined, the remaining character positions in the namespace can be delegated as desired, creating a hierarchical, topological structure that will permit aggregation of names. A label represents what I call a Sector. There can be as many subsectors as desired. The grammar can help clarify what is considered a valid 3N name.

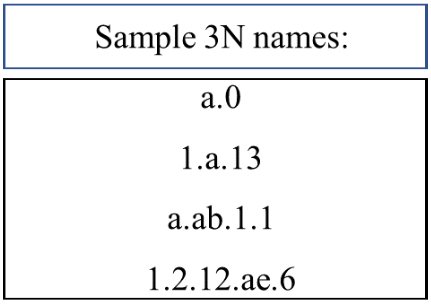

FIGURE 5. 3n node name example.

D. INFORMATION DELIVERY

The 3N communication protocol uses the node name in the packet header. In this paper, we use NNR to realize content-oriented communication and node name based routing. Without the 3N header, the packet is like a common ICN packet.

1) 3N FORWARDING MECHANISM

Once the Mobile Node connects with the Edge Node by a 3-way handshake (Figure 2), the Mobile Node asks for content from the Edge Node, which is encapsulated with a SO or a DU PDU. When a SO/DU packet reaches the Edge Node, it is de-encapsulated to process the interest packet. In case that a new PIT entry occurs, it checks the CS to see if there is content for the interest. If a content is found, the PIT will be updated with the matched interest. If no content is found in the CS, the PIT is updated. The process of the interest function checks the PIT table for a redundant interest entry request. If the redundant interest entry is found, the PIT is updated, and then the interest packet is discarded. If there is no redundancy, there will be a new entry added to the PIT. Once the pending interest request reaches the content provider, the content provider immediately satisfies the interest and updates the PIT and CS as necessary.

Node Name Routing (NNR) [21] is a routing strategy which is maintained by the node names and content names. Figure 6 shows the NNR forwarding mechanism. NNR is designed to find the best route between the publisher and subscriber.

2) INTEREST AND CONTENT PROCESSING

3N network is also an ICN network, it has ICN basic functions like PIT, CS, and FIB. The PIT is to keep track of Interests forwarded upstream toward the content source(s) so that Data can be sent downstream to its requester(s) and then the satisfying entries can be removed. CS acts as a cache of data packets. Arriving data packets are stored in this cache as long as possible to satisfy future Interest packets matching the names. Before the Interest packet is forwarded to the next node, search the CS for possible matching content. The FIB is used to forward Interest packet towards the potential source(s) of matching Data. Each Interest that needs to be

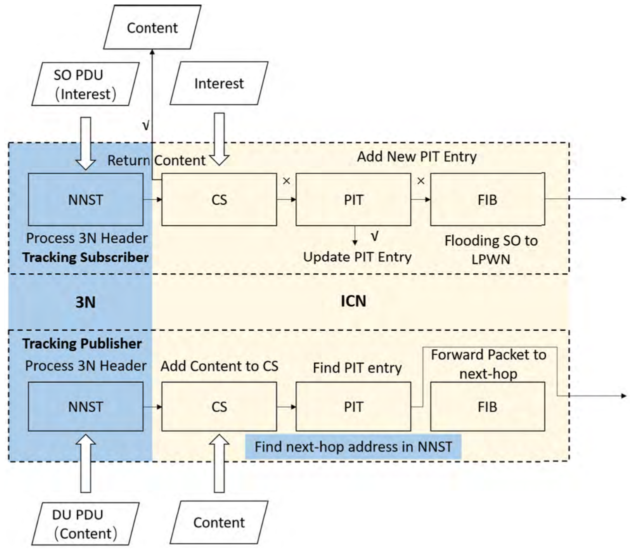

FIGURE 6. 3N NNR forwarding mechanism.

forwarded shall search for the longest prefix match in the FIB. Figure 7 shows interest and content processing.

In the 3N network, we use two types of packets to deliver interests and contents, SO packet and DU packet. When a node receives a SO packet, it will first check its CS to see if there is already matching content stored. If there is no stored content, it checks PIT if there is already an entry in PIT, then the node adds a new entry or updates an existing entry. At last, if no existing PIT entry found, then the node logs the information in FIB and continue flooding the SO packet to the other nodes. The DU packet will help the node tracing the last hop.

E. MOBILITY

In the 3N system, a typical use case is that the client node is a Mobile Node (MN), the node connects to the MN through an Access Point (AP) is an Edge Node.

1) 3-way HANDSHAKE

When a Mobile Node connects to an Edge Node. It will perform the enrollment procedure and make a 3-way handshake with Edge Node to get its node name. The Edge Nodes will have a unique base sector name. It can offer the unique node names to the clients connecting to them. Figure 2 shows the 3-way handshake procedure involves 3 steps:

1. A Client sends EN (Enrollment) request to the Edge Node.
2. The Edge Node sends OEN (Offer Enrollment) to Client.
3. The Client sends AEN (Acknowledgement) to Edge Node Server.

The Edge Node server has a unique name which is called sector name which will be used as a prefix with some extension name the clients connecting to it. The 3N names have the expiry timeout also. Once the 3N name of a client is expired, the client needs to send the REN to the same Edge Node or to

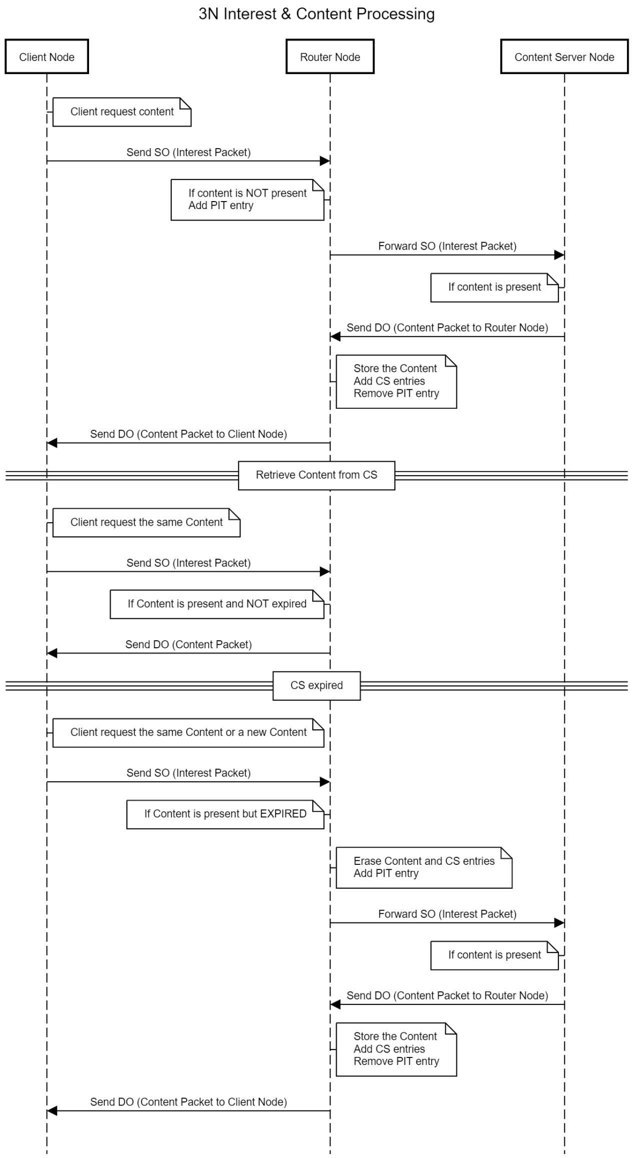

FIGURE 7. Interest and content processing.

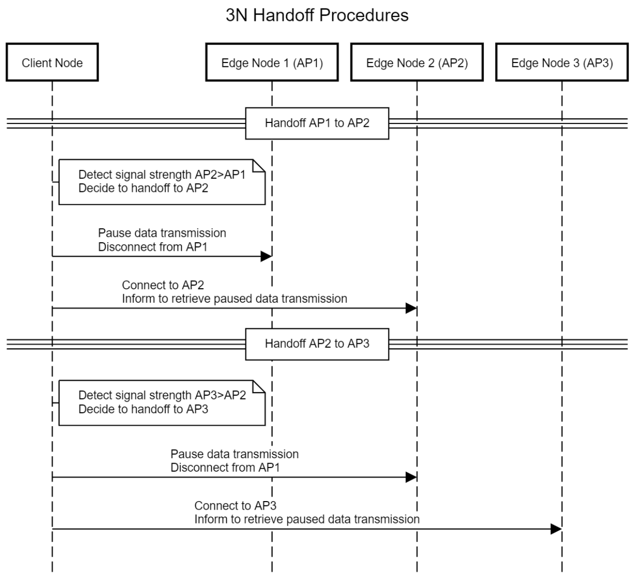

FIGURE 8. Handoff procedure.

a different one as per its wish and get a new 3N name to renew it. Upon the successful enrollment, the NNST and the NNPT tables of both the client and the Edge Node's will be updated to add the necessary information regarding its connection and the node names.

2) HANDOFF MECHANISM

Now the client can make handoff from one Edge Node to another, depending upon the AP's availability and the signal strength. Figure 8 shows the handoff procedures. Depending upon the connection to the AP during handoff the client will be connected to one of the Edge Node and will get a new node name after the Enrolment and the ongoing content download will resume from where it left off through the new Edge Node. The client will first dis-enroll from the old Edge Node and then will get enrolled with the new Edge Node after the successful handoff. When the client moved to the new Edge Node, the new Edge Node will inform the old Edge Node the client about its handoff through the INF packet.

F. SECURITY

Security mechanisms in 3N are not the critical point in this paper. It will follow the security features of ICN, which protects each data object based on the publisher's signature, rather than securing the communication channel between two endpoints. This basic feature provides data integrity and original authentication, as well as mechanisms for supporting trust and provenance through the mapping between the data signers and their source (e.g., an individual or an organization). 3N should provide mechanisms to guarantee secrecy, integrity, and availability of data as well as verifying the publisher of data. To operate the mechanisms properly, an additional mechanism to distribute cryptographic keys may be required. The new network function, caching, potentially poses a new security threat to network users. Until now, the work of authorization, access control, and privacy and security threats has been limited due to the expanded of in-network caches.

IV. EVALUATION

In this section, we have performed a series of experiments to evaluate the 3N data delivery performance via video streaming test and compare to a TCP/IP video streaming performance. We have also performed a wireless handoff demonstration under WiFi environment. Figure 9 shows the experiment topology of the 3N environment and the handoff procedures. The experiment parameters are shown in table 2.

Figure 10 shows the user interface in client node. On the left side is the TCP based streaming window, and on the right side is the 3N based streaming window. In the middle

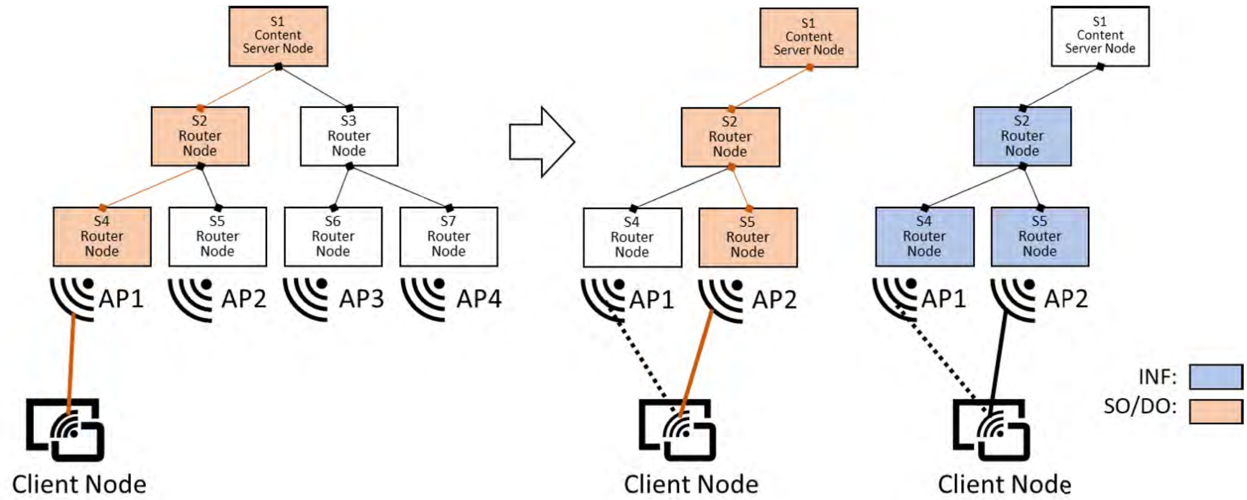

FIGURE 9. Handoff topological procedures.

TABLE 2. Experiment parameters.

Video Streaming Parameters		
Category	Parameter	Value
Application	3N streaming	
	TCP/IP streaming	
Routing Strategy	NNR	
	TCP/IP Routing	
	Stream source	4K@15fps
	Network connection	1Gbps ethernet
	Number of Clients	1∼10
Handoff Parameters		
Application	3N handoff	
	Number of Content Server Node	1
	Number of Edge Nodes	4
	Number of Mobile Client Node	1

is the control panel which can control the client node to send interest, retrieve content, and control whether to perform automatic handoff or manual handoff.

A. VIDEO STREAMING EXPERIMENT

The video streaming function in the 3N system is based on the following design concept:

- Real-time video streaming is necessary for the 3N based IoT network.
- Real-time video review enables instant playback to the users. The operation of real-time video streaming in 3N:
- Retrieve real-time frames from an embedded Web Camera to 3N content server node. Utilizing 3N stack transfer the real-time stream to 3N client nodes.(Video Streaming: Resolution 4K; JPEG, MJPEG; Protocol: HTTP)
- The 3N client saves real-time streaming to its local repository. The video can replay in the video player. The video format can be AVI, MP4, etc.
- The 3N client should show real-time streaming in a video player.
- The 3N client creates an HTTP web service and publishes the received real-time video as a MJPEG feed.
- The real-time streaming should support the 3N handoff function.

In the 3N video streaming experiment, we built a simple 3-node topology to realize the essential 3N network communication and video streaming function. During the experiment, the client sends an interest packet, which requests the video feed from the content provider. The content provider answers the client's request and starts the video stream to the client. The content provider splits the flow into segments and transfers them to the client via 3N packets. In the TCP/IP video stream experiment, we built a similar 3 node topology to realize an HTTP-based MJPEG video stream. During the experiment, the client accesses the MJPEG feed via an HTTP connection. The content provider provides the flow to the client in MJPEG format.

In the evaluation part of the experiment, we have gathered both 3N and TCP/IP video streaming bandwidth consumption data. We have added emulated clients (figure 11) in the client node. There is a total number of 10 clients receiving the video stream from the content server node in both 3N and TCP/IP streaming network. Each client stream is a separate connection to the content server node through the router node.

B. 3N HANDOFF

The handoff scenario uses a 7-node topology. First, the router nodes connect to the content server node and initial their IPC connections. Then the next level routers connect to the upper-level routers and initial their IPC connections as well.

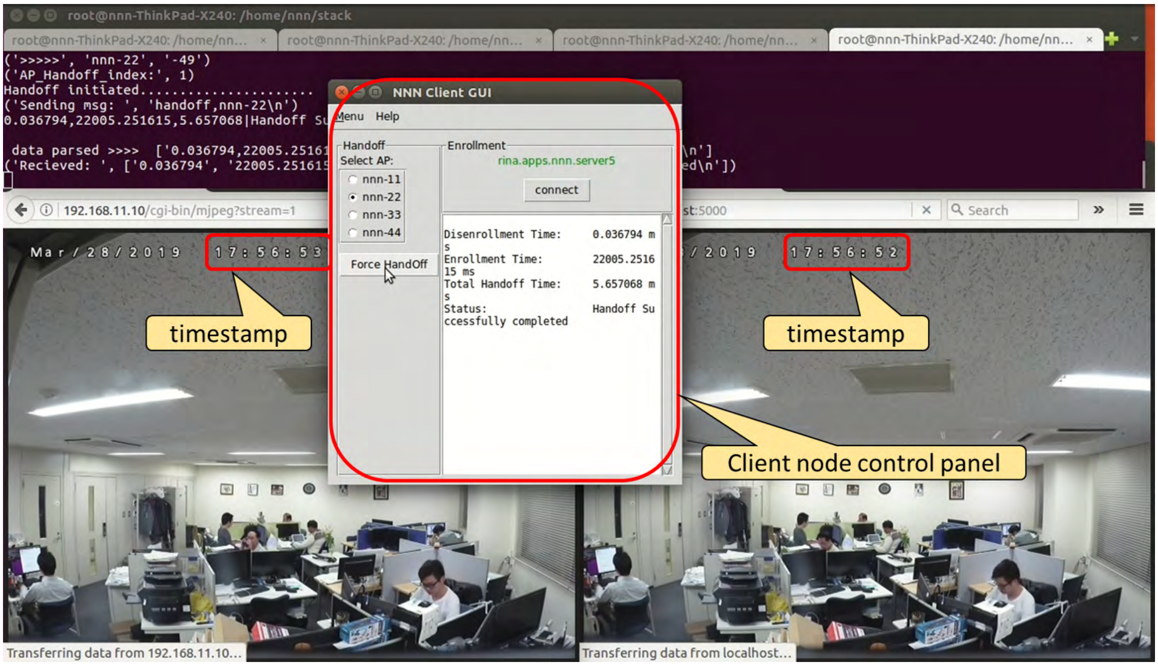

FIGURE 10. 3N client GUI panel.

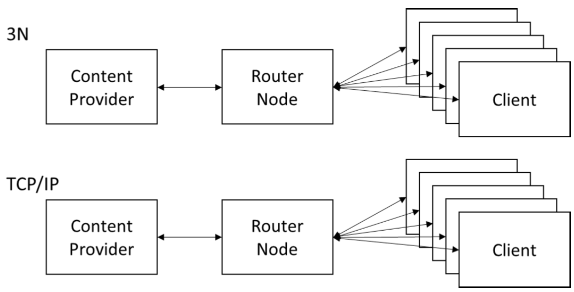

FIGURE 11. Video streaming evaluation topology.

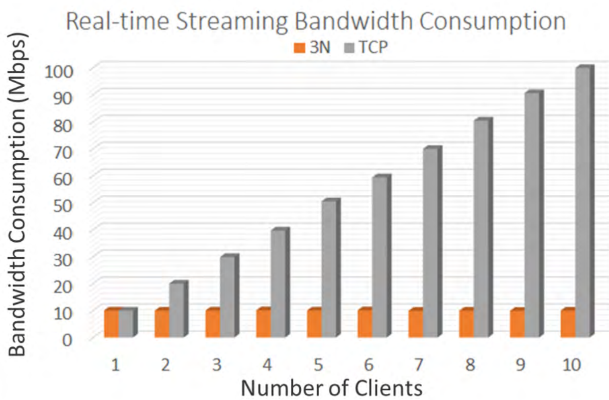

FIGURE 12. Bandwidth consumption compare.

Finally, by starting the experiment, the client connects to an edge node, initials IPC connection, and obtain its node name. After this preparation, the experiment can continue.

While in the first wireless sector, the client initials the data flow from the content container. During the experiment, the client will switch to a new wireless sector when the wireless signal reaches a point. The handoff processes take place three times.

During a handoff procedure, the client will first notify the edge node and then start to switch to the next wireless sector. After entering the next wireless sector, the client will obtain a new node name, inform the edge node its old name and continue to request for the rest of the contents. Meanwhile, the undelivered contents from the old wireless sector will be redirected to the client who are routed by the node name routing.

C. EXPERIMENT RESULTS

Figure 12 is the network bandwidth consumption of the content provider side, comparing the 3N video stream and the TCP/IP video stream. In the experiment, both the 3N and TCP/IP topologies have emulated the multiterminal scenario. The results show that in the same video resolution of 4K and only 1 terminal, both protocols share almost the same bandwidth consumption. This means that the 3N packet header only occupies a small part of the package compared with the TCP/IP header. With the increase of terminal numbers, the TCP/IP stream bandwidth consumption grows in a positive ratio, while 3N maintains a low bandwidth consumption. This is mainly because the 3N network has the CCN standard CS in each node, and the CS stores a copy of every content that had been forwarded through this node, so the other nodes requiring the same content can obtain the content from the CS. This iconic ICN function makes multiclient video streaming fast with a low bandwidth cost.

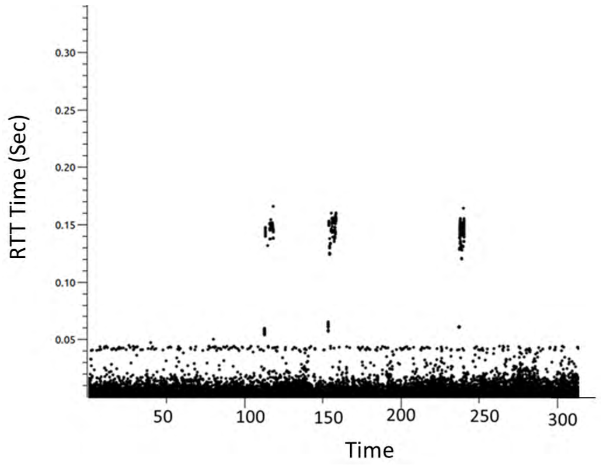

FIGURE 13. Round trip time (RTT) result.

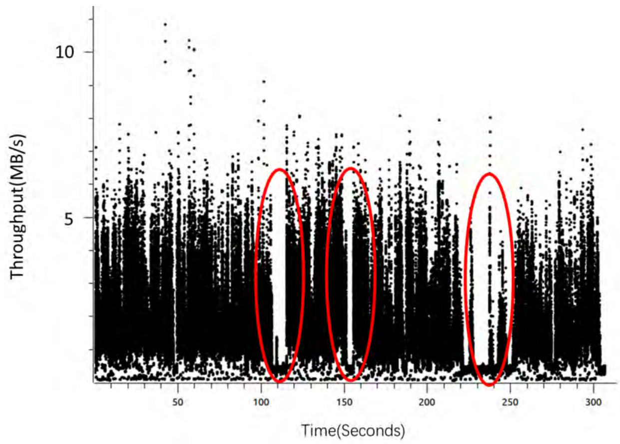

FIGURE 14. Handoff throughput.

Figure 13 and figure 14 shows the packet round trip time (RTT) and the throughput during a client mobile scenario. From the result, we could see there are three handoff procedures, they are the procedures letting the client node shifting connection among the four edge nodes, APs. In the RTT data, there are some packets RTT time above the common value; it is because some of the packets are not being delivered to the client in time and had to be forward to the client after the handoff procedure, via another edge node the client node connecting to. In the throughput result, there are data gaps which represent the period the client shifting its connection to the new edge node. Because we are using WiFi in our experiment, the disconnection and re-initiating new connection procedures are taking much time. The result is considered as a smooth handoff.

V. CONCLUSION

A 3N-based ICN system is described and implemented in this paper. The system used RINA as the fundamental communication base and realize 3N content delivery. This system has the ability to communicate in a content-centric way and improves delay and packet loss compared to common ICN. We have added a series of experiment to evaluate the 3N system performance. Video streaming compares the multi-client content delivery efficiency, and the handoff demonstrates mobility support. This materialization of 3N system, which leverages from 3N concept, demonstrates the improvement of content sharing system, network delay, and Interest timeout to satisfy the client Interest ratio in the mobility client scenario.

A 3N-based real-time video streaming system and a 3N handoff demonstration are proposed in this paper. The system applies real-time streaming functions into the content-oriented network architecture. The evaluation result shows that the 3N video streaming system has an advantage in multi-client streaming scenarios compared to TCP/IP video streaming, and the handoff procedure is successfully demonstrated. However, practical solutions require practical experiences. Future research and experiment are scheduled to achieve lower bandwidth consumption when streaming high definition video.

ACKNOWLEDGMENT

(Xin Qi, Yuwei Su, Keping Yu, Jingsong Li, and Qiaozhi Hua are co-first authors.) This paper is a research achievement by authors at Waseda University.

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