

Studies on Information-Centric
IoT Surveillance Systems
情報セントリック
IoT サーベランスシステムに関する研究

July, 2019

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Waseda University
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on Ubiquitous Communication System

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Abstract

The urban society needs surveillance network. Recently there have been many terrorisms happening globally. There are also many natural disasters, such as earthquakes and tsunamis, especially occurring in Japan. Many of the disasters are unavoidable but can be predicted. A surveillance network is necessary to aid in evacuations before and during disasters. The communication network in these situations needs to be durable and have a large coverage area. The current network technologies are quite vulnerable to the situation. The surveillance network content type is very important in terms of communication, which is crucial to help suppress the effects of the disaster [14] [15] [18] [19].

This thesis is logically separated into three main parts. The first part introduces modern surveillance solutions, such as video stream surveillance systems. These surveillance systems consume network bandwidth resources continuously; a new content-oriented surveillance system is proposed to reduce this bandwidth consumption. Instead of streaming live video, this system uses machine learning to extract useful content, but the current TCP/IP (Transmission Control Protocol/Internet Protocol) architecture may

be a bottleneck. Information-Centric Networking (ICN) has shown advantages in mobility, security, power consumption and network traffic; it was designed to replace the current host-to-host communication with a content-centric communication. Therefore, my systems use a content-centric architecture to deliver packets. In the second part, an upgraded version of my surveillance system is introduced to provide better communication coverage and a better content routing mechanism. At this stage, the network infrastructure construction, connection construction and management, and terminal intelligence are the core. A Low-Power Wide-Area Network (LPWAN) is designed for low-bandwidth, low-power, long-distance, large-scale connected IoT applications and is realistic for networking in an emergency or restricted situation; therefore, it has been proposed as an attractive communication technology to handle the unexpected situations that occur during and/or after a disaster. This system also uses a Named Node Network (3N) for its better mobility support and the Node Name Routing (NNR) strategy. Finally, a 3N-based real-time video streaming system is introduced as the latest 3N practical development.

The thesis is organized in 6 chapters, all chapters are summarized as follows:

Chapter 1 provides a general introduction to the modern surveillance system and the use of IoT supported surveillance networks and how these help people to safely evacuate during an emergency, such as disaster scenarios.

Chapter 2 describes the studies and technologies related to this thesis. Information-Centric Networking (ICN) and named node networking (3N) are introduced and referenced. Chapter 2 also introduces the Low-Power Wide-Area Network (LPWAN), which is a famous IoT network solution, and current surveillance network solutions. This is an experiment I joined in my first year in Waseda, which was supported by the Ministry of Economy, Trade and Industry project to develop and evaluate an IoT platform that works in a certain area and to evaluate the M2M network.

Chapter 3 describes a content-oriented surveillance network, which make advances in converting image data into small size content, thus reducing the network bandwidth consumption. In this chapter, I chose CCNx software for the ICN system communication base.

Chapter 4 describes a Low-Power Wide-Area Network (LPWAN)-based decentralized network structure as an extension of our previous Disaster Information Sharing System (DISS) powered by Named Node Networking

(3N), which is based on the Information-Centric Networking (ICN). LPWAN is designed for low-bandwidth, low-power, long-distance, large-scale connected IoT applications and is realistic for networking in an emergency or restricted situation; therefore, it has been proposed as an attractive communication technology to handle the unexpected situations that occur during and/or after a disaster. However, the traditional LPWAN with its default protocol will reduce the communication efficiency in a disaster situation, because many users will send and receive emergency information, which will result in communication jams and soaring error rates. This network structure optimizes the excessive useless packet forwarding and path optimization problems with node name routing (NNR).

Chapter 5 describes a Named Node Networking (3N)-based video stream system to introduce a real-time stream function to a content-oriented network. Information-Centric Networking (ICN) is a type of network architecture designed to focus on content delivery instead of host-to-host communication. This video stream system allows the content provider to stream to the client in real-time without requiring the client to download and replay.

Finally, chapter 6 summarizes the proposed technologies and this thesis.

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Chapter 1

Introduction

1.1 Background and Motivation

IoT devices, video cameras and closed-circuit televisions (CCTVs) [20] [21] [22], are becoming increasingly widespread in urban society currently. High-definition video capturing devices or sensors have been deployed in every corner of the cities' facilities. In many megacities, centralized data centers are organized to manage and serve the great quantity of real-time data streaming equipment focusing on scenarios that demand high surveillance density and a large content subscribing scale, such as flow control and anti-terrorist scenarios. With every string of live data transition between the server and the node, the central data center is always facing the critical problem of high network capacities, not only in daily surveillance activities but also in some urgent situations, such as disasters [16] [17] [23] and security events, which take place.

The current state of surveillance system uses a mature solution containing point-to-point connections between the central server and each monitoring node. An example of a mature solution is the live data transferred over

TCP/IP networks. While monitoring nodes are feeding the central server with a real-time video stream, the server is under multiplied networking loads. At this point, the only way to handle such pressures is to increase the consuming ability, mostly by upgrading the network bandwidth and processing abilities. This method increases the investments and waste of the process power, especially in idle periods. Here, the Information-Centric Network (ICN) concept is introduced [71]. It has advantages in the network traffic solutions, where multiple subscribers are requesting the same contents, by substituting the host-centric principle with the content-centric principle. With the increasing frequency and intensity of natural disasters, the impacts of various disasters [30] [31] on large urban areas are rising, so it is essential to focus on the critical issue of facilitating communications during and after the disaster. In the aftermath of a disaster, communication networks are increasingly stressed because of the heavier traffic and potential capacity loss due to infrastructure damage. However, in the event of such a disaster [32] [33], communications should be provided to deliver emergency information, such as real-time evacuation information and SOS messages to the first responders or government authorities [8] [16]. It is now feasible to provide low-cost, low-powered networks that can cover a wide range of areas, such as the Low-Power Wide-Area Network (LPWAN)

[54] [55]. These technologies allow the deployment and management of sensors using low-power wide-area clients, and the sensor network’s test link can operate at a distance up to 400 meters [56]. However, the required type of communication in a destructive disaster scenario is primarily information-centric in nature, such as the rapid propagation of warnings and evacuation plans, or the critical content from legitimate authorities to reach all users in a timely manner. It is important to shift the focus on disaster [34] communication from being an afterthought to being a priority, exploiting emerging network architectures [56].

The organization of my thesis is shown in Figure 1-1.

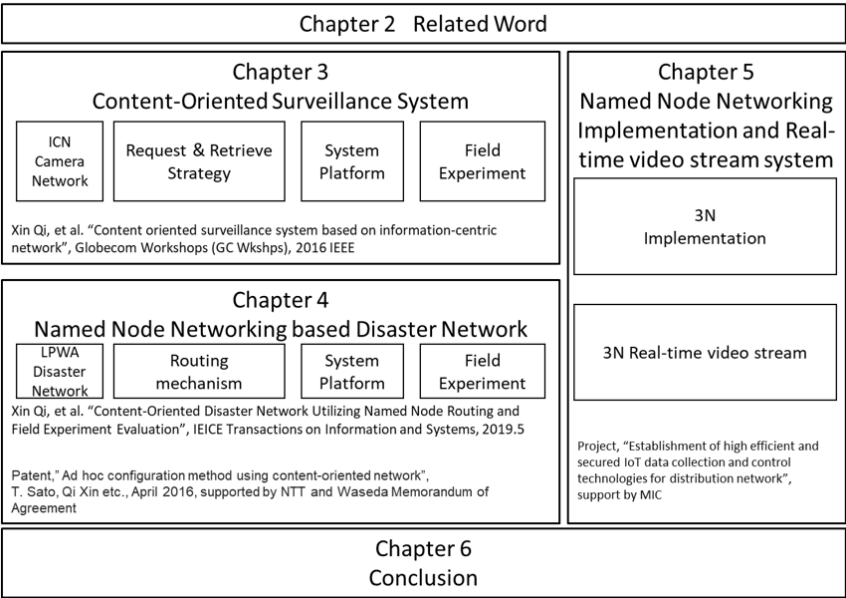


Figure 1-1 Paper organization

Chapter 2

Related Work

2.1 ICN overview

The Information-Centric Network (ICN) is also called the Content-Centric Network (CCN) and Named Data Network (NDN). The development of the ICN introduced a paradigm shift for the future of the Internet architecture away from a host-centric communication network model. It supports the retrieval of specified content data, regardless of the hard-fixed location of the content. In the ICN principle, it replaces the host-centric network architecture, such as TCP/IP, with the content-centric principle. The ICN relies on the concept of the publishing and subscribe paradigm as an alternative to the typical send and receive model. Figure 2-1 shows the TCP/IP and ICN stacks.

In the ICN communication protocol, a client node sends out an interest packet with the content name in it. The packet is forwarded inside the network and finally will be sent to the content provider containing the content packet. Once the interest has arrived, the content message sent by

the publisher will be returned to the subscriber in response, and a copy of the content will be stored in each overlapped router. Therefore, another client can obtain this content based on the content name from the nearest router that has stored this copy instead of reacquiring it from the publisher.

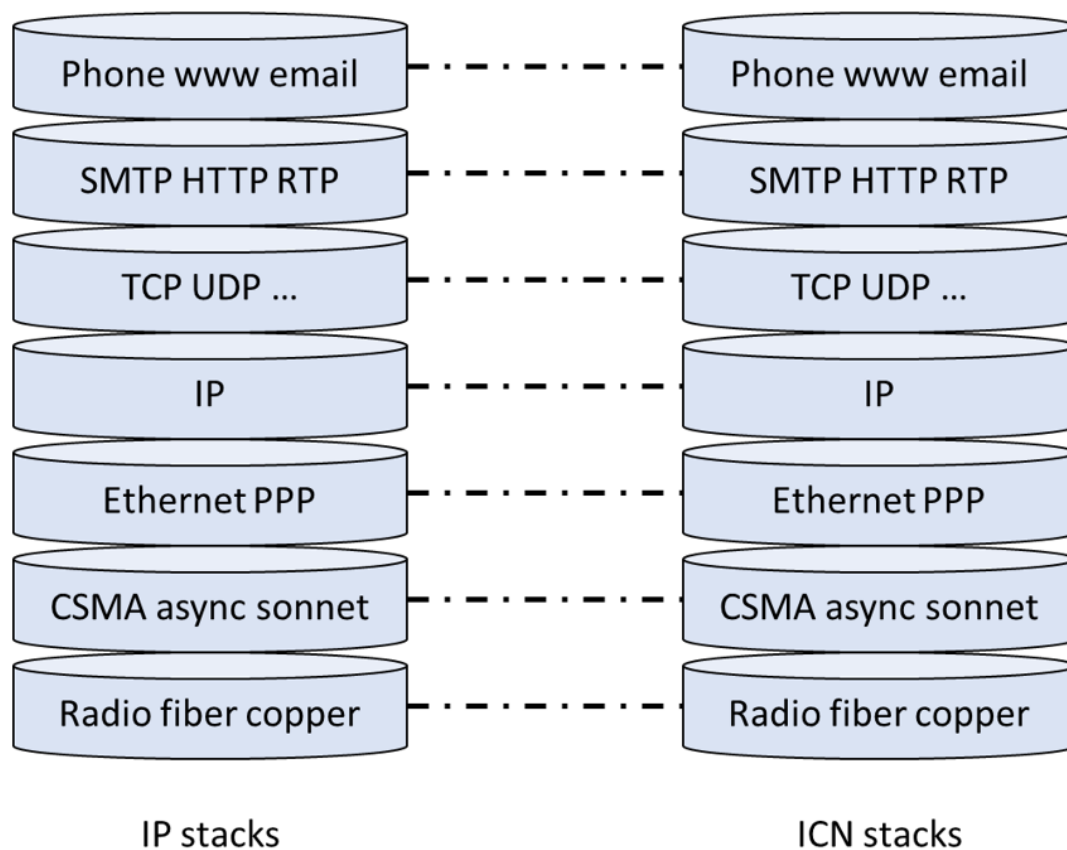


Figure 2-1 IP and ICN protocol stacks comparison

2.1.1 Named Content and Data Types

There are two types of packet used in ICN, i.e., interest and data (content), as shown in figure 2-2, and both types of packets have name elements. The name is given by the publisher and is used to find and identify the content. Several optional elements can be detailed within the content and interest.

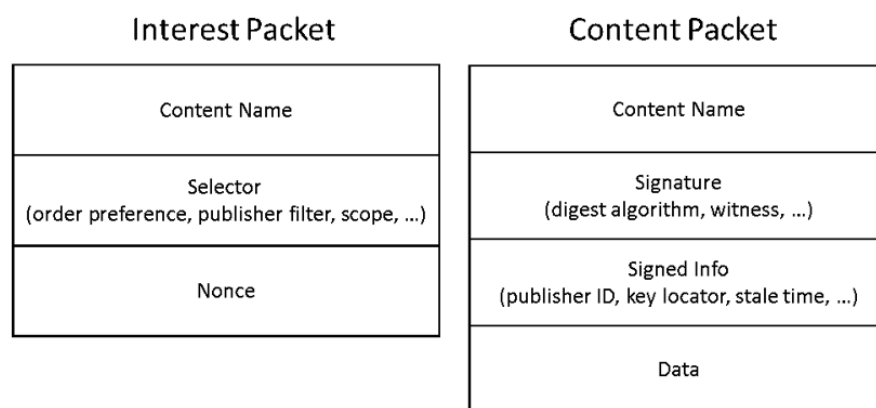


Figure 2-2 ICN packet types

2.1.2 ICN and Forwarding Engine

Commonly, an ICN node should function as follows:

- A content store (CS), such as a cache to stock content copy.

- A forwarding information base (FIB), such as a table containing the faces pointing to potential sources of content.
- A pending interest table (PIT), such as a table of sources for unsatisfied interests that keeps track of the interest forwarded source to the content source.

With all these functions, the content can be sent to its client [1] [2] [3]. In ICN networks, clients can send interest packets to pursue wanted data. Once an ICN node with a name-matched data receives the interest, they will deliver the content. Users can receive content not only from the content server but also from nodes with buffered content [4] [5] [6].

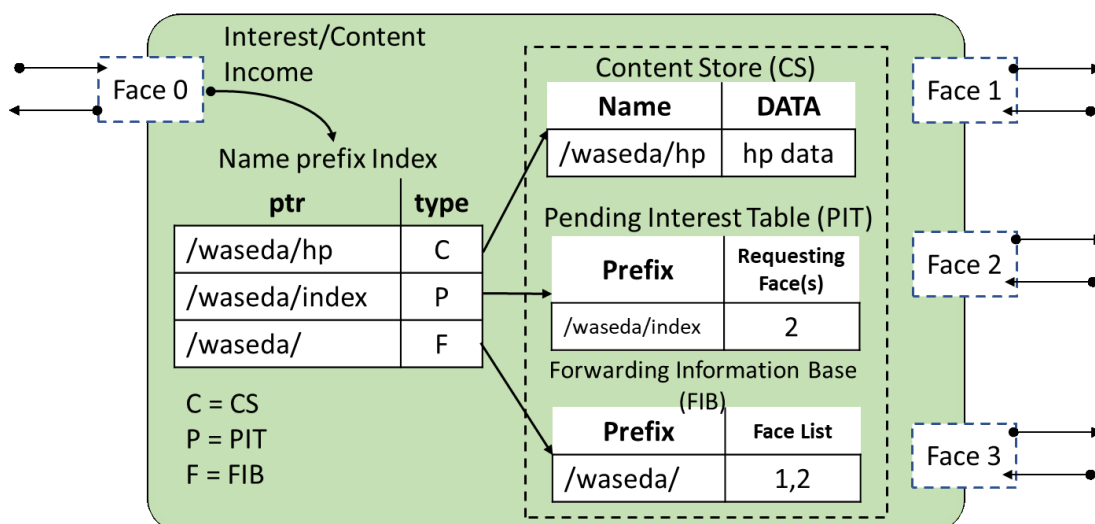


Figure 2-3 ICN packet forwarding engine

2.1.3 Named Node Network

However, because the standard CCN [39] network lacks accounting capabilities, there are doubts about controlling, managing and connecting. The dearth of accounting has the unintentional issue of being unable to warrant reliability in high user mobility and low delay scenarios. To solve the issue, my team proposed a Named-Node Network (3N) [6] [9], which is a network architecture that is an alternative to TCP/IP, as a host-centric extended solution for ICN. This paper aimed for well-organized and flexible data sharing in settings where users might essentially be mobile. 3N announces a new node namespace into the basic content-centric network construction. 3N uses a network naming system that was first introduced by Dr. Saltzer in RFC 1498 [42], which confined separated, exclusive node and content namespaces. Principally, the node namespace is being maintained with a topological assembly designed to enroll and dis-enroll in the network. 3N describes two types of protocol data units, short for PDU, which are mechanism PDUs and data transfer PDUs, as shown in Figure 2-7. This paper also introduced the node name signature table (NNST) as a routing table managed by node names. The PDUs and NNST affect the network

configuration by offering 3N names to the nodes and using the node name-based routing strategy to deliver data packets.

The node name namespace in 3N is precisely shaped to name the nodes in an ICN network. This namespace's names are termed 3N names. The humblest type of namespace in this condition is a graded namespace, which will be used in our examples in figure 2-4. The namespace organizes from a sole root where the segments are placed. The node name namespace contains a solo, multilayered assembly into which all 3N names are appropriate for. The scheme that divides the name in the network is placed on the network's physical scale and circulation. Every sector can contain a specific 3N name or a specific subsector. There is no requirement that limits the partitioning if the significant topologically is maintained [66] [67].

A 3N name is composed of labels ranging in length from 1 character to the full 16 characters permitted in the name. A name can have as many labels as required, separated by a period ("."), as long as the total number of characters used in a name does not exceed 16 hexadecimal characters. This allows variably 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 to create a hierarchical, topological

structure that will permit the aggregation of names, specifically in routing tables. A label represents what I call a sector. Following the limitations described, there can be as many subsectors as desired. Figure 2-6 shows valid examples of 3N names [61].

Sample 3N names:
a.0
1.a.13
a.ab.1.1
1.2.12.ae.6

Figure 2-4 3N name examples

The point of attachment (PoA) namespace uses information, such as the ethernet's physical MAC address, to class its names. PoA names in the correct place in this namespace will be stated.

During the initial stage of a mobile node, the node connects to an edge node and obtains a name from it. After updating the mappings in the namespaces, the mobile node can be located [73].

3N PDU Types	
Data Transmission PDUs	
SO	Includes only Source node's 3N name
DU	Includes Source and Destination nodes' 3N name
Mechanism PDUs	
EN	Enrolls node into a sector
OEN	Offers a name to an enrolling node
AEN	Acknowledges the enrollment of a node into a sector

Figure 2-5 PDU types

3N PDUs use the known actions of packet-switching networks. Like ICNs [56] [57], 3Ns focus on content distribution by using unified and interactive CSs to lessening the content provider pressure on specific content providers and to guarantee a low delay and high bandwidth efficacy. The main inspiration of 3N is an assessment of the secretarial capabilities of ICN, which is lacking in terms of linking and handling capabilities. Moreover, this secretarial dearth has the unintentional side-effect that the ICN cannot ensure steadfastness in scenarios in which high user mobility and low latency are key aspects. The nodes with topological names in a 3N guarantee that these types of setups can be accomplished in a pure and effective way. Moreover, source only (SO) packets and dual unit (DU)

packets are applied here in this chapter; their architectures are shown in figure 2-6 and figure 2-7. [58] [59]

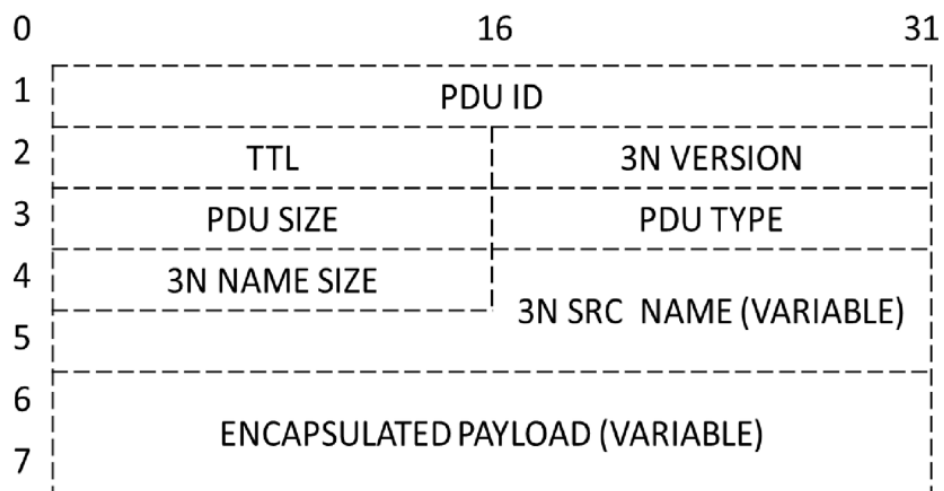


Figure 2-6 SO packet

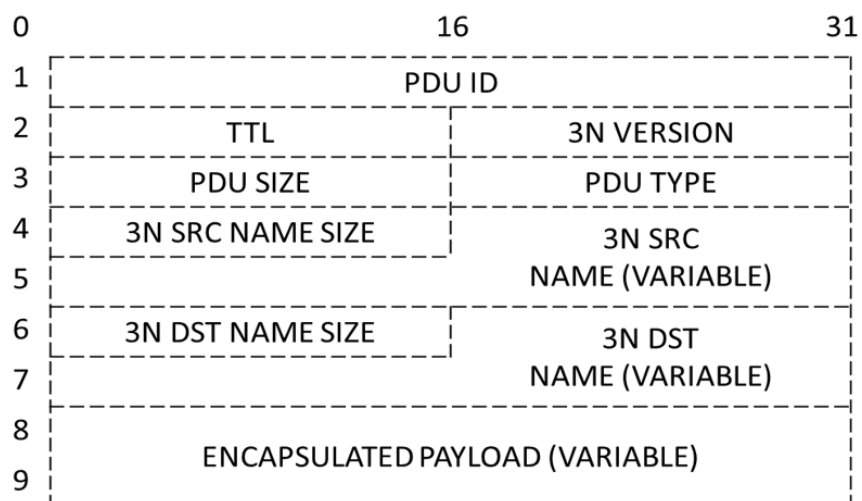


Figure 2-7 DU packet

2.2 LPWA Network

The development of LPWAN has benefited from the rapid development of the Internet of Things (IoT) in recent years (the standards by different organizations are shown in Figure 2-8). In comparison to LPWAN, the Wi-Fi module's current cost is also very low, but the communication range is not wide enough and the cellular network module, which it provides a wide coverage range, is too expensive. The LPWAN module is in the middle between Wi-Fi and the cellular network, so it is an ideal low-cost, low-power consuming and long-distance communication device, which is suitable for an "IoT private network". LPWAN is used in several applications, in addition to disaster monitoring and recovery communicating. LPWA network sensors can apprehend data bits, transmit them via devoted gateways, and then send them to the public network.

An LPWAN has the following three physical features: 1. "long-distance communication", 2. "low-rate data transmission," and 3. "low power consumption"; therefore, it is very suitable for IoT applications, such as a disaster scenario that requires long-distance transmission, less communication data, and long-term duration. Most IoT applications usually only need to transmit a very small amount of data. For example, the sensors

that control the switches in an industrial production plant only generate data when the switch is abnormal. These devices generally consume low power and can be powered by batteries for a long time. Although cellular networks can also be applied, they cannot solve the problem of high-power consumption.

	Names	
LPWA & IoT types	Cellular Network based LPWA	Non-Cellular Network based LPWA
License (Japan)	License required	License free
Frequency	LTE: 700MHz, 800MHz~2GHz	920MHz (JP)
Standards	3GPP release 13: 1) NB-IoT (2016.6) 2) cMTC (2016.3) 3) EC-GSM-IoT (2016.6)	Other alliances/IEEE: 1) LoRaWAN (2015.2) 2) SIGFOX (2010) 3) IEEE 802.11 ah (HaLow) (2016.12)

Figure 2-8 LPWA standards

The LPWA communication module used in this paper is IM920 [44], which is a 920 MHz communication module with a transmission rate of 50 kbps, a range of 400 m and consumes power at 25 mW. Unlike cellular networks, the 920 MHz LPWAN is license free. There is already an IM920-based LPWA mesh network deployed in Minami-cho, Tokushima, Japan [2] [35] [38], which is used to perform the field experiment for our proposed

network architecture. This LPWA module uses its special communication format, which combines a packet header and user data. The received packet header contains the node number, received signal strength indication (RSSI), sequence number, etc. This packet header can cooperate with our previously proposed Named-node networking (3N) to realize the Information-centric networking (ICN) implementation.

2.3 Machine Learning

While in a content-oriented network, the content name is a vital element to the whole data delivery system. Who/what is naming the contents becomes an important part of the system. In this paper, a TensorFlow platform [50] and a region-based convolutional neural network (CNN) [51] [52] [55] are used to detect objects, categorize the generated contents and name them [53] [54]. Figure 2-9 shows an example of the human detection used in the experiment. This down resolution image is authorized by MIC. In the image, the detected human objects are marked, labeled and logged. Content about this information is generated for users to subscribe.

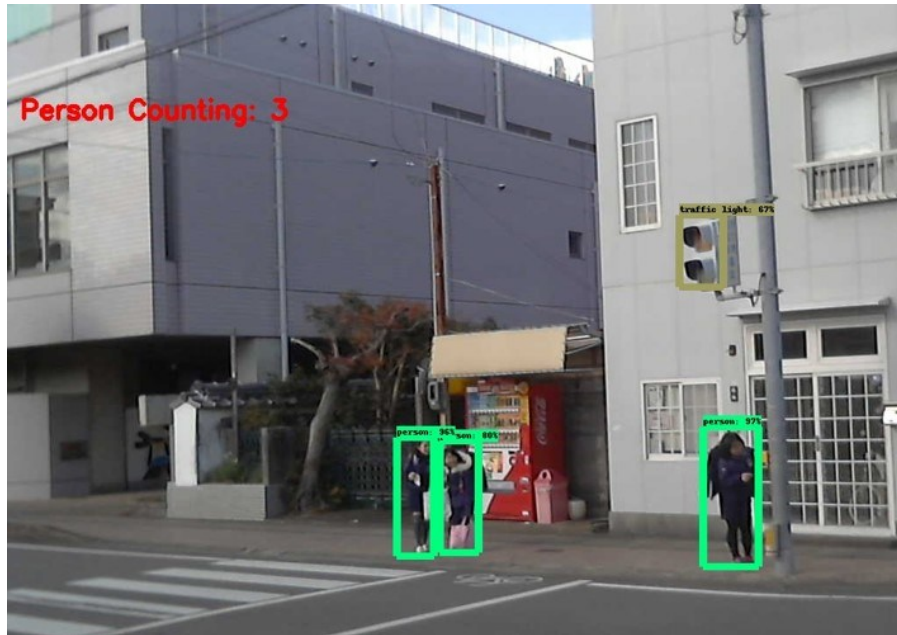


Figure 2-9 Human detection example

2.4 Real-time video streaming system

Real-time video streaming is widely used in many fields, such as modern surveillance systems [69]. A real-time video stream system is a network application protocol designed for the use of entertainment and communication systems to control streaming media servers. The protocol is used to create and control media sessions between terminals. The client side of the media server issues VCR directions, such as playback, recording and pause, to enable real-time control of the streams from the provider to the user (video on demand) or from the user to the provider (voice recording).

This technology is usually used in modern CCTV (Closed-Circuit Television) systems.

RTP (Real-time Transport Protocol) is commonly used in streaming media systems (with RTCP protocol or RTSP protocol). Because RTP itself has a Timestamp, it is used as a form in FFmpeg.

In many megacities, centralized data centers are organized to manage and serve the great quantity of real-time data streaming equipment. With every string of live data transition between the server and the node, the central data center is always facing the critical problem of high network capacities, not only in daily surveillance activities but also during urgent situations, such as disasters [24] [25] [26] and security events, that take place.

Chapter 3

Content-Oriented Surveillance System

3.1 Overview

In this chapter, I designed a surveillance system based on the named content network. Our proposed surveillance system includes three parts, i.e., the system architecture, application architecture and the content naming strategy.

3.1.1 System Architecture

The proposed surveillance system architecture contained several key elements. First, an example of the surveillance system structure would be introduced to offer an overall perspective of the whole method. The structure was divided into the camera node and the central data center. In the field experiment discussed later in this article, twenty camera nodes were connected via an ICN network and one central data center was provided on a laptop. Figure 3-1 shows the network architecture of the method. The camera nodes were connected via an ICN network and divided

into several sets covering certain areas. Inside each set, there was a node with a control function; this node could respond to a complex request by manipulating the other nodes in the set.

Figure 3-2 shows the flow chart of a full requesting procedure. The procedure started from the generation of the interest. The interest was a combination of the objective's pattern parameter and the area code for recognition. After sending out the interest to the camera nodes covering the target area, the camera nodes would instantly start to analyze the fresh captured frame with the given pattern parameter. Then, the resulting data were generated to be transmitted back.

3.1.2 Application Architecture

While the content-oriented surveillance system was successfully configured and ready to comply. The user, for example, could instruct the consumer application to send a request for the human count in area one, containing 4 nodes. An interest was generated by the application and sent out. Once the interest hit a matching control node, the control node would instruct all the nodes in the control (including itself) to gather and integrate the information with the different interest combinations, then send the content back. In the process of gathering information from the camera nodes, the camera nodes

received the interest from the control node. With the parameter is extracted from the interest's name prefix, the camera node could execute the pattern recognition application along with the parameter and output the valued data. After grabbing and transferring the desired content back to the consumer, the full request procedure is complete.

This paper applied two types of parameters to the pattern recognition application used in the experiment. They were a face counter and a cloth-color recognition based on the open source software, OpenCV. During the analysis of the application, first it located areas where possible human faces appearances in the captured frame. While counting the number of faces, it located the upper body cloth areas right below every face area. By summarizing the color value of the pixels in the area, the face count and cloth-color data are output together or separately. Algorithm 1 describes the pattern recognition procedures. Figure 3-3 shows the expression of the recognition areas applied on a person. The red zone covers the face area, and below that is the blue zone, covering upper body's cloth area. First, the recognition application checks the execution parameter to ensure that it is legal. Then, determines if it desires face counting and cloth-color recognizing. If the application is permitted to execute the face recognition

function, it would quickly recognize every face in the frame and output the count value. After the counting, the application would check if there is a cloth-color recognition command. If there is one, the application would locate the area under every face and summarize the color data and then output the color data. With the outputting of the desired data, the system could reply with the desired content.

3.1.3 Content Naming Strategy

This chapter used CCNx [39] [40] [41] to realize the ICN network architecture. According to the principles of the CCNx functionalities, the serving application must contain a certain name prefix format. Here, this paper considers the name prefix to be the identifier of the desired content. To apply different parameters to the pattern's recognition appliance, the parameters were fitted into the name prefix in a certain format. Figure 3-4 shows an example of the full name prefix in the method. Figure 3-6 shows a simple tree topology of the content naming strategy.

To manage the large scale of the camera nodes, a proper content name combination is organized. The system applies names to the contents and classifies the contents at the same time, making it efficient in sorting the huge amounts of content provided by the nodes, especially to human users.

During a request from the data center to the camera nodes, a legal CCNx name prefix would be sent within the interest. The nodes would check the name prefix level by the level until the second last one, which is designed to be the content name. According to figure 3-5, the full CCNx name prefix was separated into 2 parts, i.e., the target's content name prefix and the pattern parameter. The target's content name prefix identified the content's name, while the following parameter defined the content's type, in other words, the recognition type. After sending out the interest and hitting the target's content name prefix, the activated camera node would grab the parameter part from the full name prefix and execute the pattern recognition application with the parameter. Then, the result data is obtained, and a reply is sent to the data center with the desired content. Within seconds, the request is completed.

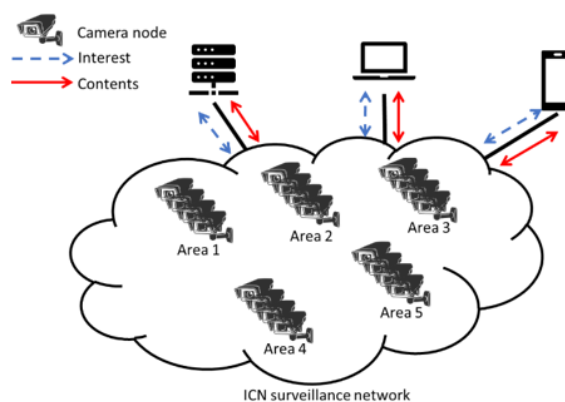


Figure 3-1 Network Architecture

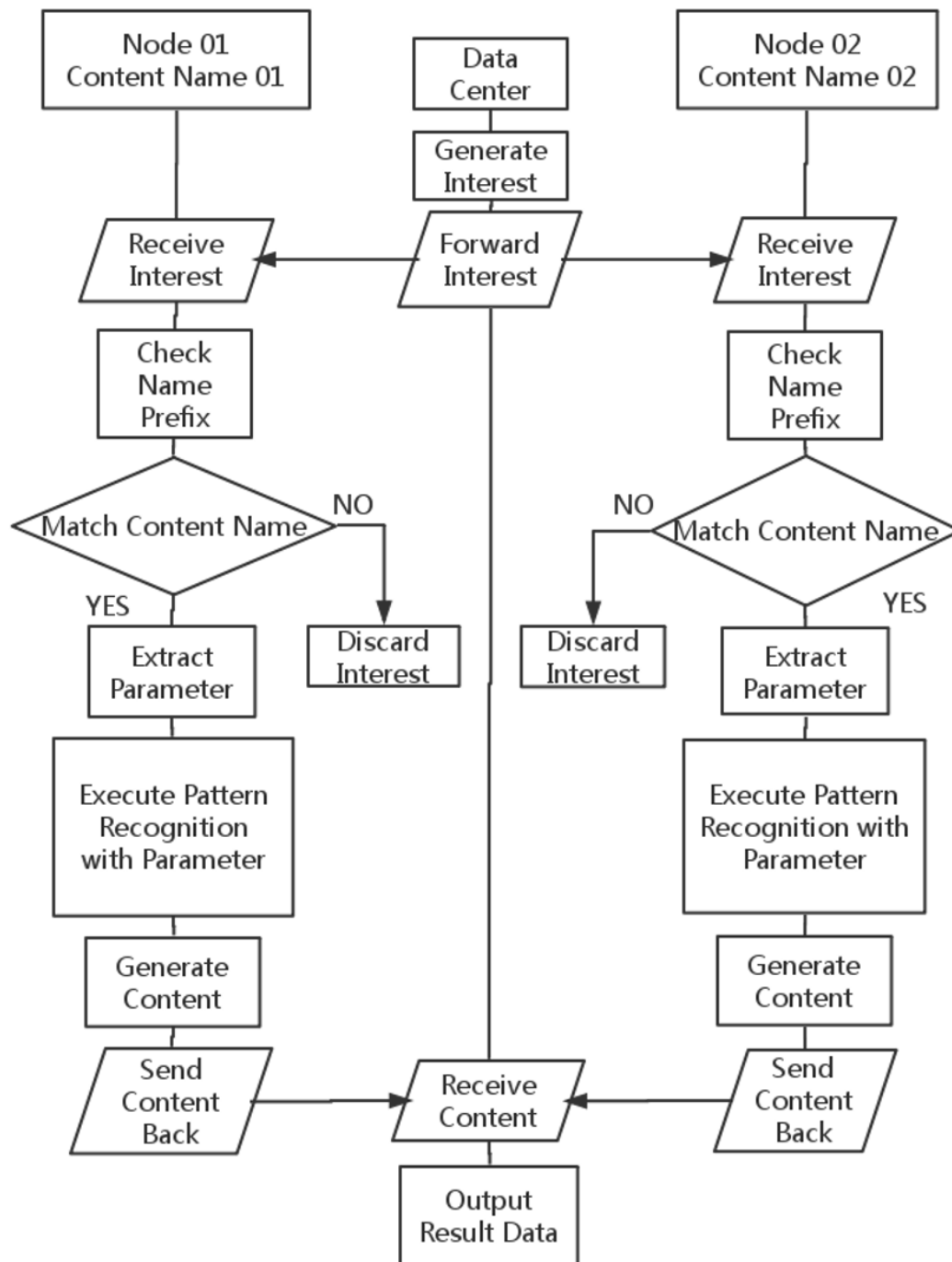


Figure 3-2 Procedure Flowchart

3.2 Field experiment

This chapter discusses a field experiment performed in 2016, at Moji Port (Mojiko), Kyushu, which has been an international trading port since the late 19th century.

To fulfill the purpose of the designed architecture. Every camera node was given a certain level of processing power. In this case, this chapter introduces the “Intel Compute Stick” as the hardware foundation and a USB Video Class (UVC) webcam as the capturing device. The power supply was as simple as a USB power cube with 5 Volts and 2 Amperes, as shown in Table 1.

Algorithm 1 Pattern Recognition Procedures	
1:	INPUT: Parameter
2:	Decode Parameter to Face-count = “FC”, Cloth-color = “CC”
3:	if Face-count == “yes” then
4:	Recognize faces
5:	Count face number → value
6:	else
7:	if Cloth-color == “yes” then
8:	Locate cloth area
9:	Convert color → color
10:	else
12:	end if
13:	output value
14:	output color

Figure 3-3 Pattern recognition algorithm

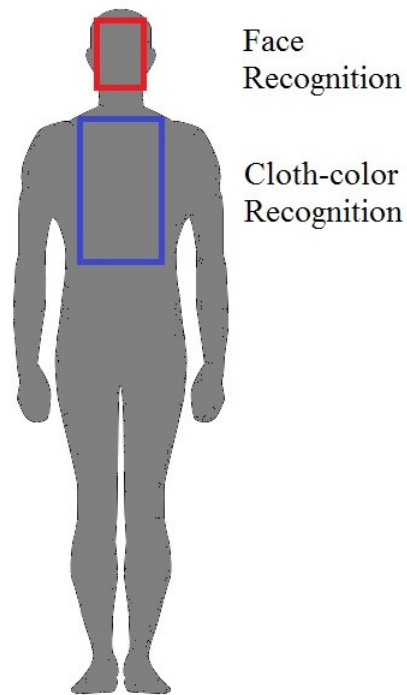


Figure 3-4 Recognition Example

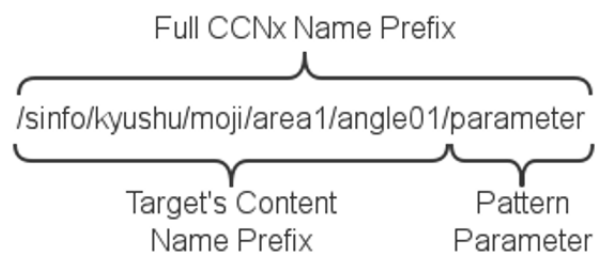


Figure 3-5 Sample of Naming Strategy

TABLE.1. hardware Setup

Power supply	DC 5 V/2 A
Hardware	Intel Compute Stick STCK1A8LFC
Capture device	UVC webcam
Network device	LTE mobile Wi-Fi access point

Every unit of the camera node accesses the Internet with a Wi-Fi connection and the units are connected to each other via a CCNx network stack.

There were 20 camera nodes in the experiment, divided into 5 sets evenly and assigned to 5 experiment locations shown in Figure 3-7. We rented one of the facilities' rooms to use as the office where our experiment was operated.

1. Kanmon Kaikyo Museum

2. Old Dalian Line Shed (Rented as office)
3. Mojiko Retro Observation Tower 1F
4. Moji Customs Building
5. Old Osaka Merchant Ship Building

Every set of the nodes shared 1 Internet connection via an LTE mobile Wi-Fi router. After the preparation and configuration of the nodes, all the nodes were powered on and put into standby mode.

The aim of the experiment was to analyze the tourist traffic and season cloth-color choice in the tour areas. To fulfill this purpose, I performed the field experiment from the opening hour to the closing hour of every tour sight, i.e., from 10 am to 5 pm. The frequency of the requests was configured to be sent once every 4 seconds. This could record the logging of the human traffic along with the logging of the cloth-color. The live processed data was transferred to the user side in real-time. Please note that in some scenarios, such as anti-terrorism, there were functions designed to retrieve the objective's frame. However, this function was not applied in the field experiment in Moji Port.

3.3 Experiment evaluation

The field experiment took place in the tour areas of Moji Port, Kyushu. The following figures, i.e., Figure 3-8 to Figure 3-12, show the experimental data of the 5 locations. The figures represented the quantity and proportion of the colors of the areas, and the colored bars represent the human count.

There were two major conclusions drawn from the experiment's results based on the representation of the human counting and cloth-color. First, I could easily determine that the density of tourists was greatest in the afternoon, except in location 2, the Old Dalian Line Shed. This might be because there were many people renting the facility's rooms on that day, including our research team. On the other hand, most of the shirt colors were found to be gray, black and other dark colors. The result shows that dark colors, such as gray and black, composed a big part of the winter cloth choice, along with a small percentage other bright colors.

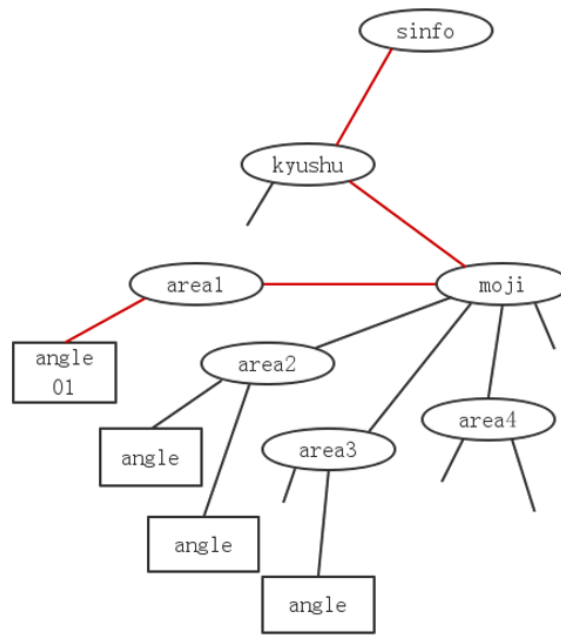


Figure 3-6 Content Naming Tree Topology

For the evaluation of our proposed method, I analyzed the throughput from location 3. Figure 3-13 shows the throughput comparison. From the figure, 2 throughput lines, i.e., blue and red, can be seen. The blue line represents the data rate of a typical surveillance system that uses video streaming as its data feed. The red line represents the data rate from the method this chapter proposed, where the data are generated only when the target content is being retrieved. For a typical high-definition video feed, the network bandwidth consumption is approximately 4 Mbps. From the throughput, in a continues time, our proposed method consumes less network bandwidth

than the traditional surveillance system. This is because the only contents being transferred in the network are those that match the target's interests. When the system is idle, the whole network consumption drops to almost zero.

The comparison result shows a great savings of network bandwidth in the field. Utilizing this benefit, the performance of this system could be very valuable in areas with low network bandwidth, and in some disaster scenarios. Additionally, the pattern recognition applications could work in anti-terrorism scenarios.

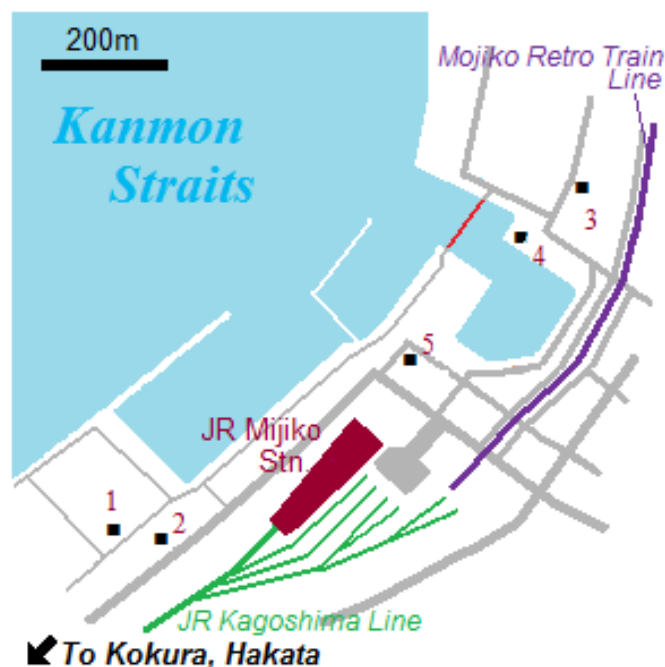


Figure 3-7 Experiment Locations

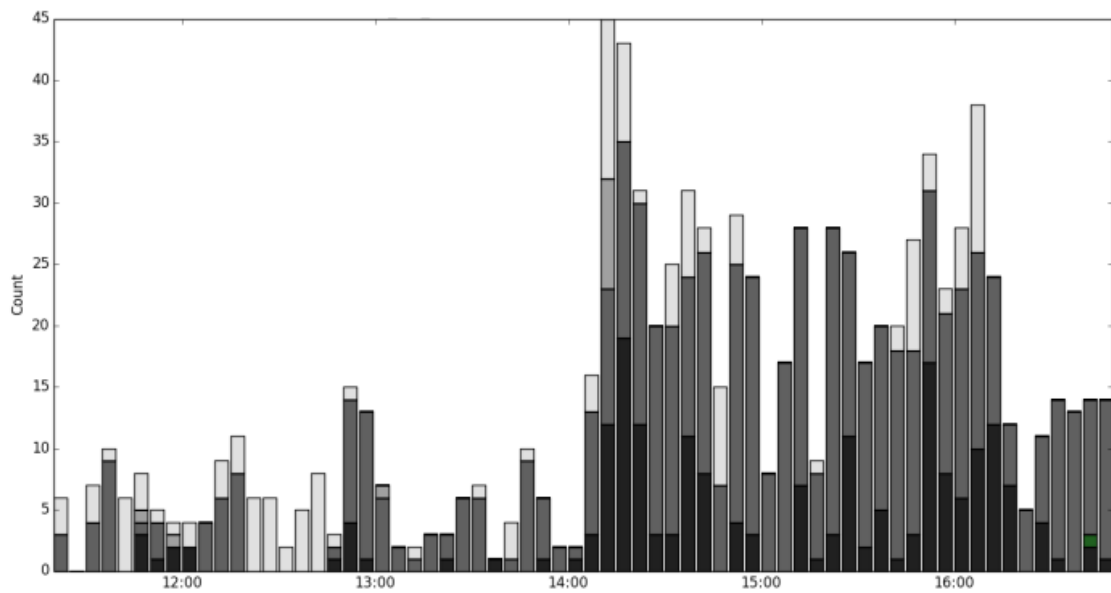


Figure 3-8 Experiment data of location 1

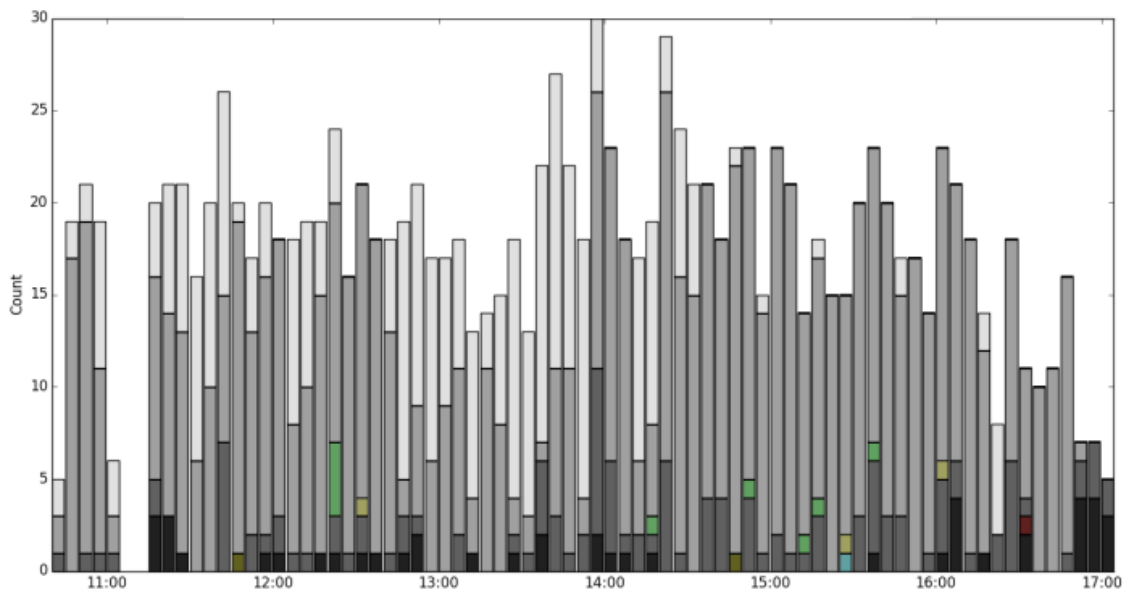


Figure 3-9 Experiment data of location 2

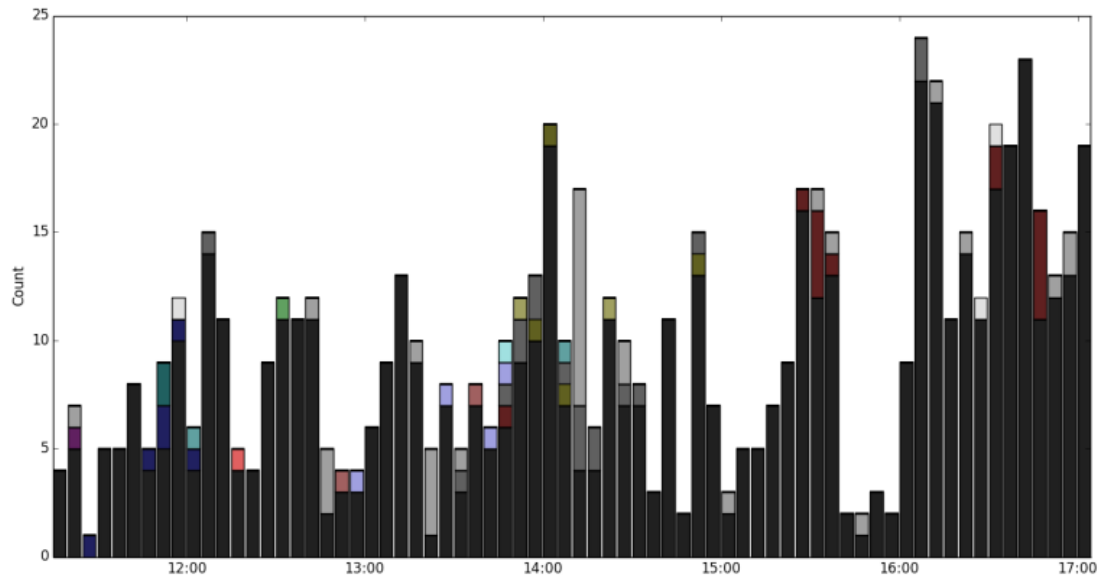


Figure 3-10 Experiment data of location 3

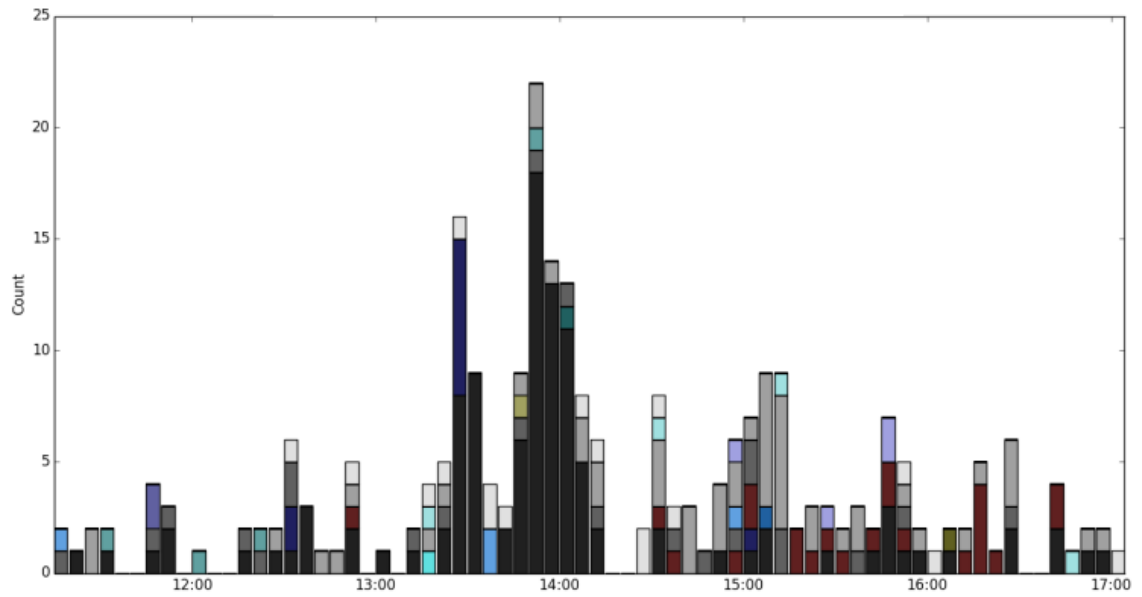


Figure 3-11 Experiment data of location 4

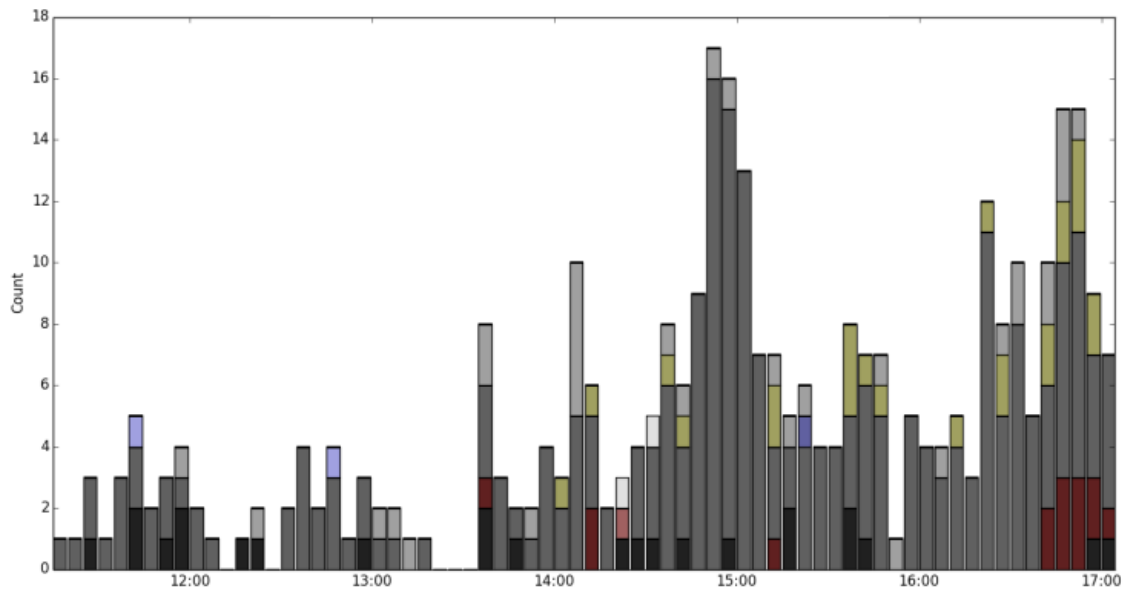


Figure 3-12 Experiment data of location 5

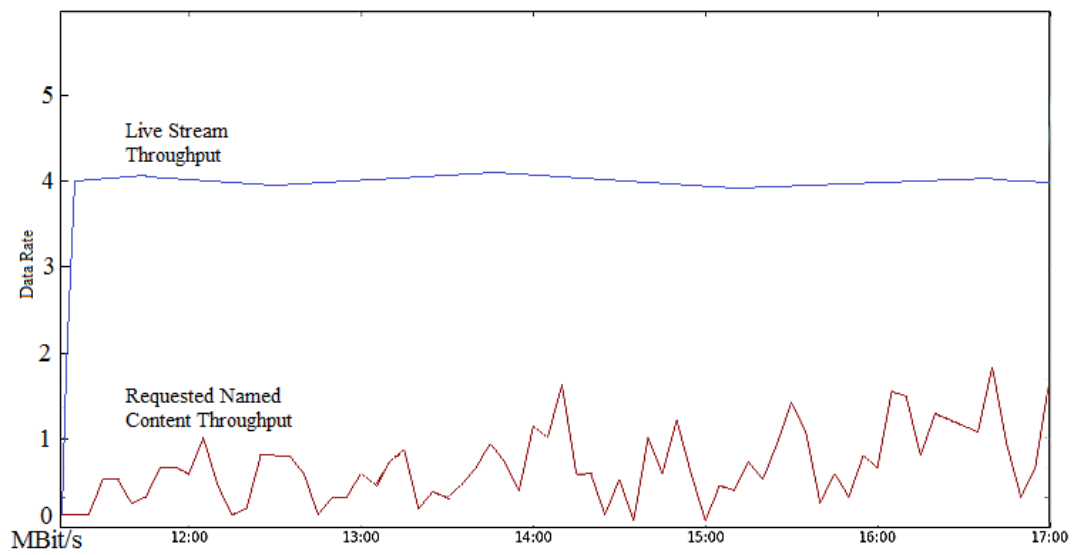


Figure 3-13 Flowchart Example

3.4 Summary

In this chapter, I have proposed a surveillance system based on a content-oriented network. The system uses named contents to deliver surveillance information. The ICN architecture in the system enhances the network performance when multiclient subscription occurs. The proposed system reduces the network bandwidth consumption [7] [8] [10].

Chapter 4

Named Node Networking-Based Disaster Network

4.1 Overview

Our proposed disaster network architecture is a combination of several parts, i.e., the LPWA mesh communication network and the DISS Box units. The LPWA network was deployed in the field experiment area in Minami-cho, Tokushima, Japan. In the experiment area, there were many LPWA forwarding nodes working on the same frequency (LPWA channel), covering the area. The mesh network automatically repeats the packets and broadcast them to every receiver by default. However, in the experiment discussed in this chapter, we managed to implement nodes with 3N basic functions to recognize the ICN packets and that have the ability to maintain the routing [60] table with NNR, which will be discussed in the next subsection. The LPWA nodes formed a mesh network and can be managed as one information distribution platform.

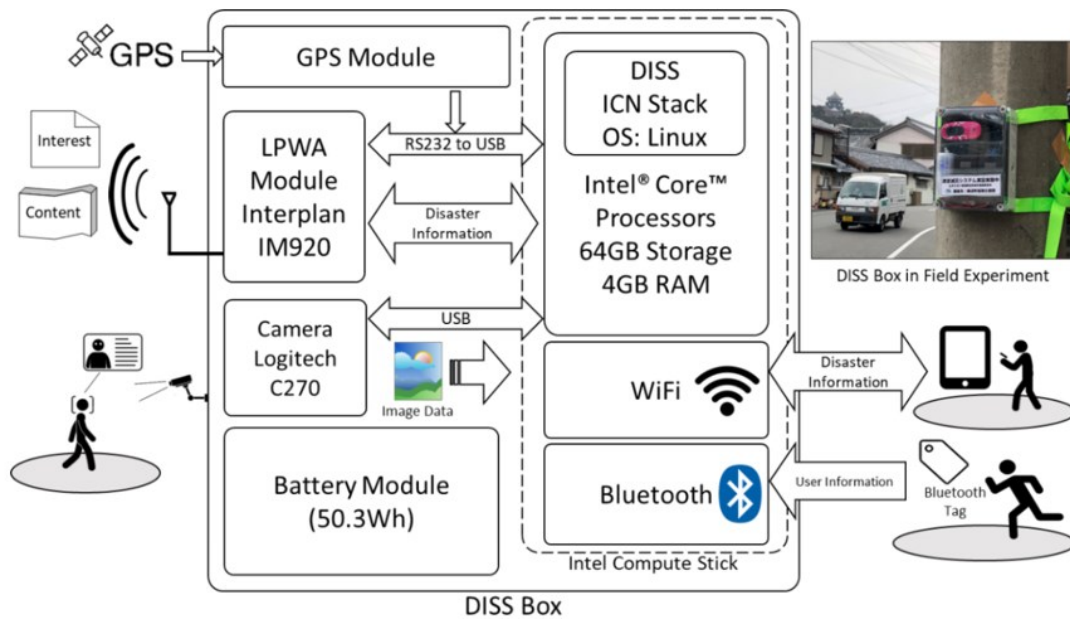


Figure 4-1 DISS Box

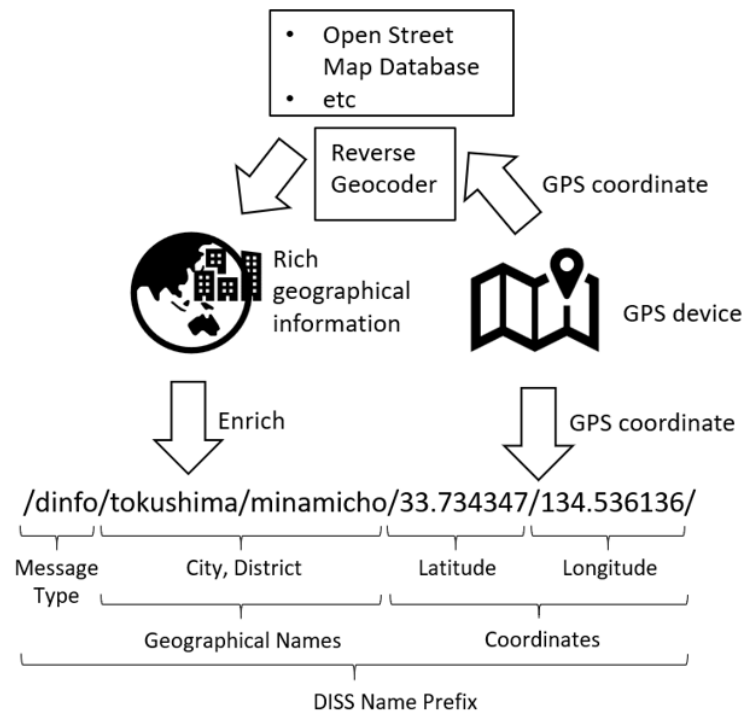


Figure 4-2 Geo-name prefix

A Disaster Information Sharing System Box (DISS Box) is assembled with several components, as follows: a central processing platform powered by a compute stick [43] [47], an image capturing unit powered by a camera, wireless communication modules and a battery module (topology shown in Figure 4-1). The high-performance compute stick provides real-time image processing power to generate useful information based on the captured image, which includes people count information and intercepted images of the interested objects. The Wi-Fi and Bluetooth module included in the compute stick provides the connectivity to the client users for disaster information publishing, and the Bluetooth tag is used for evacuating individual tagging, which was used in the previous experiment [45] [46].

4.2 Node Name Routing

In the LPWAN communication protocol, a node name (serial number) is utilized in the packet header of each sent packet. In this paper, I proposed a node name protocol to combine the LPWA's device name with the 3N's node name, to implement the 3N NNR mechanism in the network, optimizing the packet routing efficiency for the entire network. To achieve this goal, in this chapter, the LPWA packet structure is formatted into a 3N qualified structure. Using this packaging format, in this chapter, the node

name routing (NNR) mechanism is utilized to maintain the network and optimize the traffic routing actively during the data transmission.

NNR is a routing strategy that is maintained by node names. In the packet transmission of the network, the DISS content name prefix is organized in a hierarchical URI style, such as the CCN standard style. The DISS system uses a name prefix by combining the message type, coordinates and geographical names. Figure 4-2 presents an example of the name prefix. When a user wants to generate a name prefix, the GPS device generates a GPS coordinate and the node performs a geographical information search with the reverse geocoder, powered by the small size offline database of the region. Then, the node combines the enriched geographical information with GPS coordinates to generate the named content. The coordinates information can be found from a database, such as the Open Street Map (OSM).

In a general 3N network, there are enrollment procedures for nodes (fixed or mobile) that do not have a preset name.

In our experiment below, I preassigned a node name to each node. During the initialization of the network, the system would flood the network with

3N SO packets and retrieve the DU packets. The nodes would update and maintain its NNST, tracing the last and the next hop to determine the best route.

The NNR routing strategy is designed to find the best route between the subscriber and the publisher. Like the dynamic source routing (DSR) and ad-hoc on-demand distance vector (AODV) methods in TCP/IP, NNR has more advantages in optimizing the routing table in the ICN network [48] [49].

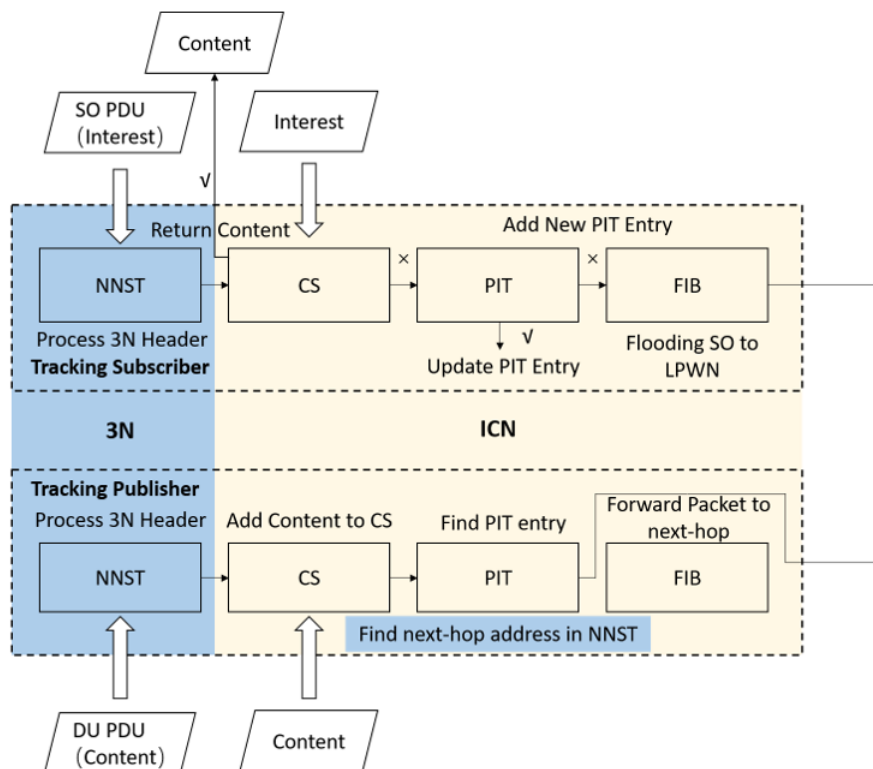


Figure 4-3 Node name routing mechanism

The forwarding mechanism in Figure 4-3 presents the packet forwarding mechanism. When a node receives a source only (SO) packet, it will first check its Content Store (CS) to see if there is already a matching content stored. If there is no cached content, it will check the Pending Interest Table (PIT); if there is already an entry in the PIT, then the node will add a new entry or update an existing one. Finally, if no existing PIT entry found, then the node will log the information in Forwarding Interest Base (FIB) and continue flooding the SO packet to the other nodes. The DU packet will help the node tracing the last hop.

4.3 Evaluation



Figure 4-4 Field experiment map and node locations

In the following section, field experiments were performed to evaluate the actual performance of NNR in the LPWAN. The experiment was performed in Minami-cho, Tokushima, Japan on Dec. 13th, 2017. Furthermore, in this location, disaster precaution and emergency response are very much valued. This experiment is an extension of the previous LPWA IoT system

experiment for tsunami disaster prevention [27] [28] [29], which performed an evacuation drill authorized by MIC. The experiment took place for 4 hours on this day, and was powered by rechargeable batteries. Figure 4-4 shows the node distribution map. Based on the map of our experiment area, the city is surrounded by water on the south and east sides. Therefore, during a tsunami evacuation, people will have to move in the northwest direction. The yellow roads on the map represent for the main roads of the city, which are also the life-lines during a disaster. Nodes 44 and 45 represent a hospital and a government building with a school next to it. Node 21, the emergency control center, is a high-altitude tower that can be used as a shelter, but it lacks accessible life-lines. Because of this authorization, I can generate an experiment database on the camera nodes at the main roads. This chapter aimed to compare the network load between ICN routing and 3N node name routing, which did not necessitate a large-scale evacuation drill to be performed, which requires complicated application and preparation. The contents were generated from the street view; to protect public privacy, unauthorized image data was not stored.

4.3.1 Field Experiment

Category	Parameter	Value
Application	CCNx	0.8.2
	3N	0.1
	DISS	
Routing Strategy	NNR	
	ICN Routing	
Access	Technology	LPWA
	Radio range	400m
	Data rate	50kbps
Scenario	Area	650x300m ²
	Experiment time	4h
	Number of Nodes	40(DISS) +6(DISS+Image Recognition)

Figure 4-5 Experiment parameters

The field experiment in this chapter extended the previous ICN-based LPWAN network [43] to a 3N-based LPWAN network. The experiment aimed to measure the performance between ICN routing and 3N node name routing, rather than a real-life evacuation drill. Around this region, I arranged 40 DISS nodes at the lamp posts in the streets and main roads (location details are shown in Figure 4-4 and the experiment parameters are shown in Figure 4-5). The DISS nodes were embedded with ICN and 3N

stacks [11] to forward communication packets, and they use the LPWA network to communicate. Additionally, 6 DISS boxes were distributed on the main roads; nodes 41-46 were in the main road of the city. In the experiment, people would take the main road and eventually be captured by the camera nodes, ensuring that the collected tracking data on the evacuation route from the previous experiment was accurate.

The experiment uses an IoT platform with data processing capabilities. ICN routing I used CCNx0.8.2 in the 6 DISS Boxes [36] [37], and 3N NNR routing I used 3N application version 0.1. During the experiment, the nodes along the street actively collected data to obtain useful information by machine learning. By using node names, it is possible to push information to the disaster prevention center's server or terminals of affected people. In the disaster scenario, the nodes also have built-in HTTP servers to visually output real-time human recognition processed images.

When the tsunami evacuation alarm is in effect, the residents would take refuge in safe places on high grounds. The general evacuation route is to move from the streets to the roads and finally to the high-altitude shelters. The DISS Boxes are on the roads of the evacuation routes. The nodes identify the evacuating people individually and generate related

information and send it to the client or evacuation command center; the command center is assumed to be located at node 21, which is on top of a hill. This chapter use this scenario to generate contents and allow the LPWAN to forward them to the command center with NNR and with an ICN routing strategy.

4.3.2 Results

Figure 4-6 and Figure 4-7 are the network traffic heat-maps using normal ICN flooding routing and NNR routing. From these two heat-maps, it can be seen that the 3N network consumes fewer network resources than the standard ICN network. Based on the traffic data gathered in the experiment, I was able to calculate the overall traffic ratio, which is 40.58%. The overhead of the 3N network is known to be less than that of the ICN network. The difference between the two figures is based on the LPWA mesh network topology; the ICN flooding routing method will broadcast interest packet to every node possibly containing a content; then, when the content packet is being transmitted, the packet will follow the PIT entry to be delivered to every node. The ICN flooding routing causes waste data traffic in the mesh network and this leads to multiplied bandwidth consumption and, in the figure, the whole area is in high traffic load. Instead of blindly flooding

packets to mesh network nodes, NNR actively updates the NNST in the nodes and finds best route for the content delivery. With this method, only the related nodes in the path of the content delivery route consume network bandwidth, so the excluded part of the nodes will remain in low traffic consumption because only the SO packet will be flooded over the whole network to determine the best route.

From the two heat-maps, the 3N network consumes fewer network resources.

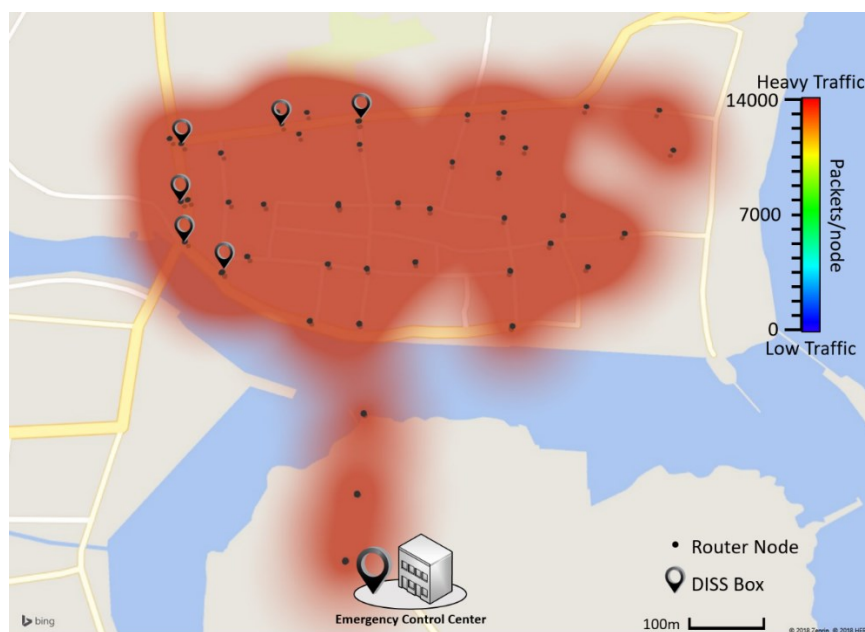


Figure 4-6 Traffic heat-map for packet transmission with ICN flooding

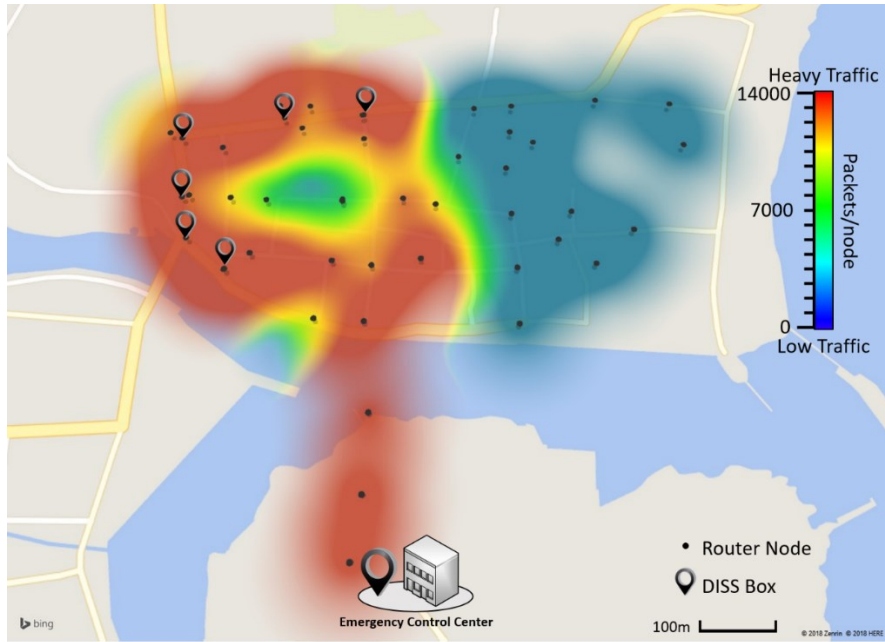


Figure 4-7 Traffic heat-map for packet transmission with NNR

Figure 4-8 shows the content packet histogram of all the nodes in the field experiment, with the comparison of two routing mechanisms. In the experiment, the emergency control center requires named content from the network. When a matched content is found, the content will be forwarded to the control center. In these procedures, the received packet ratio of the emergency control center is at approximately 16.7%, compared to the transmitted packets in the DISS boxes. There are three reasons, as follows: first, the 3N network can actively flood the network to optimize the routing table; second, the LPWA communication range is up to 400 m; and third, the DISS nodes in the city area suffer from packet drop due to weak signals.

Therefore, the control center receives approximately $1/6$ of the overall generated packets. Together with the heat-map above, the comparison of our proposed NNR and the ICN mechanism shows that the difference in those nodes excluded in the optimized routes of the whole content delivery topology. In the ICN mechanism, those nodes were flooded with the packets and this caused almost all the bandwidth of the LPWAN system and unnecessary traffic load to them. On the other hand, our NNR system optimized the content delivery mechanism and only utilized the best delivery route based on the number of hops and RSS information to handle the packets. It is very important for LPWAN to deliver the most valuable information with the least costly communication network, as more valid information can be distributed, and the rescue power can be deployed in the most effective way.

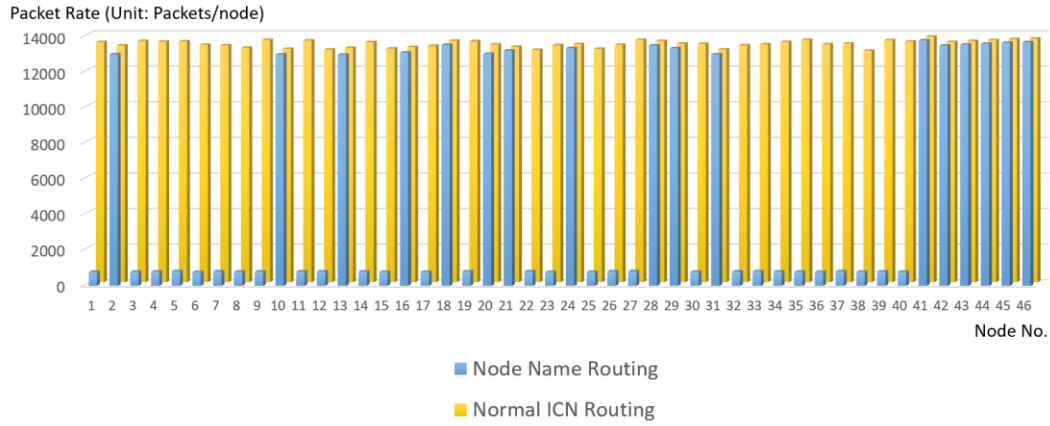


Figure 4-8 Traffic consumption of NNR and ICN

4.4 Summary

A node name routing-based LPWA disaster network is presented in this chapter. By applying NNR, the low bandwidth utilization problem in LPWAN is solved with its optimized routing ability. The field experiment results show that NNR expresses a better result regarding the overall network bandwidth usage and content delivery efficiency, which is very valuable in the disaster area where mainstream networks are down; by using the LPWAN+NNR-based self-optimized network, an emergency network can be utilized. However, future practical solutions require practical experience.

Chapter 5

Named Node Networking

Implementation and Real-time

Video Streaming System

5.1 Overview

In chapter 3 and chapter 4, I used a similar method to the content in the ICN network for extracting useful information. In this way, the ICN architecture is designed to win the content delivery contest. However, I still wonder how the ICN takes advantage in the traditional real-time video streaming method. I will evaluate and demonstrate my work, i.e., the 3N practical implementation, in this chapter.

This is a serious 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. 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 RINA (Recursive Internetwork Architecture) network [70] [71]. To overcome the challenges related to the content request, in the future, ICN can play an important role.

The Recursive InterNetwork Architecture (RINA) is a computer network combination with mixed computing and telecommunications. RINA's central attitude is that Inter-Process Communication (IPC) [72] [73] 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 or NNN mobility may be the best additional security layer.

5.1.1 System Features

The system features are as follows:

- This system successfully demonstrates the layered network architecture, i.e., 3N network over an ICN overlay network over a RINA underlying network.
- Most of the important features from 3N (for seamless mobility) and ICN (content centeredness) are retained in this system over the RINA network.
- System configuration files are extended in a well-structured manner according to the demonstration, and they are easy to understand.
- System configuration files are modifiable to change any of the system demonstration parameters for any specific requirement.
- The command prompt parameter makes it easy to start any node in the RINA network as a Client or Router or Content Provider (CP).
- The moderate level logs information is designed to indicate any failure in the system at any point, e.g., node connection failure, or data transmission failure, etc.
- The 3N seamless mobility concept helps to securely handle the three-way handshake connection between the MN and EN along with NNST and NNPT updating.
- Contents management was done based upon the ICN concept, which means any content is named uniquely based on its universal name, application name, and the content's own name, separated by forwarding slash ("/").
- Client node is capable of sending ICN-based data PDU requests for specific content to the edge node.
- The content request is then entertained by the edge node to decide whether to respond with requested content if it has it or to route the same content request over the RINA network towards the content provider.
- All the nodes in this system are capable of handling the content cache mechanism based on the ICN concept, i.e., whatever portion of the Client requested content that respective edge node has, it would then receive a response from the edge node itself without routing that data

request to CP but provided that the content is not expired at the edge node, which will be cross-checked from the CS table.

- The system is capable of cleaning all the expired content automatically.
- The FIB and PIT tables are used optimally to handle the client's content request
- Currently, the system is capable of handling the request to display the text content and downloading any requested content, i.e., text (plain, binary) files, audio files, video files.
- The optimized code of this system results in an insignificant delay in any content response.
- The client node capable for the situation in case it goes down due to any reason; then, all the current operation which were ongoing will be logged, and once the client node is up and working, all those operations will be started automatically from where it halted.
- The system is capable of working over wired and wireless [68] network scenarios.
- The smooth handoff mechanism supported by this system.
- The client GUI is provided for a one step solution for a handoff mechanism, making a request to obtain contents; additionally, it has an easy switching mechanism for auto SSID scanning to connect to a new AP if the current AP signals are weak. With the help of this GUI, I can also stop the auto handoff and switch to a forced handoff or a manual handoff mechanism.
- The integration for the logic to handle the external AI program at the CP is one of the significant features of this system.
- Well structured, properly commented and organized source code to understand the execution flow easily, which will help to extend it for future development.

5.1.2 Overall System Functional Flow

RINA has the instruments Quality of Service, multihoming and mobility, which provide a configurable and protected environment that inspires further viable marketplaces and provides continuous implementation.

The objective of this system is that to merge ICN and RINA into one platform to the possible level. Figure 5-1 shows the general 3N functional flow. For seamless mobility, the signaling mechanism used in 3N or NNN is used. By doing this, it can achieve various layered network architectures, which, in general, will be similar to the layered architecture shown in figure 5-2.

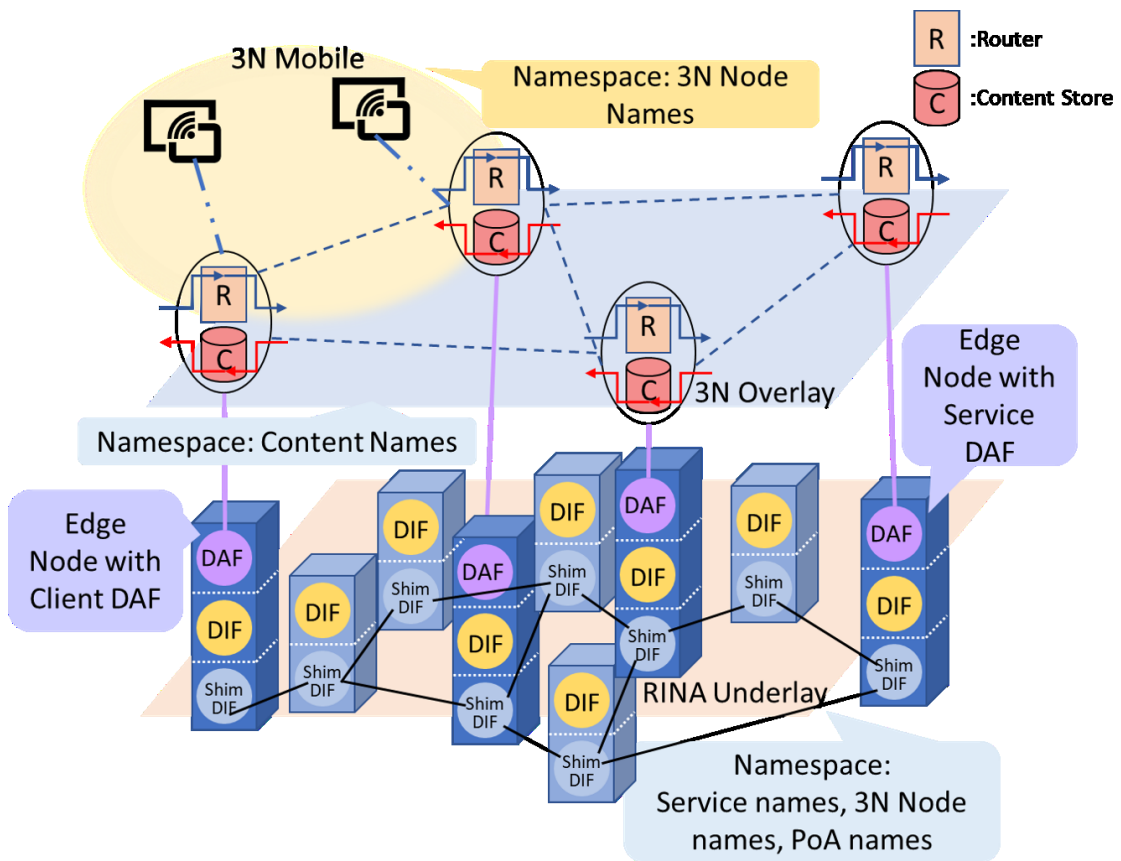


Figure 5-1 General 3N system functional flow

All the nodes in this network scenario will be named based on tire algorithm logic. As soon as the client node, i.e., MN, connects with the EN, a name will be assigned to it through the three ways handshake process. Once the MN sends the AEN, the EN is ready to serve the MN. While all these things happen at the 3N-ICN logic space, for any sending & receiving of PDUs, there must be a RINA connection beneath it. The 3N application registers with DIF, and subsequently, it registers with the bottom level shim-DIF of the nodes; then, while the three ways handshake finishes logically, there will be a DAF formation. This DAF will allow communicating between these two applications on two different nodes.

If a connection is idle, it will remain connected, once the node tenant time is expired, it will perform the three ways handshake again to obtain a new name for the node from the EN. For an active connection, the tenant time will be waved off till the ongoing operation finishes its execution. This system successfully provides logic separation of all layers in such a way that it gives the concrete impression that all the concepts decided in the objective work together.

For the content, it will need a namespace as per the ICN standard to uniquely identify the content. In general, each content will be identified by

with its universal name, application name and actual content name. All the routers are capable of caching the requested content but retaining its unique identity and expiring time is decided by its provider. Meanwhile, if the MN again makes the same content request that is being cached at the EN, it will be given the same without routing [62] the same request to the CP. The data transmission PDUs are the SO and DO, which are being smoothly handled by the system.

The AI program at CP plays a vital role in identifying the requested content when the request reaches it. The AI program decided if the requested content is there to be served or not. It can act as a plug and play module for this system. The overall system is capable of producing logs to notify us in case of its failure.

5.1.3 Node name and Routing

The 3N communication protocol uses the node name in the packet header in each sent packet. In this paper, I use NNR to realize content-oriented communication and node name-based routing.

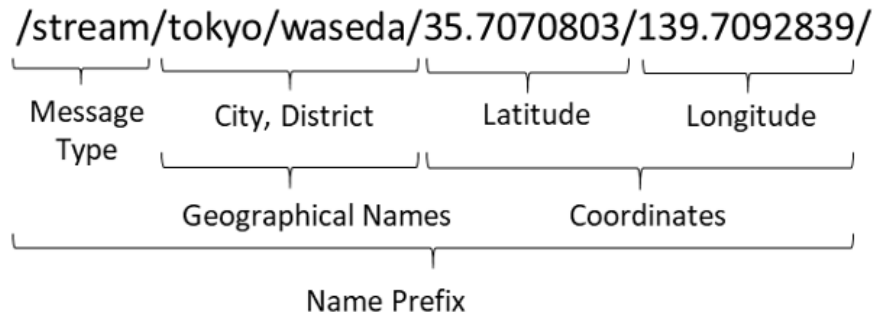


Figure 5-2 System name prefix

NNR is a routing strategy which is maintained by the node names and content names. In the stream system, packet transmission procedures, the content name prefix is in a hierarchical URI style, such as CCN [63] [65]. A name prefix includes the combination of the Message Type, Geographical Names and Coordinates. For example, Figure 5-2 presents the details of a name prefix. When the client wants to generate a legal name prefix, first, it decides what type of message is requested. Then, it can look up the reverse geocoder with the GPS coordinate generated with a GPS device. The node combines the enriched geographical information, GPS coordinate and message type to generate the proper name prefix.

A 3N name (Figure 5-3) is composed of labels, ranging from 1 character to the whole 16 characters permitted by the name. 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.

Sample 3N names:
a.0
1.a.13
a.ab.1.1
1.2.12.ae.6

Figure 5-3 3N name samples

The 3N network is designed to support native mobile client. There are node name enrollment procedures for nodes that do not have a preset name. In our experiment below, I preassigned node names to each node. During the experiment, the client generates and sends out an interest packet to request

the video stream from the content provider. When the content provider sends the content, i.e., the video stream, to the client, the client transfers the content packets into a mjpeg stream in a local HTTP server, so any supported player could view the stream live.

5.2 3N Practical System Development

5.2.1 System Design

Table 5-1 3N acronyms and abbreviations

Acronyms and Abbreviations	Meaning
RINA	Recursive InterNetwork Architecture
ICN	Information Centric Network
3N	NNN or Named Node Networking
NW or N/W	Network
TCP/IP	Transmission Control Protocol/Internet Protocol
NDN	Named Data Networking
MN	Mobile Node
EN	Edge Node
IPC	Inter-Process Communication
DIF	Distributed IPC Facility
DAP	Distributed Application Process
CDAP	Common Distributed Application Process
IPCP	IPC Process
RIB	Resource Information Base
PDU	Protocol Data Unit
SDU	Service Data Unit
PoA	Point of Attachment
PIT	Pending Interest Table
FIB	Forwarding Information Base
CS	Content Store
NNST	Node Name Signature Table
NNPT	Node Name Pair Table
CP	Content Provider
SSID	Service Set Identifier

The Named Node Networking system development is mainly focusing on the implementation of the 3N architecture based on a Recursive InterNetworking Architecture (RINA). The application should have basic ICN [64] 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. A well-designed architecture of the system to introduce ICN properties to RINA with seamless 3N mobility will ensure that the project results are distributed to a wide audience, maximizing the impact of the project, raising awareness for the project results and stimulating interest around RINA along with ICN and 3N features. This document will be helpful for any extension or future development from the developer point of view.

3N designed FIB, PIT, and CS to realize the basic ICN network. There is the implementation related to the ICN function in 3N. Once the Mobile Node (MN) connects with the Edge Node by a 3-way handshake, the MN asks for content from the Edge Node, which is encapsulated with a Source only (SO) or a Duo unit (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.

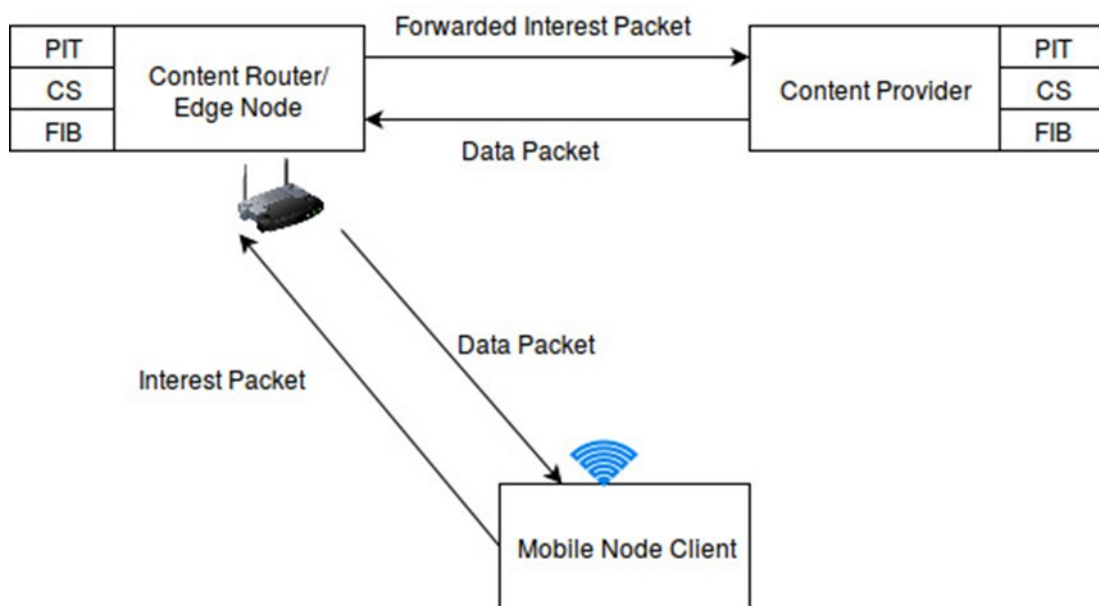


Figure 5-4 3N system protocol

The Mobile Node (MN) will make a 3-way handshake with the Edge Node. The Edge Nodes will have a unique base sector name. It can offer the unique node names to the clients connecting to them.

The three ways handshake procedure involves the following 3 steps:

1. Client sends EN (Enrollment) to Edge Node Server
2. Edge Node sends OEN (offer Enrollment) to Client
3. Client sends AEN (Acknowledgement) to Edge Node Server.

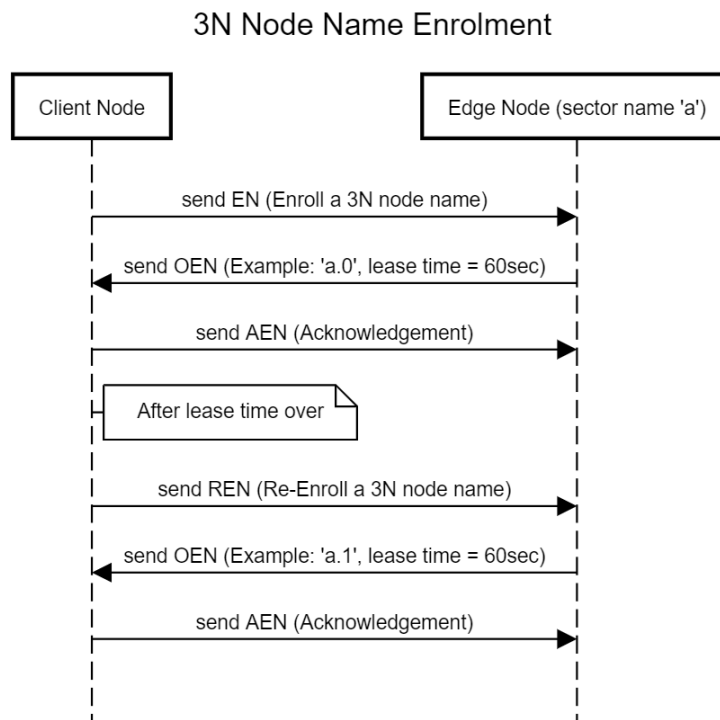


Figure 5-5 3N handshake procedures

The Edge Node server has a unique name, which is called the sector name, and which will be used as a prefix with some extension name of the clients connecting to it. The 3N names have an expiration 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 a different one as per its wish and obtain 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.

Our system development is with reference to the specification document ("Named Node Network real-time video data transmission system software coding specifications"). This is mainly to focus on implementing the coding software to realize real video data transmission. As per the specification, I understand that this project is based on the IoT common platform project. The fundamental architecture of 3N consists of the named node configuration, the content naming scheme, the content rooting function and the handoff function, which were already developed and were available to operate with a practical device; this real-time video coding is one part of the implementing program in the existing 3N protocol.

5.2.2 Request & Retrieve Content

Once the MN is connected with Edge Node by a three-way handshake, the MN will provide content request to the Edge Node, which is encapsulated with SO/DU PDU. When the SO/DU PDU reaches the Edge Node, it is de-encapsulated to process the interest packet. The PIT keeps track of pending interests.

When the Container Node forwards the data packet over the entire network to all the requesting nodes in the corresponding PIT, the entry will get deleted in the Edge Nodes upon the satisfaction of the data. The Edge Nodes buffer the content packet in the CS and add those entries into their CS Table.

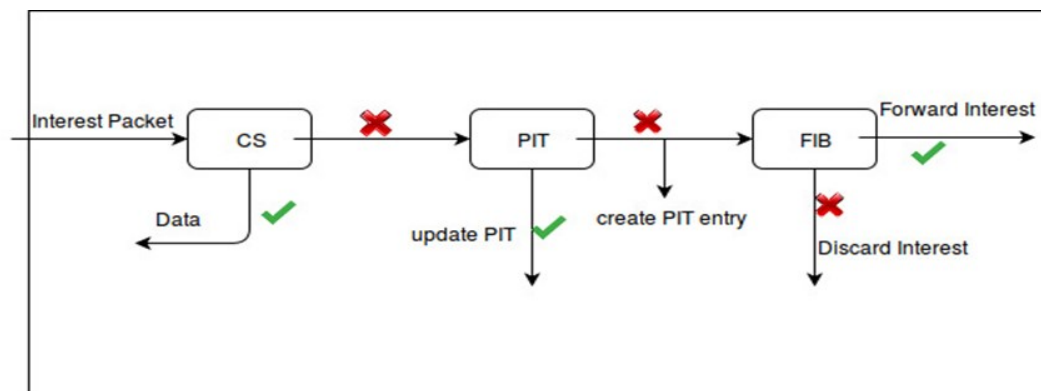


Figure 5-6 Content request and retrieval procedures

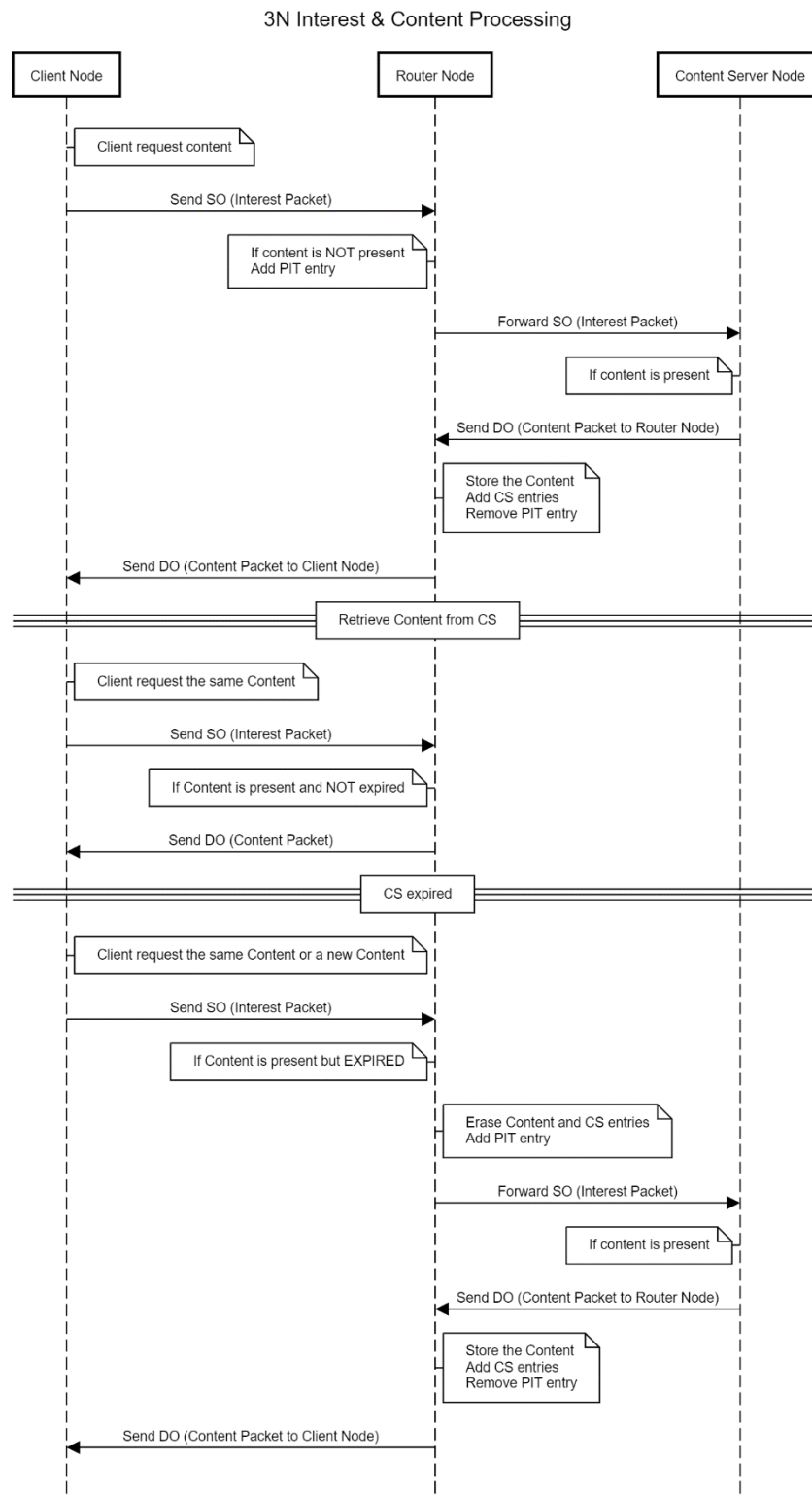


Figure 5-7 Interest and Content processing

5.2.3 Handoff Mechanism

Now the client can make the handoff from one Edge Node to another Edge Node depending upon the AP's availability and the signal strength. Depending upon the connection to the AP during handoff, the client will be connected to one of the Edge Nodes and will get a new node name after the Enrollment, 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 be enrolled with the new Edge Node after the successful handoff.

When the client moved to another Edge Node, the new Edge Node will inform the old Edge Node that the client was connected and about its handoff through the INF (inform) packet.

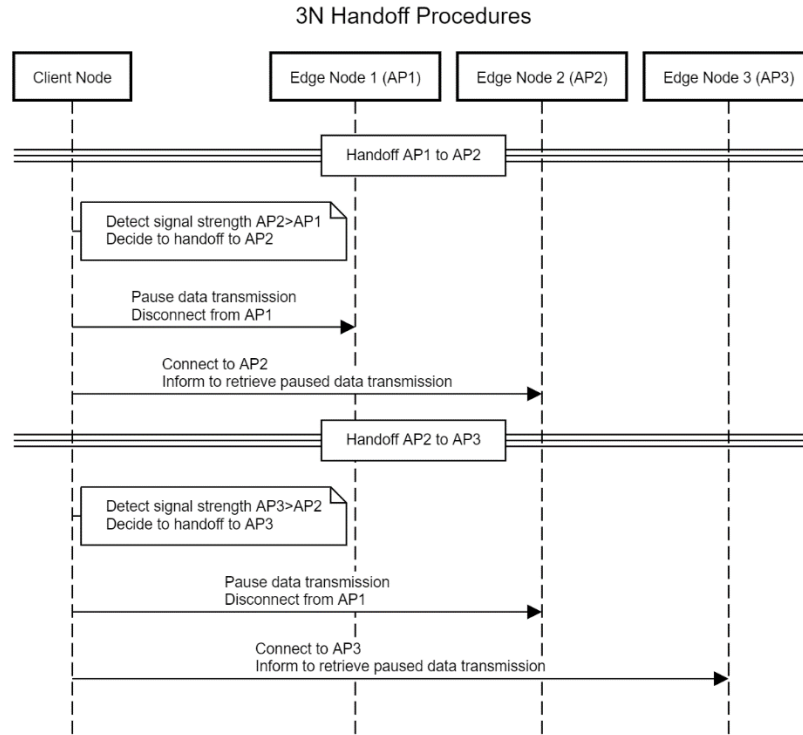


Figure 5-8 Handoff procedures

5.3 Evaluation

In this section, I performed a series of experiments to evaluate the 3N video streaming performance and compare to a TCP/IP video streaming performance. Figure 5-11 shows the experiment topology of the 3N environment and the TCP/IP environment, while Figure 5-10 shows the experiment parameters.

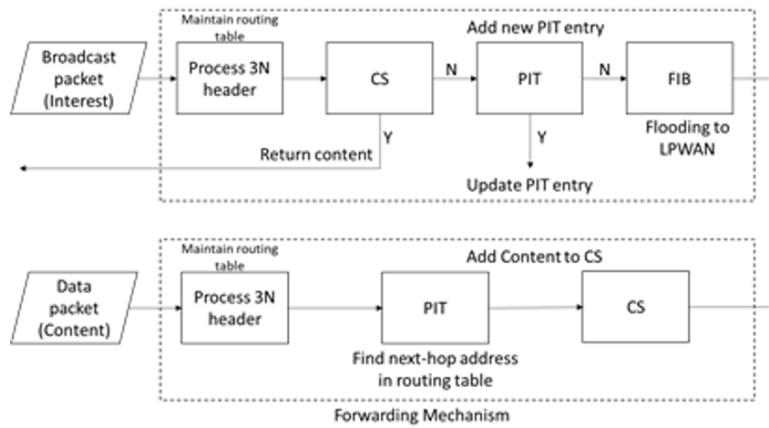


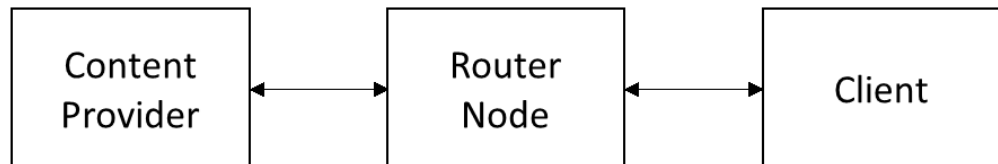
Figure 5-9 3N NNR forwarding mechanism

Category	Parameter	Value
Application	3N stream	
	TCP/IP stream	
Routing Strategy	NNR	
	TCP/IP Routing	
	Video source	4K@15fps
	Network connection	1Gbps ethernet
	Number of Nodes	3

Figure 5-10 Experiment Parameters

5.2.1 Video stream experiment

3N



TCP/IP

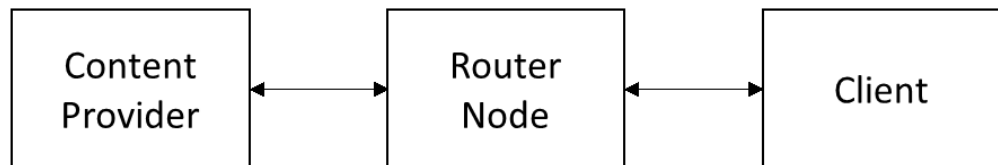


Figure 5-11 Evaluation topology

In the 3N video stream experiment, I built a simple 3 node topology to realize 3N network communication and basic video streaming. 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 stream into segments and transfers them to the client via 3N packets.

In the TCP/IP video stream experiment, I built a similar 3 node topology to realize a HTTP-based mjpeg video stream. During the experiment, the

client accesses the mjpeg feed via an HTTP connection. The content provider provides the stream to the client in mjpeg format.

5.2.2 Experiment results

Figure 5-12 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 content store (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.

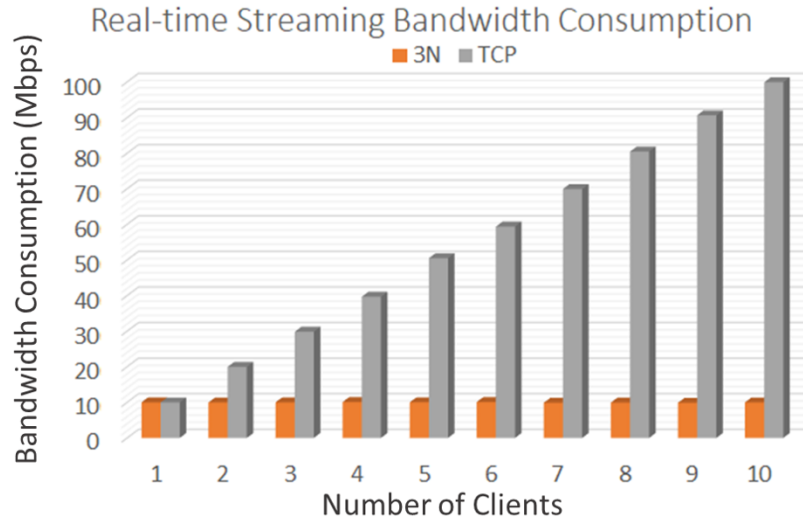


Figure 5-12 Network bandwidth consumption compare

5.4 Summary

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

Chapter 6

Conclusion

In this thesis, I proposed and developed a new type of ICN-based information sharing system using a URI-based hierarchical format. This system focuses on the content-oriented information sharing mechanism and takes it further into the surveillance system. The first system applies distributed content-oriented surveillance information sharing in a modern IoT-based surveillance network. The system also uses machine learning to extract useful content from the captured image. In this chapter, several experiments were performed to verify the system performance and accuracy.

To improve the information sharing system with area coverage and routing optimization, I proposed an NNR-based LPWA disaster network. The LPWA network provides large area coverage but with low available bandwidth. The NNR routing mechanism optimizes the network, and advanced machine learning continues to help extract useful information from the cameras. The field experiment results validate that the NNR shows an improved performance regarding the overall network bandwidth usage and content delivery efficiency. This indicates to be very valuable in disaster

areas where mainstream networks are down; by using the LPWAN+NNR-based self-optimized network, an emergency network can be implemented.

In the final section, I took the latest 3N system and created a real-time video streaming system as the latest ICN technology. The system applies a real-time streaming function in the Content-Oriented Network architecture. The evaluation results demonstrate that the 3N video stream system has an advantage in multiclient streaming scenarios when compared to the TCP/IP video stream. However, practical solutions require practical experiences.

The three proposed ICN-supported technologies provided new information sharing solutions in the surveillance and IoT field. These technologies prove to have advantages in propagation and processing contents during an emergency scenario.

Bibliography

- [1] A NOVEL ICN & DRONE BASED EMERGENCY INFORMATION SYSTEM FOR DISASTER AREA, ZHENG WEN, DI ZHANG, XIN QI, KEPING YU, TAKURO SATO, ICTSSL, IEICE TECHNICAL REPORT : 116(422), 47-52, 2017-01-26
- [2] XIN QI, ZHENG WEN, ET AL. "CONTENT ORIENTED SURVEILLANCE SYSTEM BASED ON INFORMATION-CENTRIC NETWORK," GLOBECOM WORKSHOPS (GC WKSHPs), 2016 IEEE
- [3] XIN, QI, ZHENG WEN, JAIRO LÓPEZ, KEPING YU, TAKURO SATO, ET AL. "NAMED-NODE NETWORKING (3N) IMPLEMENTATION APPROACH." IEICE 9TH ICN WORKSHOP, 2016
- [4] D. NOZAKI, K. OKAMOTO, T. MOCHIDA, X. QI, Z. WEN, S.H. MYINT, K. TOKUDA, T. SATO, K. TAMESUE, "AI MANAGEMENT SYSTEM TO PREVENT ACCIDENTS IN CONSTRUCTION ZONES USING 4K CAMERAS BASED ON 5G NETWORK," WIRELESS PERSONAL MULTIMEDIA COMMUNICATIONS 2018, CHIANG RAI, THAILAND, 2018
- [5] WEN, ZHENG, ET AL. "INFORMATION CENTRIC NETWORKING FOR DISASTER INFORMATION SHARING SERVICES." IEICE TRANSACTIONS ON FUNDAMENTALS OF ELECTRONICS, COMMUNICATIONS AND COMPUTER SCIENCES 98.8 (2015): 1610-1617.
- [6] WEN, ZHENG, ET AL. "NODE NAME ROUTING IN INFORMATION-CENTRIC AD-HOC NETWORK." IEICE TRANSACTIONS ON FUNDAMENTALS OF ELECTRONICS, COMMUNICATIONS AND COMPUTER SCIENCES 100.2 (2017): 680-687.
- [7] WEN, ZHENG, AND TAKURO SATO. "AN ARTIFICIAL NEURAL NETWORK-BASED DISTRIBUTED INFORMATION-CENTRIC NETWORK SERVICE." WIRELESS PERSONAL MULTIMEDIA COMMUNICATIONS (WPMC), 2017 20TH INTERNATIONAL SYMPOSIUM ON. IEEE, 2017.
- [8] K. YU, M. ARIFUZZAMAN, Z. WEN, D. ZHANG AND T. SATO, "A KEY MANAGEMENT SCHEME FOR SECURE COMMUNICATIONS OF INFORMATION CENTRIC ADVANCED METERING INFRASTRUCTURE IN SMART GRID," IN IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASUREMENT, VOL. 64, NO. 8, PP. 2072-2085, AUG. 2015.
- [9] J.E. LÓPEZ, A. M, L. ZHU, Z. WEN, AND S. TAKURO, "SEAMLESS MOBILITY IN DATA AWARE NETWORKING," ITU KALEIDOSCOPE CONFERENCE, PP.1-7, 2015.
- [10] NA YU, ARIFUZZAMAN MOHAMMAD, KEPING YU, TAKURO SATO, STUDY ON CCN BASED DISASTER SYSTEM, IEICE TECHNICAL REPORT, 2013

- [11] K. SHIBATA, "ICN AUTONOMOUS DISTRIBUTED COMMUNICATION FOR IoT DEVICES AND ITS EXPERIMENTAL SYSTEM FOR TSUNAMI DISASTER PREVENTION," 2018 IEICE SOCIETY CONFERENCE, TOKYO, 2018, BT-2-4
- [12] V. JACOBSON, D. K. SMETTERS, J. D. THORNTON, M.F. PLASS, N. H. BRIGGS, AND R. L. BRAYNARD, NETWORKING NAMED CONTENT. IN PROCEEDINGS OF ACM CoNEXT, 2009.
- [13] S. ARSHAD, M. A. AZAM, S. H. AHMED, AND J. LOO, "TOWARDS INFORMATION-CENTRIC NETWORKING (ICN) NAMING FOR INTERNET OF THINGS (IoT): THE CASE OF SMART CAMPUS," PROC. OF THE INTERNATIONAL CONFERENCE ON FUTURE NETWORKS AND DISTRIBUTED SYSTEMS, 6 PAGES, 2017, DOI:HTTP://DOI.ORG/10.1145/3102304.3102345
- [14] JAPAN METEOROLOGICAL AGENCY, EARTHQUAKE EARLY WARNING, 1 APRIL 2009, FROM HTTP://WWW.JMA.GO.JP/JMA/EN/ACTIVITIES/EEWLEAFLET.PDF
- [15] YAHOO JAPAN CORPORATION, DISASTER ALERT APPLICATION, FROM HTTP://EMG.YAHOO.CO.JP/
- [16] NTT DOCOMO DISASTER MESSAGE BOARD, HTTP://WWW.NTTDOCOMO.CO.JP/ENGLISH/
- [17] GOOGLE PERSON FINDER, FROM HTTPS://GOOGLE.ORG/PERSONFINDER/GLOBAL/HOME.HTML
- [18] JAPAN METEOROLOGICAL AGENCY EARTHQUAKE DATA (2001 TO 2010), FROM HTTP://WWW.JMA.GO.JP/JMA/KISHOU/KNOW/FAQ/FAQ7.HTML
- [19] NATIONAL POLICE AGENCY OF JAPAN, DAMAGE SITUATION AND POLICE COUNTERMEASURES ASSOCIATED WITH 2011 TOHOKU DISTRICT - OFF THE PACIFIC OCEAN EARTHQUAKE, JUNE 10, 2015
- [20] CURRION, P., SILVA, C. AND VAN DE WALLE, B.: OPEN SOURCE SOFTWARE FOR DISASTER MANAGEMENT, COMM. OF THE ACM, VOL. 50, ISSUE 3, PP.61-65 2007
- [21] H. CHENJI, W. ZHANG, R. STOLERU, AND C. ARNETT, "DISTRESSNET: A DISASTER RESPONSE SYSTEM PROVIDING CONSTANT AVAILABILITY CLOUD-LIKE SERVICES," AD HOC NETWORKS, VOL.11, NO.8, PP.2440–2460, NOV. 2013.
- [22] J.S. HUANG, Y.S. WANG, AND Y.N. LIEN, "DEPLOYMENT SCHEDULING OF CONTINGENCY CELLULAR NETWORK FOR DISASTER RELIEF OPERATIONS," NETWORK OPERATIONS AND MANAGEMENT SYMPOSIUM (APNOMS), 2013 15TH ASIA-PACIFIC, PP.1–6, SEPT. 2013.
- [23] T. SUZUKI, Y. SHIBATA, K. TAKAHATA, AND N. UCHIDA, "DIRECTIONAL ANTENNA CONTROL BASED MOBILE ADHOC NETWORK FOR DISASTER INFORMATION SYSTEM," WAINA, PP.231–236, MARCH 2013.

- [24] Y. SHIBATA, Y. SATO, N. OGASAWARA, AND G. CHIBA, "A DISASTER INFORMATION SYSTEM BY BALLOONED WIRELESS ADHOC NETWORK," COMPLEX, INTELLIGENT AND SOFTWARE INTENSIVE SYSTEMS, INTERNATIONAL CONFERENCE ON, PP.299–304, MARCH 2009.
- [25] W. JIANXIU, G. XUEYING, AND H. TIANRONG, "USING BAYESIAN NETWORKS IN ANALYZING POWERFUL EARTHQUAKE DISASTER CHAINS," NAT. HAZARDS, VOL.68, NO.2, PP.509–527, SEPT. 2013.
- [26] R.G.L. NARAYANANA AND O.C. IBEB, "A JOINT NETWORK FOR DISASTER RECOVERY AND SEARCH AND RESCUE OPERATIONS," COMPUTER NETWORKS, VOL.56, NO.14, P.3347–C3373, SEPT. 2012.
- [27] W. JIANXIU, G. XUEYING, AND H. TIANRONG, "USING BAYESIAN NETWORKS IN ANALYZING POWERFUL EARTHQUAKE DISASTER CHAINS," NAT. HAZARDS, VOL.68, NO.2, PP.509–527, SEPT. 2013.
- [28] R.G.L. NARAYANANA AND O.C. IBEB, "A JOINT NETWORK FOR DISASTER RECOVERY AND SEARCH AND RESCUE OPERATIONS," COMPUTER NETWORKS, VOL.56, NO.14, P.3347–C3373, SEPT. 2012.
- [29] T. SUZUKI, Y. SHIBATA, K. TAKAHATA, AND N. UCHIDA, "DIRECTIONAL ANTENNA CONTROL BASED MOBILE ADHOC NETWORK FOR DISASTER INFORMATION SYSTEM," WAINA, PP.231–236, MARCH 2013.
- [30] E. MONTICELLI, B. M. SCHUBERT, M. ARUMAITHURAI, X. FU AND K. K. RAMAKRISHNAN, "AN INFORMATION CENTRIC APPROACH FOR COMMUNICATIONS IN DISASTER SITUATIONS," IEEE LOCAL & METROPOLITAN AREA NETWORKS, USA, MAY 2014.
- [31] J. CHEN, M. ARUMAITHURAI, X. FU, AND K. K. RAMAKRISHNAN, "CNS: CONTENT-ORIENTED NOTIFICATION SERVICE FOR MANAGING DISASTERS," PROC. OF THE 3RD ACM CONFERENCE ON INFORMATION-CENTRIC NETWORKING (ACM-ICN '16), PP. 122-131, 2016. DOI: [HTTPS://DOI.ORG/10.1145/2984356.2984368](https://doi.org/10.1145/2984356.2984368)
- [32] T. YAGYU, K. NAKAMURA, T. ASAMI, K. SUGIYAMA, A. TAGAMI, T. HASEGAWA, AND M. ARUMAITHURAI, "DEMO: CONTENT-BASED PUSH/PULL MESSAGE DISSEMINATION FOR DISASTER MESSAGE BOARD," PROC. OF THE 2ND ACM CONFERENCE ON INFORMATION-CENTRIC NETWORKING, PP. 205-206, 2015. DOI: [HTTPS://DOI.ORG/10.1145/2810156.2812609](https://doi.org/10.1145/2810156.2812609)
- [33] A. HANNAN, S. ARSHAD, M. A. AZAM, J. LOO, S. H. AHMED, M. F. MAJEED, AND S. C. SHAH, "DISASTER MANAGEMENT SYSTEM AIDED BY NAMED DATA NETWORK OF THINGS: ARCHITECTURE, DESIGN, AND ANALYSIS," SENSORS (BASEL, SWITZERLAND), VOL. 18, NO. 8, 20 PAGES, 2018. DOI: [HTTP://DOI.ORG/10.3390/s18082431](http://doi.org/10.3390/s18082431)

- [34] MINISTRY OF INTERNAL AFFAIRS AND COMMUNICATIONS, WHITE PAPER INFORMATION AND COMMUNICATIONS IN JAPAN, CHAPTER 3 LESSONS OF THE GREAT EARTHQUAKE AND THE ROLE OF ICT, 2012, FROM [HTTP://WWW.SOUMU.GO.JP/JOHOTSUSINTOKEI/WHITEPAPER/ENG/WP2012/CHAPTER-3.PDF](http://www.soumu.go.jp/johotsusintokei/whitepaper/eng/wp2012/chapter-3.pdf)
- [35] OPEN STREET MAP, FROM [HTTP://WWW.OPENSTREETMAP.ORG/](http://www.openstreetmap.org/)
- [36] GOOGLE MAPS API, FROM [HTTPS://DEVELOPERS.GOOGLE.COM/MAPS/DOCUMENTATION/](https://developers.google.com/maps/documentation/)
- [37] MAP DATA AND LOCATION PROVIDER: MICROSOFT BING, ZENRIN.
- [38] HAKLAY, MORDECHAI, AND PATRICK WEBER. "OPENSTREETMAP: USER-GENERATED STREET MAPS." IEEE PERVAS COMPUT 7.4 (2008): 12-18.
- [39] PROJECT CCNx™, FROM [HTTP://WWW.CCNX.ORG/](http://www.ccnx.org/)
- [40] A. AFANASYEV, I. MOISEENKO, AND L. ZHANG, NDN-SIM: NDN SIMULATOR FOR NS-3, NDN, TECHNICAL REPORT NDN-0005, 2012
- [41] L. ZHANG, ET AL. NAMED DATA NETWORKING (NDN) PROJECT. TECHNICAL REPORT NDN-001, PARC, OCTOBER 2010.
- [42] J.H. SALTZER, "ON THE NAMING AND BINDING OF NETWORK DESTINATIONS," RFC 1498, AUG. 1993.
- [43] INTEL, "INTEL COMPUTE STICK." . AVAILABLE: [HTTP://WWW.INTEL.COM/CONTENT/WWW/US/EN/COMPUTE-STICK/INTEL-COMPUTE-STICK.HTML](http://www.intel.com/content/www/us/en/compute-stick/intel-compute-stick.html)
- [44] LPWA COMMUNICATION MODULE, MODULE IM920 BY INTERPLAN. . AVAILABLE: [HTTP://WWW.INTERPLAN.CO.JP/SOLUTION/WIRELESS/IM920.PHP](http://www.interplan.co.jp/solution/wireless/im920.php)
- [45] X. XIONG, K. ZHEGNG, R. XU, W. XIANG, AND P. CHATZIMISIOS, "LOW POWER WIDE AREA MACHINE-TO-MACHINE NETWORKS: KEY TECHNIQUES AND PROTOTYPE," IEEE COMMUNICATIONS MAGAZINE, VOL. 53, PP. 64-71, 2015.
- [46] PANASONIC, "PANASONIC I-PRO SMARTHD WV-SPV781LJ." . AVAILABLE: [HTTPS://SOL.PANASONIC.BIZ/SECURITY/CAMERA/IPRO_HD/SFV781_SPV781/](https://sol.panasonic.biz/security/camera/ipro_hd/sfv781_spv781/)
- [47] K. E. NOLAN, W. GUIBENE, AND M. Y. KELLY, "AN EVALUATION OF LOW POWER WIDE AREA NETWORK TECHNOLOGIES FOR THE INTERNET OF THINGS," IN 2016 INTERNATIONAL WIRELESS COMMUNICATIONS AND MOBILE COMPUTING
- [48] JOHNSON, DAVID B., DAVID A. MALTZ, AND JOSH BROCH. "DSR: THE DYNAMIC SOURCE ROUTING PROTOCOL FOR MULTI-HOP WIRELESS AD HOC NETWORKS." AD HOC NETWORKING 5 (2001): 139-172.
- [49] CLAUSEN, THOMAS, AND PHILIPPE JACQUET. OPTIMIZED LINK STATE ROUTING PROTOCOL (OLSR). No. RFC 3626. 2003.

- [50] M. ABADI, A. AGARWAL ET AL., "TENSORFLOW: LARGE-SCALE MACHINE LEARNING ON HETEROGENEOUS DISTRIBUTED SYSTEMS," ARXIV:1603.04467, 2016.
- [51] LI, MU, ET AL. "SCALING DISTRIBUTED MACHINE LEARNING WITH THE PARAMETER SERVER." OSDI. VOL. 1. No. 10.4. 2014.
- [52] STAUFFER, C., GRIMSON, WEL. (2000). LEARNING PATTERNS OF ACTIVITY USING REAL-TIME TRACKING. IEEE TRANSACTIONS ON PATTERN ANALYSIS AND MACHINE INTELLIGENCE, VOLUME: 22 ISSUE: 8 PAGES: 747-757. DOI: 10.1109/34.868677.
- [53] JOSHI, ARAVIND K. "NATURAL LANGUAGE PROCESSING." SCIENCE 253.5025 (1991): 1242-1249.
- [54] MAAS, C., SCHMALZL, J. (2013). USING PATTERN RECOGNITION TO AUTOMATICALLY LOCALIZE REFLECTION HYPERBOLAS IN DATA FROM GROUND PENETRATING RADAR. COMPUTERS & GEOSCIENCES, VOLUME: 58 PAGES: 116-125. DOI: 10.1016/J.CAGEO.2013.04.012.
- [55] KRIZHEVSKY, A. ONE WEIRD TRICK FOR PARALLELIZING CONVOLUTIONAL NEURAL NETWORKS. CoRR, ABS/1404.5997, 2014.
- [56] COWIE, J.H., D.M. NICOL, AND A.T. OGIELSKI, MODELING THE GLOBAL INTERNET. COMPUTING IN SCIENCE AND ENGG, 1999.
- [57] P. JACQUET AND L. VIENNOT, "OVERHEAD IN MOBILE AD-HOC NETWORK PROTOCOLS," 2000.
- [58] AN, L., CHEN, XJ., YANG, S., BHANU, B. (2016). SPARSE REPRESENTATION MATCHING FOR PERSON RE-IDENTIFICATION. INFORMATION SCIENCES, VOLUME: 355 PAGES: 74-89. DOI: 10.1016/J.INS.2016.02.055.
- [59] RATHORE, MM., AHMAD, A., PAUL, A., RHO, S. URBAN PLANNING AND BUILDING SMART CITIES BASED ON THE INTERNET OF THINGS USING BIG DATA ANALYTICS, COMPUTER NETWORKS, VOLUME: 101 PAGES: 63-80. DOI: 10.1016/J.COMNET.2015.12.023.
- [60] DROMS, RALPH. DYNAMIC HOST CONFIGURATION PROTOCOL. No. RFC 2131. 1997.
- [61] BERNERS-LEE, TIM, LARRY MASINTER, AND MARK McCAHILL. UNIFORM RESOURCE LOCATORS (URL). No. RFC 1738. 1994.
- [62] GARCIA-LUNA-ACEVES, J.J. ROUTING TO MULTI-INSTANTIATED DESTINATIONS: PRINCIPLES AND APPLICATIONS, 2014 IEEE 22ND INTERNATIONAL CONFERENCE ON NETWORK PROTOCOLS (ICNP), OCTOBER, 2014

- [63] MARC MOSKO, IGNACIO SOLIS, ERSIN UZUN, CCN 1.0 PROTOCOL ARCHITECTURE, PALO ALTO RESEARCH CENTER, 2014, FROM [HTTP://CCNX.ORG/PUBS/ICN_CCN_PROTOCOLS.PDF](http://ccnx.org/pubs/ICN_CCN_PROTOCOLS.PDF)
- [64] FANG, CHAO, ET AL. "A SURVEY OF ENERGY-EFFICIENT CACHING IN INFORMATION-CENTRIC NETWORKING." IEEE COMMUNICATIONS MAGAZINE 52.11 (2014): 122-129.
- [65] WANG, SEN, ET AL. "COULD IN-NETWORK CACHING BENEFIT INFORMATION-CENTRIC NETWORKING?." PROCEEDINGS OF THE 7TH ASIAN INTERNET ENGINEERING CONFERENCE. ACM, 2011.
- [66] DEAN, J., CORRADO, G., MONGA, R., CHEN, K., DEVIN, M., MAO, M., RANZATO, M., SENIOR, A., TUCKER, P., YANG, K., LE, Q. V., AND NG, A. Y. LARGE SCALE DISTRIBUTED DEEP NETWORKS. IN NIPS, PP. 1232–1240, 2012
- [67] T. KITAGAWAY, S. ATAYY, AND M. MURATAY, "RETRIEVING INFORMATION WITH AUTONOMOUSLY MOVING ROUTER IN INFORMATION-CENTRIC NETWORK GUIDE TO THE TECHNICAL REPORT AND TEMPLATE," IEICE TECHNICAL COMMITTEE ON ICN, TOKYO, JP, MAY 2015.
- [68] M. AMADEO, A. MOLINARO, AND G. RUGGERI, "E-CHANET: ROUTING, FORWARDING AND TRANSPORT IN INFORMATION-CENTRIC MULTIHOP WIRELESS NETWORKS," COMPUT. COMMUN., VOL.36, NO.7, PP.792–803, 2013.
- [69] MADDALENA, LUCIA, PETROSINO, ALFREDO. (2008). A SELF-ORGANIZING APPROACH TO BACKGROUND SUBTRACTION FOR VISUAL SURVEILLANCE APPLICATIONS. IEEE TRANSACTIONS ON IMAGE PROCESSING, VOLUME: 17 ISSUE: 7 PAGES: 1168-1177. DOI: 10.1109/TIP.2008.924285.
- [70] S. VRIJERS, V. MAFFIONE, D. STAESSENS, F. SALVESTRINI, M. BIANCANI, E. GRASA, D. COLLE, M. PICKAVET, J. BARRON, J. DAY, L. CHITKUSHEV 'REDUCING THE COMPLEXITY OF VIRTUAL MACHINE NETWORKING'. IEEE COMMUNICATIONS MAGAZINE, VOL. 54. NO 4, PP 152-158, APRIL 2016. AVAILABLE ONLINE.
- [71] S. VRIJERS, D. STAESSENS, D. COLLE, F. SALVESTRINI, E. GRASA, M. TARZAN AND L. BERGESIO "PROTOTYPING THE RECURSIVE INTERNETWORK ARCHITECTURE: THE IRATI PROJECT APPROACH", IEEE NETWORK, VOL. 28, NO. 2, MARCH 2014. AVAILABLE ONLINE.
- [72] J. DAY, L. CHITKUSHEV, E. GRASA, F. SALVESTRINI, D. STAESSENS. "ALTERNATIVES TO TCP/IP", RINA TUTORIAL AT IEEE GLOBECOM 2014, AUSTIN, TEXAS.
- [73] E. GRASA, L. BERGESIO, M. TARZAN, E. TROUVA, B. GASTON, F. SALVESTRINI, V. MAFFIONE, G. CARROZZO, D. STAESSENS, S. VRIJERS, D. COLLE, A. CHAPPELL, J. DAY, L. T. CHITKUSHEV. " RINA: INVESTIGATING

RINA AS AN ALTERNATIVE TO TCP/IP”. “BUILDING THE FUTURE INTERNET THROUGH FIRE”, CHAPTER 16, PAGES 492- 519. RIVERS PUBLISHERS. AVAILABLE ONLINE.

List of Research Achievements

Journal Papers

- [1] CONTENT-ORIENTED DISASTER NETWORK UTILIZING NAMED NODE ROUTING AND FIELD EXPERIMENT EVALUATION, XIN QI, ZHENG WEN, KEPING YU, KAZUNORI MURATA, KOUICHI SHIBATA, TAKURO SATO, IEICE TRANSACTIONS ON INFORMATION AND SYSTEMS, VOL. E102.D, PP. 988-997, 05 2019.
- [2] 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, XIN QI, YUWEI SU, KEPING YU, JINGSONG LI, QIAOZHI HUA, ZHENG WEN, JAIRO LOPEZ, TAKURO SATO, IEEE ACCESS, IN PRESS.

International Conference Papers

- [1] CONTENT ORIENTED SURVEILLANCE SYSTEM BASED ON INFORMATION-CENTRIC NETWORK, XIN QI, ZHENG WEN, TOSHITAKA TSUDA, WATARU KAMEYAMA, JIRO KATTO, TAKURO SATO, KOUICHI SHIBATA, 2016 IEEE GLOBECOM WORKSHOPS (GC WKSHPs), DEC 2016, PP. 1-6.
- [2] CONTENT-ORIENTED SURVEILLANCE SYSTEM BASED ON NODE NAME ROUTING, XIN QI, ZHENG WEN, TAKURO SATO, 2018 THE 37TH JSST ANNUAL INTERNATIONAL CONFERENCE ON SIMULATION TECHNOLOGY (JSST), MURORAN, JAPAN.
- [3] NAMING SCHEME USING NLP MACHINE LEARNING METHOD FOR NETWORK WEATHER MONITORING SYSTEM BASED ON ICN, TORU MOCHIDA, D. NOZAKI, K. OKAMOTO, XIN QI, Z. WEN, TAKURO SATO, 2017 20TH INTERNATIONAL SYMPOSIUM ON WIRELESS PERSONAL MULTIMEDIA COMMUNICATIONS (WPMC), DEC 2017, PP. 428-434.
- [4] CONTENT-ORIENTED SURVEILLANCE SYSTEM BASED ON ICN IN DISASTER SCENARIOS, KOKI OKAMOTO, T. MOCHIDA, D. NOZAKI, Z. WEN, XIN QI, TAKURO SATO, 2018 21TH INTERNATIONAL SYMPOSIUM ON WIRELESS PERSONAL MULTIMEDIA COMMUNICATIONS (WPMC), NOV 2018, PP. 484-489.

- [5] AI MANAGEMENT SYSTEM TO PREVENT ACCIDENTS IN CONSTRUCTION ZONES USING 4K CAMERAS BASED ON 5G NETWORK, D. NOZAKI, K. OKAMOTO, T. MOCHIDA, XIN QI, Z. WEN, SAN HLAING MYINT, K. TOKUDA, TAKURO SATO, K. TAMESUE, 2018 21TH INTERNATIONAL SYMPOSIUM ON WIRELESS PERSONAL MULTIMEDIA COMMUNICATIONS (WPMC), Nov 2018, pp. 462-466.

Domestic Conference Papers

- [1] 3N-SIMULATOR PACKAGE TRANSMISSION ON PHYSICAL NETWORK, XIN QI, LU ZHANG, ZHENG WEN, TAKURO SATO, PROCEEDINGS OF THE IEICE GENERAL CONFERENCE 2016 年, 121, 2016-03-01.
- [2] EXPERIENTIAL RESULTS OF NAMED NODE NETWORKING (3N) IN VNODE ON NETWORK VIRTUALIZATION」, XIN QI, ZHENG WEN, WATARU KAMEYAMA, JIRO KATTO, TAKURO SATO, YUKI MINAMI, KAZUHISA YAMADA, IEICE 18TH NV WORKSHOP, 2016.4.
- [3] NAMED-NODE NETWORK (3N) BASED DISASTER APPLICATION DEMONSTRATION, XIN QI, ZHENG WEN, J. LÓPEZ, Y. DU, D. NOZAKI, K. OKAMOTO, T. MOCHIDA, K. YU, TAKURO SATO IEICE 9TH ICN WORKSHOP, KOGANEI, JAPAN, 2017.8.24.
- [4] NAMED-NODE NETWORKING (3N) IMPLEMENTATION APPROACH, XIN QI, ZHENG WEN, JAIRO LÓPEZ, KEPING YU, TAKURO SATO, IEICE 9TH ICN WORKSHOP, KOGANEI, JAPAN, 2017.8.24.
- [5] THE DESIGN AND IMPLEMENTATION OF NAMED NODE NETWORK, XIN QI, ZHENG WEN, J. LÓPEZ, Y. DU, D. NOZAKI, K. OKAMOTO, T. MOCHIDA, K. YU, TAKURO SATO, IEICE SOCIAL CONFERENCE TUTORIAL SESSION, 2017.9.
- [6] ビッグデータ自律分散処理システムへの ICN の活用例, 柴田巧一, XIN QI, ZHENG WEN, 佐藤拓朗, 電子情報通信学会総合大会 2017
- [7] A NOVEL ICN & DRONE BASED EMERGENCY INFORMATION SYSTEM FOR DISASTER AREA, ZHENG WEN, DI ZHANG, XIN QI, KEPING YU, TAKURO SATO, IEICE ICTSSL, IEICE TECHNICAL REPORT: 116(422), 47-52, 2017-01-26.