Realization of Mobility-controlled Flying Router in Information Centric Network

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***Abstract*—Recently, Information-Centric Networking (ICN), is attracting attention as a network capable of flexible communication especially in IoT mobility environments. As a research on flexible controls in ICN, we have been involved in a movable router using Unmanned Aerial Vehicles (UAVs) or drones (called Flying Routers (FRs)) to realize communication in disjoint networks. In previous studies, control of Flying Routers was targeted reactively where FRs move according to the events on receiving Interest or Data. However, in order to realize a collaborative movement strategy such as content retrieval in consideration of cooperation by multiple FRs, more strategic ways which directly control FRs according to decision of path optimization. For this purpose, in this paper, we design a communication control system which strategically controls FRs by sending explicit Interests. We incorporates ICN technologies in the design of the system: naming scheme and strategy layer, which enable flexible control over FRs. Furthermore, we present a Proof-of-Concept (PoC) implementation of the system to confirm the feasibility of the design.**

I. Introduction

Information Centric Networking (ICN) is being considered as a new network paradigm where data exchanges are not conducted location basis (e.g., IP addresses) but content basis. ICN has a great potential to realize a flexible and programmable framework to construct an in-network service. Combination of name-based process discovery and in-network processing provides a strong capability and flexibility especially in IoT (Internet of Things) and/or M2M (Machine-to-Machine) environments, where small devices are collaboratively working.

In recent years, IoT devices such as sensors and cameras have come to be used in various fields such as agriculture, environmental measurement and so on. In such field, the cost of deployment of wireless networks which covers huge area relays the communication with IoT equipments is extremely high. Movable devices such as message ferry, base station vehicle in are considered to resolve such a problem. An autonomous movable router in this paper is a router that is installed in a moving object such as a car or a ship for forwarding packets. The router controls actual movements of the object by itself based on the information such as position of the node and the movement strategy. In communication for retrieving content using mobile routers, communication can be realized if there has information capable of specifying the node possessing requested content (e.g., name or position of the node). The IP address including the topology information of the network is not indispensable for retrieving contents. Therefore, TCP/IP has a big overhead in the communication.

ICN can greatly deal with communications seamlessly achieved by physical movement of routers, because the control of movement can be considered as a kind of in-network processing in ICN. ICN with moving routers extends not only the coverage area of communication, but also provides a new communication framework. Previously we propose an architecture called RMICN (Router Movable Information Centric Network) to address above-mentioned background [1]. In RMICN, Flying Routers (FRs) are introduced which supports physical movement of ICN router embedded on UAV (Unmanned Aerial Vehicle) for delivering messages between disjoint networks where partial networks are placed disjointly (not connected directly each other). RMICN is considered to support collaborative movement of multiple Flying Routers and provide a path planning method based on the demand of Interest/Data exchanges.

However, since RMICN is conceptually proposed, design and implementation of Flying Routers are still challenging. Especially, collaborative movement of multiple Flying Routers according to strategic path planning may require an explicit control of Flying Routers based on a movement plan. For unified communication in both control and data processing, these control sequences should be realized in the principle of ICN. We therefore propose an architectural design of Flying Routers which supports physical movements by invoking APIs (Application Programming Interfaces), which are directly associated with named functions in ICN (i.e., controlling FRs by sending Interests).

Namely the contribution of this paper is following,

- We design a set of APIs (in other words naming scheme in ICN) to support direct control of Flying Routers which are necessary to realize RMICN.
- We design a system architecture of Flying Router to handle above APIs as a kind of in-network processing on ICN router.

Specifically, we provide APIs sufficient to realize RMICN, i.e., path planning strategies are achieved by calling APIs we implemented. As an implementation of ICN, it is necessary to implement NDN (Named Data Networking), extending NFD (NDN Forwarding Daemon) which is packet forwarder of NDN. We consider such kind of implementation would also a good practice toward ICN in real-world. Through experimental evaluations we confirm the operation of RMICN can be realized by proposed Flying Routers with APIs, and discuss lessons learned.

This paper is organized as follows, in the next section we introduce related works. We then describe the proposed API set to support RMICN, and a design of Flying Router in real environment in Section III. Next, we describe the experimental scenario to verify the system in Section IV. Finally in Section V we summarize this paper.

II. Related Work

A. Delay Tolerant Networking (DTN)

An existing TCP/IP based network that can realize communications between disjointed networks using mobile routers is Delay Tolerant Networking (DTN) [2]. DTN is considered as an unstable network topology, long latency, where end-to-end path may not exist and delay may be measured in days for some networks.

As use cases of DTN, agricultural sensor network and disaster network can be cited as examples. As an example of the scenario, there are scenarios using sensors and actuators such as agricultural monitoring for frost detection, irrigation system [3]. In the disaster network, there are scenarios such as distribution of evacuation instructions and risk management [4]. The common problem of these applications is realization of low delay communication in a large scale network.

The network of agriculture and disaster area is characterized by a wide area, poor communication infrastructure and disjointed networks. In DTN, the methods of communication using mobile routers can be classified into two types: Message Ferry [5] and Data Mule [6]. In Message Ferry method, movement of most mobile routers is controlled for messaging reason. In [5], literature defined sum of movable router's travel time to the sensor node and waiting time for communication as delay. The delay is regarded as the path length in the Traveling Salesman Problem (TSP) [7], and the literature proposed a path planning method that achieves the shortest delay by solving TSP. However, the method does not consider the case of multiple mobile routers, and it deals with the case of only one mobile router. Furthermore, the trajectory of mobile router is always the same, and trajectory changes are not considered for efficient communication.

As for Data Mule method [6], most mobile routers are moving for purposes other than Messaging. Examples of movable routers include cows, buses and humans equipped with IoT device. The movement of movable router is random, and data collected by movable router is stochastically transferred to base station. There may need large amount of energy to keep router moving. As the battery of movable router using UAV is limited, it is necessary to make the movement of the router more intelligence. Moreover, communication efficiency is considered to be better the when the amount of mobile nodes and base stations increases. However, increasing the amount of mobile nodes and base station will have a big cost. Therefore, compared with the agricultural field and the disaster area with few mobile nodes, cities with many mobile nodes are more suitable for the Data Mule system.

In this research, in order to realize low delay communication in a large scale network, we propose a path planning method using multiple mobile routers, which dynamically changes moving path in content basis as an extension of Message Ferry.

B. Information Centric Networking (ICN)

Information Centric Networking (ICN) [8] is a network that can realize efficient communication in a disjointed network. Compared with DTN, ICN has the advantage that IP address which is topology information is not essential in communication, overhead of communication can be reduced by realizing content-based routing. As a result, it is easier to implement a strategy that considers content characteristics such as content urgency. In addition, ICN has a content caching function as standard equipment, it does not need to be implemented. Furthermore, the ICN can seamlessly implement the processing of the network layer from the application layer in ICN layer, thereby reducing processing overhead.

In ICN, disjointed network communication using multiple mobile routers is rarely considered. Regarding research on control with name, VoCCN (Voice over CCN) [9] is an instance of the control of end devices. VoCCN delivers voice calls similar to VoIP over CCN, and signaling is carried out when establishing a voice call using the name. VoIP normally carries out communication involving signaling data and voice data on separate paths, but VoCCN can make these distinctions based on name, and hence can limit the number of used paths to one.

Moreover, applicable control in IoT environments has also been studied in recent years [10]. Since the IoT features many end devices connected to a network, content-oriented communication protocols, like NDN, can be said to be more suitable than location-oriented ones, such as IP. Reference considered the application of NDN to the IoT environment and describes the physical control of the end device as part of this. As an example of physical control of the end device, the control of lighting in a smart home was cited.

In this paper, in order to show a method of realizing communication using mobile routers with ICN, we design a system that can apply various strategies for the communication and we discuss its implementation.

III. System Design

A. Application

Examples of application in RMICN are collection and distribution of information in agricultural sensor network and disaster network. In the agricultural sensor network, one agriculture field has multiple sensors, one gateway that collects information generated by the sensor and multiple mobile routers collecting sensor data from gateway. Mobility of mobile routers is controlled for communication reason. The battery of the mobile router is finite, and in order to save energy, the behavior management of the mobile router is performed by the central network coordinator. As an example of specific communication, an irrigation system can be considered. In the irrigation system, sensors measure the moisture of the soil and a sprinkler water to several fields. Sprinkler waters only on the part where the moisture is insufficient based on sensor data.

In the disaster area network, instead of a broken network infrastructure, multiple mobile routers provide instructions produced by municipalities to residents. At the same time, the router provides municipalities with safety information of residents and environmental information. In order to realize efficient communication, a gateway that can aggregate and caching contents is installed near to the residents. Behavior management of mobile routers is done by the central network coordinator. As an example of specific communication, risk management immediately after the earthquake can be considered. In that communication, residents provide information about food, injured people and environment. The municipality provides evacuation instructions for residents.

B. *Network Topology and Operation*

We show the overview of FR-based communication system (RMICN) in Figure 1. There are four types of nodes: Depot Router (DR), FR, GateWay (GW) and other nodes such as sensors, actuators, or other types of devices within the communicable range of GW. DR and GW are not directly interconnected, but FR realizes communication between nodes by physically delivering messages within its storage.

DR is a node that centrally manages the movement and communication of multiple FRs and calculates the traveling path of FR. FR is also a relay node that carries packets between DR and GW. GW collects packets from other nodes within its coverage area and communicates directly with FR. Other nodes within the communicable range of the GW does not directly communicate with FR, but it periodically transfers NDN packets to GW.

All nodes are in the RMICN communication range, which is defined in prior, and FR crawls within the RMICN communication range. In the initial state of the system, DR holds positions and node names of each node in the RMICN communication area, and does not hold the name of the content generated by each node. By visiting each node, FR announces the name of the content generated by each GW to all the nodes in the network, at the same time, retrieves and distributes the content request and the content. All moving paths are initiated at DR.

Regarding the communication control of FR provided by the system, Table I summarizes the name, operation outline, and input/output of APIs. In this paper, APIs are designed and invoked by Interest packets of ICN, i.e., name of APIs follow

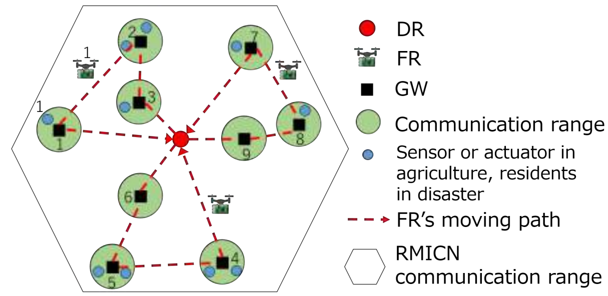

Fig. 1. Overview of FR-based Communication System

the naming scheme of ICN. To invoke an API, the name of API is specified in the Interest packet, and node that receives the packet calls the function of the strategy to execute the operation of the API.

TABLE I
LIST OF DESIGNED APIS

API Name	/Neighbor/{NodeName}/RetrieveRoutes
Role	Construct routing table in FR and node in connection with FR
Input	Name of the connected node
Output	Interest and Data packet from the opposite node
API Name	/RMICN/{PacketName}/{ConsumerName} /{ContentName}*/{SystemTime}
Role	API Name is the name of packet with sensor data or packet requesting sensor data. Save the packet to buffer store.
Input	Name of consumer, name of contents and time when packet was generated
Output	-
API Name	/FRControl/{FRName}/Crawl/ {detourTime}/{Point}* Point = /{North}/{East}/{Altitude}{PointName} PointName = {FNName} HOME
Role	Transfer traveling path and limit time to FR
Input	Name of the FR, a limit time for running the traveling path, an east-west direction distance from DR to the point, a distance in the north-south direction and a height (unit: meters), or name of the point
Output	-
API Name	/FRControl/{FRName}/PathCreate/ {PathName}/{Point}*
Role	Generate, save, edit traveling path
Input	Name of the FR, a set of traveling path's waypoints and the name of the travelling path ,
Output	-
API Name	/FRControl/{FRName}/PathRun/ {PathName}
Role	Start moving along the traveling path
Input	A character string of traveling path
Output	-

C. *Component Construction*

As for the components of the program of each node, each node has a program (named node program in this paper) named DR, FR0, GW1, GW2 shown in figure 2 and NDN Forwarding Deamon (NFD) [11], and FR has another Drone Control

Program (DCP). As a role of each component, Node program performs table buffer reference and strategy processing, NFD transfers the packet to the local component or to another node, DCP performs drone movement control.

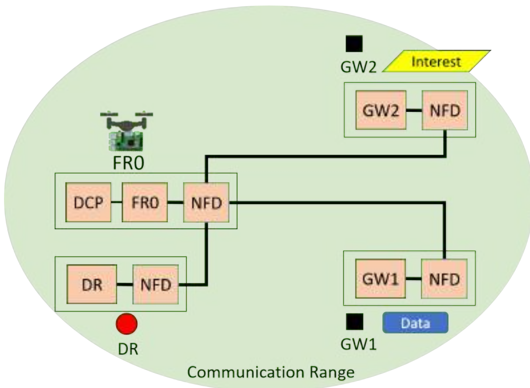

Fig. 2. Component Construction

For the modules of each node program, each node program has its own table, manager and strategy, as shown in Fig.3.

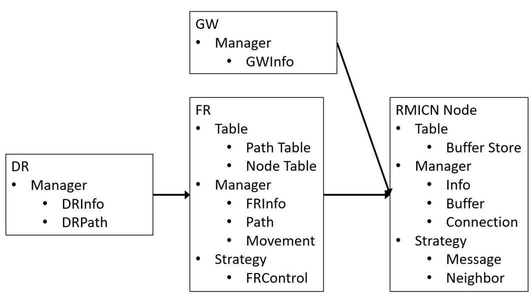

Fig. 3. Modules of Each Node Program

D. Behavior of Individual Components

NFD sends and receives NDN packets based on ICN forwarding pipeline and data structure. In this system, the packet transmission/reception function is extended to the table, manager and strategy for RMICN communication.

In addition to NFD's FIB (Forward Information Base), CS (Content Store), PIT (Pending Interest Table), Node Table, Buffer Store and Path Table are added in the table. In the Node Table, the name of the connection destination node, the type and position of the node, the face ID are stored. Buffer Store is a table for storing Interest packets requesting sensor data and Data packets storing sensor data. Path Table is a table that stores a pair of a traveling path and a name of a FR moving along the path.

A manager performs connection setting and communication by controlling the operation of tables and strategies. There are four types of managers: Connection Manager, Information Manager, Buffer Manager, Path Manager, and Movement Manager. The Connection Manager creates faces and sets listeners when nodes are connected. Information Manager manages transmission and reception of tables and packets. Buffer Manager saves and deletes the RMICN packet stored in the node. The Path Manager calculates and saves the traveling path. Movement Manager controls drone movement by calling an external program that controls the drone.

In the strategy, FRControl Strategy is designed for controlling the mobility of FR based on the name of the packet, Neighbor Strategy for exchanging RMICN packets, and Message Strategy for buffering and generating RMICN packets were added. FRControl Strategy stores the traveling path in the name of the Interest packet and transmits the packet, and the FR that received the packet carries out movement control by calling the drone control program based on the name of the packet. Neighbor Strategy performs creating FIB entries for forwarding Interest. Message Strategy performs buffering and forwarding of Interest and Data packet.

TABLE II
AN EXAMPLE OF CUSTOM DATA STRUCTURE: PATH TABLE AND NODE TABLE OF DR IN FIGURE 1

Node Name	Path
FR0	GW1, GW2, GW3
FR1	GW4, GW5, GW6
FR2	GW7, GW8, GW9

Node Name	Node Type	Location	Face ID
FR1	FR	Not Depot	Face1 ID
FR2	FR	Not Depot	Face2 ID
FR3	FR	Depot	Face3 ID
DR	DR	Depot	-
GW1	GW	Loc1	-
GW2	GW	Loc2	-
...	...	...	...
GW9	GW	Loc9	-

E. Packet Structure Design

The prefix of Interest packet is /FRControl, /Neighbor, /RMICN, and the node which received each packet calls the processing of FRControl Strategy, Neighbor Strategy, Message Strategy. We set the lifetime of Interest packets with prefixes /FRControl and /Neighbor equal to NFD default lifetime. In the Interest packet that does not need to return data such as sensor data and connection information, it stores the message successfully received the packet in the Data packet and returns it. On the other hand, regarding the lifetime of the Interest packet having the prefix of /Message, all the FRs are fed back to the DR and synchronized in order to efficiently relay the packet in consideration of the time required for FR movement and communication. Among all the FRs, let T_r be the longest time to complete the traveling path and $4T_r$ be the lifetime of the Interest packet. Because delivery of Interest packets of sensor data can be divided into three stages of Interest retrieval, Data retrieval, Data delivery in order of time. Therefore, the Interest packet with the longest time to be satisfied is an Interest packet generated by the GW immediately after the

FR visits the GW. We set the lifetime to $4T_r$ to satisfy such a packet within its lifetime. The namespace of the Data packet is the same name as the Interest packet so as to satisfy the corresponding Interest packet.

F. Sequence Design

Overrall Sequence: Immediately after the FR communication control system is started, DR, FR, GW updates information such as node name and position in each Node Table. At this time, FR is near DR, and mutually connects and exchanges Interest packet requesting sensor data and Data packet storing sensor data. Then, DR calculates the traveling path based on the position information of the GW using VRP and IACO [12] of the path planning method and stores it in its own Path Table and at the same time stores the path in the name of Interest packet and sends the Interest packet to the FR. When the FR receives the Interest packet, it stores the reception success message in the Data packet, returns it to the DR, and then starts moving according to the traveling path. When arriving near the GW in the traveling path, FR stops moving and connects with GW and exchanges packets. After packet exchange is over, the FR calculates a new traveling path based on its own packet and strategy and moves to the next GW of the path. After visiting all the GWs on the traveling path, the FR will return to the DR and if it arrives near the DR it will exchange the packet. Then, by repeating the computation of the traveling path and the movement control as described above, communication between the nodes in the RMICN communication area is realized.

Movement Control of UAV: When FR receives Interest of Crawl, it passes Crawling Path in the name of its Interest to DCP and starts DCP so that FR controls movement. After that, the FR program periodically acquires the current coordinates of UAV from DCP. When the FR arrives at the GW, registration of the FIB entry and transfer of the content-requesting interest and the content data are performed as a process upon arrival.

Registration of FIB Entry: When FR arrives around the GW, it transfers the Interest of Retrieve Route to GW, receives the name of the content generated by that GW from GW, and registers it in its own FIB of that name. Similarly, the GW receives the content name generated by another GW from the FR and the name of the content owned by the DR, and registers the name in its own FIB.

Generation and Transmission of Packet: Interest is generated after FIB entry is generated, and Data is generated after receiving Interest. In addition, packets are transferred only when connected to the transfer destination, and otherwise stored in the Buffer Store until connection with the transfer destination. However, Interest will be deleted from the Buffer Store when the Life Time is over. Data does not take Life Time into account in this study and does not delete from Data Buffer Store.

IV. Experiments

In the experiment, we confirm communication between GWs by using the APIs of the proposed system. Currently, implementation of communication can only use one Flying Router. We also confirm that the ICN naming scheme can be used as API by confirming the operation of this experiment and that strategic mobility control of FR is possible by using this system. First, this section describe the mounting environment, hardware and software. Next, we describe operation and procedure of experiments.

A. Equipment and Implementation Environment

Table III lists the software, tools, and equipment used for the implementation of FR communication control system.

TABLE III
Description of tools and equipment

Software	Version	Description
ndn-cxx	0.5.0	C++ NDN library
jndn	0.15	Java NDN library
NFD	0.5.0	NDN packet forwarder
DroneKit-Python	2.0	Control tool for drone
Mission Planner	1.3.44	A tool to display the state of the drone in the GUI
Python	2.7.0	language of Drones control tool
c++	C++ 11	language of ndn-cxx and NFD
java	java 8	language of jndn
Ubuntu	14.04 LTS	User Nodes OS
Raspbian	Sep 2016	Raspberry Pi's OS
Hardware	**Model**	**Description**
Drone	3D Robotics Solo	Programmable control, WiFi communication possible, GPS loaded
Computer	Raspberry Pi 3 Model B	With WiFi, receiving power from drone

Drone and Raspberry Pi (RPi) communicate via the Wi-Fi provided from the controller of the drone, and power is supplied from the drone via the serial port.

Location of the real machine experiment is the place of the circular area with a radius of 30m centered on the controller of the drone. The radius of Wi-Fi emitted from the controller is 30m, and the pseudo communication range of each node is 10m.

DR, FR0, GW1, GW2 are represented as (0, 0), (0, 0), (0, 30), (30, 30) when the position of the node is expressed by a pair of numbers (distance in the north direction to DR, distance in the east direction to DR). The DR program is executed on the PC, and the programs of GW1 and GW2 are executed on the RPi. GW1 creates the content, and GW2 requests the content. The name of the content is /RMICN/GW1Service/<SystemTime>, and the content in the Data packet is null.

B. Experiment Procedure and Result

As for the behaviors of each device in the experiment, when we activate the program of each node, FR takes off from the vicinity of DR and it repeats movement in the order of DR, GW1, GW2, DR. Among those movements, in the first visit to GW1, we set FR to create an FIB entry in FR so that Interest requesting content is transferred from FR to GW1. In the first visit to GW2, by setting the FIB entry with GW2, it is set to transfer Interest requesting content from GW2 to FR. At the same time, GW2 transfers Interest requesting content to FR. At the second visit to GW 1, FR transfers the interest requesting content to GW1 and at the same time receives content from GW 1. In the second visit to GW2, GW2 receives the content from the FR. As a result, communication between GWs using FR is completed.

In the experiment, we confirmed the above operation, showed the operation and message according to the design specification, and showed that ICN real environment communication using one FR is possible by using the system designed in this paper.

Fig. 4. Experimental Verification of Communication Using FR

C. discussion

In the experiment, the network to which each node belongs is not a different network, but a pseudo disjointed network communication is realized in the same network. If the distance between the mobile router and the coordinates of other nodes is within a certain distance, the mobile router determines that it has connected to the node. In the future, in agriculture and disaster applications, it is necessary to implement it in a disjointed network environment.

The scale of the experimental network is a circular region with a radius of 40m, which corresponds to the area of one agriculture filed in Japan (standard size is 20m x 50m) and one community of disaster area. As for delay, in the experiment, the delay of retrieving contents is 66s. The delay is considered to be larger than Message Ferry method, because FR needs to visit DR which does not request contents or produce contents.

For future work, we will devise the requirements on the network scale of actual agricultural application and disaster application for future work. Also, We will realize real environment RMICN communication using multiple mobile routers.

V. Conclusion

In this paper, we have focused on the naming schema of ICN and the flexibility of the strategy layer, and proposed a system for disjointed network communication using multiple mobile routers. First, we have explained the characteristics of ICN used in system use case, topology and operation. Next, we have described components of RMICN system, packet specifications and sequences of the components. Next, we have showed evaluation environment and simulation results. In the real machine verification, we have introduced software and hardware for implementation and experimental environment, and explained experiment scenario and verification procedure of communication using one Flying Router. Simulation results showed that RMICN can retrieve content faster than Message Ferry method. Experiment showed that RMICN communication using one mobile router can be realized by the system proposed in this paper.

For future work, we will devise the requirement of agriculture and disaster application and devise path planning considering the content characteristics of the application. In addition, we will implement RMICN communication using multiple mobile routers.

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