Community-Oriented Networking Technology

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We propose a community-oriented communication architecture named "Community-ORiented IcN (CORIN)". CORIN is based on the Information-Centric Networking (ICN) approach, which is one of the future networking technologies and enables the efficient data dissemination and retrieval. While ICN uses content names for data forwarding, CORIN uses community names for data sharing in order to effectively realize the many-to-many communications. It is expected that CORIN will contribute greatly to the future Cyber-Physical Systems (CPS) and Internet of Things (IoT).

1 Introduction

The Internet Protocol (IP) communication technology used on the Internet has evolved and developed as a versatile communication technology that enables humans to communicate with each other. Nowadays, low-cost sensors, radio frequency identification (RFID), and scalable and high-speed wireless communication technology have made progress and have been applied to the field of "Internet of Things (IoT)" where all kinds of physical objects and things are able to connect to the Internet or the field of "cyber-physical systems" (CPS) which enables interaction between the Internet-connected physical world and cyberspace. IoT and CPS require a system for managing the vast amount of data (i.e. big data) generated by sensors, actuators and other devices, processing such data within the network, and sharing among the interested parties, but a communication model that manages all of the big data on a server or cloud has limits in terms of the communication speed and energy efficiency. Based on a recent white paper from Cisco[1], there will be 50 billion devices connected to Internet by 2020. Therefore, there is a need for a communication protocol with even higher scalability and real-time capabilities (immediate responsiveness) than the current IP communication.

In many IoT systems and CPSs, the main communication will be the sharing of data within a *community* of objects, such as *humans* and *things*. However, the use of traditional IP communication based on a host-centric, end-to-end communication model for communication within a community with numerous objects will lead to an enormous number of communication paths or a significant increase in unnecessary communication traffic, resulting in overall degradation of communication performance and quality.

Against such a backdrop, we propose a Community-ORiented IcN (CORIN)[6], a community-oriented communication architecture using the concept of information-centric networking (ICN)[2]–[5] which has been studied as a new paradigm for future network technologies. The ICN enables communication centered on information (content) rather than the host-centric communication premised by IP communication. Specifically, information (content) is acquired from a nearby router or node that stores (or caches) the content, through communication using the name of the content, without designating the location (IP address) of a server or the information provider. In CORIN, a "community name" is designated instead of the content name used in ICN to perform communication based on communities. A community used in CORIN is a group of users with common interests in information or content or network-connected users with some kind of

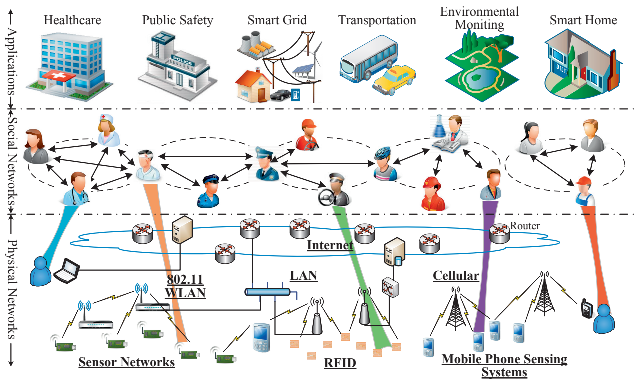

Fig. 1 Smart city services over IoT and CPS

theoretical or physical relationship with each other. In CORIN, users in the same community are connected with each other by bidirectional communication paths which enable many-to-many communications. This makes it possible to pursue an effective communication architecture that can be applied to future services under IoT and CPS (Fig. 1).

2 Related work

In traditional IP communication, IP multicast has been a protocol for achieving communications for multiple users (group members). However, in IP multicast, there is no special meaning between a dynamically assigned IP multicast address and group members or content. Therefore, a user needs to match an IP multicast address with content every time the user sends or receives the content. In addition, due to the use of IP addresses and routing protocol dedicated to IP multicast communication, a router needs to implement a routing protocol for creating and managing a special routing table different from that of IP unicast which achieves one-to-one communication. The network operation will also be complicated due to the complicated state transition of the communication paths. Such obstacles have always been pointed out with regard to technical development and diffusion of IP multicast.

Peer-to-peer (P2P) applications such as BitTorrent are in widespread use, so sharing content with multiple users by using these applications can be a solution for achieving community communication. Nevertheless, an overlay network constructed by a P2P application forms routes independent from the underlay physical network, and does not always form optimal routes. This could undermine the communication performance and delay the response time, with a further risk of flooding the network with a large volume of redundant traffic as the number of users increases, and having an adverse effect on other communication applications.

In ICN, which has been studied as a future network technology, several typical ICN architectures, including DONA[2], PURSUIT[3], CCN[4] and NetInf[5], have been proposed. Although these architectures realize the basic functions of ICN, they are not suitable for community-oriented communication in that they have not been designed to provide many-to-many routing. Thus, their scalability may suddenly drop when sharing content among a large number of users. For example, CCN and PURSUIT require the establishment of a routing tree rooted at the source node for each content (sender), so when the number of senders increases in particular, the routing table size may swell. Meanwhile, NetInf, which defines the method to discover and retrieve the closest information copy by using the concept of a hierarchical distributed hash table (DHT), also lacks consideration of a communication structure for many-to-many information sharing and does not optimize the communication paths for sharing information among multiple users.

3 Basic design of Community-ORiented IcN (CORIN)

3.1 Network functions

We define "community-oriented communication" to be where users with common interests in information such as the sensor information sent by a specific communication device or the operation status of a train or a bus are grouped into a community, and each group member communicates within the same community by specifying a community name. Assuming that communication should not rely on a possibly remotely located server or cloud in order to deal with big data, as explained in Section **1**, we considered it effective to use a communication technology which adopts name-based routing independent of IP addresses and which uses caches within the network, similar to ICN, and proposed a community-oriented communication technology, inheriting the ICN technology and its characteristic features, called CORIN[6]. CORIN uses community names (for the definition of a "community name," see the next section) instead of the content names used by general ICN, and all users belong to one or more groups called "communities."

A physical network on which CORIN operates is comprised of the following three network functions.

- Forwarding Nodes (FNs): FNs work as routers to forward data and control messages. FNs have two tables called the "Forwarding Information Base" (FIB) and the "Request Pending Table" (RPT) for their own routing control. FIB is a routing table which maintains community names (CIDs; see the next section) and the corresponding incoming and outgoing interfaces for data forwarding. RPT records the interfaces for the transmission of control messages sent from community rendezvous points (CRPs) when the users initiate new communities.
- Forwarding and Cacheable Nodes (FCNs): FCNs have all the functions of FNs, as well as a function

as a router with a cache feature. The cached data is used to forward data within the cache lifetime. One designated FCN (DFCN) exists in a route for community communication, and it serves as the root of the community communication tree.

- Community Rendezvous Points (CRPs): In CORIN, there is one CRP in each administrative domain, which records and manages the CIDs of all the communities in this domain and performs matching of the DFCN for a community. All FCNs and the DFCN know the CRP name, and have a route to the CRP's name.

3.2 Community name and information identifier

In CORIN, a unique community name (identifier) (CID) is given to every community on the network. A CID can be defined as an ID combining the "service or application" (e.g., electric power, temperature or train operation status) used in IoT or CPS, "hierarchical community name" (e.g., Company A¦Branch B¦Warehouse C, Tokyo ¦Suginami-ku, JR East¦Chuo-line¦Downline) indicating the information target, with "CORIN domain name" (e.g., Provider 1) indicating the administrative domain where the community is initiated. Combined with a CID, the "information" (e.g., Current Status, Delay Information) which a user wants to send out, acquire or share is defined by an identifier called "information identifier" (IID). Within CORIN, the character strings of CIDs and IIDs are converted into binary data or hash values as needed, and communication paths are formed for each CID to construct an environment where users designating the same CID can share information with each other. For example, members of a community identified by a CID <Temperature¦Company A¦Branch B¦Warehouse C¦Provider 1> share information identified by such IID as <Temperature¦Company A¦Branch B¦Warehouse C¦15 Degrees or Higher¦Provider 1> or <Temperature¦Company A¦Branch B¦Warehouse C¦20 Degrees or Higher¦Provider 1> with each other.

3.3 Communication routing tables

FN/FCNs that serve as data forwarding routers in CORIN have a forwarding information base (FIB), which is a routing table of the shared tree for conducting community communication. Each entry maintained by the FIB includes a CID and the corresponding incoming and outgoing interfaces for data forwarding, described as <CID, DFCN, Interfaces>.

The basic data forwarding method of an FN/FCN is that an FN/FCN performs an exact match between entries in the FIB and the CIDs in the information identifiers in the packets it receives, and if it finds the corresponding entry, it forwards the data to the remaining interfaces specified in this FIB entry, with the exception of the incoming interface (if it does not find a CID exactly matching the FIB entry, it drops the packet).

The procedures to construct and update such a shared tree include "community initiation", "community join" and "community leave", as described in the next section.

4 Community communication routing management method and information sharing method

4.1 Community initiation

To initiate community communication, an initiation process is required. In CORIN, a local area network for creating a community (administrative domain) is called a "CORIN domain," and each CORIN domain has one CRP. Under the current specifications, the name of a CRP is announced in the CORIN domain or statically configured in each FN/FCN.

If a user intends to initiate community communication, the FN/FCN to which the user connects sends a request to the local CRP. Each intermediate FN/FCN that forwards this request records the requested interface in the request pending table (RPT) and recognizes this interface to be a return-back routing entry from the CRP to this user. On receiving the request, the CRP selects a DFCN corresponding to the community name (CID) from its list of DFCNs in the CORIN domain, and replies to the user based on RPT entries. This DFCN is selected according to the number of users joining the community and other factors in order to ease the concentration of traffic to a specific DFCN. Then, the user sends out a community join request (described in the next section) including the CID and the selected DFCN, and a bidirectional path is constructed between the user and the DFCN.

Figure 2 shows the procedure whereby a user, U_1, tries to initiate a community named CID_1 in a network consisting of a local CRP, FNs (FN_2, FN_4, and FN_6), and FCNs (FCN_1, FCN_3, and FCN_5). As in the figure, U_1 sends a community initiation request to the local CRP, and each immediate FN/FCN records an entry back to U_1 in the RPT. Then, the local CRP selects FCN_3 as the DFCN, and notifies U_1 of this configuration as an initiation reply to U_1 based on the RPT. After that, U_1 sends out the community

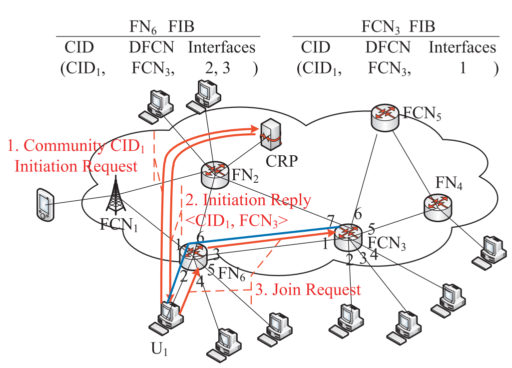

Fig. 2 Community initiation procedure

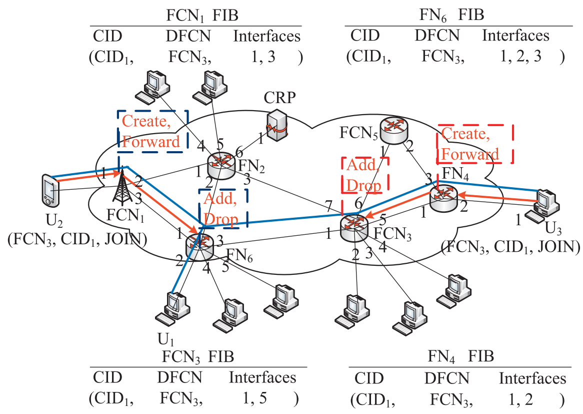

Fig. 3 Community join procedure

initiation request (described in the next section) with a community name as CID_1 toward FCN_3. The intermediate FN, FN_6, which receives the request, adds an entry as <CID_1, FCN_3, 2, 3> in the FIB, which shows that the community CID_1 is associated with interfaces 2 and 3. This join request is then forwarded to FCN_3 through interface 3.

The DFCN, FCN_3, creates an entry < CID_1, FCN_3, 1> for this community. Thus, the community initiation procedure is finished and a bidirectional path having links between U_1 and FN_6 and between FN_6 and FCN_3 is formed.

4.2 Community join

After a community is initiated, users can join it and send out, acquire and share information with each other. If a user intends to join a community, the user first sends out the community initiation request described in the previous section[*1]. Then, the local CRP which receives the request notifies the user of the specified community name (CID) and the DFCN for this CID as an initiation reply to the user. On receiving the reply message, the user sends a community join request toward the DFCN to construct a bidirectional community communication tree rooting at this DFCN. The join request is sent based on DFCN entries in the FIB.

Here, two cases can occur during the forwarding of the community join request: (1) a case where an intermediate FN/FCN already has an FIB entry for to this CID; and (2) a case where an intermediate FN/FCN does not have an FIB entry for this CID. In Figure 3, for example, U_1 is already a user in community CID_1, while U_2 and U_3 have completed the initiation request, and intend to make a request to join the community. In this case, to join the community CID_1, U_2 sends a join request toward FCN_3, which is the DFCN for CID_1. When FCN_1, which has no FIB entry for CID_1, receives this request from interface 1, FCN_1 creates an FIB entry for CID_1 and further forwards this request message through interface 3. The FIB entry is created as <CID_1, FCN_3, 1, 3>. Then, FN_6 receives the join request through interface 1. Since FN_6 already has an FIB entry for CID_1 for U_1, which is <CID_1, FCN_3, 2, 3>, FN_6 adds interface 1 to the matching entry in the FIB. The corresponding entry changes to <CID_1, FCN_3, 1, 2, 3>. At this point, the join procedure for U_2 is finished. For U_3 joining the community, FN_4, which is the intermediate FN/FCN, has no FIB entry for CID_1, so it creates such entry. After receiving the join request of U_3, FCN_3 adds interface 5 to the FIB entry, and the join procedure for U_3 is finished.

4.3 Community leave

The users in the community can leave it at will, apart from the automatic expiration[*2] of the related entries in the FIB based on the time limit set by CORIN. When they want to leave, they need to send the community leave request while specifying the CID.

Two cases can occur during the forwarding of the community leave request: (1) a case where only the interface used for the leave request is registered in the FIB entry for the CID of the intermediate FN/FCN, with the exception of the interface to the DFCN; and (2) a case where two or more interfaces are registered in the FIB entry for the CID of the intermediate FN/FCN, with the exception of the interface to the DFCN. In the former case, the FN/FCN determines that there is no user for whom it must forward data in the community, and forwards a community leave request to the DFCN, and deletes the FIB entry. In the latter

[*1] In order to have CRPs conduct user authentication in the future, a community initiation procedure is always required before joining a community.
[*2] Explanation on the automatic expiration is omitted in this paper.

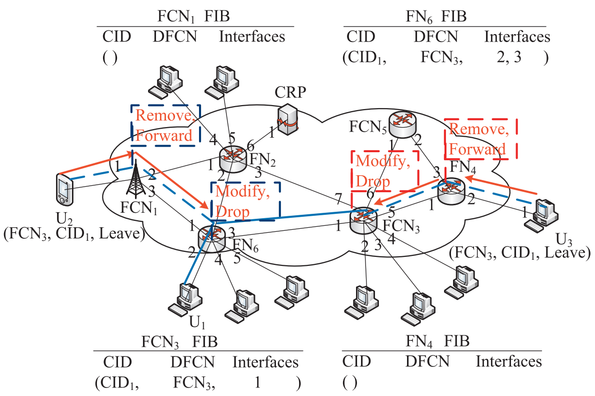

Fig. 4 Community leave procedure

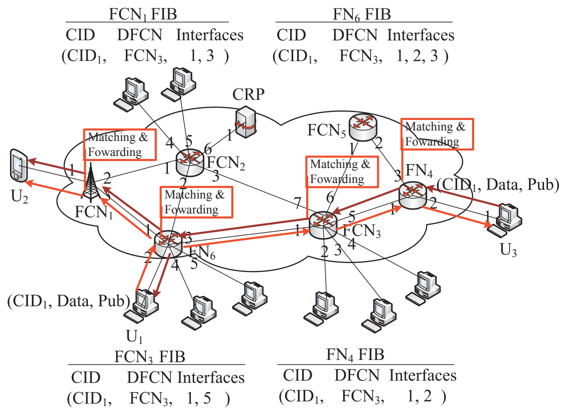

Fig. 5 Community publication procedure

case, only the interface receiving the community leave request is deleted from the FIB, and the community leave request procedure is finished.

Figure 4 shows the example procedures for two users, U_2 and U_3, to leave a community. U_2 and U_3 send the CID_1 leave request. For the request from U_2, FCN_1 receiving this packet deletes the incoming interface, interface 1, and sends out the packet to the remaining interface of this community, interface 3. Then, this packet is forwarded to FN_6, and since the only remaining interface for CID_1 is the one for the DFCN (FCN_3), it deletes this FIB entry. After deleting the incoming interface, interface 1, FN_6 finds that there is another interface for CID_1 remaining other than the one for the DFCN, and drops this community leave request, determining that there are still other users participating in the community communication for CID_1. Regarding the request from U_3, FN_4, similar to FCN_1, forwards the leave request to the DFCN, and deletes the FIB entry for CID_1. FCN_3, which receives the leave request, keeps interface 1, and finally, only U_1 remains in the community, CID_1.

4.4 Information sharing among community members

When a community communication path is formed, all users participating in the community can send out, acquire and share community-related data with each other. As described previously, an intermediate FN/FCN performs exact match between entries in the FIB and the CIDs in the data it receives and then forwards the data to the remaining interfaces in the appropriate FIB entry except the incoming interface.

Figure 5 illustrates an example of the communication path of data publication from U_1 and U_3 in a community with users U_1, U_2, and U_3. The red directional line shows the flow of Data 1 published by U_1, and the brown directional line shows the flow of Data 2 published by U_3. Take the publication from U_1 as an example. U_1 publishes Data 1 into community CID_1, FN_6 performs matching for this CID and then forwards the message to the remaining interfaces, interfaces 1 and 3. The message reaches FCN_1 through interface 1, and reaches FCN_3 through interface 3, and is forwarded respectively to U_2 and U_3. Since FCN_3 is the DFCN for this community, it caches the copy of Data 1.

5 Conclusions

In this paper, we propose CORIN, a community-oriented communication architecture using community names, by adopting the concept of information-centric networking (ICN), for the purpose of efficiently realizing communication based on *communities* of objects such as *humans* and *things*. CORIN constructs and manages many-to-many communication paths by a method that differs from conventional communication technology. Specifically, it constructs a bidirectional communication path to a community name called "CID," enabling users in the same community to send out and share information including that community name.

Community-oriented communication is expected to be utilized in the fields of IoT and CPS in the future. However, in order to apply CORIN to IoT and CPS, the implementation of security is essential, such as a function to authenticate or approve users and terminals that can initiate or join a community, the defining and implementation of such procedure, or encryption of communication. In the future, in addition to implementation and evaluation of the proposed CORIN, we will conduct research activities toward realizing an architecture that can be safely used in the fields of IoT and CPS.

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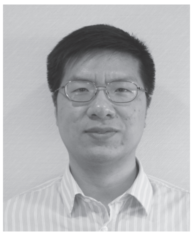

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