DHR-CCN, Distributed Hierarchical Routing for Content Centric Network

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Abstract

The goal of Content Centric Network (CCN) is to provide high-efficient mechanism to store the content which is widely stored at the network center and edge. Content name, rather than IP, is used for data transmission in CCN. It is necessary to identify content, and keep the mapping relation between content and network interfaces. With the data exponential growth, scalability in CCN will be more serious than TCP/IP. In this paper we present a Distributed Hierarchical Rrouting for Content Centric Network (DHR-CCN). This model provides the efficient information diffusion of the content name to reduce the overhead of naming routing. Moreover, this mechanism provides novel content management and organization to raise transfer speed. We define content entropy to quantify the CCN routing uncertainty. Finally, the performance of DHR-CCN has been evaluated.

Keywords: content centric network, name routing, hierarchical routing, scalability

1 Introduction

As a result of the globalization and the rapid development of network technology, IP based Internet plays a more and more important role in promoting national economy and meeting the growing need of people. However, it is setting higher requirements for security, mobility and etc. [8].

Therefore, some countries do research on architecture, principle, protocols and content distribution mechanism of Future Internet. Several main development tendency of Future Internet has been shown in some research [6], as follows:

- Content centric network architecture;
- Mobility first network architecture;
- Cloud computing centric network architecture;

For some time, the computing mode of Internet has been changed from host-centric to content-centric [5]. People pay more attention to the transmission speed and content security without concerning about where they come from. As shown in Fig.1, Content Centric Networking (CCN) [1] is a communications architecture which built on content name, rather than IP, for data transmission. CCN provides a high efficient mechanism to store and spread the content. Each packet could be potentially useful to many consumers so as to maximize the probability of sharing. CCN remembers arriving data packets as long as possible, and IP network forgets the packets and recycles its buffer immediately. Therefore the content is widely stored at network center and edges. Users could obtain large files, e.g. video objects,

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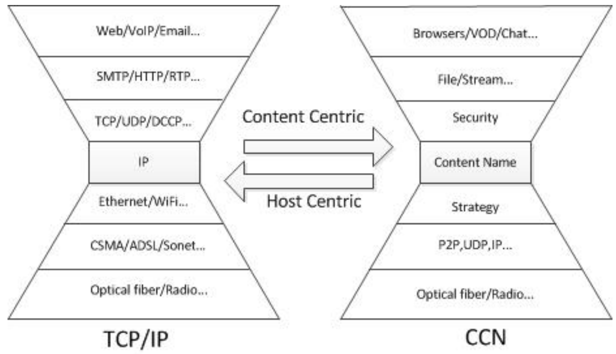

Figure 1: Protocol Stack Comparison Between TCP/IP and CCN

from the closest CCN routers [3]. In addition, multi-pathes transmission, breakpoint transmission and authentication binding are other three key characteristics of CCN [2].

It is the essence of CCN to make network could not only transform the packets but also recognize the content of packets [9]. What CCN keeps is not the location of network nodes but the name of content objects [11]. It is the fact that content objects have several orders of magnitude more than network nodes even now. With the data exponential growth, scalability in CCN will be more serious than TCP/IP[10].

In this paper, we present a distributed hierarchical routing for Content Centric Network (DHR-CCN). Our specific contributions are:

- The distributed hierarchical routing mechanism is introduced into CCN.
- The routing algorithm of DHR-CCN is proposed. This mechanism improves scalability by demarcating the name-based routing space.
- The simulation results of an extensive evaluation of our algorithm to provide a preliminary analysis of the performance of the algorithms.

The remainder of the paper is organized as follows: Section2 is devoted to a brief description of CCN architecture. We discuss scalability in CCN and introduce DHR-CCN Architecture in section3. Our distributed hierarchical routing mechanism algorithms are presented in Section 4. The performance of our solutions are evaluated by simulation and discussed in section 5. Section 6 concludes the paper and highlights future work.

2 Overview of CCN

In this section we describe the CCN network model and discuss some meaningful properties. There are six core elements in CCN, including content name, two types of packets and three tables. The content name is the identifier of the packets. The interest packet and data packet are used to search and transfer content objects [7]. The three tables keep the mapping relation among the content name, objects and interfaces. The six elements are the foundation of CCN.

2.1 Content Name

In CCN, content is found and transferred by its name. Typical content name is constructed by a combination of variable components according to particular service specific naming conventions. The network could recognize not only where the content object is, but also what information is in the packets of the content object. Content name can be viewed as a hierarchical composition, as shown in Table 1. Content name, e.g. '/google.com/videos/Avatar.mpg/V$< timestamp >$/s5/60$< FPS >$', is composed of several components. Each component represents a property of the content object (the movie). All the components together could represent completely what the content is. The CCN routers could search for the next hop interface according to the longest prefix match.

Prefix	Name	Meaning
google.com	Content name first stage	Identified at network-wide
Videos	Content type	The class this content object belongs to
Avatar.mpg	File name	The name of the content object
V$< timestamp >$	version	The version of the video
60$< FPS >$	60$< FPS >$	The frame rate of the video

Table 1: Units For Content Name

2.2 Pakcet and Tables in CCN

There are two kinds of packet, interest packets and data packets, in CCN, as follows:

- Interest packet: An interest packet includes content name and other properties of the content object. If a customer needs to look for the content object, the interest packet should be broadcasted.

- Data packet: If a CCN router receives the interest packet and the content name is matched exactly, the Date Packets will be return along with the reverse route of interest packet.

In this communication process, host address or location was not be included in the interest packet and data packet. The routing and forwarding in CCN is controlled by the three main tables: Content Store (CS), Pending Interest Table (PIT) and Forwarding Information Base (FIB). These three tables keep the mapping relations in content name, objects and interfaces.

- FIB: FIB keeps the mapping relation between prefix of the content name and next-hop interfaces. The CCN router forewords the interest packet to the destination faces. The router will forward the interest packet to several interfaces if the content name is matched more than one interfaces of FIB.

- PIT: PIT preserves the mapping relation between no-responsed content name and the last-hop face of interest packet. PIT records the content name and the upstream interfaces and provides data packets return path.

- CS: CS keeps the mapping relation between content objects, which have been stored in the cache, and their names. If the interest packet matches the data item, data packets will be sent.

2.3 Routing Process of CCN

The route protocol of CCN is similar to IP. The basis mechanism is hierarchical naming and the longest prefix matching in route lookup. A key difference is that the CCN uses content name as the routing name space. We illustrate the relationships among the six elements with a simple case. The topology of the case is shown at Fig. 2. The packets and tables are shown at Fig. 3. And the process is illustrated by Algorithm 1.

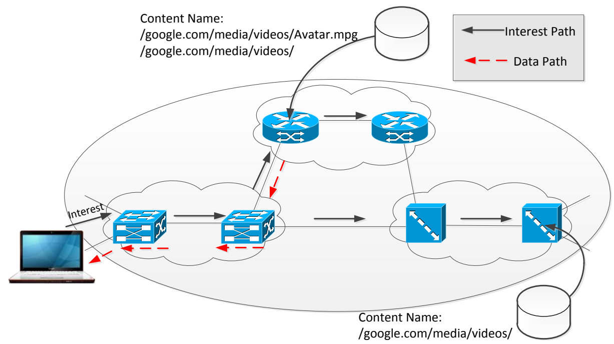

Figure 2: A Simple Example for Routing Process of CCN

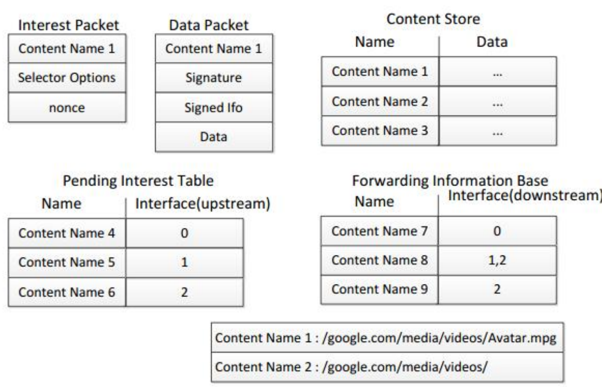

Figure 3: Packets and Tables of CCN

Algorithm 1 Routing Process of CCN

1: CCN Router B and C announce the content name prefix in a CS data item.
2: CCN Router A hears this announcement, e.g. '/google.com/media/videos/Avatar.mpg' from B.
3: CCN Router A establishes a new mapping relation for the prefix and interface for B and C at FIB.
4: CCN Router A receives a interest packet which looking for '/sina.com/media/videos'.
5: CCN Router A looks up for the prefix, and not found in the local CS. If the prefix matches the data item of CS go to step 5, else go to step 6.
6: CCN Router A will send the data packet to C and go to step end.
7: CCN Router A looks up the prefix in the local PIT. If the prefix matches the data item of CS go to step 7, else go to step 8.
8: CCN Router A adds the C in at the interface of the data item. If A receives the data packet match the prefix, it will send the data to the C, and go to step end.
9: CCN Router A looks up the prefix in the local FIB and matches the prefix.
10: CCN Router A forwards the interest packet to B.
11: CCN Router B executes the similar steps from 4 to 6. B sends data packets to C via A.
12: CCN Router A will store the data packet at CS and establish a new data item in CS.

3 DHR-CCN Architecture

3.1 Scalability Analysis in CCN

The routing topology could be abstracted into a weighted graph G (V, E). The V is the set of nodes and the E is the set of edges[5]. The topological relationship between the nodes is basic restrictive conditions. The routing process of the CCN is similar to running a maze in search of treasure. The maze is the routing topology, and the treasure is the content. The more it is learnt about routing topology, the faster it reached the end. Applying the concept of Shannon's entropy, we define 'content entropy' to reflect the CCN routing uncertainty, as Definition 1.

Definition 1

Content Entropy. Content entropy is the metric for the uncertainty of the CCN routing system. Content entropy equivalents to uncertainty of the content distribution.

Once each CCN router has the whole routing information, e.g. content distribution and topological, the 'uncertainty' of CCN routing can be eliminated. As mentioned above, the routing data item is not including the topology information of the CCN. Therefore, each interface forwarding probability of the CCN node could be assumed equal. The forwarding probability of each interface for the ith router is identified by P_i. The node degree is assumed to d_i. $P_i = 1/d_i$. Therefore, the content entropy for one CCN router is as formulation (1):

$$C_i = -\sum_{d_i} P_i log_2 P_i = log_2 d_i \tag{1}$$

Then, total content entropy C for n nodes is as formulation (2):

$$C = \sum_{i=1}^{i=n} C_i = n log_2 d_i \tag{2}$$

Content entropy increases with number of CCN routers, node degree. If the network node cannot cover all the routing information, or network can't update the routing information, it will decline routing performance. There are three elements influence in the content entropy of the CCN network, as follows:

- the size of the content name.
- the number of the nodes in the CCN network.
- the basic topological characteristics.

First of all, content name space directly determines the size of routing. The development of the network and growing demand of people enable content name space. Secondly, topological structure of CCN connection degree distribution is very dis-equilibrium[4].

3.2 Architecture of DHR-CCN

The method to solve the scalability is to reduce the influence of expanding network scale and content. According to the three key factors of content entropy theory model, a possible way to solve the routing expansion of the CCN is to introduce the hierarchical routing into CCN.

DHR-CCN divided CCN into two layers: Core Name Switched Network (CNSN) and Edge Name Switched Network (ENSN). CNSN is composed by Super Content Routers (SCRs). ENSN is composed by Edge Content Routers (ECRs). Each SCR and serval ECRs, in a certain range, composes a Content

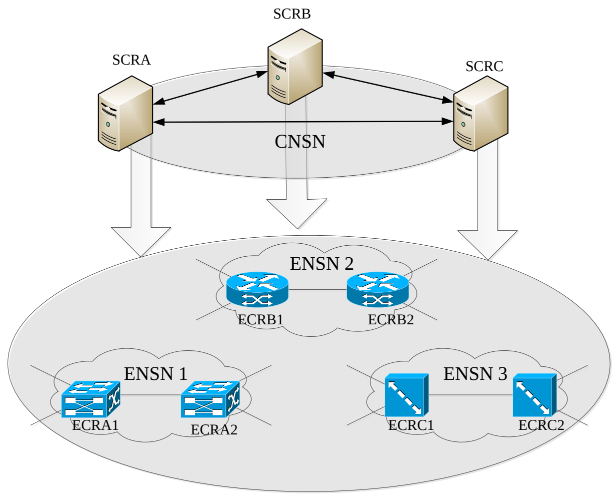

Figure 4: the Architecture of DHR-CCN

Autonomous Systems (CAS). Interest packets could be forward and inquiry in the native CAS preferentially.

As shown in Figure 4, the network is divided into CNSN and ENSN. The main responsibility of ENSN is to exchange the general information of content names of the ENSN. SCRs could be selected automatically the super nodes with the best performance. And SCRs could be assigned by ISP, too. In each ENSN, the SCR maintains and manages the group of ECRs. The transmission of CNSNs is similar to IP network. This method can store mass content routing entries in CCN routers.

The original reasons to introduce hierarchical routing into CCN are as follows:

(1) Hierarchical routing could divide the name space of routing. The routing range could be limited according to the different node types. SCRs comprise the core name switched network, and ECRs comprise the edge name switched network. The mess content name prefix data item could be stored and exchanged in core name switched network. And CRID (Content Routing Identifier) identify location of each super node of CCN.

(2) Hierarchical routing is conductive to maintain stable topology structure of CCN network.

- The connectivity of CNSN is higher than ENSN. Therefore the routing overhead for update topology and location of CCN router is reduced.
- The edge router and end nodes cloud makes migration more flexible.

(3) Content organization and polymerization could be well-distributed.

- Super content nodes could store and transfer lots of content objects according to the dynamic demand of CCN network.
- The content could be transferred preferentially in edge name switched network, and the super content node is the transferring base.

4 Algorithm

Distributed hierarchical routing for Content Centric Network provides efficient content name information which is diffused and rapid transfered for content object. The interest packet looks up for content name

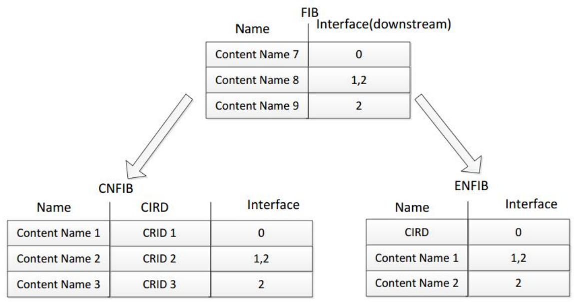

Figure 5: ENFIB and CNFIB of DHR-CCN

in Edge Content Routers (ECRs) which belong to the same Edge Name Switched Network (ENSN) preferentially. The interest packet will be forward to the Super Content Routers (SCR) and found in Core Name Switched Network (CNSN), if the content name does not exist in the local ECR. Once the content name is matched in the CNSN, the content object will transfer to the ENSN via the SCRs.

The main Algorithms include super node section, super node join and leave, routing process in CNSN and ENSN.

4.1 Super Content Router Selection

In DHR-CCN, each SCR is identified by the Content Routing Identifier (CRID) which is similar to IP addessHR-CCN could be convenient and compatible interface with existing IP network. There are two special forwarding information bases in the SCR, including Edge Network Forwarding Information Bases (ENFIB) and Core Network Forwarding Information Bases (CNFIB) as shown in Fig. 5.

The primary tasks of the SCRs are to provide the global content names searching, key storage nodes and management of the set of edge nodes. Therefore we considered SCRs should have strong computing power, mess storage, high bandwidth. We introduced the utility function for super content router selection, as formulation (3): shown.

$$u_i = w_1 * \frac{C(n_i)}{C_max - C_min} + w_2 * \frac{S(n_i)}{S_max - S_min} + w_3 * \frac{S(n_i)}{B_max - B_min} \tag{3}$$

$C(n_i), S(n_i) and B(n_i)$represent the computing power, storage and bandwidth of the ith router of the network. The sum of $/w_1, w_2, w_3/$ is 1. Therefore, the utility value of routers is obtained in formulation (3). In the network establishment stage, the system checks each node information and utility value. The algorithm of super content router selection as the Algorithm 2 shown.

It points out that the topology establishment of SCRs in the step4 is still to deserve a deep analysis. We assume the routing mechanism is similar to the IP network as a simplified solution in this paper.

4.2 Super Content Router Join and Leave

CCN system is a dynamic system. Each node can join or leave at any time. In order to prevent SCR failure and keep the nodes routing table, the SCR should has a alternative node. Once the SCR failure, the backup upgrades to be a Super Content Router. When an edge node wants to join a network, it firstly finds and registers the existing SCR. And the edge node could be the member of the Super Content Router. In this process the Super Content Router does not announce the node join and leave outside the edge network, so that to reduce the routing overhead.

If an edge node leaves a CCN, the SCR just need to update a little routing information. If a SCR leave the core CCN, the backup node should be the Super Content Router.

Algorithm 2 Process of Super Content Router Selection

1: The network management system collects the hardware information of SCRs.
2: Network management system collects the hardware information of SCRs.
3: Utility of each CCN node is calculated.
4: Network management system chooses the best performance node as the SCR.
5: SCR is assigned CRID for routing in CNSN.
6: SCR and ECRs announce the content names of their CSs in the same ENSN.
7: If an ECR receives the content names from other ECRs, the ECR will add n data item into FIB.
8: SCR collects and aggregates the content names and the interfaces of the upstream.
9: SCR establishes the ENFIB and keeps the mapping relations between resource and interfaces to adjacent ECRs.
10: SCR chooses a node with high performance as the backup node.
11: SCR establishes the CNFIB to keep the mapping relations between the resource of the ESCN and the CRID of other SCRs.
12: SCR announces the content names in ENFIB to the other SCRs.
13: SCR receives the announcements from other SCRs and adds the content names to CNFIB.
14: Each SCR synchronizes the content names with other SCRs.

4.3 Routing Process of DHR-CCN

One of the advantages of DHR-CCN is the interest packet from edge nodes could be forward with fewer hops to the Super Content Router which contain basically all content name prefix of CCN. The SCR could provide dynamic method to store and organize heat content objects. The routing process is shown as the Algorithm 3 .

Algorithm 3 Routing Process of DHR-CCN

1: ERN2 and ERN3 announce content name prefixes in a CS data item.
2: SCR A hears this announcement, e.g. '/google.com/media/videos' from B.
3: SCR A establishes a new mapping relation for the prefix and interface for SCR B and SCR C at FIB.
4: SCR A announces the content name inside the ERN1.
5: SCR A receives a interest packet which looking for '/sina.com/media/videos' from Edge node A1.
6: SCR A looks up for the prefix, and not found in the local CS. If the prefix matches the data item of CS go to step 7, else go to step 8.
7: SCR A will send the data packet to Edge node A1 and go to step end.
8: SCR A looks up the prefix in the local PIT. If the prefix matches the data item of CS go to step 9, else go to step 10.
9: SCR A adds the Edge node A1 in at the interface of the data item. If A receives the data packet match the prefix, it will send the data to the Edge node A1, and go to step end.
10: SCR A looks up the prefix in the local FIB and matches the prefix.
11: SCR A forwards the interest packet to B.
12: SCR B executes the similar steps from 4 to 6. B sends data packets to Edge node A1 via A.
13: SCR A will store the data packet at CS and establish a new data item in CS.

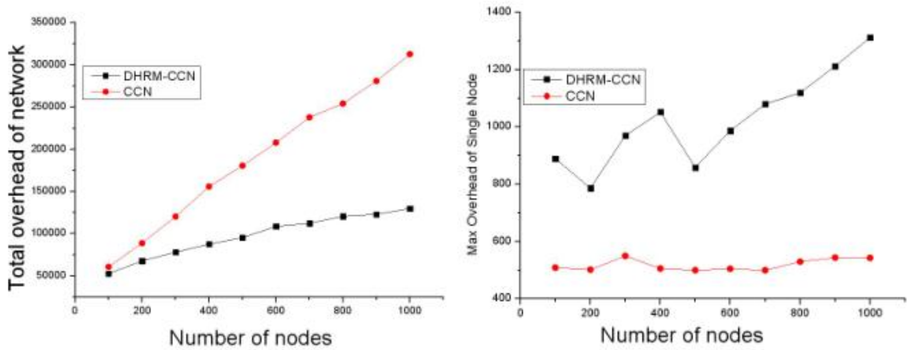

Figure 6: Overhead Comparison

5 Simulation

In this section, we evaluate the performance of DHR-CCN using large-scale simulations. First, we present the simulation environment used for the CCN. And we specify the measured variables.

5.1 Setting for the Simulation

In our simulation, a topology generator of shortest path based on IP network was extend to generate hierarchical CCN network.For comparison, the routing algorithm of CCN and DHR-CCN was implemented, including network establishment stage, routing and forwarding stage,etc.

We use the shortest path as the routing algorithm in the core name switched network for easy and accurate validation. In the network establishment stage, randomly bandwidth and hardware are assigned for each CCN routers. At the same time some Super Content Routers are selected in DHR-CCN.

The naming routing algorithm for CCN includes announcement, sending and forward interest packet, and transmission data packet. The processed of SCRs selection and auto-sync, edge nodes registration are added in DHR-CCN compared with CCN.

5.2 Simulation Analysis

Routing topology is discovered through the announcement from other routers, history of interest packet. We define the number of the packets as the overhead for topology construction to measure the cost of establishing and maintaining the CCN network and DHR-CCN. Overhead for topology consists of three parts in CCN as follows:

- Content name announcement.
- Interest packet sending and forwarding.
- Content node migration.

Overhead for topology in DHR-CCN has additional parts:

- Super Content Routers selection.
- Edge nodes Registration and leave.

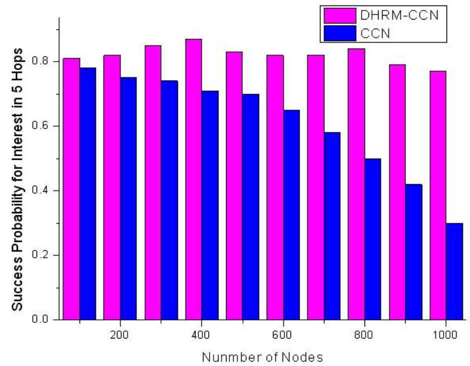

Figure 7: Success Probability for Interest in 5 Hops

- Core name switched network synchronization.

The content distribution and organization is not considered in this simulation.

As regard to the communication cost, the methods perform better than the traditional one does. Three hypotheses were proposed for the simulation, as follows:

- The CCN nodes uniformly distributed.
- The content object uniformly distributed in CCN nodes.
- The heat range for content is not considered in this simulation.

Simulation experimental results show that, overhead for topology construction were influenced obviously by size of the content name, the number of the nodes in the network, as shown in Fig. 6. The overhead of DHR-CCN is less than CCN.

Fig. 7 compares the routing success rate of interest packets for DHR-CCN and CCN in five hops.This shows that small optimized interest routing success of DHR-CCN outperform CCN. The routing success of DHR-CCN is relatively stable when number of nodes increasing, indicates a good scalability.

6 Conclusions

This paper presents DHR-CCN architecture, which introduce hierarchical routing into CCN. The network is divided into Core Name Switched Network and Edge Name Switched Network. Content Entropy is introduced to reflect the CCN routing uncertainty. The purpose of DHR-CCN is to reduce the overhead of naming routing in CCN. Moreover, this mechanism provides novel content management and organization.

In the future, we intend to analyze and measure the influence of heat degree of content objects to the CCN. The bandwidth, storage and computing power should be introduced to the hierarchy naming routing mechanism. And we will improve prototype system which based on DHR-CCN.

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