A Cluster-based Content Management Framework for Information-Centric Networking

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***Abstract*—Information-Centric Networking (ICN) is being recognized as an acceptable paradigm for changing the location dependent host-centric network architecture to the location independent content-centric network architecture. Although ICN has various types, the method for content management is similar to each other. The core concept of ICN has been developed based on the content name instead of the content location information, intermediate content caching between the sender and the receiver, packet level security and others. To achieve the objective of ICN, different architectures were proposed and analyzed based on the criteria of ICN, however there are still remaining issues to be resolved. In this paper, we propose a cluster-based content management framework for ICN which enables content registration, distribution, retrieval, caching, routing, and security support. We also present simulation results to show that our framework works better than existing ICN types in terms of content transfer time.**

Keywords—ICN, Content Management, Clustering

I. INTRODUCTION

The Internet was developed based on the host-oriented architecture and has been supporting various types of communications. Due to the wide use of the current Internet, the need for IP address has greatly increased for identifying a number of hosts. IPv6 was developed to solve the shortage of the IPv4 addresses although it is not being widely used as expected.

Considering the limitation of the host-oriented architecture, there is a growing interest in a new paradigm called information-centric networking (ICN). The main objective of ICN is to shift the current complex and inefficient Internet architecture to a simple and efficient one. The ICN networking functionalities are based on the location-independent content name instead of the location-dependent IP address. The ICN is a receiver-driven networking model where the end users can retrieve a content by simply issuing their content request message with a content name. The ICN network takes the responsibilities of forwarding the content request message, finding the content, and responding with the requested content using the proper routing path.

The representative instances of ICN are CCN [8], NDN [9], DONA [2], NetInf [5], and PURSUIT [3]. Since they still have some limitations in content management, this paper proposes a new approach for ICN called cluster-based content management framework.

The rest of the paper is organized as follows. Section II describes related studies. Section III proposes a cluster-based framework for ICN. The performance analysis is given in Section IV. Finally, we conclude the paper with a summary in Section V.

II. RELATED WORK

At the beginning of the 20th century, the first ICN approach was proposed in TRIAD [1]. At that time, it was proposed as the next-generation architecture. The main goal of TRIAD was the explicit inclusion of a content layer that provides scalable content routing, caching, content transformation, and extensible path-based addressing.

The Data-Oriented Network Architecture (DONA) project [2] was proposed in 2006 by UC Berkeley, which improved the security and architecture of TRIAD. The Publish Subscribe Internet Technology (PURSUIT) [3] project is the continuation of the Publish Subscribe Internet Routing Paradigm (PSIRP) [4] project which proposed a publish/subscribe protocol stack replacing the existing IP protocol stack.

At the same time, 4WARD [6] was proposed as a European Perspective towards the Future Internet. They mainly emphasized the technical and business scenarios that lead the development towards a framework for the Future Internet and further development has been made by the Scalable and Adaptive Internet Solutions (SAIL) [7] project. Similarly, Van Jacobson, a Research Fellow from PARC, proposed the Content-Centric Networking (CCN) [8] approach in 2007. The CCN architecture was described clearly and they also discussed the naming, routing, and security mechanism. Named Data Networking (NDN) [9] is another type of ICN that is currently working to enhance the CCN architecture. NDN has modified the CCN architecture so that they can update the functionalities of NDN to adopt the targeted goal. There are other ICN approaches also working to resolve the current Internet limitations.

III. CLUSTER-BASED CONTENT MANAGEMENT FRAMEWORK

This section describes various aspects of the proposed cluster-based content management framework for ICN: how a cluster and a cluster head are configured, how the cluster head maintains routing and caching, how the content can be registered, and how the content can be retrieved using the content name.

A. Clustering Technique

In our framework, we consider three-level clustering, i.e., clustering among eNodeBs (eNBs), routers, and content providers (CPs). In this section, we do not describe in detail how to make a cluster and a cluster head. We follow the concept of our previously published paper [10] where the procedures were described well. Figure 1 shows the overview of our cluster-based framework. The figure represents the eNBs, routers, and CPs within an individual cluster and the relationship among clusters. Each cluster has a cluster head that knows all information about the cluster such as cluster members' individual identity, their own caching size, cached content information, FIB information and manages the incoming and outgoing contents, routing of the contents, and so on. The cluster head is connected with the local cloud so that the cluster head can maintain the caching overload, consistency of the content name, content distribution based on the available cache space at each eNB, router, and CP.

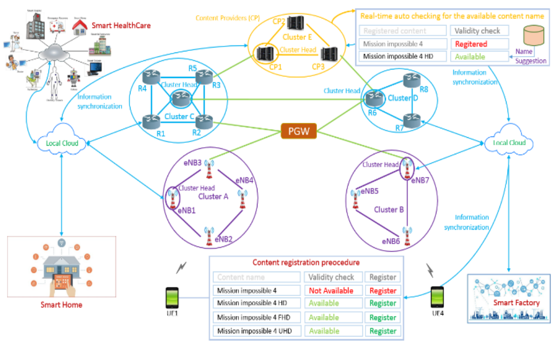

Figure 1: Overview of the proposed cluster-based framework

The local cloud is also connected with the local smart healthcare system, smart home, smart factory, IoT devices, and 5G infrastructure as they can maintain the cluster-based ICN functionalities. The local cloud also can be used for various purposes e.g., maintenance of synchronized FIB information, consistent name registration, and the recommendation of available content, content distribution and caching.

B. Content management

There are several content management procedures in different ICN types such as Resolution Handler (RH) [2], Rendezvous Node (RN) [3], local and global name resolution service (NRS) [5], local and global Name Resolution System (NRS) [7]. The main objectives of these handlers are to manage content searching for the subscribed users or general users, register the content location, and find the path between the source and the destination. In many cases, these services or systems (RH, NRS, CRS, RN) may not handle unique name registration, retrieval of the proper content from multiple similar contents with different names, content duplicity.

The cluster-based ICN architecture can resolve the above-mentioned shortcomings. First of all, we describe the procedure for unique content name registration. In our framework, users can register their content to a CP and they can only register the name based on the CP so that the cluster head of the CP can track the registered content name. The local cloud can be used only for the memory lacking in the cluster. The cluster head makes a decision based on the necessity or the situation within a cluster. The necessity of the local cloud arises based on the requirement of the total needed memory within a cluster.

The unique content name is the most important task for ICN because the content retrieval and routing are performed based on the content name. Our cluster-based framework maintains several functionalities to provide the unique content name. When a user wants to register a content in a CP, the user can check the validity of the name before submitting for registration. The validity check means that the content name is either valid or invalid for registration. If the content name is valid, the user can register the content to the CP. But, if the content name is not valid for registration, the CP suggests some names to the users for registration. A name suggestion function is responsible for suggesting the name based on the user preference. The user can either select one of the suggested names or can try for another name.

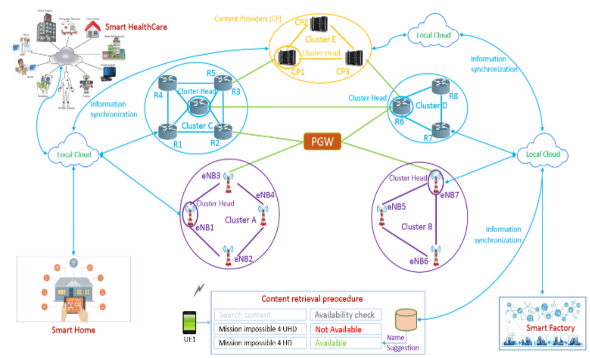

Figure 2: Content retrieval

The content retrieval is another important issue of ICN. The different types of ICN retrieve the content in different ways. We already mentioned the method of content access of different ICN types but most of them used an extra function, e.g., RH, CRS, NRS, or RN. In our cluster-based framework, we don't need any extra handlers, services, systems, or nodes. Instead, the cluster head handles the content retrieval mechanism. If a user wants to send a content request message using a unique content name, the user can check the availability of that unique user content name. If the unique content name is available, the ICN network takes the responsibility to retrieve the content based on the requested unique content name. Otherwise, the network suggests a similar or related unique content name that is already registered by another user. The user can finally select a unique content name among the suggested names and send the unique content name to the network. The network is responsible for retrieving the content from the suitable locations and sending the content to the destination.

C. Caching

The most distinguishable difference between the current TCP/IP based host-oriented network architecture and ICN is in-network content caching. The in-network devices have a minimum level of memory to store the incoming contents. The cluster head knows all the information about the cluster members, e.g., available memory amount of each member in a cluster, the list of cached contents, and one-hop cluster heads and connected clouds. The cluster head efficiently manages the in-networking caching. It distributes the incoming contents to the other cluster members based on the content popularity, time-dependency nature of the content, e.g., weather report, vehicular security related contents, and content usability. It can also store the contents in its own content store. If the cluster memory is finished, then the cluster head uses the local cloud to store the contents and the cluster head keeps track of the stored contents. The cloud can also be used for storing the huge number of uniquely registered content names so that the registered unique content names can be synchronized in a timely manner or based on the requirements. The cluster head is always connected with the neighboring one-hop cluster heads and local clouds. Therefore, the cluster head also synchronizes the related information, e.g., FIB information, the registered unique content name, stored content to the neighboring cluster heads.

IV. Performance Analysis

We simulated our cluster-based approach and used the CCN-based cellular network architecture as a basis. Figure 1 shows a representative scenario for our simulation. We used CCN (as a type of ICN) in our simulation to show the benefits of ICN. For simulation, we used NS-3 simulator, CCNx application, and DCE on a Linux Ubuntu machine.

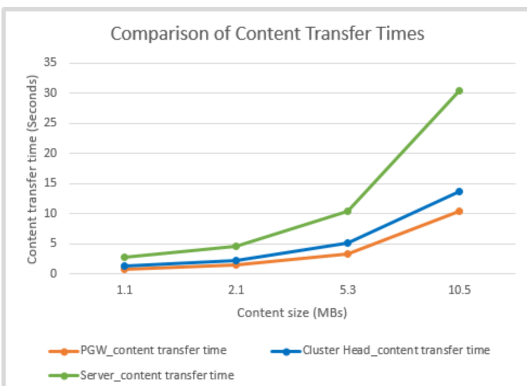

Figure 3: Comparison of content transfer time in different scenarios

The simulation result is shown in Figure 3. We considered the server, the cluster head, and the PGW as the content provider. The cluster head has the largest caching capabilities in a cluster, and it also knows the other nodes' caching capabilities within the cluster. Therefore, the cluster head can provide the best caching services within a cluster. The lowest content transfer time can be achieved from the eNB because the UE is directly connected to the eNB, but in reality eNB is not able to cache all the incoming contents because of limited caching capabilities. Similarly, the PGW is the next connected node to the UE but it also has limited caching capabilities. So, our main target is to use the storage capabilities of the routers. The routers can cache much more content and the cluster head handles the caching mechanism. In addition, Figure 3 shows that the content retrieval time from the cluster head or router is less than the content retrieval time from the content server. In reality, the servers' or content providers' distance from users are far away than our simulated environment, and the distance between UE and routers is nearly similar to our simulation environment.

V. Concluding Remarks

In this paper, we first investigated the limitations of the current ICN approaches, their potential influences and challenges in terms of naming, caching, and content retrieval. Then, we presented our cluster-based ICN framework and showed how our cluster-based ICN framework can overcome the limitations of ICN approaches. We discussed a way of uniquely identifying the content name, content retrieval, caching, and routing issues. We also simulated our cluster-based approach and presented the performance results. We showed that our cluster-based ICN framework works better than existing ICN approaches in several aspects, e.g., unique content registration, content retrieval time, caching, and routing which are the main functionalities of ICN.

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