Efficient Mobility Support for Content Delivery in Mobile Communications

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Abstract— **Due to the rapid evolution of the Internet to support content-centric devices and applications, more focus is on the content itself instead of the location of the content source. Content consumer mobility is an important aspect of content-centric networking (CCN) and future networks, but it has not been sufficiently studied. In this paper, we demonstrate that CCN can support faster communication services and provide uninterrupted data delivery in the 4G network and also in the upcoming 5G network. We propose an approach to integrate the CCN and LTE with high and seamless data delivery efficiency. We further propose a mobility management mechanism to support the network diversity by leveraging the abundant computation resources in the LTE network. To ensure seamless data delivery, we evaluate the performance of our proposed mechanism in terms of data transmission success ratio.**

***Keywords*— Content-Centric, Content Delivery, Mobility**

I. INTRODUCTION

With the exponential growth of Internet access by mobile devices in recent years, the volume of the mobile content has been increased enormously, and it is a big challenge to support fast content delivery as well as seamless mobility in the wireless network. The content-centric networking (CCN) [1][2] architecture can be useful to resolve this issue.

The main objective of CCN is to provide enhanced features including more efficient content delivery, faster content access, cost effective and secure communication. CCN makes content directly accessible and stored in any nodes in the communication path to enable faster content access to prevent the repeated transmissions of request packets to the content server, thus avoiding the network congestion. Figure 1 shows a CCN forwarding module which has three main functional entities: Content Store (CS), Pending Interest Table (PIT), and Forwarding Information Base (FIB) [1]. Content is requested by sending an Interest packet to the nearest CCN forwarding module with the name of the desired content. After receiving the Interest packet, the forwarding module performs a lookup in its CS, and Data packet is sent to the interest receiving path. If no matches are found in the CS and the PIT, Interest packet is forwarded according to the FIB, and the PIT keeps track of it. Due to the mobility, content recognition and content routing information should be flooded throughout the network, which may incur long delays to keep the data transfer continuity.

In this paper, we propose an approach to integrate the CCN and LTE to improve the content delivery efficiency. We also propose an efficient mobility management mechanism to address the network diversity and device diversity by leveraging the abundant computation resources in the LTE network. Our proposed mobility management scheme introduces a context-aware handover prediction mechanism to deal with the heterogeneity of wireless content consumers. The rest of the paper is organized as follows. Section II describes the recent work related to data delivery in CCN. Section III presents a novel approach to integrate CCN with LTE and some mechanisms for efficient and seamless content delivery in the LTE network in detail. Section IV describes implementation details and performance issues, and finally, Section V concludes the paper.

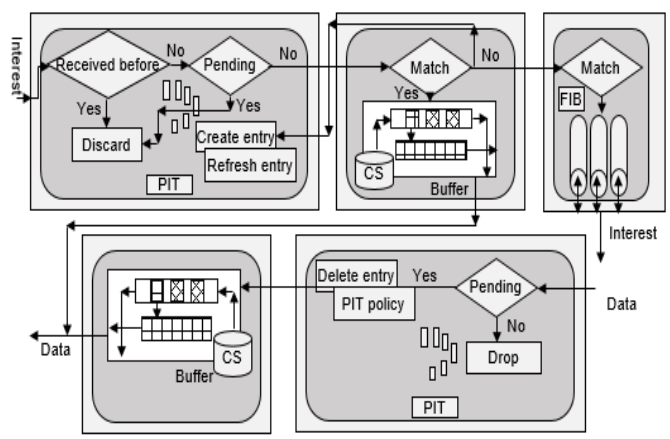

Figure 1. A Forwarding Module for CCN

II. RELATED WORK

Seamless data delivery and mobility management in wireless networks is an important research area which has been focused a lot under various scenarios. For example, Mobile IP [3] provides mobility support at the Network layer, and Session Initiation Protocol (SIP) [4] provides seamless mobility support at the Application layer. The performance of these protocols are limited due to its dependency on the IP layer, and also due to the lack of cross layer communication between lower and higher layers. They cannot come out of the host-to-host communication scenario.

To handle mobility issues and seamless data delivery in TCP/IP, integrated name resolution and routing schemes are proposed. DONA [5] introduces CCN by replacing the concept of DNS in the traditional TCP/IP based Internet architecture.

DONA requires Resolution Handlers (*RH*) for hierarchical resolution and routing. DONA reduces the applicability of name-based networking because of its path discovery complexity and location dependency. The amount of delay and overhead due to its sharing of state and global knowledge may be a big concern for DONA.

To handle data delivery and mobility issues in NetInf, name-based routing name resolution approaches are used together. It uses Multiple Distributed Hash Table (MDHT) [8] and Late Locator Construction (LLC) [9] schemes for name-based routing and name resolution. Provider publishes content alongside their locator and makes a binding to the name resolver (NR) for making it available to the other nodes. However, NetInf reduces its scope by its name resolution system which is responsible for managing registration, updates, and accumulation of names. It has similar problems to DONA.

JUNO [10] proposes the convergence layer architecture to provide information-centric functionality on top of the underlying protocol. Convergence layer performs the similar functionality like NetInf and DONA. In [11], several routing policies based on the data plane of content-centric networking are described. It presents some policy on CS, routing and content sharing, rarely focuses on how accurately the routing will be performed and how the FIB will be managed from a huge number of disseminated contents throughout the Internet and how the network architecture will be more responsive to the wireless mobile environment.

The CCN architecture [2] decouples the content from the location at the network layer and creates the possibility for content to be directly leveraged all over the network. However, CCN still has several issues to be resolved and it will succeed only if it can provide some practical solutions to the existing well-known problems, and user mobility is one of them. A proxy-based mobility mechanism [12] was proposed to provide seamless source mobility support in content-centric networking by storing the mobility status of the content source. Clustered CCN [13] introduced the cluster concept to support mobility. With the assistance of clusters or proxies, these schemes can reduce the interest dissemination and handoff latency, but the overhead and complexity of the schemes is high due their centralized dependency on the proxy or server.

III. A CCN-based Mechanism for Seamless Data Delivery in the LTE Network

Mobility support is a service such that mobility of the node should not result in any loss of data or extended periods of disconnection. It is still an evolving issue how CCN will be integrated into the LTE network. We simplify here a seamless data delivery procedure in the content-centric LTE network. The eNodeB, SGW/PGW and Mobility Management Entity (MME) can support the CCN function and protocols. The detailed data delivery procedure in the content-centric LTE network is described below and also shown in Figure 2.

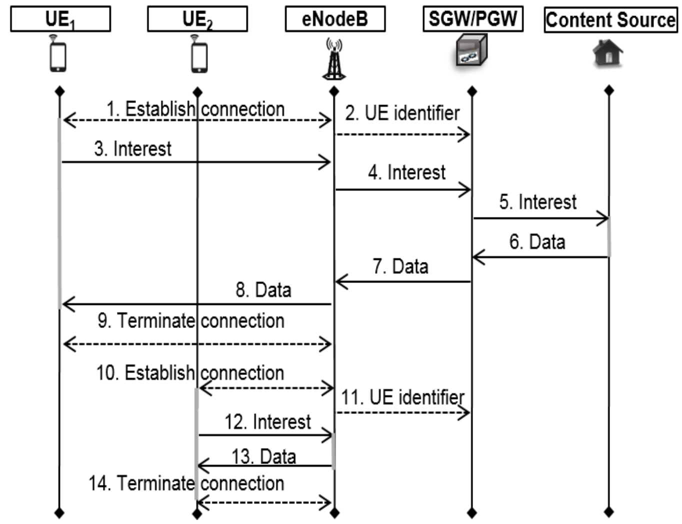

Figure 2. Data Delivery Procedure in the Content-Centric LTE Network

UE_1 establishes a connection to an eNodeB. The eNodeB sends the UE_1 information containing the node identifier and the interface identifier to the SGW/PGW. UE_1 sends the Interest packet to the associated eNodeB. After receiving the Interest packet, eNodeB operates according to the basic operation of the CCN node. The SGW/PGW receives the Interest packet from the eNodeB. After searching on its CS and PIT, if no matching data is found, it sends the Interest packet to the face of the content provider according to the FIB.

When a content provider receives the Interest packet, it searches on its CS. When the matching data is found, it sends the Data packet of the content out to the incoming face. After receiving the Data packet, SGW/PGW forwards it to the eNodeB and UE_1 based on their PIT. UE_1 terminates the connection. UE_2 establishes a connection to the eNodeB. The eNodeB sends the UE_2 information containing the node identifier and the interface identifier to the SGW/PGW. UE_2 sends the Interest packet to the eNodeB. After receiving the Interest packet, eNodeB performs according to the basic operation of the CCN node. Since it is stored in the previously attached eNodeB, it sends the Data packet to UE_2 and UE_2 terminates the existing connection.

A. Seamless Content Retrieval Using MME

Consumer mobility allows consumers to change their point of attachment without disrupting connectivity. We have defined a mathematical model that takes into account the preference of end devices, e.g., UEs, when selecting a base station for seamless and fast content retrieval services. Let x be a value for a single criteria and α be the stepness. $x_{min} \leq x_m \leq x_{max}$ where x_m is the midpoint of the variation range. These variations can be defined as a single criterion utility function as follows:

$$u(x) = \begin{cases} 0 \; if \; x \le x_{min} \\ \frac{1}{1+e^{\frac{\alpha(x_m - x)}{x - x_{min}}}} \; if \; x_{min} < x \le x_m \\ 1 - \frac{1}{1+e^{\frac{\beta(x-x_m)}{x_{max}-x}}} \; if \; x_m < x \le x_{max} \\ 1 \; if \; x \ge x_{max} \end{cases} \quad (1)$$

where

$$\beta = \frac{\alpha(x_{max} - x_m)}{x_m - x_{min}} \quad (2)$$

and α > 0 is the tuned stepness parameter. The proposed utility function satisfies the following properties: $u(x) = 0 \; \forall x \le x_{min}$, $u(x) = 1 \; \forall x \ge x_{max}$ *and* $u(x_m) = 0.5$. The point of attachment selection in the wireless networking environment is based on an aggregation of different utility functions for decision processes. Hence, we define here a multi-criteria utility function that is able to integrate the end devices' different choice metrics to select a best point of attachment. Let $R = R_1 ... Rn$ be a set of potential alternatives (e.g., possible different eNodeBs) and each alternative can be described as a different descriptor or attributes (e.g., signal strength, delay, mobility distance, reliability in terms of data transfer ratio) $x=x_1 * ... * x_n$, and each alternative attribute being described as a utility function $u(x_n)$, the simple weighted average of different alternatives $A(R_1 \ldots R_n)$ is used to maximize the selection probability of the best eNodeB as follows:

$$A_R = \sum_{i=1}^{l} w_i u(x_i) \quad (3)$$

where w_i is a weight that reflects the content receiver's preference. Weights are assigned depending on the UE's expected criteria. Mobility distance is characterized by the position of the eNodeB and the coverage area. Assuming the eNodeB position to be (X_e, Y_e), and the position of the UE to be (X_u, Y_u), then the distance d between eNodeB and UE is obtained using Equation (4) and the probability of UE being in a coverage area is obtained using Equation (5).

$$\begin{aligned} \mathrm{d} &= \sqrt{(X_e - X_u)^2 + (Y_e - Y_u)^2} \\ &= \sqrt{(\Delta X)^2 + (\Delta Y)^2} \end{aligned} \quad (4)$$

Therefore, the probability of a node being in a coverage area of an eNodeB is

$$P_r\{d \le R\} = P_r\left\{\sqrt{(\Delta X)^2 + (\Delta Y)^2} \le R\right\} \quad (5)$$

where R represents the radius of the area covered by the eNodeB.

This paper proposes a soft-handover approach where a new connection is established with the new eNodeB before breaking the current connection. In our approach, UEs have the decision capability, which are able to measure the traffic rate and the signal strength. Then the UE can apply the utility functions of Equation (3) to measure the overall weight to the eNodeB to decide whether the UE will move to a new eNodeB or not. If the UE decides to choose a new eNodeB to meet its seamless data retrieval demand, it forwards the content name and related information to the new eNodeB, then the new eNodeB forwards the Interest to the most appropriate content provider to retrieve the content. If the content retrieval is successful, the UE releases the connection with the old eNodeB and continues the content transfer using the new eNodeB. The message flow for seamless content retrieval of the UE is shown in Figure 3.

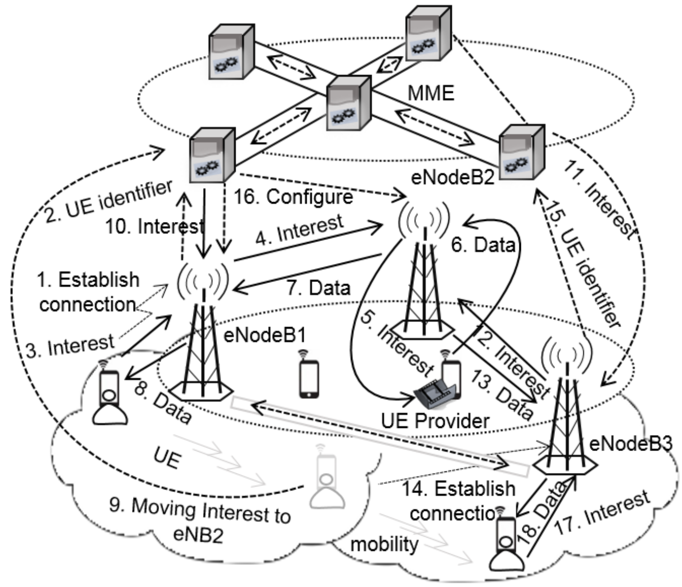

Figure 3. Seamless Data Retrieval for UE in the Highly Mobile Environment

IV. Performance Evaluation

This section presents simulation results along with discussions for the proposed mechanism that is well suited for today's communication environment, e.g., LTE. This section also analyzes the performance of the content-centric LTE network with our proposed mobility management scheme and compares it with the LTE network and basic CCN-based LTE network. The simulations were performed using CCNx [1], LENA/NS-3, Direct Code Execution (DCE) on VMware, and Ubuntu 12.04 environment.

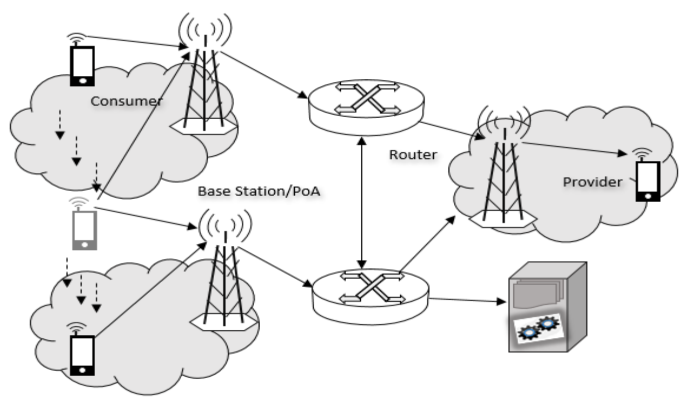

Figure 4. A CCN-based LTE Network Topology for Simulation

We used a simulation topology as shown in Figure 4. A 4 Mbytes video file is transferred between the mobile producer and mobile consumer to evaluate the simulations results. The number of eNodeBs is 3. The number of UEs covered by each eNodeB varies from 1 to 10 to show the effectiveness of our proposed mechanisms and also to show the data delivery efficiency in the low load and high load environment. To show the efficiency of our proposed mobility management approach, we varied the mobility speed of the UE ranging from 0 m/s to 10 m/s randomly. We evaluated the efficiency of the proposed approach and applicability by showing the average data delivery success ratio as performance parameters. Data transmission success ratio is the ratio of the total number of data packets received by the all consumer UEs to the total number of Data packets sent by all the producer UEs.

A. Data Transmission Success Ratio

We measured the performance of reachability and continuity of our mechanism in terms of data transmission success ratio, which implies that how much data were received correctly by the consumer in the deterministic mobility scenario and also in the random mobility scenario. However, the data transmission success ratio of our proposed approach is higher than the transmission success ratio of others because of its efficient soft handover based mobility management mechanism. Our proposed approach reduces the losses due to link failure, and mobility of nodes. In case of high mobility cases, our proposed approach uses the make-before-break approach when changing the routing path if needed. The simulation result showed a significant improvement in this case as illustrated in Figure 5.

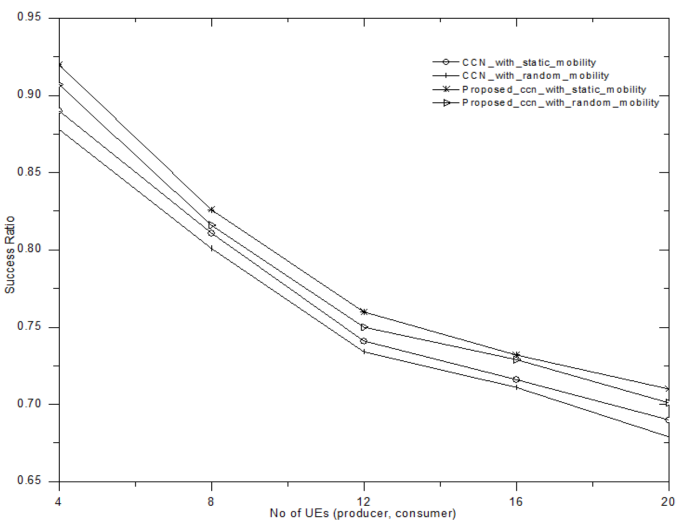

Figure 5. Data Transmission Success Ratio

V. Conclusion and Future Work

In this paper, we demonstrated that CCN can support faster mobile communication services and provide uninterrupted data delivery in the 4G network and also in the upcoming 5G network. We proposed an approach to integrate the CCN and LTE to improve the content delivery efficiency. We also proposed an efficient mobility management mechanism to support the network diversity by leveraging the abundant computation resources within the existing LTE network. We then analyzed the performance of our CCN-based content transmission mechanism in the LTE network environment. Specifically, we measured the data transmission success ratio and showed that our mechanism works better than the conventional CCN-based approach in the LTE network. By performing the experiments, we showed that the CCN can be used as an effective solution for faster content delivery and seamless data continuity in the highly mobile environment.

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