On Pending Interest Table in Named Data Networking based Edge Computing: The Case of Mobile Augmented Reality

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***Abstract*—Future networks require fast information response time, scalable content distribution, security and mobility. In order to enable future Internet many key enabling technologies have been proposed such as Edge computing (EC) and Named Data Networking (NDN). In EC substantial compute and storage resources are placed at the edge of the network, in close proximity to end users. Similarly, NDN provides an alternative to traditional host centric IP architecture which seems a perfect candidate for distributed computation. Although NDN with EC seems a promising approach for enabling future Internet, it can cause various challenges such as expiry time of the Pending Interest Table (PIT) and non-trivial computation of the edge node. In this paper we discuss the expiry time and non-trivial computation in NDN based EC. We argue that if NDN is integrated in EC, then the PIT expiry time will be affected in relation with the processing time on the edge node. Our analysis shows that integrating NDN in EC without considering PIT expiry time may result in the degradation of network performance in terms of Interest Satisfaction Rate.**

***Index Terms*—PIT expiry time, latency, remote computation, augmented reality, named data networking, edge computing.**

I. Introduction

The future world of 5G communication and Internet of Things (IoT) has been the subject of research for the past few years. Future Internet architectures will result in a fast information response time, and low latency will be a key feature of evolving 5G networks. In this paper we consider the use-case of Augment Reality (AR) to illustrate our findings. AR is not only bounded to latency, but also requires significant computational power and memory for many of its tasks. The mobile devices in AR have the limited resources and cannot provide demanded benefits and services to users. Therefore, such resource gap is fulfilled by mobile cloud computing (MCC) [1], which allows users to offload computation-intensive tasks to a number of powerful cloud servers deployed at the remote cloud platform. However, with the strict delay requirement of mobile AR applications, cloud servers suffers from extra propagation delay due to the long physical distance between mobile devices and cloud servers.Therefore, EC [2], has been recently proposed. The core idea of EC is to bring the resources at the edge of network with variety of benefits, including ultra-low latency, real-time access, and location-aware services.

However, the existing AR applications are built upon TCP/IP (Transmission Control Protocol/Internet Protocol) stack and rely on end to end communication. In order to overcome such limitations NDN [3], a proposed new Internet architecture, can be an enabler for AR applications by supporting local resource discovery and offering built-in content security. Moreover, EC paradigm, could achieve the required low latency due to physical vicinity. However, we argue that if the NDN is integrated with EC then the consequences may present some challenges to NDN specifically the PIT expiry time in relationship with the non-trivial computation of edge node.

II. Motivation

Many works in the literature have been proposed to address the PIT expiry time problem. However, if NDN is integrated with EC then all such approaches are not viable since EC provides non-trivial computations. In the following we discuss the PIT expiry time issue and the non-trivial computation issues of the EC.

A. PIT

The PIT is a data structure which keeps track of the interfaces of unserved requests. The PIT entries are purged either: when an entry in the PIT expires or when a Data is received [4]. The design of PIT is typically based on the assumption that corresponding Data messages are received in a time frame that is based on typical network Round Trip Time (RTT). PIT state is, therefore, short-lived by design. Moreover, due to caching feature for Data/results the node(s) does not need to keep a constant PIT time. The reason is that nodes near to the provider node or edge node does not need to keep PIT entry for a longer time, compared to a node that is near to the consumer node. Therefore, for the unsatisfied Interest(s), the constant value of PIT timer may result in bloating PIT; as well as not efficient for keeping millions of entries in PIT for the fixed value of PIT time. Efficient NDN forwarding

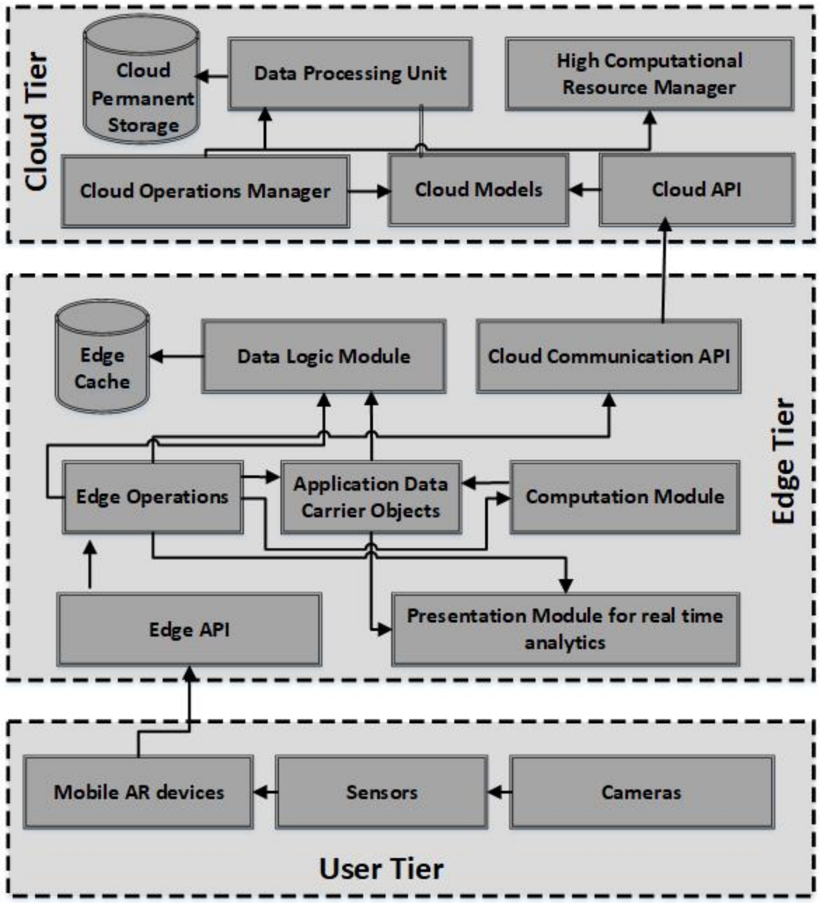

Fig. 1. An Architectural diagram for AR application with NDN based Edge Cloud Computing

requires PIT timer to expire fast so that retransmitted Interests will actually be forwarded upstream. Since the conventional NDN uses Interest-Data interaction where for each Data packet one Interest packet is transmitted. However, such Interest-Data packet interaction is unsuitable for invoking computations at the edge device that take longer than a few RTTs. More specifically the computation completion timescales can be orders of magnitude larger than NDN network timescales.

B. Non-trivial computations

Fig. 1 depicts a scenario of the AR user(s) application with NDN based ECC. In this scenario, we consider an NDN network of nodes where the NDN nodes have some edge computing capabilities [5]. Multiple AR devices simultaneously start with sensing real environment, producing raw videos, and capturing users' gestures via their cameras and sensors [6]. All the AR devices communicate and process locally via NDN network. After local processing some of the Data/tasks will be offloaded to the edge device with operation instructions which carry the specific requirements of mobile subscribers, such as object identification etc. Upon receiving the offloaded Data from AR devices, the edge device will start computation of the received Data with the received instructions from the AR users. In addition, if Edge device is not able to perform computation on these requests then the edge will forward the requests to the Cloud data center, where further processing will take place. Since there could be various kind of services requests from AR users and the computation time may vary depending upon the resources available at the edge node. Some compute intensive tasks might take longer time for computation than the less computing ones. As a result, computation timescales at the edge node may differ significantly from network timescales. Furthermore, we are using NDN based Edge Cloud computing paradigm that leverages NDN networking and forwarding features to seamlessly offload computation efficiently. Therefore, the integration of NDN with ECC raises an issue of PIT timer. As discussed in Section II (A) that the default PIT timer of NDN (which is 4 s) is enough for Interest and Data exchange. However, this constant design parameter might not enough for invoking computation at the edge node and cloud as well for many applications. The computation time may vary depends on the resources available at the edge node and the nature of tasks. Furthermore, many real time applications such as AR/VR may not afford the PIT timer with 4 seconds. Therefore, the NDN PIT timer needs to be changed dynamically with the estimated computational time at the edge node. For that we are registering two kind of events at the gateway node of NDN where the first event named as *services_event()* will be registered for services response from Edge node. As soon the AR user requests for some services from the edge node, an event for services will be registered. This event will basically handle all the services responses from the edge node. The second event will be registered for the estimated time information received from the edge node. The edge device will invoke callback API response that will carry the estimated time information for some specific task which was requested by AR user. This callback API response will trigger an event named as *update_PIT_Timer()* at the NDN nodes in user tier which will increase/decrease the PIT timer by extracting the estimated timing information from the callback API response. In this way the PIT entry will not be purged and will wait for the services/computation from the edge node.

The main theme of this paper is to evaluate the PIT expiry time with non-trivial computations at the edge node, and to present the behavior of network where computation takes longer than PIT expiry time. We achieve this goal by evaluating the requests for computing task at the edge node including network RTT and computation processing time. This is our first effort towards AR applications with NDN based Edge Cloud computing. A dynamic PIT timer mechanism and algorithm with proper simulation results will be presented in the follow up work of this paper.

III. EVALAUTION

We performed our evaluation for NDN on ndnSIM [7] with our open source Edge Cloud Computing framework [8]. The PIT expiry time is varied from 100 ms to 1900 ms in ndnSIM. The total simulation time is 120 s and the Interest frequency is 10 Interest per second.

A. Results and Discussion

We start by evaluating the Interest Satisfaction Ratio (ISR) for various expiry time values as depicted in Fig. 2. When the expiry time value is set to 100 ms, the ISR is 0%. The reason is that the computations at the edge node took longer than the PIT time of the NDN node. As soon we increase the expiry time value from 100 ms to 500 ms and 1000 ms, the ISR increased significantly. However, increasing the expiry time to higher values above 1500 ms shows 100% ISR. The reason is that all the packets are received within that time and 1500 ms shows an optimal value in our evaluation for results to come back. It should be noted here that we varied the PIT expiry time from 100 ms to 1900 ms for experimental purposes. It could vary in case of compute intensive tasks, end user requirements and application scenario.

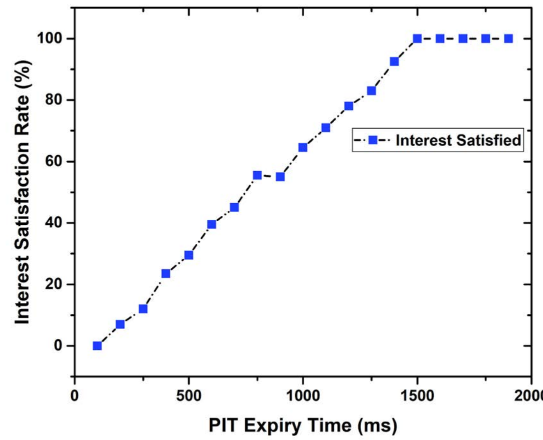

Fig. 2. Interest Satisfaction Ratio as a function of PIT expiry time

IV. CONCLUSION

In this paper, we have evaluated the expiry time of PIT while leveraging NDN with EC. Our findings show that computations at the edge node may took longer than the constant expiry time due to varied computation timescale at the edge node. We conclude that computation timescale directly affects the expiry time of PIT. If proper expiry time management is not provided for the computation time scale on the edge node, then real-time application such as AR will be severely affected due to overall latency. As a future work, we plan to provide a dynamic PIT timer mechanism that sets Interest lifetime based on estimated computation time from edge node(s).

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