

Performance evaluation of ICN/CCN based service migration approach in virtualized LTE systems

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Abstract—The continuous growth in using mobile devices (*e.g.* smart phones, tablets, *etc.*) has increased the complexity in provisioning cellular network resources. Applying the cloud computing model in LTE (Long Term Evolution) systems could be a good solution to increase LTE's performance by building a shared distributed mobile network that can optimize the utilization of resources, minimize communication delays, and avoid bottlenecks. One of the most important concepts used in mobile networks is service continuity. Mobile users moving from one sub-network to another should be able to seamlessly continue to retrieve content and use services (*e.g.* video streaming, electronic games, VoIP, *etc.*) that they want. In this paper, the Information Centric Networking/Content Centric Networking (ICN/CCN) approach is proposed to be used as a solution for service continuity in virtualized LTE systems. By using NS3 simulation experiments it is shown that the introduced approach is able to satisfy the performance related service continuity requirements.

Keywords—ICN, CCN; LTE; Service Continuity; Cloud Computing; Virtualization

I. INTRODUCTION

The continuous increase of mobile users, devices and new mobile applications and the significant growth of mobile data traffic motivated mobile operators to focus on developing enhanced or new technological solutions. The Long Term Evolution (LTE) is the fourth generation (4G) technology, which is standardized by the 3rd Generation Partnership Project (3GPP), see *e.g.*, [1]. The LTE technology is capable of providing high data rates as well as support of high-speed mobility, by supporting low latency in both the control plane and the user plane, which creates new opportunities for real-time applications such as video surveillance, telemedicine, and distance learning. In the LTE system two main network parts can be identified which are called Evolved UMTS Terrestrial Radio Access Network (e-UTRAN) and the Evolved Packet Core (EPC). The e-UTRAN consists of base stations denoted as Evolved Node-Bs (eNodeBs). The EPC is composed of several network elements. The main important ones are the Serving Gateway (S-GW), the Packet Data Network Gateway (P-GW) and the Mobility Management Entity (MME). The P-GW, as the main mobility EPC anchor point, connects the EPC to other external networks. The S-GW supports the transport of the user data between the User Equipment (UE) and the external networks. The MME is the control node that processes the mobility management signalling (*i.e.* handover) between the UE and the EPC. The eNodeBs are interconnected with each other by means of the X2 interface.

Moreover, the eNodeBs are also connected by means of the S1 interface to the EPC, more specifically to the MME by means of the S1-MME and to the S-GW by means of the S1-U. The S1 interface supports a many-to-many relation between MMEs/S-GWs and eNodeBs. The P-GW is interconnected with external networks using the SGi interface.

The Mobile Cloud Networking (MCN) project [2], is an EU FP7 projects that integrates the use of cloud computing concepts in LTE mobile networks. This is accomplished with the objective of increasing LTE's performance by building a shared distributed LTE mobile network that can: (1) optimize the utilization of computation, storage and networking resources, (2) minimize communication delays, (3) avoid bottlenecks, and (4) enable multiple network operators to create their own virtual network depending on their requirements and goals, while using a common physical infrastructure. The integration of cloud computing concepts in an LTE system can be mainly realized by : (1) extending the cloud computing concept beyond the typical (macro) data centers towards new smaller (micro) data centers that are distributed within the Radio Access Network (*e.g.*, e-UTRAN) and the Mobile Core Network (*e.g.*, EPC), and (2) deploying and running cloud-based (virtualized) Radio Access Networks, denoted as RAN as a Service (RANaaS), and Mobile Core Networks, defined as EPC as a Service (EPCaaS) [2]. The most important cloud computing principles integrated in this virtualized LTE system are the support of *on-demand provisioning* of LTE components and *on-demand elasticity*, allowing the virtualized LTE components to scale automatically, based on the data traffic load that they need to support. This trend is also in line with the emerging ETSI activities in Network Functions Virtualization (NFV). Service continuity is a critical issue in mobile networks implying access to the requested services without disruption, while the user moves from one network to another. In virtualized mobile cellular network systems, see Fig. 1, services are hosted on VMs (Virtual Machines) that may migrate across multiple physical networks (*i.e.* datacentres) with the aim of better service delivery. A service could be a content delivery or content generation and manipulation service. The migration of VMs and the services running on such VMs should occur in such a way that the disruption of an on-going service is minimized. A service continuity solution should be able to support the migration of services, implying the support for, see [3]:

- *IP address continuity*: When a user moves to another sub-network, the application will not observe the change of the IP address.

- *Session continuity*: It is a combination of IP address continuity and service context migration. Service context migration occurs when a user moves to a new location and the service context used by the function in the previous location should be able to be migrated and used by the same function at the new location.
- *Content continuity*: Refers to migration and delivery of the requested content from a location close to the mobile user. The requested content can be migrated and delivered from a location close to a mobile user.
- *Storage continuity*: Storage should be able to migrate to a new location close to the mobile user.
- *Function continuity*: The same function in a new location can be run using context used by the same function in the previous location. It needs to be supported in order to maintain function continuity.

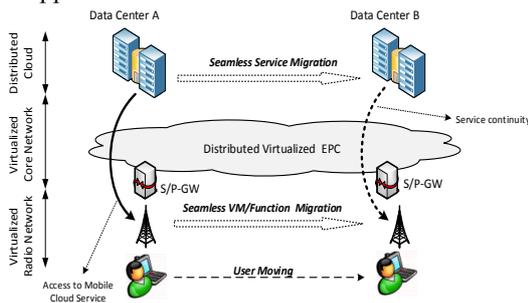


Fig. 1. Seamless service continuity in the virtualized LTE system

Currently, several technologies can be considered as possible candidates for the support of service and VM migration in virtualized LTE systems. Live VM migration solutions, for example, have been proposed in the literature [4], but none of these can be used efficiently to support the service continuity requirements listed above. In [3], we argued that the best candidate enabling technology that can efficiently be used for supporting service continuity in virtualized LTE systems is the Information Centric Networking/Content Centric Networking (ICN/CCN) technology. This paper introduces and evaluates a novel ICN/CCN approach that can be applied in virtualized LTE systems for the support of service continuity. In particular, the research questions that are answered by this paper are.

1-How can the ICN/CCN technology be applied for service continuity in virtualized LTE systems?

2-Is the proposed ICN/CCN technology able to support service continuity in virtualized LTE systems seamlessly?

This paper is organized as follows. Section II describes how the ICN/CCN approach can be integrated in the virtualized LTE system. The method and used message sequence charts are explained in Section III. Section IV describes the performance experiments and evaluation. Finally section V provides the conclusions and recommendations for future work.

II. ICN/CCN IN VIRTUALIZED LTE SYSTEMS

In [3], a comparison between different technologies that could be used for service continuity has been performed using

the requirements listed in Section 1. Based on the results of this comparison it is deduced that the best candidate enabling technology that can efficiently be used for supporting service continuity in virtualized LTE systems is the ICN/CCN technology.

Several ICN approaches have been developed, such as Data-Oriented Network Architecture (DONA) [5], Content-Centric Networking (CCN) [6], Publish-Subscribe Internet Routing Paradigm (PSIRP) [7], Network of Information (NetInf) [8] and Translating Relaying Internet Architecture integrating Active Directories (TRIAD) [9]. In [3], it has been shown that these ICN approaches undergo the lack of efficient support of session and function continuity. However, the Service-Centric Networking (SCN) concept [10], which is a new ICN based concept is able to support session and function continuity. In particular, SCN is a new networking paradigm for the future Internet, in which routing and forwarding are based on service identifiers. SCN is an extension of CCN, see Section II.A, which is designed based on an object-oriented approach, in which the contents and the services are considered as objects. The content, in SCN, not only can be retrieved but it can also be processed before being delivered to users. Moreover, services are represented as functions to be invoked by users. By using an object-oriented approach, both functions and data are integrated into objects and clients can request for both services and contents by using object names.

A. Content-Centric Networking (CCN)

The protocol used in CCN to distribute information related to the location of NDOs (Named Data Objects) published on nodes, is denoted as CCNx [6]. There are two types of CCNx messages, the *Interest message*, which contains the request for an NDO and the *Data message*, which contains the response for an *Interest message*.

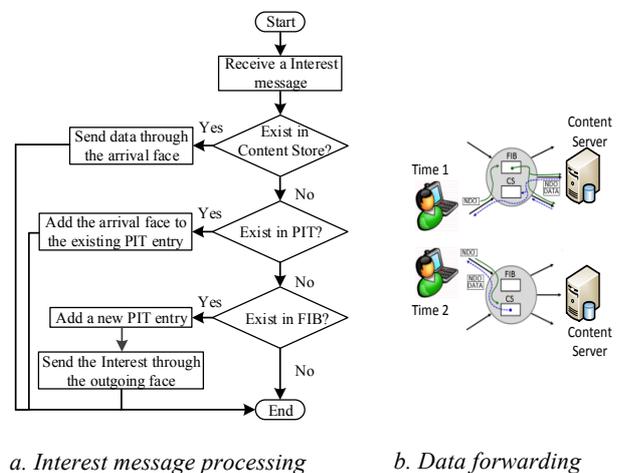


Fig. 2. CCN protocol Overview

As shown in Fig. 2, the CCNx protocol operates based on three main data structures as follows:

- *Content Store (CS)*: CS represents a buffer memory used for data retrieval by prefix match lookup on names.

- *Forwarding Information Base (FIB)*: FIB contains a list of entries with interfaces to where the *Interest messages* should be forwarded. Each entry in the FIB may point to multiple interfaces to where the *Interest messages* could be forwarded.
- *Pending Interest Table (PIT)*: PIT is used to keep track of *Interest messages* forwarded upstream. It contains information of sources of unsatisfied *Interests*. Each entry in the PIT may point to multiple sources.

B. Integrating ICN/CCN in virtualized LTE

The used virtualisation platform in our approach is OpenStack environment [12]. In order to integrate the ICN/CCN concept in the virtualized LTE, several options can be identified. Five main different possible options are distinguished in [11], that can integrate the ICN/CCN concept in the user plane of RAN and EPC. In the provided approaches, it is assumed that UE is not aware of the CCN concept. Therefore, a proxy functionality is required to intercept and translate the request message sent by a UE to a CCN message, and vice-versa. Another assumption is that, servers that deliver the content are CCNx capable. The five main possible options are as follows:

1) *Integrating CCN in eNodeB, S-GW and P-GW*: In this architecture, it is considered that eNodeB, S-GW, and P-GW are CCNx capable and are being able to maintain the FIB, PIT, and CS. It is considered that the routers deployed in the router infrastructure used to interconnect the EPS components are IP routers and are not CCNx capable.

2) *Integrating CCN in Routers Deployed in EPS Core Router Infrastructure*: CCN/IP routers that are CCNx and IP capable are deployed in the infrastructure used to interconnect the EPS components. It is considered that the EPS components (eNodeB, S-GW, P-GW) are not CCNx capable.

3) *Integrating CCN in eNodeB, S-GW and P-GW and in Routers Deployed in EPS Core Infrastructure*: This is the combination of the first and the second options. In particular, in this architecture, eNodeB, S-GW, and P-GW implement the basic concept of CCN in which FIB, PIT, and CS are maintained. Furthermore it is considered that the routers that are deployed in the EPS core router infrastructure are CCN and IP capable.

4) *Mobile CDN (Content Delivery Network) Solution*: In this architecture, content is stored and served at the edge of the EPS core network. CDN engines/repositories are used to maintain and support content retrieval and are considered to be CCNx capable. The CDN engine implements a proxy that can intercept a request sent by a UE, translate that request into a CCNx message, and maintain content retrieval.

5) *Integrating CCN in eNodeB, S-GW and P-GW and CDN Repositories*: This architecture is an integration of the architectures proposed in the first and the fourth options. As illustrated in Fig. 3, it is considered that eNodeB, S-GW, and P-GW are CCNx capable. Furthermore, it is assumed that the CDN engines/repositories are CCNx capable as well. Moreover, the routers deployed in the EPS core router

infrastructure are only IP based routers. It is important to mention that the cloud components that are used to control and support the service continuity solution are placed in one VM which is named as Virtualization Controlling Platform (VCP) [11].

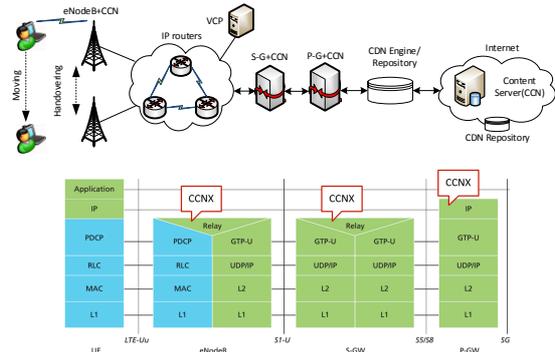


Fig. 3. Integrating CCN in eNodeB, S-GW and P-GW and CDN Engines/Repositories

By studying the advantages and drawbacks of each of the five proposed options, we concluded that the first and the fifth options are the most suitable to integrate the CCN concept into LTE.

The reasons of selecting the first integration option are:

- Enhances service continuity by accelerating content delivery to users.
- Reduces bandwidth consumption on the EPS core network and internet.
- By leveraging in-network caching, the user's traffic will be localized on the EPS core network.
- Optimizes network resources on the EPS core network and the Internet .
- Does not affect the protocols used in the EPS core network.
- Could improve the content delivery by delivering content from the location close to users.

The reasons of selecting the fifth option, are the same as the first option with the following additional one:

- Accelerates the content delivery to users and reduce bandwidth consumption on network, due to the use of the CDN engines/repositories.

III. METHOD AND MESSAGE SEQUENCE CHARTS

The logic architecture of the fifth option, described in Section II, is shown in Fig. 3. Two types of service migration solutions are supported using this approach: (1) the content migration and (2) the VM (container) along with content migration support. Due to paper length limitations this paper will only focus on the first content migration solution. The second migration solution and the detailed procedures used to support the uplink and downlink traffic supported by the above mentioned architecture are described in [11].

In the figures shown in this section, the CCN routers represent the eNodeBs that are capable of using the CCN function and protocols. Moreover, the SO represents the

service orchestrator used to control the complete (end-to-end) orchestration of a service instance (SI) [2]. The MSM (Mobility Support Manager) represents the mobility management function. The configuration of the virtualized CCNx functionalities available in the different EPS entities, see Fig. 3, is accomplished by the ICN Manager. MOBaaS represents the Mobility Prediction System, which is realised by the Mobility and Bandwidth Availability Prediction as a Service (MOBaaS). These solutions are based on the CCNx protocol [6], and are extended in order to support content migration when users are moving from one data centre to another one. In this section, in order to easy the description of the proposed solution, it is considered that the client (UE) is CCNx capable.

A. Content Migration support

In this section two solutions are described that can support content migration due to user mobility. The first content migration solution is accomplished without using mobility prediction, see upper part of Fig. 4. The second content migration support solution is accomplished using mobility prediction, see lower part of Fig. 4. The content migration procedure that is not using mobility prediction can be described using the following steps:

- *Step 1:* Client establishes a connection to CCN router 2
- *Step 2:* CCN router 2 sends the client information containing node ID and interface ID to MSM.
- *Step 3:* Client sends the *Interest message* via the CCN router 2. When the CCN router 2 receives the *Interest message*, a look-up is performed on its CS, PIT, and FIB sequentially. In this case, the matching information is only found in its FIB that informs the *Interest message* has to be forwarded to the interface pointing to the source.
- *Step 4:* CCN router 1 receives the *Interest message* from CCN router 2 and does the same procedure performed by CCN router 2. After performing look-up on its CS and PIT, and if no matching information is found, it checks its local FIB.
- *Step 5:* The CCN router 1's FIB causes that the *Interest message* to be forwarded to the interface pointing to the source.
- *Step 6:* When the source receives the *Interest message*, it looks-up on its CS. When the matching content is found, it sends the content/data using the *Data message* as the response for the *Interest message* through the arrival interface of Interest to the CCN router 1.
- *Step 7:* Before the requested Data is received by CCN router 2, the client moves to another location and terminates its connection with CCN router 2.
- *Step 8:* When the CCN router 1 receives the *Data message* forwards it to the CCN router 2, based on its PIT, and stores it in its cache.
- *Step 9:* After the handover procedure is completed, the client establishes a new connection with CCN router 3.
- *Step 10:* CCN router 3 sends the client information containing node ID and interface ID to MSM.

- *Step 11:* MSM determines that client has been moved, because it receives client information from two different routes.

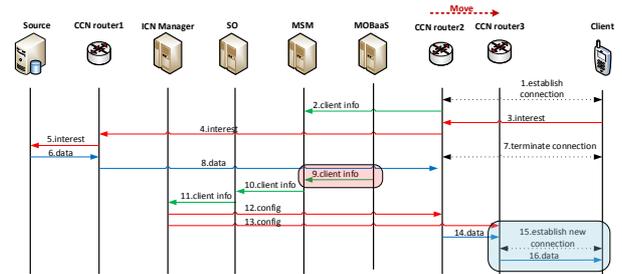
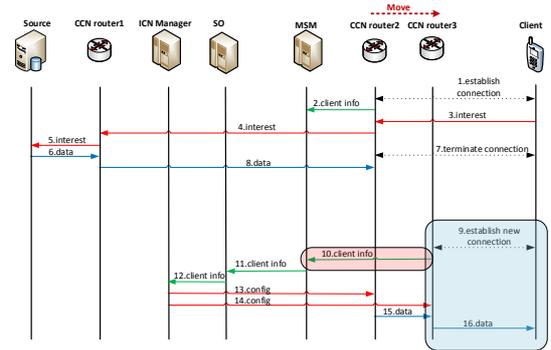


Fig. 4. Content Migration (upper part: without mobility prediction; lower part: with mobility prediction support)

- *Step 12:* MSM informs SO to notify ICN Manager about the client's location changing.
- *Step 13:* ICN Manager starts to configure PIT in the CCN router 2 to be able to forward the *Data message* to the CCN router 3.
- *Step 14:* ICN Manager also starts to configure PIT in the CCN router 3 to be able to forward *Data message* to the client.
- *Step 15:* CCN router 2 sends the *Data message* to the CCN router 3 based on its PIT and stores it in its cache.
- *Step 16:* CCN router 3 sends the *Data message* to the client based on its PIT and stores it in its cache.

When mobility prediction is used, see the lower part of Fig. 4, the procedure steps used to support content migration are similar to the previous one (no mobility prediction is used). However, in this scenario the MSM uses this prediction in order to trigger the migration of the content/data from CCN router 2 to CCN router 3 before the client starts the connection establishment procedure. In this case the ICN Manager can configure the PIT in CCN router 2 and 3 in advance and the *Data message* could be moved before the client starts the connection establishment procedure.

IV. PERFORMANCE EVALUATION EXPERIMENTS

This section describes the simulation experiments that have been accomplished in order to evaluate whether the selected ICN/CCN integration option is able to support service continuity seamlessly in a virtualized LTE system. These experiments have been performed using the NS3/LENA [13] and the NS3/ndnSIM [15] environments. The simulation topology used in the simulation experiments is shown in Fig.

3. In a cloud based LTE system EPC and (optionally) E-UTRAN components are running on VMs located inside macro or micro data centers. These data centers are spread within the tracking area covered by the LTE network which they belong to. Virtualized E-UTRAN components such as eNodeBs are located as close as possible to their peer physical entity, while the location of EPC components such as P-GW and MME can vary depending on for example, the dimension of the LTE and operator's IP backbone network, location of the data centers, efficiency reasons. All these data centers are connected with each other via the operator's IP transport network. In the following the data center traffic and EPS traffic are assumed to be forwarded via the same network. The same operator's IP transport network topology is used in all the experiments. This topology is a small part of the real network topology of one of the biggest European ISP: EBONE. The topology has been implemented in LENA using a reduced map provided by the Rocketfuel project [18].

The source code used for the implementation of the traffic generators, simulation models of all entities and infrastructures shown in the simulation topology, including the NS3/ndnSIM simulation models of the ICN/CCN, and NS3/LENA LTE, operator IP network, traffic generators and handover trigger model, used in all simulation experiments are available via [11]. The message sequence charts used in the simulation experiments are based on the ones described in Section III. Moreover, in these simulation experiments we consider that a service is handed over seamlessly if this procedure is accomplished during a time duration that is lower than 200 ms. This threshold is chosen for this purpose since for real time applications, like video streaming, a maximum one-way latency of 200 ms is used as threshold [14]. All the LTE system parameters, as used in the simulations, are typical for LTE release 8, which is implemented in the NS3/LENA M5 simulation environment [13]. In order to emulate realistic situations, it is considered that all wired and wireless links are 80% utilized, using background traffic during the simulation experiments. On the wireless links the generated background traffic forms the 70% of the total traffic (the other 30% is CCN traffic). The background traffic on the LTE wireless links is generated using the traffic mix based on [16]. It is important to mention that VoIP traffic represents the 30% of the total background traffic. The background traffic on all the wired links is mainly generated using the PPBP (Poisson Pareto Burst Process) model specified in [17], used to match the statistical properties of real-life IP network. All the CCN parameters, as used in the simulations are typical for CCN, which is implemented in the NS3/ndnSIM simulation environment [15].

It is important to mention that the procedures related to reliability and security of CCN are not used in these simulation experiments. The CCN traffic modeled in the experiments is video streaming traffic. The bit rate used for generating video streaming traffic is 464 Kbps. The size of packet (without headers) that generated by a server when it receives an Interest is 1316 Bytes. Since the CCN application that we used is a video streaming application, we consider that the traffic generated by such an application is CBR (Constant Bit Rate) traffic.

A. Performance metrics

In the experiments several metrics are used for performance evaluation. In this section only a subset of the metrics used to evaluate the selected ICN/CCN based service migration approach are introduced.

- *Average RTT for CCN Interest/Data packets when content and/or VM migration occurs:* In CCN, each request (Interest) will be satisfied by one response (Data/Content Object). The measured latency is the RTT (Round Trip Time) delay of the CCN request-response packets when CCN content and/or VMs need to be migrated.
- *Cumulative Distribution Function (CDF) for RTT for Interest/Data packets when content and/or VM migration occurs:* The CDF of RTT of CCN Interest/Data packets is used to observe the maximum RTT value that can be calculated, when content and/or VM migration occurs.
- *Average RTT in receiving CCN Data packets when content and/or VM migration does not occur:* Defined in the same way as the previously described average RTT metric, with the difference that now it is considered the content and/or VM is not migrated from one data centre to another.
- *Throughput of CCN Data packets when content and/or VM migration occurs:* The number of CCN data (response) packets correctly received by CCN mobile users divided by simulation time, when content and/or VM is migrated from one data centre to another.

B. Simulation experiments

In this research two sets of simulation experiments have been defined.

- *The Content Migration Support:* Investigates whether the integrated ICN/CCN approach into eNodeB, S-GW, P-GW and CDN Engines/Repositories supports service continuity seamlessly, while a content is migrated from one virtualized network entity to another.
- *The VM (Container) and Content Migration Support:* focuses on whether the same ICN/CCN approach can support service continuity seamlessly, while a VM (Container) and content is/are migrated from one virtualized data centre to another.

Due to paper length limitations, this paper only focus on the first set of experiments. From the second set of experiments only the conclusions of this research is reported. The results show that, without a mobility prediction system (to predict movements of users), service continuity will be difficult to be supported since the RTT of Interest/Data packet can take longer than the threshold (>200 ms) when VM and content migration occurs. For instance, if the size of migrated VM is 128 MB, seamless service continuity can be supported only if the VM can be migrated and ready in the target data centre at least 22 seconds before the handover is triggered. Therefore, solutions such as mobility prediction are needed to predict the movement of users and determine when the VM migration should be triggered in advance. More details can be found in [11].

C. Content migration support

This section discusses the simulation experiment results for the support of the content migration due to user mobility. The message sequence chart used during these simulation experiments is presented in Section III.A. The X2 interface handover procedure is used for the support of mobility. Several experiments have been performed by varying the distance between source and target data centres running eNodeBs and location of the VCP. Those experiments are divided into three sets of experiments based on the position of VCP, such as follows:

- *Position 1:* VCP and SGW/PGW are hosted in the same data centre.
- *Position 2:* VCP and target eNodeB (T-eNodeB) are hosted in the same data centre
- *Position 3:* VCP and source eNodeB (S-eNodeB) are hosted in the same data centre

In the experiments, we used a confidence interval of 95% and the confidence interval was calculated to be less than 5% of the sample mean value.

In each set of experiment, the distance (number of hops) between source and target data centres running eNodeBs is varied. The numbers of used hops are 1, 2, 4, 6, 8 and 10 hops. Fig. 5, depicts the *average RTT of Interest/Data packets* when content migration occurs. As it can be seen for all positions, the average RTT, as expected, tends to increase when the number of hops between source and target data centre is increased. Furthermore, the average RTT values when VCP is placed in position 2 and 3 are almost equal.

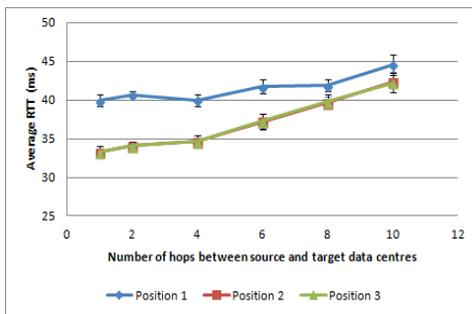


Fig. 5. The average RTT of Interest/Data packets when content migration occurs

Fig. 5 also shows that when VCP and SGW/PGW are hosted in the same data centre (Position 1), the RTT is higher than the RTT when the VCP is hosted in the same data centre as the target eNodeB (Position 2), or in the same datacenter as the source eNodeB (Position 3). This is because VCP is located in the middle (neither close to source or target data centres), in between source and target data centres (where eNodeBs are hosted). Moreover, the signaling delay associated with the communication between VCP and other entities is higher when the VCP is located in position 1.

The results associated with the *Average RTT of Interest/Data packets when content migration does not occur* are not shown in this paper. However these results in [11], shows that the RTT values in this case for all positions of VCP and all

distances (number of hops) between source and target data centres are almost equal and is around 18 ms (lower than the RTT values when content migration occurs). Furthermore it can be seen that the position of VCP and the distance between the source data centre (where the source eNodeB is hosted) and the target data centre (where the target eNodeB is hosted) do not affect the average RTT of Interest/Data packets when content migration does not occur.

Fig. 6, Fig. 7 and Fig. 8 show the CDF of RTT of Interest/Data packets when the VCP is located in positions 1, 2 and 3, respectively. The CDF of the RTT of Interest/Data packets when content migration occurs show that the maximum RTT is lower than 70 ms.

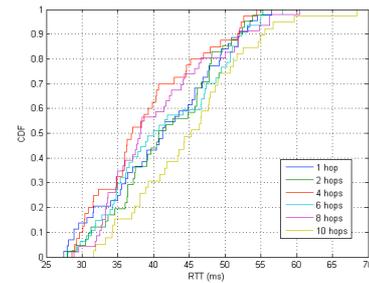


Fig. 6. CDF of RTT of Interest/Data packets when content migration occurs, VCP and SGW/PGW are in the same data centre

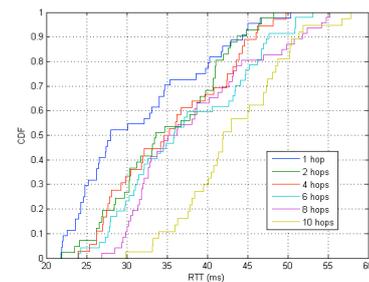


Fig. 7. CDF of RTT of Interest/Data packets when content migration occurs, VCP and T-eNodeB are in the same data centre

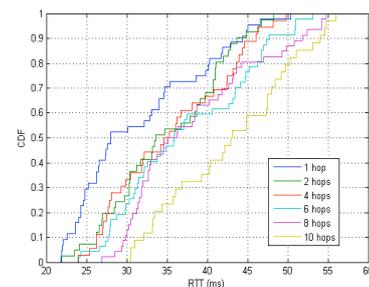


Fig. 8. CDF of RTT of Interest/Data packets when content migration occurs, VCP and S-eNodeB are in the same data centre

Fig. 9 shows the throughput of CCN Data packets when content migration occurs. In this figure, the load represents the number of Interest packets sent per second. As it can be seen, the throughput values for all positions of VCP and all distances (number of hops) between source and target data centre are very similar to each other, around 2.5 Data packets/second. It means that the position of VCP and the distance

between the source and target data centre does not significantly affect the throughput of the Data packets, when content migration occurs.

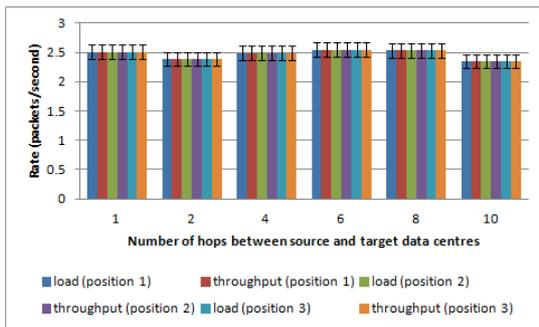


Fig. 9. Throughput of CCN Data packets when content migration occurs

V. CONCLUSIONS AND FUTURE WORK

By using NS3 experiments this paper evaluated the ICN/CCN approach, proposed to be used as a solution for service continuity in virtualized LTE systems. The simulation experiment results associated with the content migration support show that, for all performance metrics the proposed solution can work well in supporting seamless service continuity in cloud based LTE systems when mobile users move from one location to another location served by a different data centre. When content migration occurs, the average RTT of Interest/Data packet will slightly increase when the number of hops (distance) between source and data centres increases. However, the CDF of the RTT experiments show that the maximum RTT can be tolerable (< 70 ms) and is lower than the maximum specified delay threshold for video streaming, *i.e.*, 200 ms. The throughput values (when content migration occurs) for all positions of VCP and all distances (number of hops) between source and target data centre are very similar to each other, around 2.5 Data packets/second. This means that the position of VCP and the distance between source and target data centres do not have a significant impact on the throughput when content migration occurs. The total throughput is affected by how many number of Interest packets of UE (user) that has not been satisfied in the previous location (when handover is triggered). The simulation experiment results associated with the VM (Container) and Content Migration Support show that, without a mobility prediction system (to predict movements of users), service continuity will be difficult to be supported since the RTT of Interest/Data packet can take longer than the threshold (>200 ms). Therefore, solutions such as mobility prediction are needed to predict the movement of users and determine when the VM migration should be triggered in advance. The main recommendations for future work are the following. The VM and content migration approach should also be investigated when the CCN concept is combined with a mobility prediction solution. Furthermore, it should be investigated what the impact is of a proxy that translates the HTTP(s) traffic into/from CCN traffic. Finally, it is important to investigate the impact of the CCN retransmission mechanism on the service continuity performance.

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