mCSDN: A Software Defined Network Based Content Delivery System with D2D Contribution

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***Abstract*—Mobile Content Delivery systems are becoming more popular with the increasing capacity demand by mobile subscribers. In order to reduce the total outgoing traffic a Content Delivery System for Mobile Operators (mCSDN) was proposed. The strength of the proposed system inspired by the idea of using Device-to-Device Communication (D2D), and Software Defined Networks (SDN) based middleware as the orchestrator of mobile device management and content locating. The approach of the study is assumed to be "using the content from the node as close as possible to the mobile user". The video used in the proposed system is coded by using Multiple Descriptor Coding (MD-FEC). The numerical simulations and analysis show that the capacity to be provided by the proposed model outperforms the current state of the art. The system also improves the quality of the service (QoS) while reducing the power consumption.**

I. Introduction

The demand for multimedia services over mobile networks has increased tremendously over recent years. However, due to the current architecture and the capacity of the mobile networks, the service demand with because of explosive growth in traffic cannot be delivered [1]. The scientists and architects are working on solutions to cope with the extreme bandwidth requirements that includes the transformation of the traditional mobile networks into a system, which could utilize all components of the system and also includes the creation of the new architectures separating data and control planes.

Although there are lots of studies on content distribution networks (CDN), the research concentrating mobile-CDN is rather limited [2]. Yousaf et al. offers a mobile-CDN with a distributed structure where they assume that the mobile network architecture will evolve to have multiple gateways to the Internet in the near future. They also mentioned that the 70% of the traffic in mobile networks in 2016 would be prerecorded short video, which uses the transmission control protocol (TCP) as the service layer protocol.

It is clear that increasing the number of typical content delivery systems does not compromise the tremendous request for higher bandwidth from day to day [3]. Most of the researchers used the idea similar to [4], where Oztoprak et al. proposed a model to build a scalable video delivery system by utilizing peer-to-peer (P2P) communication in a wired communication environment. The idea in [4] was adapted into mobile networks by utilizing device-to-device (D2D) communication. In D2D, the researchers utilized almost all available frequency spectrums for data communication [5] [6]. The main drawback for almost all studies is the lack of a middleware to coordinate and control the content delivery among the user devices.

In most of the mobile content delivery network, the content (assumed to be video chunks) is coded in MD-FEC [7]. In Multiple Description Coding (MDC) a stream is broken up into M sub-streams (or descriptions) that can be decoded independently. In MDC, the quality of the video would be enhanced as more descriptions are correctly received [8]. MD-FEC breaks the stream up into M sub-streams whereas correct reception of any L sub-streams guarantees the recovery of the lowest L layers [7].

Software Defined Networking (SDN) proposes the separation of control and data planes of the network devices in order to bring flexibility and agility to operators [9]. The Onlab team [10] proposed The Open Network Operating System (ONOS) project which provides a highly scalable, highly available and highly performing platform and abstractions of the layers of the services for an operator. The project gained enough interest from all the operators and manufacturers around the world. Although there are many studies on SDN, there is still a need to orchestrate all mobile devices as a part of an Information Centric Networking (ICN) and as a content delivery platform.

Considering the brief summary above, one can identify the following to describe the requirements for the future content delivery and management platforms with D2D communication support: (i) the content delivery system must assist the delivery of the Internet originated data in addition to the local content sources; (ii) the reliability of the content problem should be solved if the content is extracted from the Internet; (iii) the management problem of the content delivery platform should be solved; (iv) the system should support location awareness in order to reduce the delay and increase the throughput; (v) the system should be aware of the power consumption on getting a resource from a node/base station; and (vi) the system should use the resources as close as possible.

In the current state of the art literature, the proposals do not provide feasible solutions for mobile devices and content management issues. Further, they are not reliable with respect to the resources obtained from mobile users.

A content delivery system for mobile operators (mCSDN) is proposed and described within the context of this manuscript. The proposed system employs the D2D to achieve the maximum capacity of the physical environment, by bringing a novel

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solution to manage the mobile devices utilizing software-defined networks. The proposed system utilizes SDN based content and user management middleware effectively: (i) to maximize the throughput; (ii) to reduce the power consumption; (iii) to maximize the overlay network capacity; and (iv) to provide a reliability mechanism for the content obtained from the mobile users. Moreover, the video streaming system is designed to use multiple descriptions (MD-FEC) for higher quality streams. In order to guarantee the delivery of the video, a single description will be delivered through the content cache located in the eNB of the mobile network. The additional streams will be seeded through the D2D overlay network in order to maximize the throughput of the content delivery system with guaranteed high availability.

The rest of the paper is organized as follows: Section 2 gives some brief information on mobile content delivery systems, device to device communication studies and software defined networks. Section 3 gives the architectural details of the proposed mCSDN. The experimental results are presented in Section 4. Finally, the studies are concluded in Section 5.

II. Related Work

A typical mobile network infrastructure is called Evolved Packet System (EPS) architecture. The packet data network gateway (P-GW) is the bridge between the radio world and the Internet. Since all data traffic among the users in a mobile network and Internet passes through P-GW, which are located in the core of the mobile operators, this path for all data access causes a bottleneck in accessing resources. The mobility of the users and their locations are managed by the use of Serving Gateways (S-GW) and Mobility Management Entities (MME). The radio base stations (eNB) provide high-speed radio access for the mobile devices [2]. One of the most critical drawbacks of such a system is the centralization of the Internet access the P-GW. There are some studies trying to distribute the Internet access to multiple locations. Distributing the Internet access into multiple locations provides the users the shorter path traversal in the radio network to access the resources outside the mobile network. The second problem in mobile networks is the mandatory traversal of the P-GW for accessing all data resources by using the Internet Protocol (IP). Yousaf et al. [2] proposed mSCP concentrating on TCP/HTTP based traffic with the assumption that the video traffic over TCP will constitute 70% of all mobile traffic. They highlighted two main ideas for their proposal: (i) The content of the CDN data is administered by the same authority which solves the trust problem; and (ii) The CDN can be built as an integral part of the mobile infrastructure. Upon the completion of the requirements, they proposed a CDN infrastructure with the nodes placed in every eNB in addition to the central CDN servers. Wang et al. also proposed a similar solution named as ?cooperative cell caching? where the base stations are used as a caching point for popular content.

Amram et al. [19] introduced a QoE based transport optimized Mobile CDN platform where they proposed to push the popular content to peering/and or sibling caches proactively. They also offered peer-to-peer model for content exchanging among the caches and network aware redirection of user devices to the appropriate cache in order to reduce the load of the mobile network. Almashor et al. [11], Tong et al. [12] and Sung et al. [13] proposed similar systems where the mobile users also share the content they already have with the other mobile devices across the network. They have been inspired from the peer-to-peer video streaming and content delivery approaches proposed for wired networks as in [4]. Sung et al. further highlighted the energy consumption of the D2D communication in order to increase the lifetime of the mobile devices.

The researchers in D2D domain concentrated on the mobile device contribution to a content delivery network for the following goal: to maximize all available channels including the radio network and unlicensed data channels for improving throughput, energy efficiency, spectral efficiency, delay and fairness. The researchers highlighted the throughput-power tradeoff in D2D communication to build a reliable environment while maximizing the throughput of the overlay network. [5] and [6] performed a survey on D2D studies in which they classified the studies into two main categories: (i) sharing the cellular spectrum of the mobile operator (i.e. inband); and (ii) unlicensed spectrum (i.e. outband). In the inband channel usage, the cellular usages and D2D communications are performed in the same cellular links. On the contrary, the outband channel usage proposed to employ all available channels either cellular or Wi-Fi, Wi-Fi Direct, Bluetooth etc. mediums. While inband communication is strong in providing powerful control to the users, outband communication is very strong in maximizing the channel capacity.

Fodor et al. [14] proposed to control the D2D communication through a cellular network. The result of the simulations conducted by the authors showed that knowing the location of the mobile device can reduce the energy consumption 25 fold for the mobile devices, which are geographically very close to each other.

D2D communication is widely used for video transmission and content distribution in cellular networks [15] [16]. [15] proposed a location-aware scheme, which keeps track of the location of the users and their requests. If the data requested by a node is available in the nearby node, a base station (BS) instructs them to eliminate the re-transmission and the data is copied from the nearby node. The drawbacks of the method are the higher power consumption and control overhead in utilizing the location awareness. [16] proposed a mechanism utilizing the reuse of content in the mobile devices in D2D communication. They assumed to use sustainable throughput in D2D communication without considering the power requirements.

Wang et al. [1] highlighted that caching in mobile networks has been proven to be capable of reducing the mobile traffic by two-thirds. They proposed a content caching and delivery mechanism for 5G networks. They pointed out that the future Internet would use content-centric networking (CCN) architecture. The main purpose of preferring such architecture is to store data in every network node, receiver oriented and chunk based transport for data. The future networks will also be based on the solutions combining 3G, 4G, Wi-Fi, all integrated deployments by operators as well as users. Such networks are also called Heterogen Networks (HeNet).

By considering the literature summarized for the physical infrastructure and the relationship among the mobile users and the radio network, we can draw the following general conclusion: all mobile devices and the network nodes should be used to cache and then forward to neighbors upon request in order to maximize the throughput and minimize the power consumption. The main drawback for almost all studies is the lack of a middleware to coordinate and control the content delivery among the user devices. The literature further indicates that the researches concentrating on software-defined networking (SDN) seems to solve this problem by the separation of control and data planes.

Bradai et al. [3] highlighted that the centralized data plane functionalities introduce scalability issues in LTE. They pointed out that using SDN architecture would overcome the scalability problem. They also pointed out that adapting SDN to mobile networks would be a challenging problem due to the user mobility, management of radio resources and addressing resource scarcity and similar problems. They concluded that, SDN originates from the need to solve the fast evolving telecommunication network configuration management problems. Kim et al. [9] proposed a method to improve the efficiency of ICN content management using the SDN concept in a Wireless Mesh Network (WMN) environment. They used SDN for the purposes of providing the content caching identification, cache location decision, and cache distribution. They pointed out that the proposed scheme was very effective when the users are locally converged.

III. SDN Assisted Mobile Content Delivery Network - mCSDN

The technological improvements in the mobile telecommunication area allowed users to watch videos through their computing devices at any location. The intensive request to video with high bandwidth requirements results in the need of a high amount of network capacity.

The proposed mCSDN is composed of the following components: (i) a CDN server(s) located in the core of the mobile operator as the main source of the content seed (if the operator also acts as a content provider); (ii) SDN based caches located in the base station in order to keep network assisted caching servers as close as possible to the mobile users; (iii) the mobile nodes with the capability of the D2D communication preferably with multiple radio network interfaces (i.e. LTE and Wi-Fi). The management software shall track the mobile users contributing to the content delivery system in order to enhance the reliability of the content, location-awareness and power consumption requirements on the data exchange with a node. The users should be forced to use the data as close to each other as possible.

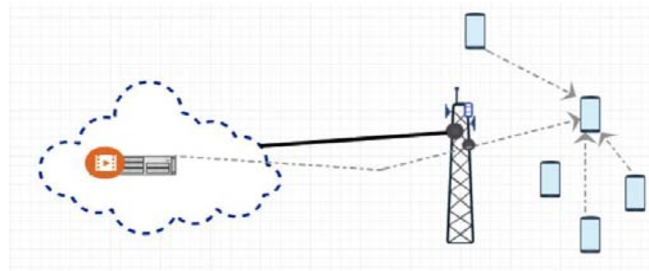

Fig. 1. The proposed model including the central CDN server and the mobile users with D2D communication capabilities.

A. Model A

The proposed model was inspired from the scalable video streaming services offered by P2P assisted applications [4]. The proposed system starts building a proximal discovery for the contents served by the CDN systems. The middleware software mediating the content discovery operation indexes all content either in the CDN server or in the mobile devices using the system.

The video content in the system is encoded by using MDC [17] [8] with 4 descriptions. The quality level of the video play out is divided into three categories: (i) the minimum acceptable quality which requires single description for acceptable streaming; (ii) good quality with having three descriptions at the same time; and finally; (iii) perfect quality with the existence of all descriptions.

In the first model (model A), the proposed system in Fig. 1 works as depicted in the following pseudo algorithm:

- A user queries the directory (SDN assisted middleware) for content.
- The proximal discovery system returns with the devices having the content and the owned description(s).
- The user selects the best suitable device (through the stream collection part of the proximity discovery system) to collect the descriptions. The selection is mainly focusing on the availability of the content and the distance (select the devices as close as possible) in order to reduce power consumption and increase the throughput
- The user repeats step 2 until reaching as much description as required by the selected quality level.
- The system prefers to select the users as close as possible to the user to reduce the latency and energy consumption during the data transmission.
- If there is a quality degradation risk during the play out, the system keeps the CDN as the slave description access source (if available).
- The collected descriptions are played out through the favorite media player of the user.

B. Model B

In the second model, a content cache is placed in the eNB node with the functionality of caching the most frequently used content in the cell area. Although this feature is offered

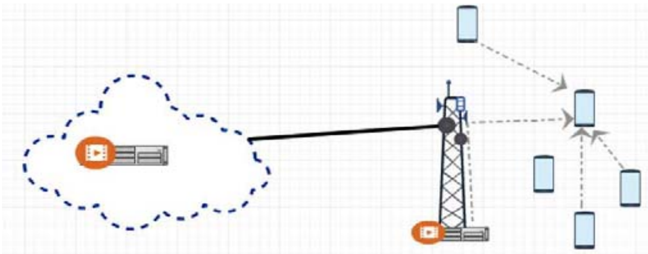

Fig. 2. The proposed model including the central CDN server, content cache in the base station, and the mobile users with D2D communication capabilities

by several studies [5] [6], the massive usage of this approach will be used after having SDN deployments in our networks. Most of the SDN based architectures in the telecommunication world try to bring the intelligence as close to the edge as possible. The content cache is located in the base station, which is the closest point to the subscribers in the mobile network. The modified algorithm (model B) with content cache in Fig. 2 works as depicted in the following pseudo algorithm:

- A user queries the directory (mCDN platform) for content.
- The proximal discovery system returns with the devices having the content and the owned description(s).
- The first description stream is selected from the content cache located in the eNB nodes.
- The user selects the best suitable devices (through the stream collection part of the proximity discovery system) to collect the remaining descriptions. The selection is mainly focusing on the availability of the content and the distance (select the devices as close as possible) in order to reduce power consumption and increase the throughput.
- The user repeats step 2 until reaching as much description as required by the selected quality level.
- The system prefers to select the users as close to the user as possible to reduce the latency and energy consumption during the data transmission.
- If there is a quality degradation risk during the play out, the system keeps the content cache as the slave description access source (if available).
- If the description does not exist in the content cache, the system keeps the CDN as the slave description access source. The system uses the Internet access links to update the content of the cache servers distributed among the eNBs when necessary.
- The collected descriptions are played out through the favorite media player of the user.

IV. Experimental Results

The simulations are written by using MATLAB. In the simulations, the maximum distance of a user to a base station (macro cell) is assumed to be 500 meters. It is assumed that there are 4 microcells (hotspots) in the macro environment each having 50 meters as the communication distance. The average distance of microcells is established at as 20 meters (at least 10 meters from each other). There are 1000 users totally in the macro cell, while 600 of them are located within 60 meters of the cluster centers of microcells. The rest are randomly sprinkled throughout macro cell. Dense traffic model is used with Poisson arrival. The summary of the simulation environment parameters are explained in Table I. The average LTE channel capacity is 150 Mbps for downlink and 50 Mbps for uplink (for 2x10 Mhz LTE system) [18]. The user-to-user communication is assumed to occur through an unlicensed LTE channel (40 Mhz in 5 Ghz spectrum) and Wi-Fi (40 Mhz channel in 5 Ghz). The dense traffic is measured at 650 Mbps for a median user data rate when the microcells are configured to use Wi-Fi and 1995 Mbps when configured to use LTE-U. The results of the experiments on capacity are summarized in Table II. In the second experiment, the number of microcells is increased to 8 with a similar distribution scenario. With this configuration, the dense traffic is measured at 900 Mbps for a median user data rate when the microcells are configured to use Wi-Fi and 4450 Mbps when configured to use LTE-U.

TABLE I
Simulation environment parameters

Parameter	Parameter Value
LTE Radius	500 meters
Number of Microcells	4 or 8
Microcell Radius	50 meters
Distance bw Macrocell BS	20 meters
Number of Users	1000
Number of Users in Macrocells	600

TABLE II
The simulation results of the dense traffic calculation for different configurations and capacities

Parameter	Capacity	Spectrum/Macrocells
LTE-U Channel Capacity	40 Mhz	5 Ghz Spectrum
Wi-Fi Channel Capacity	40 Mhz	5 Ghz Spectrum
Total traffic with only Wi-Fi	650 Mbps	4 Macrocells
Total traffic with Wi-Fi/LTE-U	1995 Mbps	4 Macrocells
Total traffic with only Wi-Fi	900 Mbps	8 Macrocells
Total traffic with Wi-Fi/LTE-U	4450 Mbps	8 Macrocells

Those numbers are the achievable simulation capacities for the above mentioned simulation parameters. The main difference between Wi-Fi-based D2D communication and LTE-U-based D2D communication is the coverage area of the technology. The typical coverage area distance for a Wi-Fi network is 50 meters, while it is 500 meters in LTE-U. Without D2D support, the maximum achievable data transfer rate for LTE was 200 Mbps, whereas it is almost 2 Gbps with D2D support and with 4 microcells and it can reach up to 4.5 Gbps with 8 microcells.

Since the scope of this study is not evaluating different technologies for D2D communication, we should concentrate on the performance of the proposed system. Let us assume

TABLE III
TOTAL VIDEO CAPACITY AVAILABLE BY THE ENVIRONMENT BY ONLY 20% CONTRIBUTION OF D2D SYSTEMS

Type of Infrastructure	**Capacity**
CDN in EPC Core	75 Mbps
Caching at every eNB	300 Mbps
Caching at eNB + D2D (Wi-Fi Only)	700 Mbps (4 Macrocells)
Caching at eNB + D2D (Wi-Fi +LTE-U)	1.2 Gbps (8 Macrocells)

the bandwidth of the uplink capacity as 150 Mbps (since it is the maximum capacity achievable by the LTE network). With the assumption that half of the capacity is used by other applications, the maximum achievable bandwidth by video users is 75 Mbps. After this point the users will experience packet drops and quality problems in the video. For model A, the requests beyond 75 Mbps cannot be served. The maximum capacity of the system can then be set as 75 Mbps. In addition to the radio channel capacity, the capacity incurred by the D2D infrastructure should also be considered.

For model B, since the radio node contains a caching module by the proposed SDN based eNB, the cache contains the most popular and frequently accessed content. In addition, it is assumed that the mobile devices to access the content available in the cache use the LTE-U capacity. The uplink capacity for the video is used to access the content unavailable in the cache. As depicted in Table III the total capacity for video delivery becomes 300 Mbps + 75 Mbs where the latter will be used to update the content of the cache engines to keep the content up to date. In addition, the contribution of the D2D system is assumed to be 20%. This results in 400 Mbps and 900 Mbps contribution of the D2D networks respectively in video streaming subsystems. These values increase the total streaming capacity of the system to 700 Mbps and 1.2 Gbps respectively. The simulation results also indicate that the average delay for a packet becomes much smaller than the configuration without the D2D system contribution.

V. CONCLUSIONS AND FUTURE WORK

A content delivery system for mobile operators (mCSDN) was proposed and described within the context of this manuscript. The proposed system was inspired by the idea of using D2D communication, and SDN-based middleware as the orchestrator of mobile device management and locating the content. The philosophy of the proposed system is ?using the content from the node as close as possible to the mobile user?. This enables one to achieve minimal energy usage and maximum throughput. The video is coded by using Multiple Descriptor Coding (MD-FEC) and the realistic benefit of the proposed system will be highlighted according to some video scenarios. The numerical simulations and analysis for different sizes of video chunks are performed to give more information about the usability of the system.

One of the main contributions of the proposed system is the integration of inband and outband channels by building a SDN-based control. Moreover, the proposed system increases the quality of the user experience.

For future studies, a metric will be proposed to measure the maximum achievable throughput of the D2D-assisted mCSDN. That value will be the target to re-organize the architecture used to achieve the best service available by the infrastructure.

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