Network-coded Cooperative Communication in Virtualized Mobile Small Cells

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Abstract—With the exponential growth of mobile devices in 5G network, massive content delivery in a cellular network is the upcoming challenge for researches. Due to large data traffic, energy efficiency becomes increasingly important as well as the user throughput requirement increases. In this paper, we propose Network-coded Cooperative (NCC) communication on virtualized Mobile Small Cells (MSCs) to minimize energy consumption on MSCs realizing the benefits of Mobile Edge Computing (MEC). The proposed approach adopts MEC and Software Defined Networking (SDN) to evaluate the gains in terms of user throughput that can be achieved when data contents are moved from cloud to the edge of the Radio Access Network. Moreover, the data contents are transferred to user equipments (UEs) in a cooperative approach to reduce the energy consumption in MSCs. The evaluation results show a decrease in the energy consumption per UE of 62% for the best case, due to a decrease of the LTE channel usage in favor of WiFi, which consumes less energy.

Index Terms—Network Coding, Mobile Edge Computing, Virtualized Mobile Small Cell, Network-coded Cooperative Communication, Energy Efficiency

I. INTRODUCTION

With the rapid development of smart mobile applications, the requirements of wireless mobile networks are increasing. The network requirements for future networks include higher data rates, lower latency, and larger capacity. Moreover, low energy consumption is an additional requirement for mobile network design. According to Cisco [1], by 2022, the number of devices connected to IP networks will be more than three times the global population, i.e. 28.5 billion networked devices, up from 18 billion in 2017. Moreover, mobile traffic will increase sevenfold between 2017 and 2022 reaching 77.5 exabytes per month, IP video traffic will be 82 percent of all IP traffic, Virtual Reality (VR) and Augmented Reality (AR) traffic will increase 12 fold, consumer Video-on-Demand (VoD) traffic will nearly double, and Content Delivery Networks (CDNs) will carry 72 percent of internet traffic. This has led recognizing the need for a new mobile networking paradigm, as it is intended to support a very wide range of innovative services.

The industry association 3GPP [2] defines 5G as fifth generation cellular network technology. 5G is expected to not only introduce major changes in the air interface, but also from a flexible network management perspective. Specifically, it leverages Software Defined Networking (SDN), Network Function Virtualization (NFV), and Mobile Edge Computing (MEC) concepts to manage scalable and flexible networks. 5G will support emerging use cases, including applications requiring high data rate communications, a large number of connected devices, and ultra-low latency and ultra-high reliability applications.

The emerging applications need immersive content distribution over the network, such as enhanced multimedia services that support high user density. The most significant use case is broadband access in a crowd, where a large number of handsets and devices per unit area require multimedia content with a satisfactory end-user experience. Examples include multimedia content distribution in an entire mobile small cell (MSC) or infotainment applications in shopping malls, stadiums, open-air festivals, or AR/VR games such as Pokemon Go1. Content distribution in the mobile small cells require low latency and high reliable communication in order to provide instantaneous response to the requesting user [3]. In the mobile small cells, base stations are deployed nearby to the user equipments (UEs) to provide better services to the emerging applications.

Network Coding (NC) has been introduced to overcome the problem of traffic density by increasing network throughput. Moreover, the combination of NC and cooperative relaying in a Mobile Cloud (MC) leverages network performance. The aforementioned interplay is known as Network-Coded Cooperative (NCC) networks. The number of UEs cooperating in a MSC while using NC has been modelled for multiple users (100). However, testbed implementations were developed for a low number of UEs in the MC due to hardware constraints. To overcome the hardware constraints, such as limited number of devices of NC and cooperative relaying in Mobile Communication as presented in [4], we propose NCC communication in virtualized MSCs. We extend the proposed approach by leveraging MEC and SDN to emulate a virtualized network to perform our evaluation. The virtualized platform is developed to study the correlation between MCs, possible

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interferences, and mobility between MCs, we need to increase the number of nodes, MCs, and thus the costs.

In this paper, we propose virtualized MSC to analyze the performance of NCC communications. Moreover, the proposed approach analyzes the energy consumption of the MSC. As illustrated in Fig. 1, the system architecture is composed of a MEC server, multiple UEs, and a cloud server. MEC server is considered to be deployed nearby eNB. Multiple UEs combine to form an MSC. The cloud server provides backhaul communication to MSC. The UEs in MSCs can communicate with each other through the short-range technology, i.e. WiFi. The NC server is deployed on the MEC server, which encodes the packets and transmits them to the UEs in a round robin manner. The UEs receive a part of the content transmitted by the server and distribute the content to other UEs in the MSC via WiFi multicast. The purpose of having virtualized UEs in the proposed scheme is to perform analytics in terms of energy consumption, throughput, and latency in each of the phase. However, due to hardware limitations, the analysis cannot be performed extensively on physical UEs. Therefore, we simulate virtualized UEs to perform the analysis. The traffic in the network is controlled by the SDN to provide a scalable and flexible solution to the network.

The remainder of the paper is structured as follows. Section II gives a brief overview of state of the art. Section III provides the description of the proposed work. Section IV explains the solution of NCC communication in virtualized MSCs. Section V evaluates the proposed approach. Section VI concludes the paper.

II. BACKGROUND AND RELATED WORK

NC [5] has been introduced as a key enabler towards efficient content distribution by increasing network throughput [6]. Random Linear Network Coding (RLNC) [7] is one variation of NC, designed for wireless random networks with high mobility. RLNC protocols do not send raw packets from source to destination, but they group them together in blocks (often called generations). They create a new set X of packets obtained from the linear combination of the original source packets matrix S, and a random coefficient matrix C. Each coded packet contains information from every source packet in the generation. At the destination, the receiver inserts every linear independent packet in the decoding matrix X. When it is full, it performs Gaussian elimination to the matrix, retrieving the original source matrix S. The main strength of RLNC resides in its ability to recover from losses without the need of acknowledgments or retransmissions. In the event of losses, the sender simply needs to send some extra coded packets to fill the decoding matrix. These packets are known as redundancies.

Cooperative relaying [8] has been introduced to increase network throughput and to lower energy consumption. Fitzek and Katze [9] define a MC as a group of nodes inside a small cell that share their resources opportunistically, cooperating with each other to obtain a common benefit. This technology offloads the traffic from a high range communication (i.e. cellular network) to a short range communication (i.e. WiFi). The data rate ratio between the short range technology and the long range technology is denoted as R. If R > 1, the average throughput observed by UEs increases. Moreover, long range technologies often consume more power than short range technologies. If the difference is noticeable, energy consumption will decrease, and thus the smartphones’ battery life will increase.

The combination of RLNC and cooperative relaying is known as NCC Networks [10] and has been proven to improve network performance [11], in particular, multicast scenarios for massive content distribution in cellular networks [12]. Various universities and research institutes developed testbeds to evaluate these systems [13]. However, they could not escalate the system due to hardware constraints.

Data offloading from the cellular network through small cell networks is becoming popular in 5G to reduce the load, as well as to increase the capacity of cellular networks [14]. Data traffic offloading from the cellular network through WiFi networks reduces costs and traffic load from cellular networks. Due to the exponential increase of mobile devices, fulfilling the capacity of cellular network resources like network bandwidth is becoming challenging for network operators [15]. Moreover, data offloading to WiFi networks can reduce mobile users monthly bill incurred by cellular usage, and enhance the battery life since WiFi consumes less energy as compared to the cellular network [16]. In the proposed approach, data traffic is offloaded from cellular network to WiFi in an opportunist manner, where UEs in MSC participate in the data distribution.

The Small Cell Forum [17], defines “Small Cells” as low-powered radio access nodes whose coverage ranges from ten to several hundred meters. The virtualization of MSCs allows enhanced mobile edge computing capabilities to enable network service deployment and end user management. The Small Cell cloud-enhanced e-Node Base Station (SCCeNB) brings the cloud computing capabilities close to mobile users through small cell networks reduces the computation delay and energy consumption [18]. MEC and cloud-enabled MSCs are emerging technologies that benefit from the underlying softwarization process in the telecommunication field. In MEC,
cloud services are offered at the edge of the network in the close proximity of mobile devices. The purpose is to reduce latency and provide highly efficient network operation with real-time exposure and context-aware services [19]. Moreover, to overcome the hardware constraints of NCC schemes testbed, virtualized MSCs are developed.

MEC server leverages SDN to provide softwarized programmable network where data and control planes are separated, and forwarding decisions are made on centralized SDN controllers. The management of cloud-enabled MSCs utilizes the SDN paradigm to provide configuration and management of the underlying network. The SDN controller sends packet rules to the switches and configures them with information about the traffic they are handling using OpenFlow.

III. PROPOSED SOLUTION

This section describes the NCC protocol proposed in [10] and implementation of NCC protocol on virtualized MSC.

A. NCC Protocol

The NCC protocol comprises the following two phases:

1) **Cellular phase:** The eNB distributes the \( g \) packets of the generation on the \( n \) UEs connected via time-multiplexed (TDMA) unicast sessions in a round-robin fashion. Each UE is assigned an index that defines the order in which it will receive the data packets from the eNB. For instance, as illustrated in the left part of Fig. 2, the first packet is sent to the first (black) UE, in the first time slot. At the second time slot, the eNB sends the second data packet to the second (blue) UE and so on. When the first round of packets have been sent, the eNB will send the next packet to the first UE again, that is, packet \( n + 1 \) of the generation. At the end of this phase all \( g \) packets will be distributed among the UEs, and some UEs will have either \( g/n \) or \( g/n + 1 \) packets, depending on the order index assigned.

2) **Cooperative phase:** Right after the UE receives a packet from the eNB, it will distribute the packet to the remaining UEs using the short-range technology via WiFi multicast. Since we expect a higher data rate in the short-range technology than in the long-range technology, the packet will be distributed before a new packet arrives from the eNB to the UE with the following order index. In case the packet needs to be distributed along with redundancies, a TDMA schedule is created among the UEs in the MC. In each time slot, different client transmits the packets to distribute all resources in the MSC uniformly.

A timing diagram of NCC protocol is depicted in Fig. 2. In this diagram, the protocol recovers from an error occurred in the second time slot with the first coded transmission. This example comprises three nodes, a generation of five packets and one coded transmission.

B. Virtualized MSC

MEC requires a flexible platform to provide SDN capabilities for different application scenarios as discussed in Section I. The MEC platform orchestrates network and processing resources, and emulates behavior and performance of the underlying network infrastructure. This section describes our proposed NCC communication in virtualized MSC.

The proposed approach is based on overlay network [21] that logically interconnects all the participating UEs in MSC in the physical network. The SDN-based network allows isolation of overlay network through OpenFlow rules. The overlay network contains virtual objects (VOs), which represents a counterpart of UE in MSC, application components, and functionalities such as computing/storage. Each virtual UE is identified by a MAC address to enable the communication among the virtual UEs in the overlay network.

The proposed approach demonstrates the NCC in virtualized MSCs, MEC server has been developed as illustrated in Fig. 3. MEC server is assumed to be deployed on the eNB where UEs in the MSC are considered as the virtual machines running inside the MEC server. The network consists of a live video server, multiple video-receiving clients and the multicast communication between the clients. NC server application is installed on the MEC server that transmits data packets to UEs through unicast sessions. Whereas, the UEs in the MSC are connected through the network provided by the MEC server. The UEs forward the data packets received by the server to each other using multicast. The coded packets are transferred afterwards in order to recover the errors occurred in the previous transmissions.

IV. EVALUATION

A. Setup

Virtualized MSCs are deployed on the compute node. To consider zero errors in the first phase of data transmission, i.e. data transmission from server to UEs, NC server application is installed on compute node. The video server transmits the video stream and the UEs receive the video stream and

![Timing diagram for the proposed NCC protocol. A eNB distributes five packets over three nodes. An extra redundancy packet helps to recover from an error in the second transmission of the MC phase (Source: [10].)](image-url)
displays it after decoding. The network between the UEs is the self-service network provided by the OpenStack API. In this network, the UEs transmit the data packets using multicast transmission. The NC server is deployed on a different network. The network between the server and the UEs consists of multiple OpenFlow SDN switches. OpenvSwitch is used in the setup as an OpenFlow switch and is connected to the compute node to provide a computational resource to the network. The compute nodes host the virtual machines that act as UEs to provide client capabilities.

The testbed demonstrates the implementation of the NCC cooperation in MSCs. In the proposed architecture, virtualized MSCs are considered to implement NCC network. The key components of the testbed are Openstack cloud platform [22] to manage network functions and OpenDayLight SDN controller [23] to manage the network flows. In the setup, the orchestrator utilizes OpenStack APIs to start virtualized MSC functions and instructs the SDN controller to manage the flows in NCC communication. The virtual machines are spawned on a compute node that acts as UEs (virtual objects). The SDN controller establishes the connection between the NC server and the UEs. Additionally, the SDN controller receives the network statistics and manages the network flows of the networks.

The compute node hosts virtual machines, where each VM runs a client and one VM runs a server. KVM is used as a hypervisor on compute node to host virtual machines. Moreover, hardware acceleration has been enabled to increase the throughput. One MSC is deployed as an overlay network and the spawned virtual machines belong to the same network.

B. Configuration Parameters

Table I lists the configuration parameters. The coding ratio for two clients is considered to be 50%, however, with three and four clients the coding ratio is considered 40% and 30%, respectively.

![Fig. 3. Virtualized MSC](image)

![Fig. 4. User throughput per UE in MSC](image)

C. Results

In this section, we present the energy consumption and the average transmission and reception throughput in each UE. We use a single unicast transmission as the reference point and we evaluate the setup for different settings of $n \in \{1, 2, 3, 4\}$.

The average throughput breakdown is shown in Fig. 4. We observe a decrease in the LTE reception traffic at the rate:

$$LTE^{n \rightarrow}_{rx} = \frac{LTE^{1 \rightarrow}_{rx}}{n}.$$  (1)

Regarding WiFi, in the case $n = 2$, the results state that the amount of data transmitted and received is same. This occurs because with two nodes in the MSC, the information transmitted from one node will be received by the other one. Please note that there is a little amount of redundancies in the LTE channel as well in order to provide full resilience against errors in the LTE channel. Hence, the WiFi throughput does not exactly match the LTE-A throughput for $n = 2$. To summarize, we observe similar results to the analytic ones in [9], [10].

Fig. 5 shows the average energy consumption per UE. To calculate the energy consumption, we use the model proposed in [9]. The power consumption of LTE and WiFi is tuned as explained in section IV-B. We observe a huge impact in the average energy consumption, dropping to a 38% of its original value when four nodes cooperate in the MSC. We observe a steep decrease at the beginning, followed by a linear and constant decrease as the number of nodes in the MSC increases. The main contributor to the energy consumption is the LTE antenna since the reception consumes twice as much...
power as WiFi. Hence, it is expected that a major drop in LTE reception will provoke a major energy consumption decrease. Taking equation 1, we observe that the major decrease is between $n = 1$ (100%) and $n = 2$ (50%). From that moment, LTE contribution to the decrease of energy consumption over $n$ (33%, 25%, 20%, etc).

V. CONCLUSION

In this paper, an energy efficient Network-coded Cooperation scheme is presented on virtualized mobile small cells. The virtualized MSC is implemented on a MEC in the overlay network to perform the analysis in softwarization platform. In the presented scheme, a video streaming server is placed on the MEC server, which streams the data packets to the UEs in a unicast manner. All the UEs in MSC distributes the data packets in a cooperative manner to reduce the energy consumption and achieve high user throughput. The proposed architecture is analyzed by energy efficiency and user throughput. The evaluated results shows that the NCC scheme is energy efficient as compared with traditional LTE channel communication. Moreover, the proposed scenario results in higher user throughput in MSC.

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