Enhanced C-RAN Architecture Supporting SDN and NFV Functionalities for D2D Communications

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Abstract. Future Fifth Generation (5G) cellular systems will be characterized by ultra-dense areas, where users are gradually asking for new multimedia applications and hungry-bandwidth services. Therefore, a promising solution to boost and optimize this future wireless heterogeneous networks is represented by the Cloud Radio Access Network (C-RAN) with the joint use of Software Defined Networking (SDN) and Network Function Virtualization (NFV). In such a scenario, low power base stations and device-to-device communications (D2D), involved into traditional cellular network, represented a possible solution to offload the heavy traffic of macrocells, while guaranteeing user experience as well. Nevertheless, the high centralization and the limited-capacity backhauls makes it difficult to perform centralized control plane functions on a large network scale. To address this issue, we investigate the integration of two enabling technologies for C-RAN (i.e., SDN and NFV) in the current 5G heterogeneous wireless architecture in order to exploit properly proximity-based transmissions among devices. Then, in order to validate the applicability of our proposed architecture, we consider the case of D2D pair handover where we show that our solution is able to decrease the number of signaling messages needed to handoff the D2D pair from a source to a target base station and, at the same time, the time execution for the entire handover process.

Keywords: Wireless network virtualization · SDN · NFV · C-RAN · D2D · Handover

1 Introduction

Future 5G networks are expected to deal with different multi-connectivity and multi-technology tiers all of them deployed within the same ares of interest. For this reason, such kind of environment are one of the foreseeable mission-critical

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hybrid networks connecting machines and humans to provide various public services through highly reliable, ultra-low latency and broadband communications [1,2]. The benefits expected to be introduced by future 5G systems, indeed, are widely and will change completely the perception that the end-users have with the surrounding environment. Nevertheless, jointly with these enhancements, the avalanche of data traffic and new multimedia services, e.g., massive sensor deployment and vehicular to anything communication, will lead to strict requirements concerning latencies, signaling overhead, energy consumption, and data rates [3].

To overcome these issues, D2D communications have gained momentum among the research community as a possible enabling technology for 5G future systems. However, Proximity Services (ProSe) standardization is still on going and only few works in literature proposed solutions and architectures in order to manage efficiently short-range transmissions in current and future cellular networks [4,5]. For this reason, it is expected that the integration of D2D communications within the cellular infrastructure may be facilitated by SDN, NVF, and C-RAN.

For instance, in [6] the integration of D2D communications exploiting the paradigms of SDN and NVF is addressed. Specifically, the authors consider how to manage properly a pool of radio resources belonging to multiple Infrastructure Providers (InPs) through short-range transmissions in virtual wireless networks with the aim of maximizing the network-wide welfare. An SDN-controlled optical mobile fronthaul (MFH) architecture, instead, is proposed in [7] for bidirectional coordinated multipoint (CoMP) and low latency inter-cell D2D connectivity in a 5G mobile scenario. In particular, the SDN controller *OpenFlow* is exploited in order to control dynamically CoMP and inter-cell D2D features by monitoring the behavior of both optical and electrical SDN switching elements.

Although a *centralized* SDN-NFV solution works well for the standard cellular infrastructure (i.e., core and access network), this approach results not completely suitable when focusing on proximity-based communications. To this end, a possible solution is represented by a distributed approach where part of the features typically located in a *global* SDN-controller are implemented in *local* SDN-controllers deployed, in a *distributed* way [8], inside the radio access network (i.e., the local controller usually is implemented within the base stations/access points). The concept of hierarchical SDN has been also addressed in [9], where the authors propose a hierarchical D2D communications architecture with a centralized SDN controller communicating with the cloud head (CH) to reduce the number of requested LTE communication links, thereby improving the overall system energy consumption. However, in this last work the word *hierarchical* is referred only to the direct links used between an SDN controller and a cloud head (i.e., similar to the cluster head of a grouped users). In our work instead, we aim to efficiently manage D2D communications by using jointly a multi-layer SDN infrastructure and an enhanced C-RAN architecture.

Beside SDN and NFV, indeed, the C-RANs, differently from the conventional RANs, decouple the baseband processing unit (BBU) from the remote radio head (RRH) allowing centralized operation of BBUs and scalable deployment of light-weight RRHs as small cells. To the best of our knowledge, only few papers in literature deal with the C-RAN architecture for proximity-based communications. In particular, in [10] the authors propose a D2D service selection framework in C-RAN networks. The optimal solution is achieved theoretically by using queue theory and convex optimization. Further, an energy efficient resource allocation algorithm through joint channel selection and power allocation design is presented in [11]. The approach proposed by the authors includes a hybrid structure that exploits the C-RAN architecture (i.e., distributed RRHs and centralized BBU pool). Nevertheless, the aim of our work is not to exploit the existing C-RAN concepts like has been made in the cited works, but to propose enhancements in the current C-RAN infrastructure concerning new modules and procedures for proximity services is future 5G scenarios.

Therefore, the aim of this work is to propose a new hybrid architecture where hierarchical SDN will be used in conjunction with the C-RAN to improve not only the users' experience (i.e., QoE), but also to decrease drastically the amount of signaling messages performed by the cellular radio access and core network. The scenario considered deals with the usage of low power base stations (i.e., femtocells, microcells, picocells) and proximity connections (i.e., D2D) in a heterogeneous scenario in order to offload the heavy traffic among the macro BSs, and from these ones toward the core network infrastructure. The proposed solution will also guarantee an improved quality of service (QoS) in terms of spectrum utilization, energy efficiency and mobility management. The motivation behind the utilization of a hierarchical SDN architecture is that, normally, the high centralization as well as the limited-capacity backhauls makes it difficult to perform centralized control plane functions on a large network scale. Thus, in our work distributed local SDN controllers (in help to the global SDN controller) are dynamically set up and configured in a programmable way, such that all the transmissions paths and the system, generally, can be well managed. Finally, with a practical example we show that the usage of local SDN controllers, jointly with the concepts of NFV and new D2D-aware C-RAN architecture, will allow D2D users' handover to be managed efficiently by avoiding signaling overload and useless network procedures.

The rest of the paper is summarized as follows. In Sect. 2 the enhanced Software Defined Proximity Services Networking (eSDN-ProSe) architecture is described with particular emphasis on the SDN and C-RAN integration over ProSe network deployment. A possible application of the proposed architecture is provided in Sect. 3 whereas conclusive remarks are illustrated in Sect. 4.

2 Enhanced Software Defined Proximity Services Networking (eSDN-ProSe) Architecture

The basic theory and key technology of the wireless network design, management and scheduling, based on the cloud architecture and multi-resource virtualization, is a great driving force to solve the problems and challenges faced by the heterogeneous ultra-dense future 5G scenarios. The C-RAN architecture has the characteristics of communication computing integration, which can meet the needs of high performance computing in large-scale complex networks. On the other hand, network virtualization and SDN paradigm can integrate network resources and achieve centralized control thus improving the overall usage of the radio resource and managing efficiently uncontrolled and unplanned environment driven by the mobility of the users and network entities (e.g., mobile femtocells). Therefore, designing a network architecture with the combined use of C-RAN, NFV, and SDN functionalities is an effective way to achieve an efficient management of the overall system.

2.1 Hierarchical Enhanced-SDN Architecture (eSDN)

The idea behind the proposal of a hierarchical SDN architecture, is not only to expand the network connections and the way the users grant the access, but also offload the macro layer traffic and improve the radio resource management and issues related to mobility. In fact, in such a solution part of the *global* controller functionalities are moved to *local* controllers deployed within the access nodes (i.e., the base station) and, in a limited way, also on the different devices and users. Thereby, the huge pressure on the macro base stations in ultra dense mobility-aware environments can be relieved. In addition, the single node access failure and backhaul link delay problems, typical of such scenarios, are widespread. To overcome these issues, we propose a hierarchical SDN architecture with NFV functionalities, where D2D communications, that represent a feasible solution for traffic offloading, can be managed "locally" with deployed SDN controllers (either global or local) within base stations (or generally within the access nodes).

Our vision is, indeed, to enhance the current LTE cellular network infrastructure with a novel SDN architecture based on OpenFlow (or other available SDN controller software), and virtualized networks where different service providers (SPs) can dynamically share the physical substrate of wireless networks operated by mobile network operators (MNOs). In addition, given the significant amount of modifications needed to integrate "natively" D2D communications in future 5G systems (i.e., both control plane and data plane of radio access networks and core networks), SDN and NVF can provide a versatile framework for the integration of new communications schemes (i.e., D2D) in legacy cellular systems (i.e., LTE, LTE-A).

To cope with this purpose, in a D2D-based network environment an SDN controller (either deployed globally or locally) will be responsible for detecting the user traffic so that the potential D2D users can be paired if it is feasible. In addition, this new architecture entity will introduce new useful functions (e.g., traffic earmarking for gateways, new radio resource management schemes for access points) and new signaling protocols between network entities under the legacy wireless mobile network framework. Indeed, if two networks devices will be identified as potential D2D partners, the network controller further decides whether to perform D2D transmission or to utilize an access point to relay the information. Moreover, since it is a virtual wireless network, it will also consider which access point is responsible for relaying the traffic if the access point relay mode is selected.

Nevertheless, even if SDN can assure a considerable management of proximity-based transmissions, in such a situation one of the key questions is how to make the best use of the precious radio resources. One solution to overcome this issue is to decouple the control and data planes and to have the control logic located inside a controller (i.e., globally or locally distributed) via the software defined networking paradigm. The benefit is that networks controlled by the SDN architecture are also mapped into virtual infrastructures and elements in order to make it available “everywhere” and “anywhere”. Then the virtual entities are aggregated and sliced into different virtual networks by a virtual resource manager or hypervisor.

In conclusion, the improvements of the proposed architecture are that network coverage and network access during instances of very high demand are cost effectively increased at the additional cost of an overlay network and SDN infrastructure, thereby increasing revenue. Furthermore, in the rare instances when there is a lack of the network infrastructure (i.e., due to a disaster or tragic event), communications are still guaranteed by D2D-based transmissions among the devices.

2.2 C-RAN Deployment for the eSDN

The virtualization and softwarisation paradigms are gaining ground in the mobile networking ecosystem, particularly in conjunction with C-RAN. In this field, great effort has gone into virtualizing radio access technology as this enables the virtualization of edge functions of the core network without incurring additional hardware costs. Concerning the enhancement already introduced by the current C-RAN architecture in the current cellular an wireless architectures, our main idea is to propose new C-RAN modules and procedures for proximity services that can cooperate in an efficient way with the NFV and SDN paradigms. The reason, is that works present in literature only deal with the exploitation on the C-RAN architecture to improve the performance of D2D communications without focusing, indeed, if this architecture (at the present stage) is effectively suitable or not for managing short-range transmissions.

Looking at the common C-RAN architecture, the main idea is the replacement of self-contained base stations at each radio mast with shared- and cloud-based processing and distributed radio elements. In particular, the related main components/entities are: *(i)* the BBUs that represents the pool of processing resources useful to provide enhanced functionalities (i.e., signal processing and cells coordination capabilities) to all the network base stations within a given area of interest; *(ii)* the Fronthaul layer consisting in all the transmission links exploited to carry the baseband information that have to be transmitted in the RAN; *(iii)* the RRHs entities identified as the antenna equipment to whom the end-user connect toward the RAN.

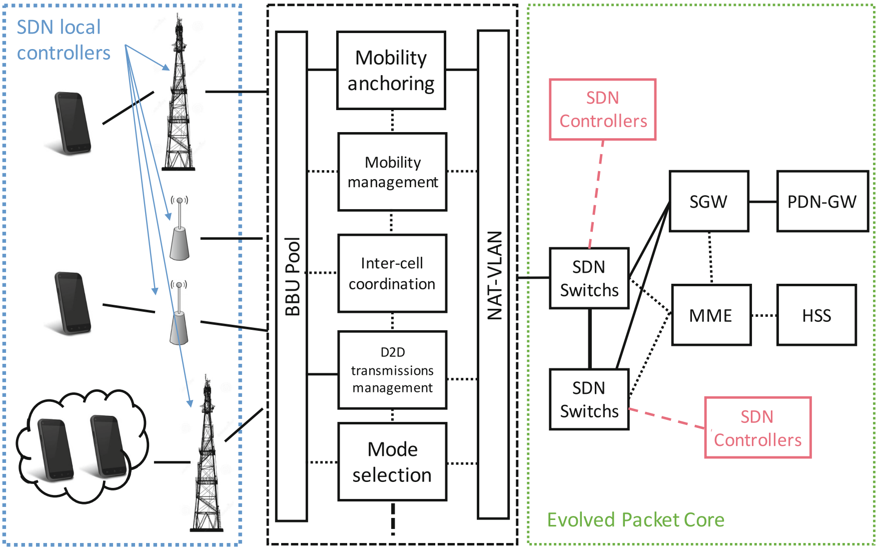

Fig. 1. Proposed C-RAN D2D-aware Architecture

However, the exploitation of the C-RAN architecture in current LTE systems poses limitations and challenges regarding the overall network efficiency procedures. Indeed, the core network of current 4G networks is experiencing a fast growing of signaling messages given by the usage of new transmission paradigms and technologies. Although a portion of this new signaling is required for new services and new devices types, over 50% of the signaling is related to mobility and paging, due to the greater node density. Focusing of an expected avalanche of short-range transmissions (i.e., D2D connections) performed not only by users (i.e., through smartphone or tablet) but also by a multitude of sensors and "smart" devices referred to the Internet of Things (IoT) paradigm, is clear the need of a more signaling-effective architecture in order to face these issues [12].

To this end, in this paper, jointly with the hierarchical enhanced-SDN architecture already mentioned in Sect. 2.1, we improve the current C-RAN paradigm in order to manage in an efficient way the D2D transmissions performed by the users/devices without overload strongly the already stressed LTE core network. In particular, starting from the C-RAN baseline already proposed in [13], we propose to major enhanced to be added in the C-RAN core in addition to the existing ones. As is shown in Fig. 1, the first module is identified as *D2D transmission management* whereas the second one is named as *mode selection*.

The idea at the basis of these new features is to virtualize possible D2D transmitters together with the cells in order to exploit the VLAN and NAT functionalities already proposed in [13]. In particular, the D2D transmission management is responsible to identify the possible D2D forwarder/transmitter and perform all the procedures to establish the D2D links among the users. The transmission mode selection entity, instead, selects the interface on which the users download/upload a given data content. Of course, the selection may be performed based on given metrics of interest, the application considered, or the scenario taken into consideration.

The need of the mode selection module is also justified by upcoming new wireless technology that are the hard core of the future 5G systems. In particular, users that in the past 3GPP Release 12 could exploit direct connection over licensed (e.g., LTE) and unlicensed (e.g., WiFi) bands, now have the chance to exploit also higher frequencies dealing with the new paradigm of the milliterwave (mmWave) communications. In such a case, users will have the possibility to switch among four possible mode of transmissions when using D2D communications: (i) below 6 GHZ licensed bands (e.g., LTE), (ii) below 6 GHz unlicensed bands (e.g., WiFi), (iii) above 6 GHz licensed bands (e.g., 28 GHz mmWave), and (iv) above 6 GHz unlicensed bands (e.g., 60 GHz mmWave).

3 Applicability of the eSDN-ProSe Architecture: The Case of D2D Pair Handover

As a possible example of the applicability of the proposed eSDN-ProSe architecture, in this section we analyze the case where a pair of D2D users (with an active connection) are moving across the overlapping zone of two eNodeBs and have to perform a handover procedure from, e.g., a source eNodeB and a target eNodeB. In such a case, following the 3rd Generation Partnership Project (3GPP) LTE standard handover procedures[1], the handoff of the entire D2D pair results in an expensive process in terms of signaling messages overhead and resource allocation (and reservation) between the two eNodeBs [14] and the core networks. To overcome these issues, exploiting our proposed eSDN architecture, we are able to reduce sensibly the number of messages that have to be exchanged between the source and target eNodeB and toward the Evolved Packet Core (EPC) network entity. In particular, all the messages exchanged (e.g., the handover request message with its acknowledgement) through the X2 protocol between the source and target eNodeB could be avoided and demanded to the new evolved EPC. Further, the part related to the new path request and the bearer setting, typical of the legacy 3GPP X2 handover protocol, thanks to the C-RAN and NFV functionalities could be performed directly within the core network, without overload with signaling messages the links that connect the EPC with the radio access base station. Finally, for the lack of clarification, in Fig. 2 is shown the possible message flow diagram of the new D2D handover procedure proposed.

In details, the evolved EPC (i.e., enhanced with SDN, NFV, and C-RAN functionalities) is responsible of gathering the measurements reports from the D2D pair and, if needed, starting the handover requests and the RRC reconfiguration. In such a case, the source and target eNodeB have to deal only with

[1] Please, refer to the 3GPP specification 23.009 – Available at: http://www.3gpp.org/DynaReport/23009.htm.

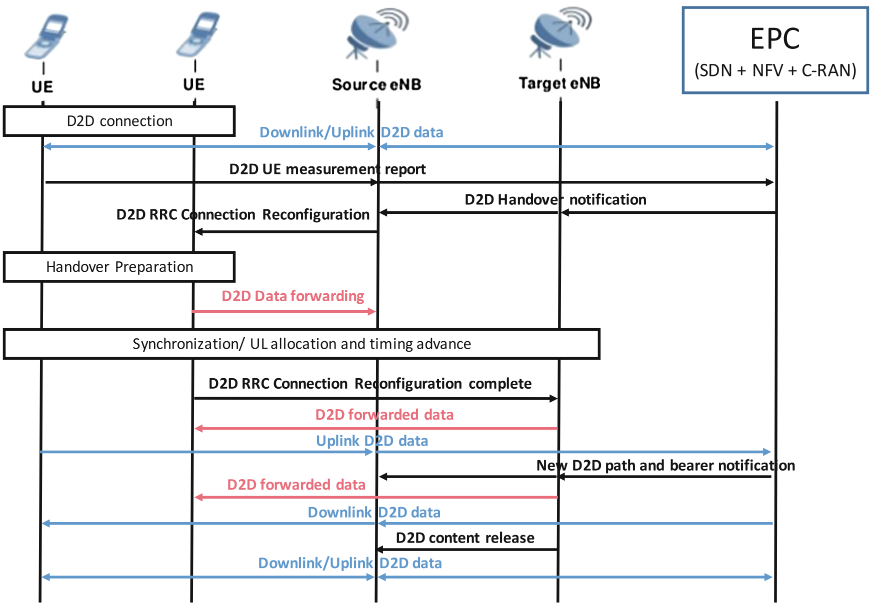

Fig. 2. Possible example of D2D handover procedure exploiting the eSDN architecture

the RCC synchronization and pre-allocation (from the target eNodeB) of the spectrum resources in order to host the upcoming D2D pair. Once that all the procedures regarding the resource allocation and RRC configuration are completed, the EPC, by exploiting the SDN and NFV functionalities, establish a new data flow for the D2D pair and inform with a bearer notification either the source and target eNodeB of the new D2D data path. Finally, the source eNodeB releases the resource previously allocated for the D2D users and these ones can continue their D2D transmission within the target eNodeB (i.e., their D2D connection is never interrupted). It is worth noticing, that the EPC is able to decide whether or not the handover has to be performed by scheduling the periodic channel measurements sent by the D2D pair. In addition, the exploitation of the new D2D-aware C-RAN functionalities described in Sect. 2.2, allows the EPC to start the handover procedure and inform both the involved eNodeB that the RRC configuration and pre-resource allocation have to be started.

In conclusion, this novel approach is able to reduce substantially the signaling messages overload when considering the handover of a D2D pair between two eNodeB of the same operator. In particular, the amount of signaling needed to offload the D2D pair and perform all the handover procedure is reduced up to 9 messages instead of the legacy LTE X2 handover protocol that requests, at least, 22 messages[2].

[2] For the lack of space the messages diagram of the legacy LTE handover has been omitted, but the reader can have a look at the 3GPP specification 23.009 (available at http://www.3gpp.org/DynaReport/23009.htm) for a detailed description.

4 Conclusions

In this paper we have presented a D2D-aware hierarchical SDN architecture where NFV and C-RAN functionalities are used to improve the users' Quality of Service (QoS) in an ultra-dense heterogenous scenario where the network traffic is expected to offloaded, not only through small cell (e.g., picocell or femtocell) disseminated within the given area of interest, but also through direct links among users (i.e., by using D2D transmissions). After describing the hierarchical SDN and NFV infrastructure (i.e., named enhanced SDN – eSDN), a new D2D-aware C-RAN architecture has been proposed with the aim of managing efficiently the connection establishment of the D2D links among users in proximity. For the best of our knowledge, this is still an aspect that has not been well investigated in literature and the present work is one of the first that is providing a novel solution to this important topic. Finally, in the last section of the paper we have provided a practical example about how this new D2D-aware eSDN architecture could be exploited by focusing on the case of handover procedure of a D2D pair between a source and target eNodeB. In such a case, we have shown that our solution is able not only to decrease drastically the number of signaling messages needed to perform all the D2D handover procedures, but also achieve good results in terms of time needed to perform the entire handover process thus allowing to avoid the ping pong effect and the unnecessary handover requests on the network operator-side.

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