Performance Evaluation of Dual Connectivity in Non-standalone 5G IoT Networks

Liangrong Zhao[1,2](✉), Zhangdui Zhong[1], Yong Niu[1], and Hong Zhou[2]

[1] State Key Laboratory of Rail Traffic Control and Safety, Beijing Jiaotong University, Beijing, China
liangrongzhao@bjtu.edu.cn
[2] Nokia Bell Labs, Beijing, China

Abstract. Internet of Things (IoT) is considered as a major emerging technology with huge potential in social efficiency and civilian market. However the scarce available spectrum poses obstacles for the increasing amount of IoT devices. The coming 5G new radio (NR) of next generation is expected to exploit the spectrum of super high frequency by utilizing a heterogeneous network comprising the currently Long Term Evolution (LTE) systems and the 5G NR via dual connectivity (DC). This paper gives an overview of the new DC features introduced in Release 15 and an outline of the features and operation procedures in comparison with DC in LTE systems. We also tune the key parameters for different scenarios and it is demonstrated in system level simulations that the performance of DC for 5G NR deployment is significantly improved as compared to the DC in LTE.

Keywords: Dual connectivity · E-UTRA · New radio · Non-standalone · Edge User Equipment (UE)

1 Introduction

As the IoT is developing repidly, an increasing number of IoT devices are being connected to the Internet, which makes it difficult to meet the growing requirements for a higher user capacity. Aimed to achieve Ultra-Reliable Low Latency Communication use-case, non-standalone (NSA) NR is introduced in Release 15 as the first stage of 5G NR [1,2]. The initial specification work is concentrated on NSA NR mode, which is an interim deployment configuration using DC to achieve a smooth transition to 5G.

On top of Evolved Universal Terrestrial Radio Access (E-UTRA) DC in Release 12 [3], Multi-RAT Dual Connectivity (MR-DC) is standardized in order to achieve a hybrid networking consisting of E-UTRAN and NR nodes. The basic concept of DC is given in [4] and [5]. Depending on the type of core network,

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MR-DC can be divided into two categories. The MR-DC with Evolved Packet Core (EPC) is E-UTRA-NR DC (EN-DC), where the control plane (C-plane) is anchored on LTE while the user plane (U-plane) data is transmitted via master node (MN) and secondary node (SN) configured with LTE and 5G NR respectively to boost data-rates and reduce latency. The completion of MR-DC with next generation core is targeted for June 2018.

Based on different radio protocol architectures, 3GPP has standardized three types of EN-DC solutions: Option 3, Option 3a and Option 3x, which all have DC specified in [3] as baseline for interworking between NR and E-UTRA.

This article gives an overview of EN-DC features introduced in Release 15 in comparison with previous specifications on DC. The details of three solutions in EN-DC are outlined with radio protocol architecture, network interface and operation procedures. Performance results of system-level simulations carried out in configuration with unbalanced bandwidth at macro and micro layers are presented to show the benefits of EN-DC.

The rest of the paper is organized as follows: Sect. 2 introduces the protocol architectures and the network interface of solutions in EN-DC. Section 3 outlines the changes on operation procedures in EN-DC and Sect. 4 presents the simulation setup with a set of tuned parameters, as well as the performance results. Finally, Sect. 5 highlights the conclusions.

2 Radio Protocol Architecture and Functionality

2.1 User Plane

From the perspective of UE, the radio bearers for U-plane connection in MR-DC, fall into three categories, which are MCG bearer, SCG bearer, and Split bearer. The radio protocol architecture for three bearers from UEs prospective in EN-DC is of no difference with that in E-UTRA DC.

While these three bearers, from the perspective of network, can be terminated either in MN or SN, which means PDCP entity is located in the corresponding node. PDCP is not necessarily in the same node with RLC entity whose location determines whether the bearer is MCG bearer or SCG bearer. This is a huge difference between EN-DC and E-UTRA DC. The radio architecture for three bearers from a UE prospective in EN-DC is shown in Fig. 1.

2.2 Control Plane

A new RRC state RRC_INACTIVE is introduced in 5G NR mainly to minimize signaling and consumption on top of two current RRC states, RRC CONNECTED and RRC IDLE. Specifically, when an RRC connection is established, UE is in RRC_CONNECTED or RRC_INACTIVE, which is an intermediate state designed to avoid frequent switching between RRC_CONNECTED and RRC_IDLE. The concrete details are not completed yet and EN-DC currently does not support RRC_INACTIVE state [6].

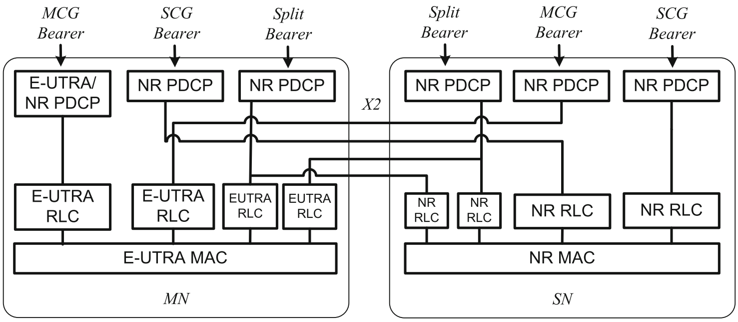


Fig. 1. Radio protocol architecture for MCG, SCG and split bearers from a network perspective

There is not much a difference between C-plane network interface in MR-DC and E-UTRA DC as the coordination of C-plane connection is still based on the non-ideal backhaul X2-C between the MN and SN.

3 Operation Procedural Aspect

The operation procedures defined in [3] are mostly applicable for Option 3/3a only with some minor changes on SN Addition and SN Modification as follows. Further necessary enhancements for Option 3x are given on top of that as the specifications for SN terminated split bearer are not given.

3.1 SN Addition

The major changes in SN Addition procedure for Option 3/3a are mostly because of the newly introduced split SRB and SRB3. When MN sends gNB addition request to gNB, MN will request SN to allocate radio resource for split SRB if MN wants to configure the bearer. MN always provide SN with all the necessary security information to establish SRB3 based on the decision of SN.

3.2 MN Initiated SN Modification

The MN, in this procedure, initiates SCG configuration changes to perform handover within the same MN while keeping the SN. If bearer type needs to be changed, it may result in adding the new bearer configuration and releasing the old one for the respective E-RAB in the procedure. In case of intra-MN handover, UE needs to apply the new configuration and apply synchronization to the MN after the MN initiates RRC Connection Reconfiguration, which makes random access necessary for UE before MN replies with RRCConnectionReconfigurationComplete.

3.3 SN Initiated SN Modification

It is different from the SN Modification in previous specifications that SN can initiate SN Modification without the involvement of MN. When SRB3 is established by SN, SN can directly send RRCConnectionReconfiguration message via SRB3 to UE without the need to send a request to the MN. It is also up to the SN whether to initiate Random Access.

4 Performance Evaluation

The performance of EN-DC is illustrated in the comparison with E-UTRA DC in the same scenarios and radio architectures, i.e. Option 3 in EN-DC is compared with 3C in E-UTRA DC and Option 3a with 1A. Considering there is no counterpart in E-UTRA DC for Option 3x with a SN terminated split bearer, we put Option 3x in comparison with Option 3a and 3C as they all have a split bearer.

4.1 Simulation Setup

The system-level simulation is mostly based on the HetNet scenarios in [7], where macro and small cells are deployed at different frequency layers. The network topology is a wrap-around model that consists of 7 three-sector MNs with 21 macrocells deployed at 2.6 GHz. Each macrocell has a condensed cluster of 4 randomly deployed small cells within a circular area with a 50 m radius, operating at 3.5 GHz and 28 GHz respectively in E-UTRA DC and EN-DC. The inter-site distance for macrocells is 500 m (ISD) [8].

Carrier bandwidth at macro layer in both E-UTRA DC and EN-DC scenarios is 20 MHz, while the bandwidth configured for small cells is 20 MHz and 100 MHz in E-UTRA DC and EN-DC respectively. Cell selection is based on the measurement results of the reference signal received quality (RSRQ) in A4 event which is triggered when the RSRQ of neighbouring cell is better than threshold [9,10].

For scenarios where a split bearer is configured, a request-and-forward flow control algorithm is applied aiming to match the data rate experienced in the SN [11]. In the simulation, we evaluate the performance by throughput of edge UE and medium UE, in the unit of Kb/s.

Each call has a fixed payload size of B = 5 Mb and will be terminated if its payload is successfully received by the UE, in which case the corresponding UE will be also removed from the simulation.

4.2 Analysis of Key Parameters

It is important to find a proper set of parameters to optimize the performance results of EN-DC, including Option 3/3a/3x. We first evaluate the performance of Option 3 and Option 3x in comparison with 3C over the traditional backhaul

Table 1. Flow control parameter settings for X2 latency

Parameters	Settings					
X2 latency (ms)	1	2	5	10	20	50
Target buffering time (ms)	10	10	15	20	30	50
Flow control periodicity (ms)	1 or 5					

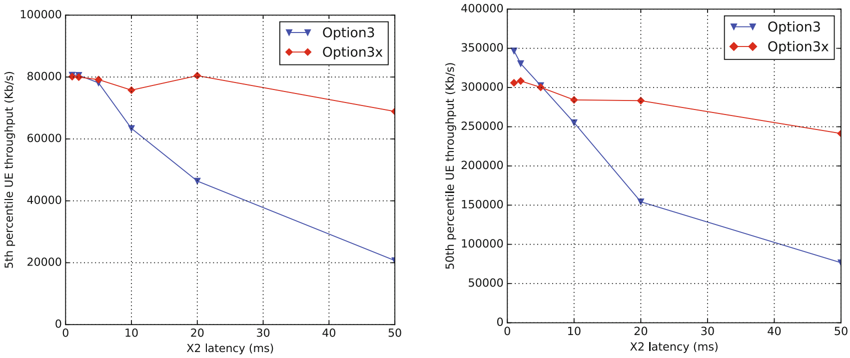
with different X2 latency along with corresponding target buffering time and flow control periodicity shown in Table 1.

Flow control periodicity denotes how often the data request is sent and the number on LTE side is 5 ms while NR side is 1ms. In Option 3, for instance, data request is sent from SN, which is a NR node, so the flow control periodicity for Option 3, in this case, is 1ms. Target buffering time increases with a higher X2 latency to compensate for the fast variations of the user throughput in SN. It is found in [12] that the optimal setting of target buffering time depends on the X2 latency and flow control periodicity and an approximate expression for target buffering time is found to be

$$\theta \approx \min\{\frac{\Delta + 40}{3}, 20\} + 5\log_2(\frac{\rho}{5}) \tag{1}$$

where θ is target buffering time, Δ is X2 latency, and ρ is flow control periodicity.

It is observed in Fig. 2 that the bearable X2 latency for Option 3 and Option 3 x is within 5ms or the performance, especially the performance of Option 3, will be heavily compromised.



(a) 5th percentile throughput (b) 50th percentile throughput

Fig. 2. 5th and 50th percentile throughputs with different X2 latency

We next analyze how to tune the setting of thresholds in −dB for RRC event A4, which is the minimum RSRQ a UE should reach when connected with SN to be a DC UE. A4 Threshold determines whether a UE is served by MN and SN simultaneously or only MN and consequently has a great influence on the performance of edge UEs. Optimal A4 threshold is supposed to get edge UEs a tolerable throughput with a balanced load between MN and SN and the A4 threshold for 1A and 3C is consequently assumed to be −14 dB, which results in over 90% of the UEs, with various offered loads, configured in DC and less than 10% only with MN. In order to find the most optimized A4 threshold for EN-DC, the performance results of three options in EN-DC are given with the offered load per macro area at 120 Mbps.

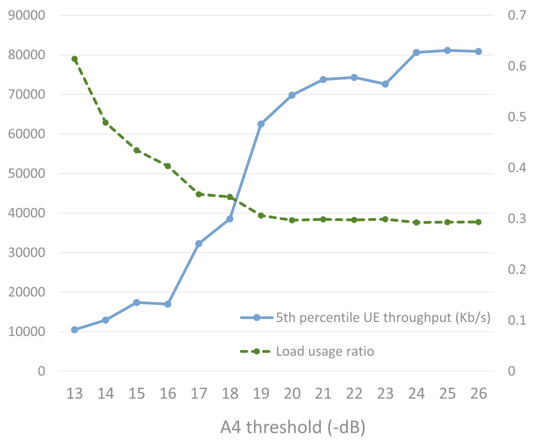


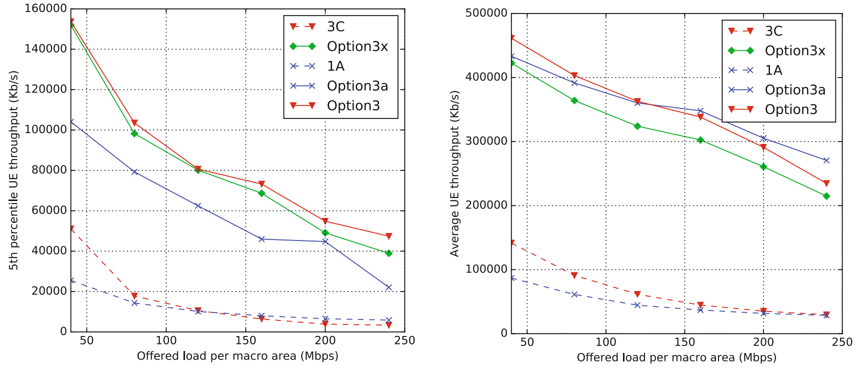
Fig. 3. 5th percentile throughput and load status with different A4 thresholds in Option 3

It is shown in Fig. 3 that the throughput of the edge UEs (lowest 5%) is improved as A4 threshold increases when the number is under 24 and there is not much a noticeable enhancement in throughput after the A4 threshold is over 24. Due to the high bandwidth at micro layer, migrating more UEs to SCG does not increase the load of SN as shown in the Fig. 3. Even if the A4 threshold is low enough for most of the UEs to be configured with DC, there are always a few UEs whose performance is too bad to be connected to SN. Consequently, they cause a huge load burden on MN as they can only be connected to MN. As a result, we consider the optimized A4 threshold for Option3 is −24 dB, with which the load of MN is around the lowest and the throughput is almost at the peak.

Similarly, the best optimized A4 threshold for Option 3a and Option 3x is −20 dB and −22 dB, respectively.

4.3 Performance Results

The benefits of using EN-DC are illustrated in comparison between E-UTRA DC and EN-DC. Figure 4 shows the 5th percentile and the mean UE throughput



(a) performance of edge UE (lowest 5%) (b) performance of average UE

Fig. 4. Performance comparison of edge and average UE between EN-DC and E-UTRA DC

with different offered traffic per macrocell area, which denotes the throughput experienced by at least 95 percent of the UEs and all on average, respectively.

Quite obviously, the UE throughput of EN-DC (including Option 3/3a/3x) in general is markedly higher than E-UTRA DC with an average gain of roughly 500% (including 1A and 3C) due to a larger bandwidth and higher transmission power at micro layer.

The throughput improvement on edge UEs (lowest 5%) is not as considerable as how it is on the average ones and the increasing offered load degrades the performance of edge UEs faster than it does mediocre UEs. It is observed from Fig. 4(a) that the maximum tolerable offered load per macrocell area increases enormously if there is a target of minimum throughput for at least 95% of the UEs to experience. The highest tolerable offered load for a throughput no less than 40 Mb/s increases from approximately 50 Mbps in 3C to about 210 Mbps in Option 3a and 240 Mbps in Option 3x, corresponding to a capacity gain of 320% and 380% respectively.

5 Conclusion

In this paper, we have summarized the key features of the EN-DC in NSA NR for IoT network deployment. A proper set of key parameters for the best performance in each option is analyzed and the UE throughput of EN-DC has been compared with E-UTRA DC to evaluate the potential of EN-DC. Carried out in configuration with unbalanced bandwidth at macro and micro layers, system-level simulation results show that EN-DC can provide a significant improvement in the average performance and a huge capacity gain for a target outage throughput.

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