Next-Generation Communication Systems: X2-Based Signalling Techniques for Downlink Uplink Decoupling

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Abstract- The quality of service is significantly impacted by cell selection in cellular networks. Based on downlink received power, the conventional cell selection algorithm is used. Mobile network providers continue to struggle to provide capacity and coverage despite the widespread deployment of macrocells. The deployment of numerous tiny cells has come to be seen as a promising approach to solving this issue. Although there is a substantial gap in the transmit strength of the various base station types, this success broadens the heterogeneous cellular networks. Efficiency can be increased by using Downlink and Uplink Decoupling (DUDe), which associates the downlink cell with the downlink received power and the uplink cell with the uplink pathloss. Although the higher layer signalling for the DUDe method has not yet been detailedly provided, this proposed work offers a fix for the issue. This paper examines four alternative signalling strategies to establish decoupled up/downlinks connections in the radio access network for the next-generation communication systems with handling mobility. Uplink coupling, downlink coupling, uplink coupling, and downlink decoupling scenarios are all covered by our suggested signalling mechanisms. Using MATLAB simulation, we analyse the suggested signalling mechanisms and present the effects of using the DUDe mechanism, which mostly shows improvements for the uplink. The upgrades suggest that it meets a specific need in light of next-generation communication systems, where a vast array of smart gadgets demand extremely high standards of service.

Index Terms LTE-A, 5G, decoupling, uplink, downlink, macrocell, small cell, handover, MATLAB.

I.INTRODUCTION

The rapid growth of mobile connectivity demand and the wide range of smart devices in smart environments and smartcities are expected to fulfill services' requirements and be market drivers for small cells, especially indoors. Different use cases ranging from health and home security to interactive gaming have increased demand for high data rates, high reliability, and low latency, which demand further advancements to existing communication systems. The communication systems have made advancements in this direction by applying a combination of several systemicconcepts such as the use of millimeter-wave communications and small cells, the use of multiple Radio Access Technologies (RATs), increasing the density of evolved NodeBs (eNBs) and Next Generation NodeBs (gNBs), the use of device-to-device (D2D) communications, the use of mobile edge communication (MEC) using software defined networks

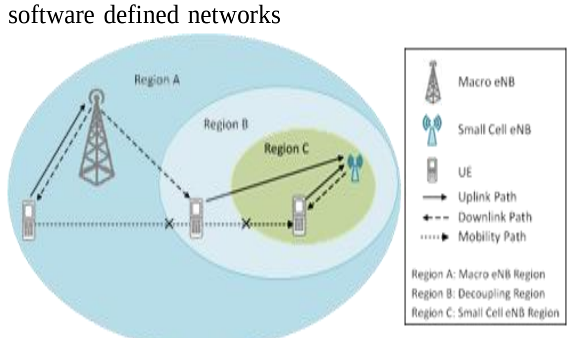

FIGURE 1. System model for the up/downlink decoupling.

(SDN) and network function virtualization (NFV), the use offix mobile convergence (FMC), prioritized access to the spectrum, large intelligent surface and software defined materials, orbital angular momentum, and visible light communications to be able to serve the growing number of wireless devices (predicted to be around 37 billion connected devices by the year 2025) with a continual increase in demand for communication systems data traffic.

Achieving an agreed level of Quality of Service (QoS) will be very important in next- generation wireless communications for such defined performance criteria as well as energy efficiency, particularly for reduced capability devices such as smartwatches and other wearables.

Furthermore, efficient cell association can improve delivered QoS. Cell association in cellular networks has traditionally applied the downlink received signal strength, which is adequate for homogeneous networks. In a heterogeneous network (HetNet) that overlays high power andlow power cells: macro and small cells (macrocells andsmall cells, respectively), due to the cell transmit power disparities, users may face a phenomenon called the uplink and downlink (up/downlinks) imbalance problem: the best serving cell, based on the received signal, is different for both up/downlinks, meaning up/downlinks power transmissions and interference levels differ significantly.

In other words, the downlink coverage of the macrocell is much broader thanthe small cell due to the significant difference in the transmit powers of both. However, all the transmitters (battery- powered mobile devices) in the uplink have the same transmit power and thus the same range.

Hence, a UE connected to a macrocell in the downlink, from which it receives the highestsignal level, may want to connect to a small cell in the uplink where the pathloss is lower.

Downlink uplink decoupling (DUDe) is suggested in 3GPP where the downlinkassociation is based on the downlink received signal power and the uplink is based on the pathloss (Fig.1). The gains andmotive of DUDe based on a real testing scenario grounded by Vodafone's LTE network cellular is also demonstrated in with a focus on the physical layer considerations, which shows sum-rate gains in the order of 100-200% in dense HetNet. To address user mobility, we can divide the network environment into three regions based on pathloss for uplink

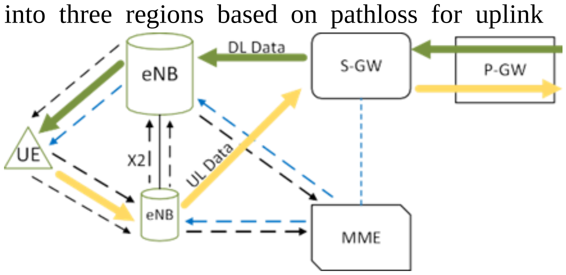

FIGURE 2. Suggested DUDe architecture

selection and received signal strength indicator (RSSI) for downlink eNB (macrocell) selection, as shown in Fig.1.In region A, where the macrocell pathloss and RSSI factors show better connection than the small cell, the up/downlinksare connected to the macrocell. In region B, where thepathloss of the small cell is better than the macrocell while the RSSI of the macrocell is better than the small cell, the up/downlinks are connected to the small cell and macrocell,respectively. In region C, where the small cell's pathloss andRSSI of the small cell are better than the macrocell, both uplink and downlink are connected to the small cell.

For the up/downlinks connections, a mechanism needsto be in place to handle the two connections' flows underthe same session from a higher layer point of view, including updating the core network (CN), as shown in Fig. 2.In this architecture, the UE can transfer data and control messages to both the eNBs. Also, a complete separation of the up/downlinks traffics are considered, i.e., if the UE communicates in the only uplink to the small cell, no downlink is maintained in the small cell. Control messages can be transferred between eNBs within the X2 interface. Hence, this architecture requires the signalling information to be sentwith minimal delay via the downlink of the macrocell. The challenge here is that the X2 needs to facilitate close-to-zero delay communications; the advantage is that radio capacity iscompletely freed in the small cell's uplink and the macrocell's downlink.

Considering the suggested DUDe architecture, we look atthe current cellular technology. 3GPP defines two deployment scenarios for 5G: Standalone (SA) and Non-standalone(NSA). In the SA scenario, the 5G new radio (NR) and the 5G CN are operated alone. In the NSA scenario, the NR cells arecombined with LTE radio cells using dual connectivity to pro- vide radio access and evolved packet core (EPC), or 5G core (5GC) provide CN depending on the choice of operator. The SA option is a simple solution for operators to deploy and manage as an independent network by typical inter- generation handover between 4G and 5G. The NSA scenariois chosen by the operators that wish to leverage existing 4G deployments, combining LTE-Aand NR radio resourceswith existing EPC and/or that demand new 5GC to deliver 5G mobile services. In the NSA scenario, due to the combinationof LTE-A and 5G, more resources are used, and this is cost-efficient, but this solution requires tight interworking with the LTE radio access network. Three types of NSA are defined in3GPP as follows:

Option #3- using EPC and an LTE eNB acting as masterand NR en-gNB

acting as secondary;

Option #4- using 5GC and an NR gNB acting as masterand LTE n

geNB acting as secondary;

Option #7- using 5GC and an LTE eNB acting as masterand an NR gNB acting as secondary.

Concerning the 5G development process, as the transition from EPC to 5GC is time-consuming, option #3 of theNSA scenario is selected first by the operators. This workalso looks at signalling requirements considering the NSA scenario with option #3 to handle decoupled up/downlinks connections for a decoupled scenario. The UE can performdecoupling based on either signal strength/ pathloss measurement or as a result of mobility to a macro/small cell.The main contributions of this paper are four signalling mechanisms in considering mobility scenarios for handlingDUDe: First, uplink decoupling where the UE moves from region A to region B (Fig. 1). Second, downlink couplingwhere the UE moves from the region B to region C. Third,downlink decoupling where the UE moves away from theregion C towards region B. Fourth, uplink coupling wherethe UE moves from region B to region A. The handling ofsignalling mechanisms for the DUDe at the Network layerwill provide a possibility of taking the most advantages fromthe DUDe and make it practical for the next generations ofcommunication systems. Moreover, we analyse our proposed signalling mechanisms using simulation to compare network performance when up/downlinks connections are decoupled.The rest of this paper is presented as follows: Section II provides an overview of the related research; section III discusses four possible proposed signalling scenarios for handling decoupled communication. Simulation results andanalysis are presented in section IV. Finally, section V provides the conclusion and future research directions.

II. RELATED WORKS

The DUDe concept has been discussed in future cellular networks in [5], [7], and [8]. Boccardi et al. [9] discussed how to decouple up/downlinks in existing LTE-A networks from the architecture perspective. the authors discussed three approaches, namely centralised processing, shared cell-ID, and dual connectivity. For centralised processing and shared cell-ID approaches in a practical LTE-A rollout, the deployment is thus limited to remote radio units connected to a centralised baseband processing node. The dual connectivity approach is limited for inter-frequency deployments, and two cells operate separately, handling their scheduling and control signalling. The disadvantage is that radio capacity is busy in the downlink for the small cell and the uplink for the macrocell. Uekumasu et al. [10] considered the case where the up/downlinks use different frequency bands and proposed two macrocell selection methods in DUDe using multiple frequency channels. Wan Lei et al. [13] investigated the 5G NR and 4G LTE coexistence through the UL sharing known as up/downlinks decoupling. The 5G-NR provides a tool to extend its coverage with C-Band deployment. It makes it possible to deploy a C-Band 5G-NR network using existing LTE sites for seamless coverage, demonstrating the feasibility of DUDe for the described NSA 5G deployment scenario. Jia et al. [14] investigated dual connectivity for all possible up/downlinks decoupled access modes, derived association probabilities after simplifying the conditions for the association, and derived uplink coverage probabilities using tools from stochastic geometry to achieve uplink average coverage probability. However, in [9], [10], [12], and [13], authors did not discuss mobility handling and required handover mechanisms when a session is transmitted over decoupled up/downlinks connections. Smiljkovikj et al. [11] outlined DUDe enabling architectures, based on 3GPP architecture, from the perspective of Access-Stratum (AS) and Non-Access Stratum (NAS) signalling where AS signalling refers to Layer 1, Layer 2, and RRC control messages exchanged between UE and small/macrocell. NAS signalling refers to control messages exchanged between UE and the CN. It includes, e.g., establishing and managing bearers, authentication and identification messages, mobility management, and tracking area update. Authors proposed three options for the possible architectures: NAS-Decoupling with radio access network (RAN)

Anchor Point, NAS-Decoupling with CN Anchor Point, and AS-Decoupling with RAN Anchor Point. However, the authors have left signalling mechanisms designing and analysing to future researches. Elshaer et al. [5] studied physical layer gains that the DUDe technique can achieve in terms of uplink capacity and throughput and studied the effects of the DUDe approach on interference using a realistic scenario of a cellular network with a dense HetNet deployment. It was shown that the DUDe technique could achieve between 100% and 200% improvement in the 5th percentile uplink throughput and even more than that in the 50th percentile throughput. Furthermore, authors have shown that the outage rate is decreased from 90% to below 10% on the macro layer in networks with high minimum throughput requirements. Yet, the authors have left alternative control signalling delivery mechanisms in the CN as future work. Authors in [30] proposed a location-based scheme for coupled/decoupled cell association. They divide the user into two types. First uplink-downlink Coupled Association users and the second uplink-downlink decoupled access called the CoA users and DUDe association policy. Also, the authors proposed the practical realisation and, based on the proposed scheme, simple analytical closed-form expressions for decoupled users derived without ignoring noise to quantify decoupled access advantages. However, they studied the physical layer parame Giluka et al. [25] proposed handover schemes for up/downlinks decoupling in HetNets from the physical layer perspective. They presented various handover schemes with up/downlinks decoupled access. Mathematical analysis for up/downlinks decoupling shows the signal-to-noise-plusinterference ratio (SINR) received by the small cell in the decoupling region will be greater than that of the macrocell, even after including the interference due to other small cells. The authors simulated two scenarios, first a single small cell scenario and a multiple small cells scenario. In the first case, which is called the single cell non-interference scenario, they considered one macrocell and one small cell and analysed power consumption which resulted in decreased power consumption. In the second case which is called the multiple cells interference scenario, they considered one macrocell, multiple small cells and, multiple devices to create interference and analysed the cumulative distribution function of uplink SINR received by different small cells. Results show decoupling always outperforms the coupled connection. In particular, the authors measured the consumed power by a UE based on a mathematical formula and illustrated the results for 1 to 90 UEs within a DUDe scenario. They reported UEs are consuming more power in the conventional scheme even if they are performing fewer number of handovers in comparison to using the DUDe scenario. Also, the authors reported the transmit power of a UE for the DUDe vs. conventional scheme. In the DUDe case, the transmit power is lower than the conventional scheme, due to existing the decoupling region in the DUDe mechanism [25]. However, they did not propose the detail of signalling for the network layer and they did not study the performance metrics of the network layer. The general LTE-A architecture divides into RAN and a CN. In [26], the Third Generation Partnership Project (3GPP) presents the signalling mechanisms in the CN and RAN for X2 based handover. The presented CN signalling mechanisms contain all the message sequences between Mobility Management Entity (MME), Serving Gateway (S-GW), and Packet Delivery Network Gateway (PDN GW). For the handover scenario, 3GPP represents two signalling message sequences; the first for X2 based handover without S-GW relocation and the second X2 based handover with S-GW relocation. In the first case, the MME sends a Modify Bearer Request to the S-GW, and S-GW forwards the message to the PDN GW, then PDN GW sends the Modify Bearer Response message to the S-GW, and S-GW forwards the message to the MME. In the second case, the MME sends the Create Session Request message to the target S-GW, and the target S-GW forwards the message to the PDN-GW, then PDN GW sends the Modify Bearer Response message to the target S-GW and the target S-GW forward the message to the MME. After the MME receives the Create Session Response message, the MME sends a Delete Session Request message to the source S-GW and the source S-GW replies by the Delete session Response message. Also, the 3GPP mentions Dual Connectivity in RAN and CN. In Dual Connectivity concept, a cell and other network elements should support two different RATs and if the UE supports Dual Connectivity as well, it can take the advantage of both RATs one as a primary and the other as secondary. However, the required DUDe signalling mechanisms are not covered within the standard [26]. While [5] and [25] shows the physical layer gain, we are aiming to propose a solution for higher layers signalling to focus on intra PDN GW mobility. Based on [7], we concentrate on AS-decoupling with RAN anchor point as we consider NSA scenario option #3 (EPC is the core, LTE eNB acting as a master, and NR gNB acting as secondary radio resources).

III SIMULATION SETUP

Dual Connectivity, an extension first introduced in 3GPP Rel-12, allows a terminal to be simultaneously connected to two cells to aggregate data flows or DUDe (Fig. 2). The two cells operate separately, handling their scheduling and control signalling and thereby significantly relaxing the backhaul requirements compared to the centralized baseband approachin previous research. Both cells have data connections to the S-GW andcontrol connections to MME. Depending on which cell serves as an uplink or downlink cell to the UE, the uplink cell has acontrol and data connection to the UE in the only uplink direction, and the downlink cell has a control and data connectionto the UE in the only downlink direction. Therefore, for the UE, the radio resources of the uplink cell in the downlink direction and the radio resources of the downlink cell in the uplink direction are free.

In a DUDe scenario, we have proposed details of messagessequence of four possible cases in terms of access level signalling architecture to work with the discussed core signalling in reference paper.

1. Up/downlinks are connected to the macrocell and uplink is transferred from the macrocell to the small cell (transferring from Region A to Region B in Fig. 1).
2. Up/downlinks are connected to the small cell and the macrocell, respectively, and downlink is transferred from the macrocell to the small cell, i.e., reverts from the decoupled state to the coupled state (transferring fromRegion B to Region C in Fig. 1).
3. Up/downlinks are connected to the small cell and downlink is transfers from the small cell to the macro-cell (transferring from Region C to Region B in Fig. 1).
4. Up/downlinks are connected to the small cell and the macrocell, respectively, and uplink transfers from the small cell to the macrocell, i.e., reverts from the decoupled state to the coupled state (transferring from Region B to Region A in Fig. 1).

For the first case, where up/downlinks connected to macro- cell (downlink eNB) and uplink is transferred from macrocellto small cell (uplink eNB), based on the UE's measurement reports on the RSSI of the current cell and the neighboring cells' pathloss, the macrocell can decide to decouple uplink and downlink cells. The first step in this process is to send an Uplink Decoupling Request message from the macrocell (where the uplink and downlink connect to that) to the smallcell (where the uplink will transfer to it). As described in ETSI TS 136 423, this message contains all relevant information about the subscriber and all relevant informationabout the connection to the UE. The small cell then checks if it still has the resources required to handle the additional subscriber.

Mainly, supposedly the connection of the subscriber requires a specific QoS. In this case, the small cell mightnot have enough capacity on the air interface left during a congestion situation and might thus reject the request. If thesmall cell grants access, it prepares itself by selecting a newCell Radio Network Temporary Identifier (C-RNTI) for the UE and reserves resources on the uplink. So, the UE performs a non-contention- based random-access procedure once it tries to access the small cell. This is crucial as the UE is not synchronized, which is unaware of the timing advance necessary to communicate with the small cell.

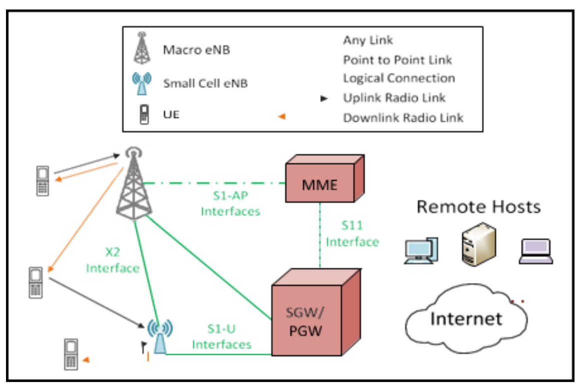

FIGURE3. Simulation scenario for decoupled up/downlinks.

IV RESULTS AND DISCUSSIONS

The connection will be more likely to be either to the MCell or the SCell in both UL/DL depending on the distance from the device to the Cell. Regarding the capacity, the study is focused on the case where the access should be decoupled Figure (4). To analyse the situation, there are taken two possibilities into account. On one side, it has been computed the uplink capacity of the decoupling access to the n-th SCell (i.e., performance the DL with the MC and the UL with the n-th closer SCell). On the other side, is computed the uplink capacity when is performed by the MCell. This comparison allows us to show if, even with a fronthaul limitation, the capacity of decoupling the access is still higher than the DRP environment in SBA. For n = 1 Figure (5), The capacity decoupling the access is 10 times higher than in a DRP Association. However, as the fronthaul starts to disable SCells (n increases) the decoupling capacity decreases and approaches the DRP capacity.

For n = 4, the capacity of the decoupled access is similar to the DRP capacity. In Figure (6), we can see that for n = 4 it is still worth to decoupling the access. for n = 5, however, the capacity for the DRP is higher than the DUDe. This means that 4 Cells can be unavailable and it is worth to decoupling the access.

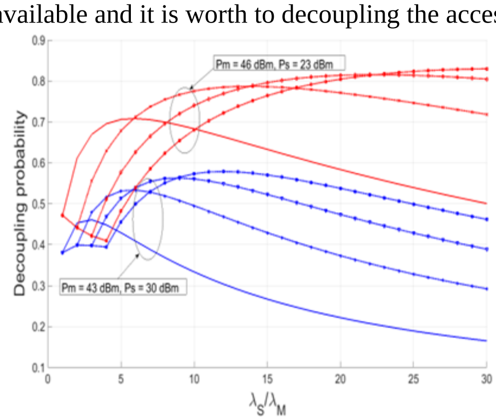

FIGURE 4: Decoupling probability for n=1,2,3,4 and Pm/Ps = 20,200. Pm = 46 dBm and Ps = 23 dBm for Pm/Ps = 200 and Pm = 43 dBm and Ps = 30 dBm for Pm/Ps =20, α = 3, λm = 1

The outage probability for n = 4 Figure (16) is still better than in a DRP. We could go even further and see that until the 6th or the 7th SCell where in about 60 % of the threshold zone is worst on the decoupling and we cannot consider it reliable. Therefore, if there is more interest in achieve a good OP, we can allow to connect the 6th or the 7th SCell. However, if we don't want to lose capacity, we only can reach the 4th Scell. This outage probability is achievable for the lower thresholds.

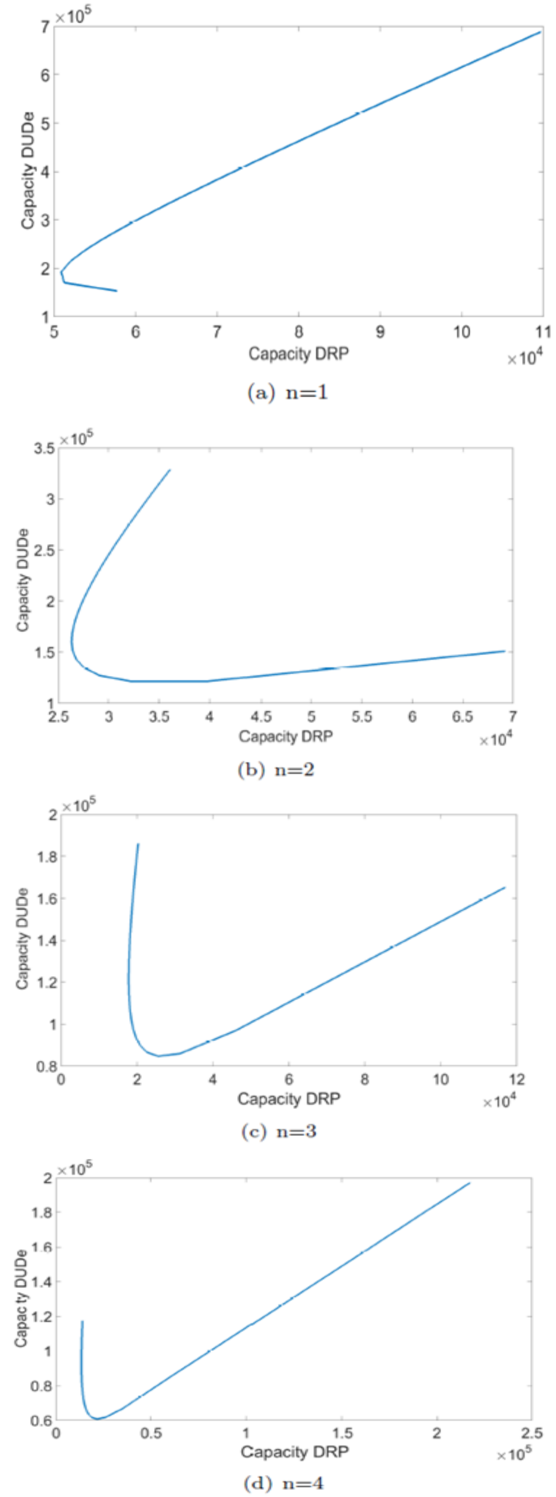

FIGURE 5: Pm = 46 dBm, Ps = 23 dBm, α = 4, λm = 1.

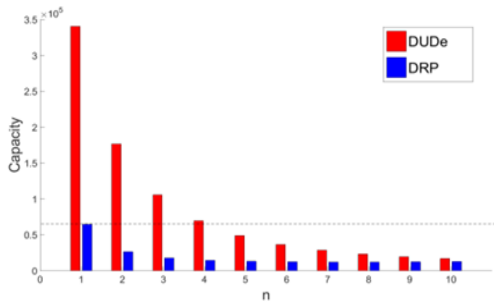

FIGURE 6: Capacity SBA Dude and DRP. Pm = 46 dBm, Ps = 23 dBm, α = 4, λm = 1, λs = 20.

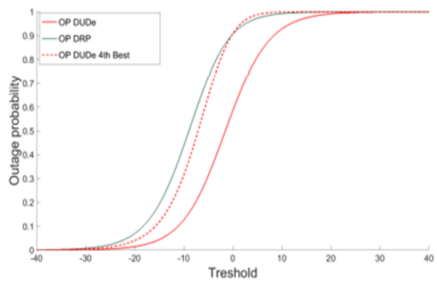

FIGURE 7: Outage probability nth SBA DUDe and DRP. Pm = 46 dBm, Ps = 23 dBm, α = 4, λm = 1, λs = 20, n=4.

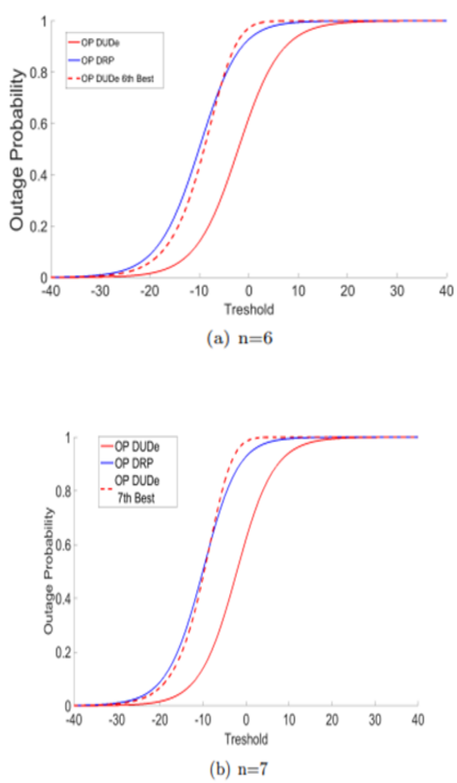

FIGURE 8: Reliability Outage Probability. Pm = 46 dBm, Ps = 23 dBm, α = 4, λm = 1.

V CONCLUSION AND FUTURE WORK

This work has studied the advantages of allowing decoupled associations in Dual-Connectivity scenarios, where the users are allowed to simultaneously consume radio resources from two cells. With the aim of improving the user throughput as well as the overall connectivity experience, it is proposed that the user decouples the UL connection and introduce UL specific association rules in the context of multi-connectivity in HetNets.

This allows the user to experience maximum flexibility when deciding which cells to aggregate spectrum from. The system has been modelled using stochastic geometry and a Poisson cluster process of two SCells and one MCell has been considered; it has been recognized that the probability of the decoupled events is certainly high.

The future work includes the reduction of packet loss and delay for both mobility and fixed location scenarios.

Further research is required to calculate the value of pathloss of each UE in the actual environment. We suggest three approaches for this aim: First, by using the pathloss prediction algorithms, second, by the actual measurement maps in the target environment, and third by using the diffraction of small/microcell send power and UE receive power.

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