

A Method for Uplink Split Bearer Implementation and Evaluation in 5G Non-Standalone Mode

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Abstract - In recent years, the evolution of mobile networks has seen a significant transition from 4th LTE to 5th generations. Among all the deployment scenarios of 5th generation mobile network, the Non-Standalone mode (NSA) takes advantage of existing 4th LTE infrastructure while integrating 5G capabilities into the system to improve overall performance. One of many features driving this enhancement is the implementation of Split Bearers. User Equipment can transfer data to both 4G and 5G base station at the same time. This function allows us to utilize the wider range of LTE mobile station antennas, improving data throughput and optimizing radio resources. This paper explores split bearer mechanisms in the uplink path, our new channel quality monitoring method and our modifications in mobility scenario in case User Equipment moves between base stations. Finally, Uplink Split Bearer is integrated into our 5G Network with numerous 4G & 5G base stations to evaluate the benefits in the real-world system.

Keywords - 5G split bearer, uplink split bearer, mobility scenario with uplink split bearer, uplink data switch path algorithm, uplink dual-connectivity

I. INTRODUCTION

The 5G Non-Stand-Alone scenario is introduced in [1] with the main components as shown in Figure 1, including the LTE mobile station (eNB), EPC infrastructure Core Network and 5G NR mobile station (en-gNB).

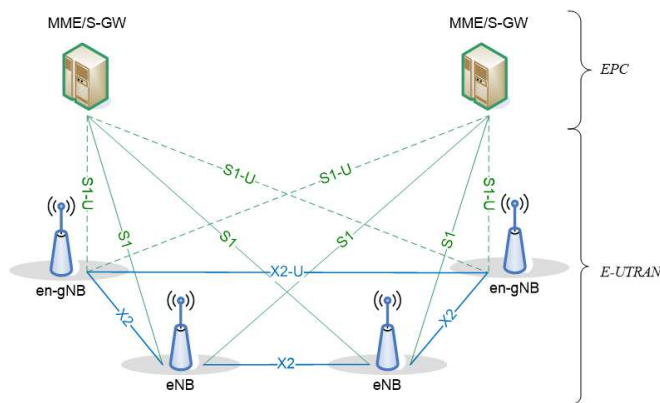


Figure 1. EN-DC Overall Architecture

The en-gNB maintains the S1-U interface for user data to the Core Network and eNB serving S1 interface for control data. These two base stations connect through the X2-U for data forwarding. It means that User Equipment (UE) is connected to 5G network by maintaining connections to eNB to receive control data and en-gNB to receive user data.

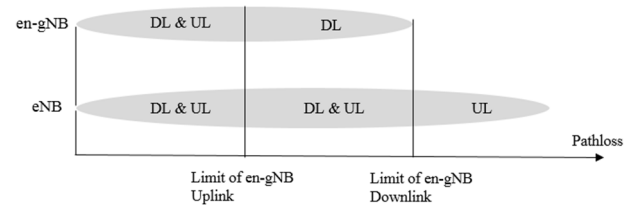


Figure 2. Illustration of signal strength for eNB and en-gNB station

However, the eNB signal coverage is wider than its newer generation en-gNB [2]. 5G mobile network opens new spectrum by the introduction of sub-6GHz and mmWave, which can also be deployed in NSA mode alongside with LTE. These bands deliver faster speed and lower latency, making them ideal for applications that require real-time responsiveness. But it also has shorter wavelength, leads to shorter range and is more susceptible to obstructions such as buildings or trees while LTE provides higher reliability as studied deeply in [3].

Therefore, in order to utilize the existing interfaces from UE to eNB and en-gNB and the better coverage of eNB over en-gNB, UE can send uplink and downlink data to the Core Network by both station by using the Split Bearer defined in [1]. These split bearers allow user data from UE to be transmitted to Core Network through both eNB and en-gNB, which can provide higher data rate and signal coverage. Split bearers for multi-connectivity have been observed to significantly increase efficiency in LTE system as in [4].

Most researchers focus on utilizing the downlink data path and made significant findings that Split Bearer not only improves throughput but also optimizes UEs satisfaction in [5-7]. While most depends on simulators to demonstrate the effectiveness of Split Bearer, our solution is deployed in the real-field system. Research papers also need to develop their algorithm to distribute downlink data packets for eNB and en-gNB to improve fairness while maximizing the total throughput utility [8-10].

In this paper, we provide an approach for Split Bearer Mechanism in the uplink. Reference [11] reveals the uplink switching technique using Machine Learning to predict achievable throughput before switching from NR to LTE, we develop an uplink channel quality monitoring solution based on channel feedback and aim at protecting uplink data integrity while maximizing throughput with less complexity. In [5], T. Mumtaz *et al.* highlighted the critical role of maintaining call continuity and ensuring targeted QoS for users in Dual-Connectivity model. In order to integrate Split Bearer into our field network with many eNBs and en-gNBs, we introduce our modifications in handover procedures to maintain data path in

all mobility scenarios. The paper is structured into four parts. Part II provides an overview of current data path from UE to Core Network and information on bearer types as well as handover scenarios. Part III describes our new implementation on uplink split bearer, especially our method to switch uplink data path based on channel quality and modifications for mobility problems. The results of our implementation measured in real field systems are also provided in this part. Finally, the conclusion is shown in part IV.

II. TRADITIONAL PACKET PROCESSING SOLUTIONS

A. Data path and bearer types

In NSA mode E-UTRA-NR Dual Connectivity, a UE is connected to one eNB acts as a Master Node (MN) and en-gNB acts as a Secondary Node (SN).

There are 03 types of bearers exists and are defined in [1] as follows:

- MCG Bearer: a radio bearer with a RLC bearer only in the Master Cell Group
- SCG Bearer: a radio bearer with a RLC bearer only in the Secondary Cell Group
- Split Bearer: a radio bearer with RLC bearers in both node Master and Secondary Cell Group

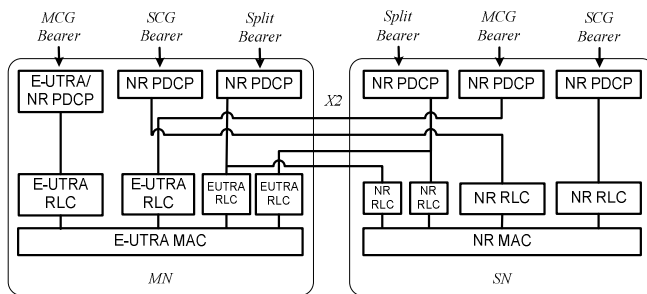


Figure 3. Network side protocol termination options for MCG, SCG and split bearers with EPC (EN-DC Architecture)

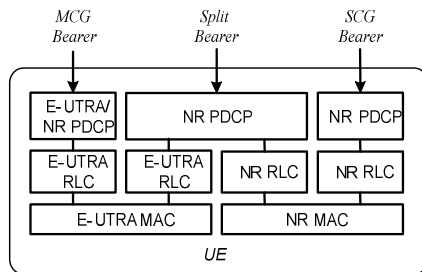


Figure 4. Radio Protocol Architecture for MCG, SCG and split bearers from UE perspective

Figure 3 and Figure 4 from [1] shows all the bearer types and the protocol stack in eNB, en-gNB and UE. Normally, UE uses the SCG bearer for data transmission when connected to 5G and MCG bearer for data transmission when connected to 4G.

For SCG Bearer, at UE side, packets are processed through NR MAC layer for multiplexing and scheduling, NR RLC layer

for segmentation and error correction and NR PDCP layer for header compression and encryption. These processed packets then transmitted and decoded at en-gNB in the reverse order, starting with NR MAC layer followed by NR RLC layer and then NR PDCP layer. After UE finish the attach procedure to en-gNB, it only send/receive data using SCG Bearers while still keep the MCG Bearers with eNB. This approach uses only radio resource from en-gNB to allocate for data transmission of UE.

B. Mobility

1) Inter eNB Handover without change en-gNB

This is the handover process for UE while moving from

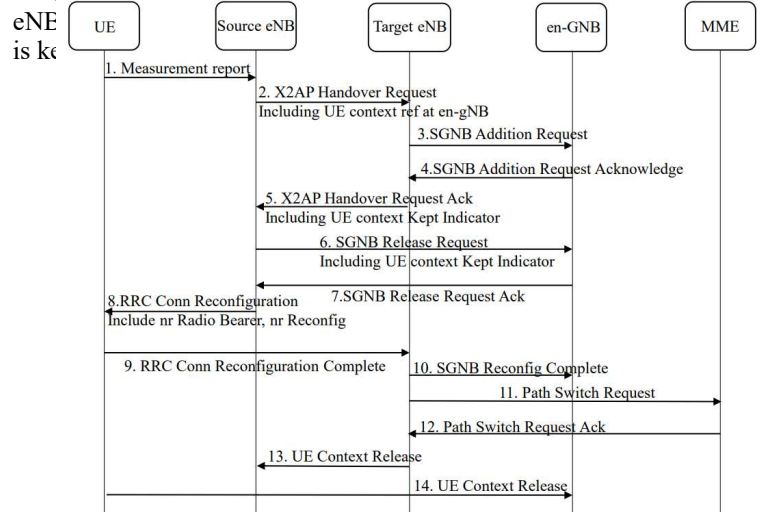


Figure 5. Scenario for inter eNB handover without change en-gNB

The details of the inter eNB Handover without change en-gNB are described as below:

- Step 1: UE in NSA mode send measurement report to trigger handover 4G.
- Step 2: Source ENB send HANDOVER REQUEST to target eNB include UE Context Reference at the SgNB field.
- Step 3: Target eNB send SGNB ADDITION REQUEST to en-gNB
- Step 4: en-gNB send SGNB ADDITION REQUEST ACK to eNB Target
- Step 5: Target eNB send HANDOVER REQUEST ACK to Source eNB includes UE Context Kept Indicator
- Step 6: Source eNB send SGNB RELEASE REQUEST to en-gNB include UE Context Kept Indicator field
- Step 7: en-gNB send SGNB RELEASE REQUEST ACK to source eNB.
- Step 8: Source eNB send RRC CONNECTION RECONFIGURATION including MobilityControlInfo, NR Radio Bearer and NR Reconfiguration field to UE
- Step 9: UE RACH to target eNB and send RRC CONNECTION RECONFIGURATION COMPLETE.

- Step 10: Target eNB send SGNB RECONFIGURATION COMPLETE to en-gNB.
- Step 11: Target eNB perform PATH SWITCH REQUEST procedure to MME
- Step 12: MME return PATH SWITCH REQUEST ACK.
- Step 13: Target eNB send UE CONTEXT RELEASE to Source eNB do delete UE in source.
- Step 14: Source eNB sends UE CONTEXT RELEASE to en-gNB to inform SGNB that UE had been deleted in it.

2) Intra eNB Handover without change en-gNB

Below is the handover process of UE which wants to change to another cell within the same eNB station.

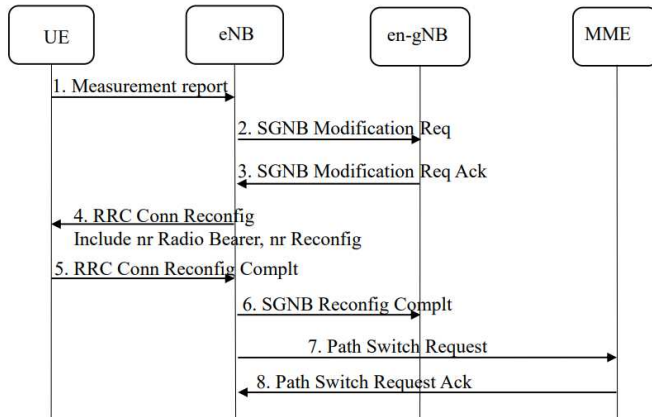


Figure 6. Scenario for intra eNB handover without change en-gNB

- Step 1: UE in NSA mode send measurement report to trigger handover 4G.
- Step 2: eNB send SGNB MODIFICATION REQUEST to 5G
- Step 3: en-gNB send SGNB ADDITION REQUEST ACK to ENB
- Step 4: Source eNB sends RRC CONNECTION RECONFIGURATION including MobilityControlInfo, NR Radio Bearer and NR Reconfiguration field to UE
- Step 5: UE RACH to target cell and send RRC CONNECTION RECONFIGURATION COMPLETE.
- Step 6: eNB send SGNB RECONFIGURATION COMPLETE to SGNB.
- Step 7: eNB performs PATH SWITCH REQUEST procedure to MME
- Step 8: MME return PATH SWITCH REQUEST ACK.

III. UPLINK SPLIT BEARER SOLUTION

A. Uplink Split packet process

The uplink split function is enabled/disabled by configurations at PDCP-Config as described in [12] specs:

```
moreThanOneRLC
primaryPath
```

```
SEQUENCE {
    SEQUENCE {
        cellGroup
        CellGroupId
        logicalChannel
        LogicalChannelIdentity
    },
    ul-
    DataSplitThreshold
    UL-DataSplitThreshold
    SplitBearer

    pdcp-Duplication
}
OPTIONAL, -- Need R
OPTIONAL -- Need R
OPTIONAL, -- Cond
BOOLEAN OPTIONAL -- Need R
```

primaryPath indicates the cell group ID and LCID of primary RLC entity as specified in [13] for UL data transmission when more than one RLC entity is associated with the PDCP entity.

ul-DataSplitThreshold stands for the threshold of data rate that UE used to send data in secondary path.

The proposed solution for uplink split mechanism is shown in Figure 7.

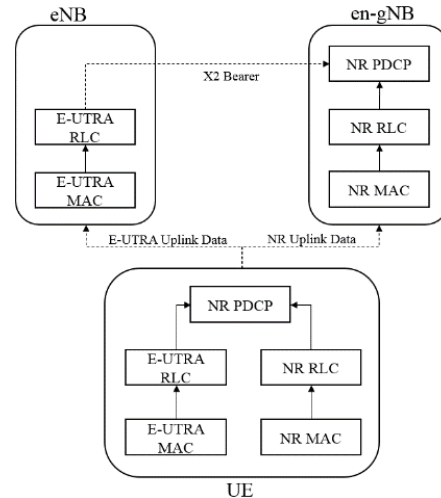


Figure 7. Proposed uplink data path including network protocol from UE to eNB and en-gNB

When uplink split bearer is configured, the uplink data path has significant changes at UE sides and both eNB/en-gNB. UE now can choose to send uplink data through eNB or en-gNB depending on the configuration of primary path and secondary path threshold introduced in III.A. If a packet is intended to send through eNB path, it starts with the E-UTRA MAC layer, then E-UTRA RLC layer and finally NR PDCP. NR PDCP entity is used to process uplink data no matter which data path UE send the uplink packet. The packet then is processed at eNB to decode E-UTRA MAC and E-UTRA RLC before passing to NR PDCP at en-gNB by X2 interface. The data stream from both eNB and en-gNB are then combined at NR PDCP entity and assigned continuous Sequence Number before send to Core Network.

Besides, the E-UTRA MAC at eNB layer keep schedule Scheduling Request to receive further Uplink data and schedule downlink feedback for the received uplink data.

B. Data path switching algorithm

With split bearers now available, the network has an ability to reconfigure UE primary path and secondary path.

When the primary path is via eNB, UE can only send uplink data to eNodeB to overcome the low-quality channel of en-gNB. When the primary path is through en-gNB, UE can decide and send uplink data to both base stations based on its data rate. Our intention is not only to improve uplink throughput but also protect the uplink data integrity when poor channel condition is detected.

In our implementation, the path switch decision is controlled based on the channel quality, represented by average value of wideband signal interference ratio (AVG_WB_SINR) or Discontinuous Transmission (DRX) by UE. These parameters require less effort than using Machine Learning to predict the exact throughput as [11]. Besides the effectiveness, all the algorithm deployed in field system must meet the real-time requirement. Figure 8 shows the logic for path switching of uplink data including 03 states:

- State (1): UE uses uplink data path through 4G eNB as primary path. The E-UTRA MAC, E-UTRA RLC and NR-PDCP are used as depicted in the lower diagram
- State (2): UE is configured to use en-gNB as primary path. The NR MAC, NR RLC and NR PDCP are used.
- State (3): UE use en-gNB as primary path but depends on its data rate to send data on eNB as secondary path.

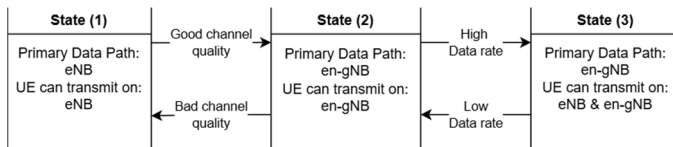


Figure 8. Logic states and conditions for switching uplink path control

When en-gNB detects that the channel quality is changed, an indication is sent to the Control Layer to request a reconfiguration message to switch the primary data path correspondingly. The dash boxes show which entities are used to decoded message from UE in each case.

There are two methods for making the path switch decision at en-gNB, based on AVG_WB_SINR or DTX by UE. Both methods aim at monitoring the channel quality and switching the data path to achieve better data performance.

1) Average Wideband SINR

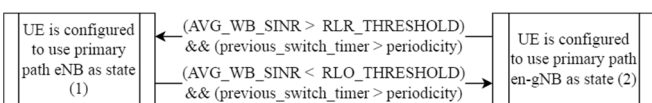


Figure 9. Logical conditions to control the uplink path based on Average Wideband Signal Interference Ratio (AVG_WB_SINR)

The value of AVG_WB_SINR is derived from the reported value of PUSCH channel, as an average value and used to

indicate the channel quality for uplink. When the AVG_WB_SINR is higher or lower than thresholds and the previous switching timer is long enough, the path switching is triggered. The periodicity timer is used to ensure that the reconfiguration is not performed within a short period of time.

2) Discontinuous Transmission (DTX) by UE

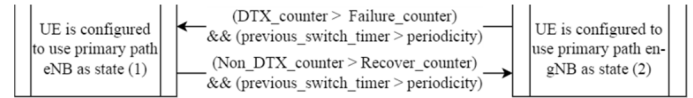


Figure 10. Logical conditions to control the uplink path based on Discontinuous Transmission (DTX) by UE

When the channel quality is poor, the acknowledgement (ACK)/negative acknowledgement (NACK) feedback from UE may be collided and cannot be recognized by the MAC layer. It is the case when the DTX is detected at en-gNB side. In these cases, the switching decision can be made to protect uplink data from UE.

C. Mobility

There are many cases happen when UE moves along while connecting to 5G NSA Network. The context of UE including Tunnel Id, Sequence Number, and data packets need to be transfer between many eNBs and en-gNBs to maintain its data path. We've tested and developed our own modifications in controlling messages between our eNBs and en-gNBs to serve those needs.

1) Inter eNodeB Handover without change gNodeB

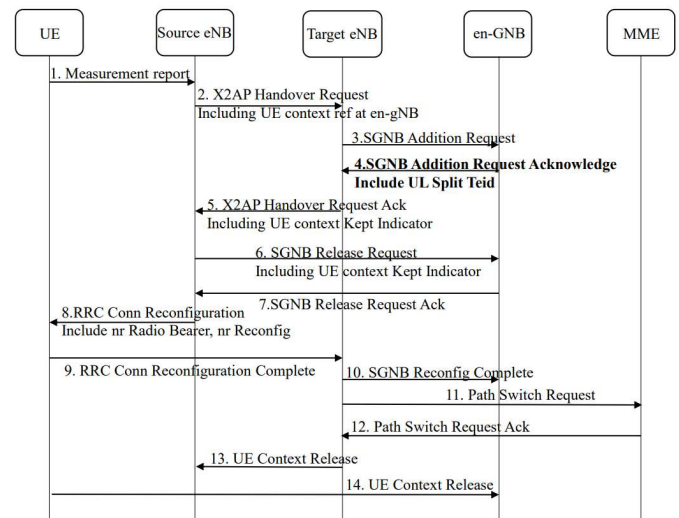


Figure 11. Scenario for inter eNB handover without change en-gNB including modify Uplink Split Tunnel

As introduced the inter eNB handover process in section II.B.1, in this scenario, UE will move from original eNB base station to another eNB base station without change en-gNB. The modification in this scenario in Figure 11 is that en-gNB now have to prepare the Tunnel Id configurations in step 4. SGNB Addition Request Acknowledge and send to target eNB. Target eNB then can create a data tunnel that can send uplink packet to the en-gNB.

2) Inter/Intra gNodeB Handover without change eNodeB

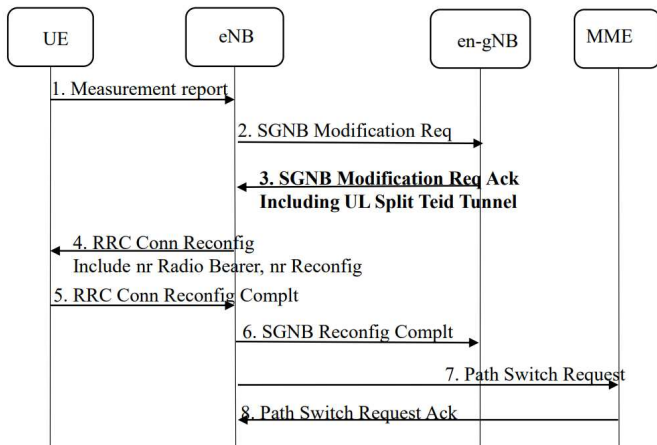


Figure 12. Scenario for intra eNB Handover without change en-gNB including modifying Uplink Split Tunnel

Similar to the scenario in Figure 6 for the case of intra eNB handover, in case of uplink split bearer available, the eNB need to know the configuration for Uplink Split Tunnel Id at en-gNB. Therefore, in step 3. SGNB Modification Request Acknowledge, the UL Split Tunnel Id is provided so that the eNB can update its destination address for uplink path.

D. Results

We've tested and integrated the uplink split bearer function into field system of 5G NSA. The en-gNB base station used in the test operates at bandwidth 100MHz, band 41 which is equivalent to 2500MHz or 2.5 GHz 5G band. The height of the station is 42 meters, and the coverage area is 900 meters. The eNB base station has a bandwidth of 20MHz, band 3 at 1800 MHz.

1) Specific location test

All the test throughput below is an average of 200 samples, each sample is recorded every second on test device. The test results recorded at the location with the received signal strength from the en-gNB based station are -70 dBm, -95 dBm, -110 dBm and -120 dBm respectively.

TABLE I: AVERAGE UPLINK THROUGHPUT RECORDED ON TEST DEVICE

Tested position signal strength from en-gNB	Average Uplink Throughput of 200 test samples	
	Normal 5G Uplink Path SCG	With Uplink Split Enabled
At -70dBm	78.9 Mbps	124.3 Mbps
At -95dBm	36.8 Mbps	73.7 Mbps
At -110dBm	1.4 Mbps	18.2 Mbps
At -120dBm	UE released, cannot send uplink data	6.4 Mbps

From Table I, we can see that the uplink split bearer function has improved significantly uplink throughput at all tested positions. Especially at good signal strength, the throughput is almost equivalent to combined uplink throughput of eNB and en-gNB. At cell-edge position -120dBm, Uplink Split Bearer also helps improve service quality.

2) Route test

In the route test, we enable the uplink split feature all over our network of multi eNB and en-gNB. The test device moved around in between numerous base station with the velocity of 30Kmph. Figure 13 shows one of our route map between 03 en-gNB stations, the eNBs not shown in the figure.



Figure 13. A route map between 3 en-gNBs shows how we conduct the test

We use the HTTP uplink service with one sample include 30 seconds of uploading and 10 seconds off. The result from Table II. is the average of 1,353 test samples recorded on 3rd October 2024.

TABLE II. ROUTE TEST RESULT ON 1,353 SAMPLES

KPI	Result	Unit
AVG_PHY_5G_UL_THP (Kbps) + 4G_UL_THP (Kbps)	60,691	Kbps
AVG_PHY_5G_UL_THP(Kbps)	33,308	Kbps
AVG_PHY_4G_UL_THP(Kbps)	27,382	Kbps
MAX_PHY_5G_UL_THP(Kbps)	73,470	Kbps
MAX_PHY_4G_UL_THP(Kbps)	54,850	Kbps
AVG_RSRP_5G	-80.4	dBm
MAX_RSRP_5G	-50.5	dBm
MIN_RSRP_5G	-113.7	dBm
AVG_RSRP_4G	-82.7	dBm
MAX_RSRP_4G	-58.0	dBm
MIN_RSRP_4G	-102.3	dBm
AVG_Ue_Tx_PUSCH_POWER_5G (dBm)	21.3	dBm
MAX_Ue_Tx_PUSCH_POWER_5G(dB m)	26.0	dBm
AVG_Ue_Tx_PUCCH_POWER_5G (dBm)	-0.7	dBm
MAX_Ue_Tx_PUCCH_POWER_5G(dB m)	23.0	dBm
AVG_PUSCH_POWER_4G(dBm)	18.1	dBm
MAX_PUSCH_POWER_4G(dBm)	22.2	dBm
BLER_PUSCH_5G (%)	9.5	%
AVG_MCS_5G	16.5	MCS
AVG_RB_5G	219.8	Resource Block

We can see clearly that uplink traffic from eNBs contributes remarkably to the overall uplink throughput. The resources from the eNBs make a large contribution and are better utilized to ensure bandwidth for the 5G- NSA Network.

IV. CONCLUSION

This paper has provided information regarding traditional data path operations and proposed our implementation of Uplink Split function within 4G and 5G NSA network. We have introduced our solution utilizing the average wideband SINR and Discontinuous Transmission (DTX) for monitoring channel quality. This approach ensures the efficiency of path switching and optimizing the radio resources while still improving throughput performance. Our proposed solution aims at enhancing the robustness and reliability of uplink data transmission by dynamically adapting to the wireless environment with less complexity to meet the real-time criteria of high load system. Furthermore, we develop the solution for mobility problems which aim at maintaining the data path when UE is moving between base stations of eNBs and en-gNBs.

Through real system testing and deployment, we have validated the effectiveness of our proposed method. The results indicate a significant improvement in uplink data performance, demonstrate clear benefits of our approach to the real system. The path switching and monitoring techniques also enhance overall efficiency and reliability to 4G and 5G NSA network.

Our future work will focus more on optimizing data switching algorithm, exploring the ability in fully split bearers including downlink split bearers and combining with other techniques such as Carrier Aggregation.

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optimization and operation for 4G/5G



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