Application Note

MEASURING DATA THROUGHPUT WITH THE CMX500

Solutions and Tipps for NR FR1 in TDD Downlink Mode

Products:

- ► R&S[®]CMX500
- ► R&S[®]CMsequencer
- R&S[®]CMsquares
- ► R&S[®]XLAPI

Yong Shi | 1SL379 | Version 2e | 08.2022

https://www.rohde-schwarz.com/appnote/1SL379



Contents

1	Overview	.3
2	Key Aspects of Maximum Data Throughput	4
2.1	NR Maximum Data Throughput	.4
2.2	Optimization of Resource Allocations	.5
2.2.1	Position of SSB and CORESET0	.6
2.2.2	TDD DL-UL Pattern	10
2.2.3		11
2.2.4		12
2.2.0	Modulation	15
2.2.7	Hybrid Automatic Repeat Request	16
2.2.8	Optimization in LTE	17
2.2.9	MIMO / Dual Connectivity / Carrier Aggregation1	19
3	Solutions and Tipps	20
3.1	System Requirements	20
3.1.1	Hardware	20
3.1.2	Software2	22
3.2	DUT Management	30
3.3	Supported Test Topologies	33
3.4	Max Throughput Wizard in CMsquares	34
3.4.1	Steps in Wizard	35
3.4.2	Measurements in Maximum Throughput Workspace	38
3.5	IP Tune	19
3.5.1	Preparation	19
3.5.2	Tuning with IP Tune	50
3.6	Throughput Testing with XLAPI Solution	52
3.6.1	Preparations	53
3.6.2	Modify Sample Script	56
3.6.3	Script Structure and Settings	59
3.6.4	DUT Control	31
3.6.5	Run the Script	j4 ∼₄
0.0.0)4)2
3.7	I nrougnput Testing in CMisequencer	56
3.7.1	I est Scripts Configuration and Execution	57 7 /
3.1.2	керопз	′4

4	Summary75	5
5	Literature	6

1 Overview

5G New Radio (NR) is a radio technology specified by 3GPP and was first released in 3GPP release 15. It is designed to target three use cases, i.e. enhanced mobile broadband (eMBB), massive machine type communication (mMTC) and ultra-reliable low latency communication (URLLC). Among these three use cases, eMBB represents actually a further evolution of mobile broadband communication from LTE standard. According to the technical performance requirement defined by IMT-2020, by deploying 5G technology, peak data rates of eMBB application are expected to reach 20 Gbps in downlink (DL) and 10 Gbps in uplink (UL) direction, respectively. Typical use cases of eMBB are data hungry applications, such as high resolution 8K video streaming, virtual reality (VR), augmented reality (AR) etc.

Verification of a 5G capable user equipment (UE) with respect to its achievable maximum data throughput under controllable and deterministic test conditions is an essential process during the design phase of the product. Performance centric verification through identification of the data throughput bottleneck, product benchmarking against a golden device enhances tremendously the user experience in the end.

This document focuses on 5G NR frequency range 1 (FR1) with TDD duplex mode in E-UTRAN New-radio Dual Connectivity (ENDC) operating mode. As 5G NR physical layer offers a plethora of flexibility, the motivation here is to provide a kind of guideline of relevant parameter settings to stimulate device under test (DUT)'s max throughput capacity. The status quo of the R&S solutions at the time when the application note is created are described. Shown feature sets are constantly evolving, so the screenshots used and the parameters shown may change.

The remaining document is organized in the following way:

Chapter 2 highlights some key influence aspects of the data throughput in 5G NR

Chapter 3 presents the throughput measurements and test solutions based on R&S®CMX500 radio tester

Last but not least, Chapter 4 concludes the document with a brief summary.

The following abbreviations of R&S® products are denoted in this document:

- R&S[®]CMX500 Radio Communication Tester is referred to as CMX
- ► R&S[®]CMsequencer graphical scripting interface is referred as CMsequencer
- ▶ R&S[®]CMsquares web based graphical user interface is referred to as CMsquares
- ► R&S[®]XLAPI scripting interface is referred to as XLAPI

It is assumed that the reader of this application note has fundamental understanding of 5G NR technology. If not, then please refer to the 5G NR eBook [1] for more detailed overview on the fundamentals, procedures, testing aspects of the technology. In addition, the reader should have hands-on experience on CMX platform. If not, please refer to CMX user manual [2].

2 Key Aspects of Maximum Data Throughput

In this chapter, we are going to tackle some key aspects that influence data throughput.

To maximize data throughput, it is all about system deployment, carrier bandwidth, modulation and optimization of the resource to reduce the overhead that in turn leave more resource allocations for the data transmission.

2.1 NR Maximum Data Throughput

Specified in TS38.306 [3], the maximum supported theoretical NR downlink data rate is shown in Equation 1

data rate (in Mbps) =
$$10^{-6} \cdot \sum_{j=1}^{J} \left(v_{Layers}^{(j)} \cdot Q_m^{(j)} \cdot f^{(j)} \cdot R_{max} \cdot \frac{N_{PRB}^{BW(j),\mu} \cdot 12}{T_s^{\mu}} \cdot (1 - OH^{(j)}) \right)$$

Equation 1 NR maximum theoretical downlink data rate (TS38.306 [3])

Parameters	Description
J	The number of the aggregated component carriers (CC) or band combinations
$v_{Layers}^{(j)}$	Maximum supported MIMO layers for j-th CC
$\boldsymbol{Q}_{\boldsymbol{m}}^{(j)}$	Maximum supported modulation order for j-th CC, 2 (QPSK), 4 (16QAM), 6 (64QAM), 8 (256QAM)
f ^(j)	Scaling factor for j-th CC. Value can be selected among 1, 0.8, 0.75 and 0.4.
R _{max}	A fixed number 948/1024 = 0.926.
$N_{PRB}^{BW(j),\mu}$	Maximum RB allocation in the BW with numerology μ for j-th CC, refer Table 5.3.2-1 in TS38.101-1 [4] and TS38.101-2 [5]
BW(j)	Maximum UE supported bandwidth for j-th CC
μ	Numerology µ=0 (15kHz SCS), 1 (30kHz SCS), 2 (60kHz SCS), 3 (120kHz SCS), 4 (240kHz SCS) [6]
T^{μ}_{s}	Average OFDM symbol duration in a subframe with normal cyclic prefix for numerology μ , $T_s^{\mu} = \frac{10^{-3}}{14 \cdot 2^{\mu}}$
ОН ^(j)	Frequency range and direction of data transmission dependent overhead factor. 0.14 (FR1, DL), 0.18 (FR2, DL), 0.08 (FR1, UL), 0.10 (FR2, UL)

Table 1 Description of parameters of the data rate calculation

Scaling factor $f^{(j)}$ is an optional UE capability that reflects the association of the maximum number of layers and maximum modulation order with the band combination [7]. It can take the values 0.4, 0.75, 0.8 and 1. Without specifying the scaling factor in UE capability, the default value 1 is applied.

The R_{max} value 948 given in Table 1 is the uttermost target code rate from 3GPP TS 38.214 [8], Table 5.1.3.1-1 and Table 5.1.3.1-2. The actual applied value should be adopted based on the UE capability which is linked to the Modulation Coding Scheme (MCS) of the associated MCS table, e.g. MCS 19 of Table 5.1.3.1-1 (64QAM MCS table) in 3GPP TS 38.214 [8] indicates the target code rate of 517.

The Overhead (OH) factor **OH**^(j) is introduced to reflect the overhead in downlink PHY signaling, incl. SSB, TRS, PDCCH, DMRS, PTRS and CSI-RS.

For a given numerology (subcarrier spacing SCS), 3GPP TS38.101-1 [4] Table 5.3.2-1 defines the maximum Resource Block (RB) allocation (N_{RB}) with respect to corresponding transmission bandwidth (see in Table 2).

SCS (kHz)	5 MHz	10 MHz	15 MHz	20 MHz	25 MHz	30 MHz	40 MHz	50 MHz	60 MHz	70 MHz	80 MHz	90 MHz	100 MHz
	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N _{RB}
15	25	52	79	106	133	160	216	270	N/A	N/A	N/A	N/A	N/A
30	11	24	38	51	65	78	106	133	162	189	217	245	273
60	N/A	11	18	24	31	38	51	65	79	93	107	121	135

Table 2 Maximum resource blocks (TS38.101-1 [4] Table 5.3.2-1)

As defined by 3GPP TS38.101-1 [4] Table 5.3.5-1, each NR band has its individual support of the channel bandwidth with associated SCS. An example shown in Table 3 (extracted from TS38.101-1 [4] Table 5.3.5-1) indicates the support of the channel bandwidth with respect to Subcarrier Spacing (SCS) in NR band n78.

NR	SCS	UE Cha	annel bar	dwidth	(MHz)									
Band	(kHz)	5	10	15	20	25	30	40	50	60	70	80	90	100
n78	15		10	15	20	25	30	40	50					
	30		10	15	20	25	30	40	50	60	70	80	90	100
	60		10	15	20	25	30	40	50	60	70	80	90	100
Table 3 C	hannel ba	ndwidth	of NR bar	nd n78 (extracted f	rom TS3	38.101-1	[4], Table	5.3.5-1)					

By giving following parameters in Equation 1,

- ► Number of carriers (J) = 1
- ► Number of layers (v) = 2
- ▶ Modulation (Q = 8) = 256QAM
- ▶ MCS = 27 (R_{max} = 948/1024)
- ► Scaling factor (f) = 1
- ▶ Band = n78
- Subcarrier spacing SCS (μ) = 30 kHz (μ = 1)
- ► Bandwidth = 100 MHz
- Maximum RB allocation = 273
- ► Overhead = 0.14

The calculated theoretical maximum data throughput = $10^{-6} * 2 * 8 * 1 * (948/1024) * (273 * 12) * (14 * 2^1) / 10^{-3} * (1 - 0.14) = 1168$ Mbps

The above described maximum downlink throughput calculation assumes the full occupation of DL slots allocation within each radio frame, i.e. FDD. For TDD operation, due to the time duplexing nature of UL and DL slots allocation within a radio frame, the maximum downlink data throughput is decreased proportionally. In addition, UE supported highest MCS needs to be considered by the calculation that affects the R_{max} value. All in all, the throughput calculated by Equation 1 servers as a theoretical upper bound.

On CMX, the actual scheduled throughput can deviate from the theoretical value due to the applied scheduling configurations, e.g. TDD DL-UL pattern, number of PDSCH DMRS positions etc.

2.2 Optimization of Resource Allocations

Like LTE, Physical Downlink Shared Channel (PDSCH) is shared between different users in NR. Certain amount of the RBs are allocated by the eNB to each user. In order to verify the FR1 TDD downlink maximum throughput, the resources allocation of PDSCH need to be maximized. To achieve this, following aspects need to be considered.

- ▶ Position of Synchronization Signal Block (SSB) and Control Resource Set (CORESET)
- TDD slot configuration
- Optimization of PDCCH
- Optimization of PDSCH / PDSCH DMRS
- Optimization of PUCCH / PUSCH
- Mixed slot activation

Combined HARQ

Additional considerations to boost the throughput are

- LTE: Optimization
- MIMO / Dual Connectivity / Carrier Aggregation

2.2.1 Position of SSB and CORESET0

SSB

Synchronization Signal Block (SSB) comprises the primary synchronization signals (PSS), secondary synchronization signal (SSS) and PBCH (including PBCH data and PBCH DMRS).

Each SSB occupies 240 subcarriers (SC) that corresponds to 20 RBs in frequency domain and 4 OFDM symbols in time domain as shown in Figure 1.



Figure 1 NR Synchronization Signal Block (SSB) [1]

SSB transmission in time domain is based on the SSB pattern (Case A to E) according to Table 4 where maximum number of SSB transmission per half frame is defined. The periodicity of the SSB pattern can be 5ms, 10ms, 20ms, 40ms, 80ms or 160ms. However, UE assumes 20ms as a default periodicity during the initial cell search.

	Subcarrier Spacing (SCS) (kHz)	OFDM start symbol position within a half frame	Value set of n	Maximum number of SSB per half frame Lmax	Frequency Range
Case A	15	{2, 8} + 14n	n = 0 ,1	4	FR1: f <=3 GHz
			n = 0,1,2,3	8	FR1: f > 3 GHz
Case B	30	{4, 8, 16, 20} + 28n	n = 0	4	FR1: f <=3 GHz
			n = 0 ,1	8	FR1: f > 3 GHz
Case C (FDD)	30	{2, 8} + 14n	n = 0 ,1	4	FR1: f <=3 GHz
			n = 0,1,2,3	8	FR1: f > 3 GHz
Case C (TDD)	30	{2, 8} + 14n	n = 0 ,1	4	FR1: f <=2.3 GHz
			n = 0,1,2,3	8	FR1: f > 2.3 GHz
Case D	120	{4, 8, 16, 20} + 28n	n = 0,1,2,3,5,6,7,8,10,11,12,13,15,16,17,18	64	FR2
Case E	240	{8, 12, 16, 20, 32, 36, 40, 44} + 56n	n = 0,1,2,3,5,6,7,8	64	FR2

Table 4 SSB transmission pattern

Although the size of SSB (Figure 1) is fixed, the number of transmission positions within the defined SSB transmission pattern can be limited through a SSB bitmap which is signaled to UE in IE ssb-PositionsInBurst of SIB1 and RRC (RRC reconfiguration) message in NR standalone (SA) and nonstandalone (NSA) mode, respectively. As illustrated in Figure 2, we leave per default only 2nd position in SSB burst to be activated on CMX.



Figure 2 An example of SSB transmission bitmap in NSA mode

Whereas in the frequency domain, the SSB should be positioned to the lower edge of the bandwidth part (BWP) as close as possible for maximum throughput testing. This condition is automatically met as long as the predefined test frequency range (Mid, Low or High) is chosen on CMX. Details are described below.

CORESET/CORESET0

Physical downlink control channel PDCCH carries the DCI (Downlink Control Information) which indicates the DL/UL resources for PDSCH/PUSCH and in addition, the slot format, PUSCH and PUCCH power control command and SRS power control command.

Control Resource Set (CORESET) is a region in the resource grid where PDCCH is located. The combination of time and frequency domain resource determines the CORESET dimension. The UE can be configured in total up to 12 CORESETs in a serving cell which is identified by its index from 0 to 11.

CORESET with index 0 (CORESET0) is a special CORESET carrying DCI for decoding the SIB1 before RRC connection is established. Therefore, a normal CORESET can be configured by RRC while CORESET0 is configured by predefined parameters. Its frequency domain assignment is not like other CORESETs on the 6 RBs grid rather determined relatively to the SSB.

If SIB1 is presented, then the controlResourceSetZero and searchSpaceZero contained in the IE PDCCH Config SIB1 of MIB (see Figure 3) are the index number within the applicable look-up tables¹ in 3GPP TS38.213 Chapter 13 [9]. Out of the look-up table, the size of CORESETO in the resource grid (number of RBs, RB offset to SSB and number of symbols) is determined by the index number given by controlResourceSetZero. CORESTO monitoring occasions (system frame number and slot information that UE needs to know to monitor the PDCCH) is determined by searchSpaceZero. For more readings, refer to 3GPP TS38.213 Chapter 13 [9].



Figure 3 Example of CORESET0 configuration in MIB

¹ The selection of look-up table depends on the SSB SCS, PDCCH SCS and minimum bandwidth of the operating band.

Figure 3 gives an example of CORESET0 configuration (controlResourceSetZero = 2) in MIB. By looking up the Table 13-4² in 38.213 [9], configurations given in Table 5 are linked to index 2 are applied where offset RBs refers to the number of RBs relative to the lowest start RB of SSB. The other way around, if the CORESET0 should start at RB 0 to align with the lower edge of the BWP in order to leave more resources allocated for PDSCH, then the SSB should start at RB 2.

Index	SS/PBCH block and CORESET multiplexing pattern	Number of RBs N ^{CORESET}	Number of Symbols	Offset (RBs)
2	1	24	2	2

Table 5 COREST0 configuration in Table 13-4, 3GPP 38.213 [9] with controlResourceSetZero = 2

Selecting an arbitrary carrier frequency of an NR band and configuring the parameters in such a way that SSB and CORESET0 are positioned in the edge of the BWP is a time tedious task and often failure prone. To cope with this challenge, predefined 3GPP test frequency range (Mid, Low or High) can be utilized. The standardized test frequencies of each individual NR band can be found in TS38.508-1 [10], Table 4.3.1.1.1.x-y, where placeholder x indicates the NR band, y indicates the associated SCS (1=15 kHz SCS, 2=30 kHz SCS, 3=60 kHz SCS). In each table, the listed parameters associated to 'Mid', 'Low' or 'High' test frequency range ensures that the SSB and CORESET0 are positioned to the lower edge of the BWP as close as possible and RB offset between SSB and CORESET0 is considered as well.

As an example, Table 6 is the test frequency definitions extracted from TS38.508-1 [10], Table 4.3.1.1.1.78-2 for n78, 30 kHz SCS.

² This table is selected based on configuration (SSB SCS 30 kHz, PDCCH SCS 30 kHz, 10 MHz min bandwidth for band n78 defined in 3GPP TS38.101-1 Table 5.3.5-1 [4])

Bandwi dth [MHz]	carrierB andwidt h [PRBs]	Range	9	Carrier centre [MHz]	Carrier centre [ARFCN]	point A [MHz]	absoluteF requency PointA [ARFCN]	offsetToC arrier [Carrier PRBs]	SS block SCS [kHz]	GSCN	absoluteF requency SSB [ARFCN]	k _{ssb}	CORES ET#0 Offset [RBs] Note 1	CORES ET#0 Index Note 1	offsetToP ointA (SIB1) [PRBs] Note 1
10	24	Downlink	Low	3305.01	620334	3300.69	620046	0	30	7711	620352	18	2	2	4
		&	Mid	3549.99	636666	3508.95	633930	102		7881	636672	6	2	2	208
		Uplink	High	3795	653000	3609.24	640616	504		8051	652992	16	1	1	1010
15	38	Downlink	Low	3307.5	620500	3300.66	620044	0	30	7711	620352	20	2	2	4
		&	Mid	3549.99	636666	3506.43	633762	102		7879	636480	6	1	1	206
		Uplink	High	3792.48	652832	3604.2	640280	504		8048	652704	16	3	3	1014
20	51	Downlink	Low	3310.02	620668	3300.84	620056	0	30	7711	620352	8	2	2	4
		&	Mid	3549.99	636666	3504.09	633606	102		7878	636384	18	3	3	210
		Uplink	High	3789.99	652666	3599.37	639958	504		8044	652320	2	1	1	1010
40	106	Downlink	Low	3320.01	621334	3300.93	620062	0	30	7711	620352	2	2	2	4
		&	Mid	3549.99	636666	3494.19	632946	102		7871	635712	6	3	3	210
		Uplink	High	3780	652000	3579.48	638632	504		8030	650976	8	0	0	1008
50	133	Downlink	Low	3325.02	621668	3301.08	620072	0	30	7711	620352	16	1	1	2
		&	Mid	3549.99	636666	3489.33	632622	102		7867	635328	18	0	0	204
		Uplink	High	3774.99	651666	3569.61	637974	504		8024	650400	18	3	3	1014
60	162	Downlink	Low	3330	622000	3300.84	620056	0	30	7711	620352	8	2	2	4
		&	Mid	3549.99	636666	3484.11	632274	102		7864	635040	6	3	3	210
		Uplink	High	3769.98	651332	3559.38	637292	504		8016	649632	4	0	0	1008
80	217	Downlink	Low	3340.02	622668	3300.96	620064	0	30	7711	620352	0	2	2	4
		&	Mid	3549.99	636666	3474.21	631614	102		7857	634368	18	2	2	208
		Uplink	High	3759.99	650666	3539.49	635966	504		8003	648384	10	3	3	1014
90	245	Downlink	Low	3345	623000	3300.9	620060	0	30	7711	620352	4	2	2	4
		&	Mid	3549.99	636666	3469.17	631278	102		7853	633984	18	0	0	204
		Uplink	High	3754.98	650332	3529.44	635296	504		7996	647712	8	3	3	1014
100	273	Downlink	Low	3350.01	623334	3300.87	620058	0	30	7711	620352	6	2	2	4
		&	Mid	3549.99	636666	3464.13	630942	102		7850	633696	18	2	2	208
		Uplink	High	3750	650000	3519.42	634628	504		7989	647040	4	3	3	1014

Note 1: The CORESET#0 Index and the associated CORESET#0 Offset refers to Table 13-4 in TS 38.213 [22]. The value of CORESET#0 Index is signalled in the four most significant bits of the IE pdcch-ConfigSIB1 in the MIB. The offsetToPointA IE is expressed in units of resource blocks assuming 15 kHz subcarrier spacing for FR1 and 60 kHz subcarrier spacing for FR2.

Table 6 Test frequencies for NR band n78 and SCS 30 kHz (TS38.508-1, Table 4.3.1.1.1.78-2 [10])

Thus, following parameters need to be set exemplary on CMX to position SSB and CORESET0 for the max downlink throughput testing:

- ► Frequency Range, e.g. FR1
- Duplex mode, e.g. TDD
- Frequency Band Indicator, e.g. N78
- Subcarrier Spacing, e.g. 30 kHz
- Carrier Bandwidth, e.g. 100 MHz (set DUT's maximum supported bandwidth)
- ► Range, choose one of the predefined ranges 'Mid', 'High' or 'Low'.



Figure 4 Frequency settings and visualization of frequency config on CMX

Figure 4 highlights the frequency settings in CMsquares. Intuitively, the actual position of SSB and CORESET in frequency domain of the BWP is visualized in the 'Frequency Configuration' window. As we can clearly see that both of them are located at the lower edge of the BWP.

2.2.2 TDD DL-UL Pattern

5G NR provides high flexibility to configure the transmission and receiving in time domain in TDD mode. The parameters dl-UL-TransmissionPeriodicity, nrofDownlinkSlots, nrofDownlinkSymbols, nrofUplinkSlots and nrofUplinkSymbols determine the TDD pattern for UL and DL allocation in a radio frame.

The configuration in Table 7 enables maximum downlink resource allocation for PDSCH which is essential for downlink maximum throughput testing in TDD mode. Whereas the number of uplink slots and symbols are kept on the minimum level for just sending the ACK/NACK in the uplink direction for the HARQ process.

Parameter	Value	Description
dI-UL-TransmissionPeriodicity	5 ms (10 slots)	Periodicity of TDD DL/UL pattern
nrofDownlinkSlots	8	Number of consecutive full DL slots at the beginning of each DL-UL pattern
nrofUplinkSlots	1	Number of consecutive full UL slots at the end of each DL-UL pattern
nrofDownlinkSymbols	12	Number of consecutive DL symbols in the beginning of the slot following the last full DL slot
nrofUplinkSymbols	1	Number of consecutive UL symbols in the end of the slot preceding the first full UL slot

Table 7 TDD DL/UL pattern for max downlink throughput

TDD DL-UL pattern configuration given in Table 7 is illustrated in Figure 5 where slot 0 to slot 7 are scheduled for downlink, slot 8 is a partial slot and last slot 9 is for uplink. In partial slot 8, the first 12 symbols are for downlink, the last symbol is for uplink.



Figure 5 TDD DL/UL pattern according to configuration of Table 7

In CMsquares, TDD DL-UL pattern can be configured as shown in Figure 6.



Figure 6 Configuration of TDD DL-UL pattern in CMsquares

2.2.3 Optimization of PDCCH

Optimization of PDCCH is performed in both time and frequency domain to reduce its dimension in the resource grid.

Aggregation level (AL) determines the size of a Search Space (SS). In Table 8, a list of ALs and their mapping with respect to control channel elements (CCEs), RE, resource element groups (REGs) and PDCCH size is given. For scheduling PDSCH, DCI format 1_1 is used. We apply here AL2 to convey DCI 1_1 with considerable good forward error correction performance.

Aggregation Level	Number of CCEs	Number of RE	Number of REG	PDCCH (QPSK modulated, excl. DMRS) (bits)
1	1	72	6	108
2	2	144	12	216
4	4	288	24	432
8	8	576	48	864
16	16	1152	96	1728

 Table 8 UE specific Search Space (USS) Aggregation Levels

In the time domain, PDCCH is reduced to 1 OFDM symbol. This assignment is implicitly configured through PDSCH resource allocation in time domain (see 2.2.4 for details).

AL can be set in CMsquares as shown in Figure 7.

General	LTE Cell 0	🔺 NR Cell 0	
		ON	
▼ UE S	cheduling		
Schedu	iling Mode	Fixed	~
Schee	luling Type Downlink	User Define	ed
Schee	luling Type Uplink	User Define	ed
	Wizard		RMC
Slot A	ssignment	0	
51017	ssignment	U	onnguration
Downlink	Scheduling	C.	onnguration
Downlink	Scheduling AC Padding	 ✓ 	onnguration
Downlink MA Bandwi	Scheduling AC Padding dth Part ID	 ✓ 0 	onnguration
Downlink MA Bandwi Aggreg	Scheduling AC Padding dth Part ID ation Level	✓ 0 Level 2	v
Downlink MA Bandwi Aggreg Searc	Scheduling AC Padding dth Part ID ation Level	✓ 0 Level 2 2	v
Downlink MA Bandwi Aggreg Searc	Scheduling AC Padding dth Part ID ation Level th Space ID MCS Table	 ✓ 0 Level 2 2 256 QAM 	v

Figure 7 Aggregation Level (AL) setting for PDCCH in CMsquares

Optimization of PDCCH in both time and frequency domain is illustrated in Figure 8.





2.2.4 Optimization of PDSCH

Recall that TDD DL-UL pattern is configured for max downlink throughput testing according to the parameter settings mentioned in chapter 2.2.2.

Now, we will get a level deeper to see how to optimize PDSCH resource allocation in time domain with respect to the assigned number of symbols in each slot.

In time domain, following aspects have to be taken into accounts:

For all downlink slots (slot 0 to slot 7), reserve 1 symbol (symbol index 0) for PDCCH to reduce the control overhead (see 2.2.3). The remaining 13 symbols (starting from symbol index 1) are allocated for PDSCH. Figure 9 depicts the time domain resource assignment for TDD DL slots.



Figure 9 TDD downlink slot configuration for maximum downlink throughput

In partial slot 8, use 12 DL symbols (symbol 0 is reserved for PDCCH), 1 UL symbol (the last symbol for PUCCH). One symbol (symbol 12) remains unassigned which serves as a guard period. The guard period is necessary for a TDD system to ensure enough switching time from DL to UL transmission. Time domain assignment of partial slot 8 is illustrated in Figure 10 below.

Due to the internal processing time of individual UE, the optimization by utilizing the partial slot 8 for TDD is not always possible. Only UE with high processing performance can apply this kind of optimization. Therefore, this is optional and can be activated or deactivated in UE scheduling configuration in CMsquares if required.



Figure 10 TDD partial slot configuration for maximum downlink throughput

In frequency domain, the maximum available number of RBs are determined by the channel bandwidth and SCS. For example, if 100 MHz channel bandwidth and 30 kHz SCS is considered, then max 273 RBs can be assigned according to Table 2 on Page 4.

- ► For DL slot 1 to slot 7, complete 273 RBs are allocated to PDSCH without exceptions.
- DL slot 0 should be scheduled carefully. Based on the CORESET0 predefined configuration (see Chapter 2.2.1), SSB start RB is 2 (see Table 6, considered example: n78, 30 kHz SCS, 100 MHz CBW, 'Mid' frequency range). SSB itself occupies 20 RBs. Therefore, the earliest start RB for PDSCH should be 23. Thus, the remaining maximum number of RBs for PDSCH in slot 0 are 250. According to SSB position bitmap in time domain (see the example in Chapter 2.2.1), SSB occupies 8th, 9th, 10th and 11th symbol of slot 0. By taking all these facts into account, resources in slot 0 are now assigned as shown in Figure 11 below.

RB															
3		PDSCH													
2		PDSCH													
	:							:						:	
3		PDSCH													
7		PDSCH													
6		PDSCH													
5		PDSCH													
4	PDCCH	PDSCH													
3	PDCCH	PDSCH													
2	PDCCH									PBCH	PBCH	PBCH			
1	PDCCH									PBCH	PBCH	PBCH			
0	PDCCH									PBCH	PBCH	PBCH			
9	PDCCH									PBCH	PBCH	PBCH			
	1							1	PSS	РВСН	SSS	PBCH		1	
5	PDCCH									PBCH	PBCH	PBCH			
ļ	PDCCH									PBCH	PBCH	PBCH			
3	PDCCH									PBCH	PBCH	PBCH			
2	PDCCH									PBCH	PBCH	PBCH			
1	PDCCH														
)	PDCCH														
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	S

Figure 11 Resource allocation of Slot 0 (symbol 0 is reserved for PDCCH)³

- Schedule DL data in slot 0-8 with possible MIMO scheme and maximum MCS 27 if '256 QAM' MCS Table is applied. These settings are UE capability dependent.
- Allow minimum number of PDSCH DMRS. Try to adopt no additional PDSCH DMRS positions (set dmrs_AdditionalPosition to pos0)⁴

Figure 12 shows an example of PDSCH settings in CMsquares based on the optimization considerations explained in above text with few exceptions. MCS 19 is chosen in this case which reflexes maximal MCS support of the DUT being tested. Mixed slot 8 is deactivated which is limited by the used DUT too.

³ For sake of simplicity, the occupation of DMRS is not illustrated in the graph.

⁴ No additional PDSCH DMRS position (Pos 0) may cause higher BLER for UE with bad receiver performance. In this case, one additional PDSCH DMRS position (Pos 1) needs to be configured which will then reduce the scheduled throughput.

 Network Configu 	uration																							
Navigation Collapse Exp	pand LTE	NR NR	* Favorite																					
General 🚷 LTE Cell 0	Cell 0		_																					
	ON																							
▼ DM-RS			•																					
Downlink																								
Mapping Type A		NR Cell 0 > UE Slot Sci	neduling																					×
Additional Position	Pos 0	Slot Index	0 DL	1 DL	2 DL	3 DL	4 DL	5 DL	6 DL	7 DL	8 DL	8 UL	9 UL	10 DL	11 DL	12 DL	13 DL	14 DL	15 DL	16 DL	17 DL	18 DL	18 UL	19 UL
Mapping Type B					_	_	Z	_			~	Z	. .	Z	_	.	~	,
Additional Position	Pos 1	No. of RB	250	273	273	273	273	273	273	273	273	1 × 1	273	273	273	273	273	273	273	273	273	273		273
Uplink		Start RB	23	0	0	0	0	0	0	0	0	- × -	0	0	0	0	0	0	0	0	0	0		0
Mapping Type A		MCS - Modulation	19-64 💊	19-64 🗸	19 - 64 🗸	19-64 🗸	19-64 🗸	19-64 🗸	19-64 🗸	19-64 🗸	19-64 🗸	•	10-16 🗸	19 - 64 🗸	19-64 🗸	19-64 🗸	19-64 🗸	19-64 🗸	19-64 🗸	19-64 🗸	19 - 64 🛩	19-64 🗸		10 - 16 🗸
Additional Position	Pos 2	Modulation	64 QAM	64 QAM	64 QAM	64 QAM	64 QAM	64 QAM	64 QAM	64 QAM	64 QAM		16 QAM	64 QAM	64 QAM	64 QAM	64 QAM	64 QAM	64 QAM	64 QAM	64 QAM	64 QAM	-	16 QAM
Mapping Type B		DCI Format	DCI 11 🗸	• DCI 11 •	DCI 11 🗸	DCI 11 🛩	DCI 11 🗸	DCI 11 🗸	DCI 11 🗸	DCI 11 🗸	DCI 11 👻		DCI 01 🗸	DCI 11 🛩	DCI 11 🗸	DCI 11 🗸	DCI 11 🗸	DCI 11 🗸	DCI 11 👻	DCI 11 🗸	DCI 11 👻	DCI 11 🗸	-	DCI 01 🗸
Additional Position	Pos 2	MIMO Scheme	4xN 🛰	4xN ¥	4xN 🛩	4xN 🛩	4xN 🛩	4xN 🛩	4xN 🛩	4xN 🛩	4xN 🛩	· ·	Nx1 👻	4xN 🛩	4xN 🛩	4xN 🛩	4xN 🗸	4xN 🛩	4xN 🛩	4xN 🛩	4xN 🛩	4xN 🛩		Nx1 🛩
PRACH		▼ Time Domain Alloc																						
PUSCH		Start Symbol	1	1	1	1	1	1	1	1	1	- A.	0	1	1	1	1	1	1	1	1	1		0
SRS		No. of Symbols	13	13	13	13	13	13	13	13	11		13	13	13	13	13	13	13	13	13	11		13
TDD Common		Channel Mapping	TYPE A 🛰	TYPE A 🗸	TYPE A 🗸	TYPE A 🛩	TYPE A 🛩	TYPE A 🗸	TYPE A 🗸	TYPE A 🗸	TYPE A 🗸) ÷	TYPE A 🗸	TYPE A 🛩	TYPE A 🗸	TYPE A 🛩	TYPE A 🛩	TYPE A 🗸	TYPE A 🛩	TYPE A 🛩	TYPE A 🛩	TYPE A 🛩		TYPE A 🛩
 UE Scheduling 	_	Slot Offset (k0 k2)	0	0	0	0	0	0	0	0	0	- ÷	2	0	0	0	0	0	0	0	0	0	-	2
Scheduling Mode	Fixed																							
Downlink Scheduling Type	User Define	4										T								, v	фріу 🗸	Apply and	close	× cancet
Uplink	User Denner																							
Wizard		RMC																						
Slot Assignment	Co	onfiguration	_																					
Downlink Scheduling																								
MAC Padding	~																							
Bandwidth Part ID	0																							
Aggregation Level	Level 2		~																					
Search Space ID	2																							
MCS Table	256 QAM		~																					
Vrb to Prb Mapping	Non Interlea	sved	~																					

Figure 12 PDSCH scheduling in CMsquares with activated partial slot 8

2.2.5 Optimization of PUCCH/PUSCH

PUCCH/PUSCH is used for the UE to send uplink control information (UCI) to gNB.

UCI contains following contents

- ACK/NACK of PDSCH
- Scheduling request (SR)
- Channel status indicator (CSI)

For DL throughput testing, resources allocated for UL channels need to keep on a minimal level. Therefore, followings are considered for PUCCH/PUSCH optimization:

- ▶ Short PUCCH is used (PUCCH format 2) which allows only 1 or 2 OFDM symbols.
- Set the last symbol in partial slot 8 for PUCCH, see also Figure 10
- Set PUSCH in slot 9 to 13 symbols (symbol 0-12) and set last symbol for PUCCH. The resource allocation of UL slot 9 is illustrated below in Figure 13.



Figure 13 TDD uplink slot configuration for maximum downlink throughput

2.2.6 Modulation

Several modulation types are defined in NR to be used for PDSCH, i.e. QPSK, 16QAM, 64QAM and 256QAM that corresponds to modulation order 2, 4, 6 and 8, respectively. 3GPP 38.214 [8], Chapter 5.1.3 specifies three MCS tables (MCS index table 1, 2 and 3). The combination of MCS table and MCS index determines the modulation type/modulation order and the target code rate of the PDSCH.

To perform maximum throughput testing, proper selecting of MCS table in CMsquares (see Figure 14) and choosing of MCS index in the UE scheduling configuration (see Figure 12, e.g. MCS 19) for PDSCH is important to achieve the maximum target code rate. As a rule of thumb, to reach higher DL throughput, always select higher modulation order. However, drawback is the higher vulnerability that is being introduced as the so-called Euclidian distance shrinks and the bit error rate probability rises. Thus, the caused data retransmissions will negate the gain obtained from higher order modulation. A trade-off between modulation order and number of retransmissions due to bit error rate has to be considered. Nice MCS tuning feature is developed in CMsquares to explore the optimal MCS index (see 3.5.2 for the details). Apparently, the selection of MCS table and MCS index depends on the UE capability.

Downlink Scheduling	
MAC Padding	
Bandwidth Part ID	0
Aggregation Level	Level 2 🗸
Search Space ID	2
MCS Table	256 QAM 🗸
Vrb to Prb Mapping	64 QAM Low SE 256 QAM
Uplink Scheduling	64 QAM
Bandwidth Part ID	0
Aggregation Level	Level 2 🗸
Search Space ID	2
MCS Table	64 QAM 🗸

Figure 14 MCS table selection in CMsquares

Table 9 provides the mapping information between 3GPP specified MCS tables and MCS table selections in CMsquares. For more information about MCS, please refer to 3GPP 38.214 [8] Chapter 5.1.3.

3GPP 38.214 [8] MCS Table for PDSCH	MCS Table in CMsquares
Table 5.1.3.1-1: MCS index table 1	64QAM
Table 5.1.3.1-2: MCS index table 2	256QAM
Table 5.1.3.1-3: MCS index table 3	64QAM Low SE

Table 9 Mapping of MCS tables defined in 3GPP 38.214 [8] and MCS tables in CMsquares

2.2.7 Hybrid Automatic Repeat Request

Hybrid automatic repeat request (HARQ) is a MAC protocol to improve the re-transmission. If the receiver detects the error in the received data, it will buffer the data and at the meanwhile request the transmitter for the retransmission.

Unlike the fixed HARQ ACK/NACK timing (4 ms in FDD) in LTE, NR applies a fully configurable parameter K1 to define the offset in number of slots between the DL slot where the data is scheduled on PDSCH and the reception of the associated acknowledgement (ACK/NACK) carried on PUCCH in UL.

Depending on whether partial slot 8 is activated or not, K1 is optimized in such a way that the HARQ of DL slots are aggregated and sent in one UL slot (i.e. in UL slot 9 or UL portion of the partial slot 8). This optimization is automatically performed by Maximum Throughput Wizard (see 3.4) or by running the XLAPI script (see 3.6) on CMX. Details are illustrated in Figure 15 and Figure 16 showing that the K1 assignment of each DL slot with activated and deactivated partial slot 8, respectively.



Figure 15 K1 configuration over one radio frame (20 slots, 30 kHz SCS) with activated partial slot 8





2.2.8 Optimization in LTE

In NSA case, LTE acts as a master node or anchor that can be utilized for data transmission in addition to NR. To maximize the data throughput over LTE, following aspects need to be considered:

- Set proper DUT supported duplex mode (FDD or TDD) and supported band.
- Set DUT supported maximum channel bandwidth and associated maximal number of RBs in LTE. E.g. 20 MHz channel bandwidth corresponds to 100RBs

- Use MIMO, e.g. use MIMO 2x2, transmission mode: spatial multiplexing
- Set highest supported MCS, e.g. MCS 27 (with 256QAM Table)
- Reduce PDCCH to 1 symbol

Figure 17 presents an overview of the configurations in LTE in CMsquares that need to be prepared for the maximum data throughput over LTE.

	General Cell 0	Cell 0			Genera	l 🚯 LTE Cell 0	A NR Cell 0				
• Frequency and Band • UE Scheduling Upple Mode Food • Trequency (and guaration • Scheduling (Mode Trequency (configuration • Scheduling (Mode Downlink • VE Scheduling Response 100 Trequency (and guaration • Scheduling (Mode Response 100 Trequency (and guaration • Scheduling Bange Choice Mid Band • Frequency (2Mode) • MHz Scheduling (Mode) • Scheduling (Mode) Transmission Mode • MCS Table Power • MCS Table 256 GAM * POSCH Symbols 1 3ymbol * POSCH Symbols 1 3ymbol * POSCH • OB * Power • Power * Passe Enable *Allow Fading* * Power • Passe * Passe Final Config • OB * Power • Passe * Passe • Set		OFF					OFF				
Duplex Mode FDD Image: Note Field Image: Note Fielding Scheduling Mode Fielding Scheduling Mode Fielding Downlink Frequency Configuration Image: Note Fielding Scheduling Mode Field Image: Note Scheduling Mode Fielding Resource Block 100 Image: Note Fielding Image: Note	 Frequency and 	Band			🔺 🔻 UI	E Scheduling	_				
Frequency Band Indianal Property Bandwalk Image: Configuration Image: Configuration Resource Blocks 100 Image: Configuration Image: Configuration Resource Blocks 100 Image: Configuration Image: Configuration Image: Configuration Carrier Frequency 2140.0 MHz Image: Configuration Image: Configuration Image: Configuration Carrier Frequency 2140.0 MHz Image: Configuration Image: Configu	Duplex Mode	FDD]	~	Sche	duling Mode	Fixed		~		
Ubitedu Frequency Configuration Visitad RMC Secure Stacks 100 Visitad Carrier Frequency 2140.0 MHz Configuration Daminis Visitad Configuration Configuration Carrier Frequency 2140.0 MHz Configuration Database Configuration Configuration Configuration Tork Separation Default Visitad MLz Diameter Configuration Configuration Configuration Tork Separation Default Visitad Visitad Visitad Carrier Frequency 1980.0 Configuration Configuration Visitad Visitad Factorier Frequency 1980.0 Configuration Visitad Visitad Visitad Fower Power Power Power Power Power Power Visitad Configuration Visitad Configuration Visitad Configuration Staffame Ca Ca Ca Ca	Frequency Band	1	1	~	Sch	eduling Type	User Define	d			
Downlink Wiza' RMC Resource Blocks 100 Viza' Resource Blocks 100 Viza' Resource Blocks Md Band Viza' Carrier Frequency 2140.0 Mt/z Tx-Rx Separation Default Viza' Frequency 2140.0 Mt/z Carrier Frequency 2140.0 Mt/z Resource Blocks 100 Viza' Pisse Fallow Fading'' Viza' Acterna Config Viza' Viza' MMX Schere MMXD S2 Viza' Acterna Forts 2 2 2 2 2 2 2 2 2 2 2 <th>Indicator</th> <th>Fred</th> <th>Juency Confia</th> <th>uration</th> <th>Sch</th> <th>eduling Type</th> <th>User Define</th> <th>d</th> <th></th> <th></th> <th></th>	Indicator	Fred	Juency Confia	uration	Sch	eduling Type	User Define	d			
Resource Blocks 100 'Resource Mild 'Resource Mild Band Carrier Frequency 2140.0 MHz Carrier Frequency 2140.0 MHz Carrier Frequency 2140.0 MHz Carrier Frequency 2140.0 'Piccel Region If PicCCH Symbols 1 Symbol 'Resource Blocks 100 'Resource Blocks 100 'Resource Blocks 100 'Resource Blocks 100 'Resource Blocks 100 'Staffinand Ports 2 'Staffinand Ports 2 'Staffinand Ports 2	Downlink					Upunk Wizard		RMC			
Standarding Assignment Comparison Bange Choice Mid Band V Carrier Frequency 210.0 Milz Carrier Frequency 210.0 Milz Carrier Frequency 210.0 Milz Tx-Rx Separation Default V Resource Blocks 10 V Resource Blocks 10 V Resource Blocks 10 V Respective 200.0 Milz Respective 200.0 Milz Respective 200.0 Milz Sandoddition 0 V Feequency 1950.0 Milz Carler Frequency 1950.0 Milz Fact V Ethera Config Power FACH Pace Pace PSS Antena Config V V Mild Band V V V Satisfamme 0 0 0 V V Satisfamme 0 0 V V V V Satisfamme 0<	Resource Blocks	100	1	~		Subframe		Configuration			
Balantholic Mid Band Carrier Frequency 2140.0 MHZ Carrier Frequency 200.11 Carrier Frequency 200.11 Carrier Frequency 200.0 MHZ Fading Peace Fading Peace Peace Pascher Pascher Pascher Pasch Pascher Pascher	Frequency	20 MHz	1	~	Downlir	Assignment nk Scheduling		configuration.			
Carrier Frequery 2140.0 MHz EARFCN 300 MHz Tx-Rx Separation Default V Resource Blocks 100 V Bandokidk MHz V Resource Blocks 100 V Resource Blocks 100 V Range Choice Mid Band V Carrier Frequery 1950.0 MHz Carrier Frequery 1950.0 MHz Image Choice Mid Band V Carrier Frequery 1950.0 MHz Frequery 1950.0 MHz Image Choice MMO Scherre MMO Scherre MMD Scherre MMD Scherre MMD Scherre BS Antenna Ports 2 3 4 5 6 7 6 9 Stoffannes NCCE V NCC	Range Choice	Mid Band		~	Transn	nission Mode	TM3: Open	Loop Spatial N	Multiplexi 🗸		
and and any and any and any	Carrier Frequency	2140.0		MHz		MCS Table	256 QAM	<u> </u>	•		
Uptink Tx-Rx Separation Default PDCCH Region PDCCH Region PDCCH Region Resource Blocks 100 V PDCCH Region PDCCH Region Resource Blocks 100 V CArlerenting PDCCH Region Semantic Miller 20 MHz COBX LOBX LOBX Carler Frequency 1950.0 MHz Fading Power Fading	EARECN	300				MAC Padding	2				
Tx-Rx Separation Default Resource Blocks 100 COL Reporting Place Enable "Allow Fading" Fading Col Reporting Col Col Col Col Col Col Col Col Col Col	Uplink	300			PDCCH	Region	•				
Resource Blocks 100 CQI Reporting CDRX Bandwidd CDRX UE Timer and Constants Fading Carrier Frequency 1950.0 MHz Fading Please Enable "Allow Fading" Please Enable "A	Tx-Rx Separation	Default		~	# PD	CCH Symbols	1 Symbol		~		
Frequency Bandwidth 20 MHz V Range Choice Mid Band V Carrier Frequency 1950.0 MHz EARCK 18300 MHz Carrier Frequency 1950.0 MHz EARCK 18300 Pease Enable "Allow Fading" V Additional Spectrum 0 Pease Enable "Allow Fading" V > PRACH V V V V > PRACH V V V V > PRACH V V V V V > PRACH V V V V V V SR5 V V V V V V V V V V SR5 V </th <th>Resource Blocks</th> <th>100</th> <th></th> <th>~</th> <th>► C0</th> <th>QI Reporting</th> <th></th> <th></th> <th></th> <th></th> <th></th>	Resource Blocks	100		~	► C0	QI Reporting					
Bandwidth Immune Immune <th>Frequency</th> <th>20 MHz</th> <th></th> <th></th> <th>► CI</th> <th>ORX</th> <th></th> <th></th> <th></th> <th></th> <th></th>	Frequency	20 MHz			► CI	ORX					
Aninge Crower Fading EARFCN 18300 Additional Sperture 0 Feding Please Enable "Allow Fading" Power 0 PRACH 0 PUSCH 0 SRS 0 Antenna Config 0 MIMO Scheme MIMO 2x2 Antenna Ports 0 # CRS Antenna Ports 0 Subframe 0 0 0 0 0 0 0 <th>Bandwidth</th> <th>Adid Daved</th> <th></th> <th>•</th> <th>► UI</th> <th>E Timer and G</th> <th>onstants</th> <th></th> <th></th> <th></th> <th></th>	Bandwidth	Adid Daved		•	► UI	E Timer and G	onstants				
Carrier requency 1950.0 MH2 EARFCN 18300 Cell Timing 0 Power Packet PRACH PUSCH Yourget Publich Staff rame 0 0 1 2 Yourget NCCE2 NCCE2 <th>Range Choice</th> <th>MIG Band</th> <th></th> <th>· · · ·</th> <th>▼ Fa</th> <th>ding</th> <th></th> <th></th> <th></th> <th></th> <th></th>	Range Choice	MIG Band		· · · ·	▼ Fa	ding					
EARFON 13300 Additional Spring 0 Power Power Power PSACH PUSCH SRS Antenna Config MIMO Scheme MIMO Sc	Carrier Frequency	1950.0		MHz	Please E	Enable "Allow	Fading"				
Auditoria spectral 0 • Cell Timing • • Power • • PRACH • • PUSCH • • SRS • • Antenna Config • MMO Scheme MMO 2x2 • Antenna Ports • # CRS Antenna Ports • # CRS Antenna Ports • Subframes • Subframes • Subframe 0 0 1 2 2 • Vinkit Upin Subframe 0 0 1 2 2 • • Vinkit Upin POCCH Format NCCE2 v NC	EARFCN	18300									
Cell Timing Power PRACH PSS * Antenna Config MIMO Scheme MIMO 2x2 * Antenna Ports # CRS Antenna Ports # CRS Antenna Ports 2 * * Star 9 Continx 0 1 2 * * 1 2 2 * * 5 6 7 8 8 9 2 2 * 1 2 2 * 1 2 3 4 5 6 7 8 9 2 101 10 102 10 102 10 102 10 102 10 102 10 102 100 102 100 100 100 100	Emission	0									
Power PRACH PBACH PUSCH SRS Antenna Config MIMO Scheme MIMO 2x2 Antenna Ports # CRS Antenna Ports Z Z J J J	Cell Timing										
PUSCH \$R5 Antenna Config MIMO Scheme MIMO 2x2 Antenna Ports # CRS Antenna Ports 2 Dowlink Uplink SubFrame 0 1 2 3 4 5 6 7 8 9 POCCH Format 0 1 2 3 4 5 6 7 8 9 PDCCH Format 0 1 2 3 4 5 6 7 8 9 PDCCH Format 0 1 2 3 4 5 6 7 8 9 CI Format 0 1 2 3 4 5 6 7 8 9 7 R/V 0	Power PRACH										
SRS Antenna Config MIMO Scheme MIMO 2x2 Antenna Ports # CRS Antenna Ports SubFrame 0 Uptink POCCH Format DC12A <	PUSCH										
• Antenna Config MIMO Scheme MIMO 2x2 • Antenna Ports # CRS Antenna Ports # CRS Antenna Ports 2 • • • • • • • • • • • • • • • • • • •	► SRS										
MIMO Scheme MIMO 2x2 v Antenna Ports v v # CRS Antenna Ports v v Downlink Vplink v	 Antenna Config 	1	_								
Antenna Ports 2 <	MIMO Scheme	MIMO 2x2		~							
# CRS Antenna Ports 2 3 4 5 6 7 8 9 2 2 2 3 4 5 6 7 8 9 2	Antenna Ports										
NCCE2 NCCE2 <th< th=""><th># CRS Antenna Ports</th><th>2</th><th></th><th>~</th><th>•</th><th></th><th></th><th></th><th></th><th></th><th></th></th<>	# CRS Antenna Ports	2		~	•						
Downlink Uplink Subframe 0 1 2 3 4 5 6 7 8 9 7 PDCCH Format NCCE2	LTE Cell 0 > UE Subframe	s Scheduling									×
SubFrame 0 1 2 3 4 5 6 7 8 9 PDCCH Format NCCE2	Downlink Uplink										
PDCCH Format NCCE2	SubFrame	0	1 ✓	2	3	4	5	6 ✓	7 ✓	8	9 ✓
DCl 2A	PDCCH Format	NCCE2 V	NCCE2 ¥	NCCE2 ¥	NCCE2 ¥	NCCE2 V	~	NCCE2 V	NCCE2 ¥	NCCE2 V	NCCE2 ¥
RV 0	DCI Format	DCI 2A 🗸	DCI 2A 🗸	DCI 2A 🗸	DCI 2A 🗸	DCI 2A 🗸	~	DCI 2A 🗸	DCI 2A 🗸	DCI 2A 🗸	DCI 2A 🗸
Start RB 0	RIV	0	0	0	0	0		0	0	0	0
Number RB 100 100 100 100 100 100 100 100 100 100 100 Code Word 1 T65 Index 33	Start RB	0	0	0	0	0		0	0	0	0
 Code Word 1 T65 Index 33 v 34 v 34 v 34 v 35 v 36 v 37 v 37 v 38 v	Number RB	100	100	100	100	100		100	100	100	100
TBS Index 33	▼ Code Word 1										
MCS 27	TBS Index	33 🗸	33	33 🗸	33 🗸	33	~	33 V	33 🗸	33	33 ¥
Tes in Bits 97896	MCS	27	27	27	27	27		27	27	27	27
Code Rate 0.88 0.85	TPS in Pitr	07906	07905	07906	07905	07906		07906	07206	07906	07906
Uue rate 0.00 0.85 0.85 0.85 0.85 0.85 0.85	Code Date	91090	97690	31030	31030	97690		31030	31030	31030	57690
	Code kate	0.88	0.85	0.85	0.85	0.85		0.85	0.85	0.85	0.85

Figure 17 LTE configurations for max downlink throughput testing

Bear in mind that the split data radio bearer (SCG split bearer) needs to be selected during the EN-DC activation procedure which utilizes LTE data traffic in addition to NR. Per default, only SCG bearer without split is going to be established. For more details, refer to 2.2.9.3.

2.2.9 MIMO / Dual Connectivity / Carrier Aggregation

2.2.9.1 MIMO

MIMO is a pretty established multiple antenna technology in a modern wireless communications system, such as in NR. This allows the data signals to be sent on multiple MIMO layers simultaneously over the same radio channel. By deploying MIMO technology, higher data rate can be achieved. As given in Equation 1 on page 4, MIMO is one of the determine factors that influence the overall data throughput. Apparently, the more MIMO layers the UE supports, the higher data throughput is going to be expected.

The DL MIMO settings in CMsquares are part of the UE PDSCH scheduling as shown in Figure 12.

In this document, MIMO 2x2 is given as an example based on the DUT capability. MIMO support depends also on the hardware capacity of a test and measurement equipment (see more details in 3.1.1).

2.2.9.2 Carrier Aggregation

Carrier Aggregation (CA) is an approach to concatenate multiple component carriers to increase the channel bandwidth which then in turn enhances the overall data throughput. As indicated in Equation 1, higher number of aggregated component carriers contribute to higher data throughput in the end. There are different kinds of CA scenarios specified, i.e. inter-band contiguous, inter-band non-contiguous, intra-band. 3GPP defines the predefined particular band combinations for CA. In comparison to dual connectivity (DC) (see 2.2.9.3), CA splits the user traffic between carriers on MAC layer.

2.2.9.3 Dual Connectivity

Dual connectivity (DC) allows a UE to simultaneously connect to multiple cell groups, i.e. Master Cell Group (MCG) and Secondary Cell Group (SCG). In contrast to CA, DC has a bearer split in PDCP layer.

Typical DC deployment scenario in NR is so called ENDC operation mode in NSA mode where LTE carrier servers as MCG and NR carrier as SCG.

In ENDC operation, four dedicated radio bearer (DRB) types are defined as shown in Figure 18, i.e. MCG bearer, SCG bearer, MCS split bearer and SCG split bearer. They differ in the PDCP implementation (either NR PDCP or E-UTRA PDCP) and underneath RLC/MAC/PHY layer.





Per higher layer signaling, a suitable bearer type can be adopted to meet the needs of applications. Peak data throughput needs to aggregate data traffics over both LTE (MCG) and NR (SCG). In this case, SCG split bearer has to be considered, since it utilizes both NR and LTE RLC/MAC/PHY layer underneath to transfer the data.

As per default, the ENDC mode on CMX establishes a SCG bearer. If desired, SCG split bearer can be established during ENDC mode activation process. The configuration steps in CMsquares are shown in Figure 19.

	C Network square		Activate EN-DC Mode		×
	Cells Beams		PSCell	NR Cell 0	~
	✓ Live Mode	🖉 Edit	Dedicated EPS Bearer		
	PLMN 0		Linked Bearer ID	APN (cmx), ID (5)	~
	EDC Tracking Area 0		QCI	Voice Video Or Interactive Gaming (7)	~
			Max DL Bitrate	2000000	kbit/s
	Cell 0		Max UL Bitrate	2000	kbit/s
	ON NR		Guaranteed DL Bitrate	2000000	kbit/s
	Cell 0		Guaranteed UL Bitrate	1000	kbit/s
			Multi-RAT - Dual Connectivity	solit 🖌 🖌 soci solit	3
			Data Flow	Spire - Sco Spire	
0	Click on lower right corner		Split Bearer Traffic Distribution	Auto	~
			Mode		
	Activate EN-DC Mode Disconnect Mobility Carrier Aggregation		RLC Mode	Unacknowledge	· ·
	Configure Establish-Bearer			4 ✓ Apply and Close ×	Cancel

Figure 19 Configure SCG split bearer in CMsquares

- 1. In 'Network square', click on little triangle symbol at lower right corner of the 'Activate EN-DC Mode' button
- 2. Click on opened 'Configure Establish-Bearer' option
- 3. In 'Activate EN-DC Mode' window, choose 'SCG Split' and set max expected DL bitrate and guaranteed DL bitrate accordingly, select RLC 'Unacknowledge' mode.
- 4. Confirm the settings with 'Apply and Close'

3 Solutions and Tipps

CMX is a mobile radio tester that is applicable for testing a UE from different aspects, i.e. RF, Protocol, IP services etc., including the data throughput testing. It is an ideal test platform to fulfill the measurement requirements in which CMX emulates various test scenarios with configurable network parameters. There are several test approaches (Throughput Wizard, CMsequencer, XLAPI) that can be adopted on CMX for throughput testing. In this section, these test solutions are introduced.

For detailed information about the CMX operation, please refer to CMX Base user manual [2].

3.1 System Requirements

3.1.1 Hardware

As a scalable test measurement instrument, CMX is the central piece of the hardware requirement. Along the product evolution path, CMX is continually developed from the initial setup in combination with CMW, including minimum footprint configuration (1xCMX+1xCMW) right up to the maximum CMX500+CMWflexx4 setup (1xCMX+4xCMW). Figure 20 and Figure 21 shows exemplarily the minimum footprint setup and CMX500+CMWflexx2 (1xCMX+2xCMW) setup, respectively.



Figure 20 CMX minimum footprint setup



Figure 21 CMX500+CMWflexx2 setup

A milestone of the product development is achieved through the launch of CMX One-Box-Tester (CMX-OBT). The highly integrated CMX-OBT features LTE signaling/measurement, NR signaling/measurement and data application services which are all included in one single box (see Figure 22). Please refer to the press release of the product launch in [11].



Figure 22 CMX One-Box-Tester (CMX-OBT) setup

More information about each setup mentioned above, including the cabling etc. can be referred in [2].

To allow a particular network configuration, certain hardware setup requirement needs to be fulfilled. Table 10 below provides an overview of the network configuration versus its minimum required HW setup.

Network Configuration	Minimum Required HW Setup
LTE 4x4	Minimum footprint setup or CMX-OBT
LTE 2x2, NR 2x2	Minimum footprint setup or CMX-OBT
NR 4x4	Minimum footprint setup or CMX-OBT
LTE 4x4, NR 4x4	CMX500 + CMWflexx2 or CMX-OBT

Network Configuration	Minimum Required HW Setup
LTE 2x2, NR 4x4, NR 2x2	CMX500 + CMWflexx2 or CMX-OBT
LTE 2x2, LTE 2x2, NR 4x4	CMX500 + CMWflexx2 or CMX-OBT
NR 4x4, NR 4x4	CMX500 + CMWflexx2 or CMX-OBT
LTE 4x4, NR 4x4, NR 4x4	CMX500 + CMWflexx3 or CMX-OBT
LTE 2x2, LTE 2x2, NR 4x4, NR 4x4	CMX500 + CMWflexx3 or CMX-OBT
LTE 4x4, LTE 4x4, 2 x LTE 2x2, NR 4x4	CMX500 + CMWflexx37 or CMX-OBT
LTE 2x2, LTE 4x4, LTE 4x4, NR 4x4	CMX500 + CMWflexx27 or CMX-OBT
LTE 4x4, LTE 4x4, LTE 4x4, NR 4x4	CMX500 + CMWflexx27 or CMX-OBT
LTE 2x2, LTE 2x2, LTE 4x4, NR 4x4, NR 4x4	CMX500 + CMWflexx37 or CMX-OBT
LTE 4x4, LTE 4x4, LTE 4x4, LTE 4x4, LTE 4x4, NR 4x4	CMX500 + CMWflexx37 or CMX-OBT
Table 10 Summary of network configuration vs. CMX HW setup	

3.1.2 Software

3.1.2.1 Composite Software

Composite Software (CSW) is a complete software package containing all the software components that are required for the operations on CMX (system control, cell configurations, measurements etc.). It includes:

- ► Web based user interface WebUI (CMsquares)
- Signaling testing (for protocol stack verifications, NR and legacy technologies)
- ► RF testing (for RF measurements, NR and legacy technologies)
- Data application testing (application servers and data service measurements)
- CMsequencer (generation of test scripts / test plan and test automation)
- XLAPI (CMX scripting interface)
- Message logging tool

In addition to CSW, an extra tool called Automation Manager is needed as long as the DUT control via CMsquares is desired (see more details in 3.1.2.3). DUT control is an integral part of all test solutions. With the help of Automation Manager, manual intervention with DUT is therefore waived.

3.1.2.2 Throughput Testing Tools

In this section, commonly used tools for throughput testing are described. They are either downloadable or accessible directly from Data Application Unit (DAU)⁸ home page by entering DAU IP '172.22.1.201' or FQDN '<u>www.cmx.dau/tools</u>' in DUT's browser provided that the DUT is in the attached state and DRB is established beforehand.

3.1.2.2.1 Traffic Generator

Traffic generator is part of the built-in web server of the DAU. It provides fast check of the UL and DL data rate.

Access: DAU home page > Traffic Generator

⁷ Require LTE baseband combining

⁸ Data Application Unit (DAU) is a piece of hardware in CMX that allows End-to-End (E2E) IP data transfer and performs user plane (U-Plane) tests for an IP connections to a DUT.



Figure 23 Traffic generator

3.1.2.2.2 iPerf2

iPerf2 is a commonly used network testing tool to verify TCP and UDP throughput in both UL and DL data connection between two communication peers. It can be operated in both server and client mode. The peer configured in server and client mode expects to receive and send the data packets, respectively. If not otherwise stated, the term iPerf is interchangeable with iPerf2 in the remaining of this document.

Figure 24 illustrates from both CMX and DUT aspect the associated iPerf mode and direction of data transmission. So, the server and the client represent the receiver and sender, respectively.



Figure 24 iPerf mode from both CMX and DUT aspect

In case the iPerf application does not exist on DUT, download and install it first.

Access: DAU home page > Tools Downloads > Select 'iPerf2' > Select 'iPerf2 Android apk' to start to download the installation file for Android devices

627⊻�©	日本14	r≈ 0	5.00 ⊻ 4• 🛱 🕲	日 田 二 100% D	5.07 ⊻ ⊻ ↔ - 68	5甲。(100% 0
△ 172.22.1.201	۵	I	▲ 172.22.1.201/tools-down	lor 🗈 🗄	▲ 172.22.1.201/tools-downlos	6
BRONDE & SCHWARZ		۵	OUT # 172.22.1.100	۵	OUT IP: 172.22.1 196	۵
Traffic Generator	Streaming Server		Tools Downloads iPerf2 measures TCP and		iPerf2 measures TCP and UDP net performance	twark
RESTFul API	File Explorer	-	iPerf3 messures TCP and UPP network performance	→	Perf is a widely used tool for network perf measurement and tuning. It is significant to partorm tool that can produce standardiz performance measurements for any news has client and server functionality, and can data streams to measure the throughput to two ends in one or both directions. Typical context of the stream of the throughput re- of data transferred and the throughput re-	formance as a cross- ed ork. (perf n create between the at perf the amount reasured.
Live	Tools Downloads				Downloads D iPert2 Windows	
			RS Throughput App 2 Installation package for #As Throughput App 2		D Invert2 Android lansing D Invert2 Android apk Black to Dominew	
• < (• < 0		• 4 0	

Figure 25 Install iPerf2 tool on DUT for Android OS

After the iPerf tool is downloaded and installed, launch the tool on DUT (see Figure 26).



Figure 26 Launch iPerf tool on DUT

On CMX, iPerf tool is available together with the installation of the CSW software that is accessible from CMsquares. Parameter configurations of the iPerf tool are populated as configuration fields in CMsquares. The iPerf service square is generated automatically by Max Throughput Wizard (see 3.4) as part of the Max Throughput workspace.

To run iPerf tool, please bear followings in mind:

- The same transport protocol type (UDP or TCP) and port number should be configured on both server and client side.
- Always start iPerf service on the server side at first, then on the client side.

In Table 11, some frequently used iPerf command arguments are listed (for more details about iPerf, please refer to [12]). The last column in the table shows the corresponding fields in iPerf configuration square of the CMsquares.

iPerf Argument	Description	Comment	Configureation Field in CMsquares
-C	Client mode	Client only option	Mode
-s	Server mode	Server specific	Mode
-u	Use UDP	General option9	Protocol
-р	Server port for the server to listen on and the client to connect to. Default port is 5001	General option	Port
-i	Output interval of measurement report in second	General option	Interval
-t	Measurement time duration in second	General option	Statistic Count
-f	Display data formatting. b: bits / B: bytes / k: kilobits / K: kilobytes / m: megabits / M: megabytes / g: gigabits / G: gigabytes	General option	See footnote ¹⁰
-b	Bandwidth (specified in UDP), e.gb 1M. It gives the maximum bit rate to be transferred for UDP	Client, UDP specific	Bandwidth
-1	Length of butter to read or write, default values are: 128 KB for TCP, 1470 Bytes for UDP over IPv4, 1450 Bytes for UDP over IPv6.	General option	Packet Size
-w	This argument sets the socket buffer sizes to the specified value. For TCP, this sets the TCP window size that is determined by bandwidth delay product (BDP). For UDP it is just the buffer which datagrams are received in, and so limits the largest receivable datagram size.	General option	Window Buffer Size
-М	Set TCP maximum segment size (MSS).	General option, TCP specific	Packet Size
-P	Number of parallel client threads to run	Client specific	Parallel Connections

Table 11 Frequently used iPerf arguments

In the following text, fundamentals of TCP MSS, TCP window size and parallel connection in conjunction with iPerf tool are explained. Usually, these parameters can be used to tune the throughput that under certain circumstance positively influence the data throughput.

TCP Maximum Segment Size (MSS)

It is a parameter that specifies the largest amount of data in bytes that a device can receive in a single TCP segment (exclude TCP header), It is decided during the three-way handshake of TCP connection establishment.



Figure 27 Ethernet Frame Structure

As illustrated in Figure 27, MSS is calculated as follows

MSS in bytes = MTU - IPv4 or IPv6 header length - TCP header length

Equation 2 MSS size calculation

⁹ General option is valid for both client and server

¹⁰ The unit is selectable in the drop-down menu of the associated parameter in CMsquares

Given that 1500 bytes for Ethernet Maximum Transmission Unit (MTU), 20/40 bytes for IPv4/IPv6 header and 20 bytes for TCP header (without TCP options), it results in maximum 1460 bytes and 1440 bytes MSS in Ethernet, for IPv4 and IPv6, respectively.

TCP MSS can be explicitly specified by using -M option of the iPerf command and 'Packet Size' field in CMsquares.

TCP Window Size

In TCP world, to ensure the data sent by the sender does not overflow the receiver, TCP flow control is essential. The TCP window size or TCP receive window size in conjunction with receiver socket buffer size plays a vital role in the standardized flow control procedure.

The allocated receiver socket buffer is used to store received data (before the receiving application processes them) and the receiver sets the TCP receive window size (Advertised Window) in the TCP segment header to indicates to the sender the amount of free space remaining in its buffer. The sender is not allowed to send more than the Advertised Window number of bytes unless another ACK (with new Advertised Window) is received. The TCP receive window size should never exceed the allocated socket buffer size, since

TCP receive window size

= Receiver socket buffer size

- number of bytes waiting to be pulled by the receiving application

TCP receive window size has great impact on the data transmission rate of the sender and thus influences the data throughput. Too small window size causes frequent overrun of receiver buffer that urges the sender to pause which has negative effect on the data throughput. To optimize the data throughput, TCP receive window size should be set big enough so that the sender keeps the pipeline full, i.e. sending the data continuously. A throughput delay product or bandwidth delay product (BDP) is considered as a starting point to configure the minimum TCP receive window size to achieve optimal throughput. The calculation of minimum TCP receive window size is given in Equation 3 below.

TCP receive window size $(Bytes) = Throughput (Kbps) / 8 \times RTT(ms) = BDP (Bytes)$

Equation 3 Calculation of minimum TCP receive window size

The operating system configures the default TCP receive window size, e.g. 6 Mbyte for Linux OS. User specific TCP receive window size can be configured by using iPerf's -w option and 'Window Buffer Size' field in CMsquares as the case may be.

Parallel Connections

Sometimes, due to the limit of the OS in terms of window size, the throughput is limited in a single iPerf connection. In that case, a solution to further increase the throughput is to use multiple parallel streams by using -P option of the iPerf command and 'Parallel Connections' field in CMsquares.

3.1.2.2.3 iPerf3

Similar to iPerf2, iPerf3 is a newly implemented network tool for performance measurement and tuning. It has a smaller and simpler code base. Unfortunately, it isn't backwards compatible with iPerf2.

iPerf3 tool for Windows OS can be downloaded from DAU home page

Access: DAU home page > Tools Downloads > Select 'iPerf3' > Select 'iPerf3 Windows' to start download the installation file for Windows OS

3.1.2.2.4 R&S Throughput App2

R&S Throughput App2 (in short: Throughput App) is a fully automated throughput testing tool developed by R&S. It controls the throughput generator and sink from CMX, contains iPerf (TCP/UDP, IPv4/IPv6), FTP and latency measurement. The usage of Throughput App is always in conjunction with IP Tune (see 3.5).

It supports throughput measurements in both uplink and downlink directions even for several parallel streams and automatic retrieval of the logs from DUT. The tool features:

- ► FTP client
- HTTP client
- iPerf client and server
- ▶ Natperf same as iPerf but allows to traverse Network Address Translation (NAT), refer to 3.3
- Ping
- UniPing client and server (supports transport protocol UDP/TCP)
- Stun same as UniPing but allows to traverse NAT, refer to 3.3
- Runs on Android, Windows 10, Linux and iOS

In case the application does not exist on DUT, download and install it first.

Access: DAU home page > Tools Downloads > Select 'RS Throughput App 2' to start to download and install the app on DUT



Figure 28 Install RS Throughput App 2 on DUT

Launch 'R&S Throughput App 2'



Figure 29 Launch RS Throughput App2

Please refer to [13] for more detailed information about the usage of 'R&S Throughput App 2'.

3.1.2.3 Automation Manager

Automation Manager is an optional external tool developed by R&S to control a DUT, e.g. power cycle the DUT, switch on/off airplane mode, place a call etc. It becomes mandatory if test automation is desired. In this case, DUT control should be set to 'Automatic' in CMsquares (see Figure 30). As a result, Automation Manager will undertake DUT control instead of manual interaction on DUT.

 DUT Configurat 	ion			۶
Navigation Collapse Ex	cpand Load Sav	e As	* Favorite	Q Search
General Control	DUT Control			*
Control Mode	Manual	Automatic	^	Favorite
Manual Mode Setting]s		_	
User Prompt Timeout	180	5		General
Automation Settings				
Automation Framework	External Control A	pplication	~	Sequencer
External Control App	lication Settings			Sequencer
IP Endpoint	localhost:4754			DUT

Figure 30 Automatic DUT control in CMsquares

After Automation Manager is separately installed (not included in the CSW installation) and launched on CMX, an icon appeared in the Windows status bar of the CMX (see Figure 31) indicates that it is up and running on the system.

🗾 🖳 💠 🏋 😫 🐁 🤝 🧞 💟 🕪 🛄

Figure 31 Automation Manager running status in Windows status bar

In general, Automation Manager is a sort of interpreter. Its input is the text expression. Through a defined mapping between the text expression and associated action command in Automation Manager, the corresponding action command is forwarded to the connected DUT. The DUT executes then the action command in the end. The action command adopted here can be any acceptable commands implemented on the DUT, e.g. adb command for Android OS, AT command etc. In this document, we will focus on only AT commands as action commands.

In the following text, an example is shown on how to include the AT commands for turning on or off airplane mode in Automation Manager.

First of all, ensure the correct channel is added and configured that allows the communication between the DUT and Automation Manager. Normally, DUT is connected to the CMX via USB cable. The communication port is mapped to a virtual COM port in the Windows system that can be identified through device manager utility (Modems section) in Windows. An example shown in Figure 32 indicates a configuration of a channel with name 'UE' in automation manager where COM4 is used as a virtual COM port (Access in Automation Manager: 'Tools' > 'Channel Setup').

hannel List	_		RS232 Settings			
Channel Name	Channel Type	Default Channel	Comm Port:	COM4	-	
SIMULATOR	TCPIP R5232	Yes	Bits Per Second:	115200	-	
			Data Bits:	8	-	
			Parity:	None	-	
			Stop Bits:	1	-	
			Flow Control:	Nee		
				Inone	-	
			Retry Attempts:	0		
Add	Remove	Modify	Retry Delay:	0	_	
ew Channel						
Channel0	R5232	•				

Figure 32 An example of channel setup in Automation Manager

'Forward Conversion' Tab in Automation Manager's main GUI takes care of the conversion between the text expression and associated action command. Figure 33 shows an example in 'Forward Conversion' tab that allows to turn on/off airplane mode on DUT via Automation Manager.

File Edit View Tools Help	
ROHDE&SCHWARZ	Monitor Test Channel Start SIMULATOR Rep: ATOK Stop Cmd: AT <cr><lf> Delay: 0</lf></cr>
Forward Conversion Reverse Conversion Session Lo	a
Simulator Command Ignore Duplicates	Action Channel Release Port Pre-Delay(ms) Post-Delay(ms) Process Response
Please switch off the airplane mode. Allow Please switch on the airplane mode. Allow Allow	<cr> SIMU false 0 0 false 1</cr>

Figure 33 'Forward Conversion' tab in Automation Manager

Detailed definition of expressions and their associated action commands from Figure 33 are shown in Figure 34 below.

Command Expression: Please switch off Duplicated Response	the airplane mode.		gnore Duplicate	Expression Please switch on Duplicated Response	he airplane mode.	Г	Ignore Duplicate
Actions Replacement: Before 0	After Cha 0 UE	annel	Release Port	Actions Replacement Before 0	After Cr	nannel E 💌	Release Port
Action	Channel	Pre-Delau(ms)	Edit	Action	Channel	Pre-Delav(ms)	Edit
OK/CB>/LE> AT+CFUN=1(CB>(LF>	SIMULATOR	0	Add	OK <cr><le> AT+CFUN=4<cr><lf></lf></cr></le></cr>	SIMULATOR	0	Add
			Remove				Remove
			Move Up				Move Up
< III		÷	Move Down	< III.		÷.	Move Down

Figure 34 Definition of expressions and their action commands in Automation Manager (turn ON/OFF DUT using airplane mode by AT commands)

Table 12 summarizes mapping of the AT commands associated to the airplane mode and the accepted command expressions in Automation Manager. It is important to be noted here that the exact expressions given in the table should be entered in the Automation Manager as can be seen in Figure 34.

Expression	Action	Remark
Please switch off the airplane mode.	AT+CFUN=1 <cr><lf></lf></cr>	Switch off the airplane mode on DUT
Please switch on the airplane mode.	AT+CFUN=4 <cr><lf></lf></cr>	Switch on the airplane mode on DUT
Table 12 DUT controls in Automation Manage	er (airplane mode ON/OFF)	

Rohde & Schwarz | Application Note Measuring Data Throughput with The CMX500 29

It is recommended to test the functioning of DUT control before the other measurement activities start. Enable automatic DUT control in CMsquares (see Figure 30) and then proceed with following steps (see Figure 35)

ROHDE&SCHWARZ	9	Stop Crid AT	CRO-CLF> Delay: 0	Tet 3-
Forward Conversion Reverse Conve	ersion Session Log			
12/06/21 14:16:34.199	INFO	: Ct	ceate client socket	~
12/06/21 14:16:34.202	INFO		nnected	
12/06/21 14:16:34.499	SINULATOR	1> PI	lease switch on the airplane	mode.
12/06/21 14:16:34.512	INFO	: 0	cate - UE	
12/06/21 14:16:34.513	UE	: < AT	F+CFUN=4 <cr><lf></lf></cr>	
12/06/21 14:16:34.955	UE	:> k1	F+CFUN=4OK	
12/06/21 14:16:34.974	INFO	s Re	tlease - UE	
12/06/21 14:16:34.975	INFO		Esponse consumed, AT+CFON=40K	
12/06/21 14:16:43.868	INFO	: 0	onnected	
12/06/21 14:16:44.087	SIMULATOR	:> P1	lease switch off the airplane	mode
12/06/21 14:16:44.089	SIMULATOR	: < 09	(<cr><lf></lf></cr>	
12/06/21 14:16:44.096	INFO	: Cr	Cate - UE	
12/06/21 14:16:44.097	UE	: A1	F+CFIDE LOE	
12/06/21 14:16:44.523	INFO	t Re	lease - UE	
12/06/21 14:16:44.524	INFO	: Re	sponse consumed, AT+CFUN=10K	
nusses - Test Environment - X -				
C () localhost:5555/devices	il/testenvironment			
C (i) localhost:SSS/device. RES * CMSquares - (CSW 6.90.47.0) mviconment ji Workspace C Network square	+ Cabling	and DUT s	C 200 Out 200m in Touch Reservicy P Dut Configuration	S Control D Home TE Hip
C O Icalhost5555(device.	u/testenvironment Fest Environment - CN + Cabling Cabling	INSOO plus CMW	Pert Zoom Out Zoom in Touch Research P	\$ ↔ 0 0 0 10 000 12 0 0 + As Favor e
C () localhost5555/devices →	I/Testenvironment fest Environment - CV + Cabling Delete	and DUT s	Dem Out Zoom In Touch Research + Dem Configuration The Text Research + Dem Configuration General Control DUTControl General Control DUTControl ThatBack and exempt	S C C O torne TE Ho As Feroire
C ① locahost5555/device. RES * (Magures) RES * (Magures) (SW 6394720) Network square Cells Mode Not storke > Go Live	I/Testenvironment Fest Environment - CN Cabling Delete	and DUT s	Control Zonin Tour Resoluty Dut Configuration Dut Configuration General Control Loss Form General Control Mobile originated operations	S C O O O O O O O O O O O O O
C () localhost.5555/devices C (SW 6.50.47.0) Rikonnent J Workspace Cells Cells Cells Cells Cells Cells Cells	V/testerwironment Fest Environment - CV + Cabling Cabling Delete +	and DUT s CMW	Control Zoon in Such Resolution Don Dut Zoon in Such Resolution Dut Configuration Control Control Control Control Control Con	S O O O O O O O O O O O O O
C C O Decahost55555devce	V/testenvironment Test Environment - CV Cabling Cabling Delete +	and DUT s CMW	Dut Configuration Dut Configuration Dut Configuration Dut Configuration Mobile originated operations Mobile originated operations Mobile originated operations Settion on Arginer	Some T2 Pop
C ① localhost55555device K5 * Clogarane (CW 650527) Notacher C ① Vetrade upare C D Magnetic C D Vetrade upare C D Vetr	Whesterwironment Test Environment - CM + Cabling Delete + Del	and DUT 5==] DUT State	the second	S Otome TE Poo As Recover
C O O O O O O O O O O O O O O O O O O O	V/testenvironment Test Environment - CV + Cabling Cabling Delete - Dot	ntsoo plus CMW	Dut Configuration Dut Configuration Dut Configuration Dut Configuration Dut Configuration Mobile originated operations Protec Cycle Self-or in Applicate SynChr of Applicate SynChr o	Aprile TE Hop
C C C C C C C C C C C C C C	V/testervironment Test Environment - CV + Cabling Cabling Cabling Delete + NR	NOSOD plus CMW	et 20m 04 20m N 200 N 20	AD D D Home TE Pop
CON DEcalifications SSSS devices Con Ess * Chargeners Markensen Markensen Con Control Con	V/testenvironment - CV + Cabling Cabling Delete Port NR Idle	Indoo plus CMW	Date Configuration Date Configuratio	Y U. Optione TE Prop
Add PLINK +	V/testenvironment Test Environment - CV + Cabling Cabling Cabling Cabling Delete + NR NR Mile	INSOO plus CMW	Control Zoom Note Resolution Control Control Control Control Control Contro Control Control Contr	A D D tome TE PO
Add PLINN +	V/testerwironment - CW + Cabling Delete Dot NR NR ITE	INSOD plus CMW	Control 2009 in Doub Resoluty i Duct Configuration Co	S Dome TZ HID
C O localhest5555/device K55 * Chaquee K55 * Chaquee Workgace Workgace C O Memode square C O Memode square C O	Vitesterwirconnent Fest Environment - CV Cabling Cabli	Ind DUT to 2 St	Control 2001 N 200	A Proce
Con	Vitestenvironment Fest Environment - CW Cabling Cabling Delete T NR Mile LTE Mile	NS00 plus CMW	Add Series in South Response of South Series Control of South Series (Series) South Series (S Or Open Tz Ho
C O locahest55554erice Kess * choquese Kess * choquese Workspace Workspace C O Network cigare C O Network cigare C O	Whetherwiteoment	In sequence Tr. 25	Configuration Configu	S D D D D D D D D D D D D D D D D D D D
C O localhost5555/device K65 Clocalhost555/device K65 Clocalhost55/device K65 Clocalhos	Whetherwitenment - CV test Environment - CV test Environment - CV Cabling Cabl	DUT State	Auto Call Series Ser	2 0 0 000 0 0 00 00 0 0 0 00 0 0 0 00 0 0 0 00 0
C O localhost5555/device * Est * Choques * Workspace * Workspace * Workspace * Workspace * Workspace * Workspace * Workspace * So Live * So Live	Whetsenvironment Test Environment - CV Cabling	and DUT to 2500 plus CMW	Dot Configuration	Store II D
C O localhost5555/sterice K55 * Cobaure K55 * Cobaure Workspore Workspore Cob	Whestenvitcoment. Hest Environment - Clu Cabling Cabling Cabling Cabling Delete Delete Mile Mile Mile Mile Mile	and DUT X DUT State DUT State Gobbi Strekes X Data Ge	Control 2 Join No. 1000 Headed Settlen No. Angle A Settlen	2 0 0 3 0 5 0 5 0 5 0 5 0 5 0 5 0 5 0 5
C O O O O O O O O O O O O O O O O O O O	Wheterwiterunerit.	and DUT	Dot Configuration Dot Configuration Dot Configuration Dot Configuration Dot Configuration Dot Configuration Mobile originated spentions Mobile originated spentions Mobile originated Send Sub Send Sub Send Sub Related Call Cal	2 D D D D D D D D D D D D D D D D D D D
O localhost5555/device F65 * Cobarrer Workspore Workspore Workspore Cob C	Whestenvitconnent Test Environment - Clu Cabling Cabli	In the second se	Control 2001 N 200	S D D D

Figure 35 Start and verify DUT control function

- 1. Select the channel that is associated to the DUT (not channel 'SIMULATOR') in Automation Manager
- 2. Press 'Start'
- 3. Press 'Test' to test the connection. If the connection is successful, the string 'ATOK' should be returned in the field 'Rsp:'
- 4. Furthermore, in CMsquares, go to 'DUT Control' tab and press on 'Switch on Airplane Mode' and 'Switch off Airplane Mode', the corresponding AT command will be sent from Automation Manger to DUT and executed on DUT respectively. Verify the execution results presented in the 'Session Log' tab in Automation Manager to ensure the successful DUT control.

For more details about the Automation Manager, please refer to [14].

3.2 DUT Management

To route the signal from CMX to the right DUT antenna port, and vice versa, mapping information of DUT's supported band and its associated antenna port needs to be kept and the physical cabling between the DUT's antenna port and CMX's RF port has to be configured as a preliminary requirement on CMX before starting the network emulation. For doing that, DUT Management is the central place on CMX to maintain those settings.

In the subsequent text, most important operations in DUT management are described.

1. Pressing icon 🗟 on the global toolbar enters DUT management area in CMsquares (see Figure 36).

≡ +	→ 💠 R&S ® CMsquares - Libra	ary - CMX500 (Complete S	Setup 7.0.2.103)									Res	et Zoom Out Zoom In	S Touch	Reliability Hor	te TE	Conn	O K
💐 File E	xplorer 🔲 DUT Management 🛝	Frequency Dependent At	ttenuation 📑 SIM Profiles	Support Report	ts													
Add	Rename Duplicate Delete Activate	Bands & Connectors	Sim Slot 1 📋 +															
	Default DUT Profile	Bands	Connector Centric Bar	d Centric											DUT Conne	ctor		
	Default DUT Profile (2)	NR n25			Frequency Rand	Set				TX			BX.		+ Add De	i 🥒		
	Default DUT Profile (3)	NR n26			requercy barre	- Sec				14			101			0.004		
	Default DUT Profile (4)	NR n28	LTE FDD 1	×	LTE FDD 2	×	LTE FDD 3	×	TX0	Main LTE+NR-FR1	×	RX0	Main LTE+NR-FR1	×	Main LiE+M	.K-FK I		
- Ö	Default DUT Profile (5)	NR n29	LTE FDD 4	×	LTE FDD 5	×	LTE FDD 6	×										
	Default DUT Profile (6)	NR n30	ITE EDD 7	~	ITE EDD 8	~	ITE FOD 9	~										

Figure 36 Access to DUT Management in CMsquares

2. If needed, create a new DUT by choosing 'Add' option within DUT Management (see Figure 37).

≡ •	- 🔶 🔹 R&S ® CMsquares - Libr	ary - CMX500 (Complete Setup 7.0.2.103	3)			Reset Zoom Out Zoom in Touch Reliability Home TE Conn Help
💐 File i	xplorer 🔲 DUT Management 🐴	Frequency Dependent Attenuation	SIM Profiles Support Reports			
Add	Rename Duplicate Delete Activate	Bands & Connectors RF Connection	ns Sim Slot 1 📋 Sim Slot 2 📋	Sim Slot 3 📋		
	Default DUT Profile	Hide Default Connections				
	Default DUT Profile (2)	 Connections 				
	Default DUT Profile (3)	₹ ‡ Name	T 🛊 DUT Connector	Test System Connector	T 🛊 FDA MRT to DUT	T 💠 FDA DUT to MRT
	Default DUT Profile (4)					
	Default DUT Profile (5)					
	Default DUT Profile (6)					
	Demo DUT (Y)				No Rows To Show	

Figure 37 Add a new DUT in DUT Management

3. For the selected DUT, create an entry for each DUT antenna connector. An example in Figure 38 shows that 6 antenna connectors are entered for the selected DUT.

DUT Co	nnector	
+ Add	Delete	Ø Edit
ANT1(N	178 TRX)	
ANT3 (E	31 TRX)	
ANT4 (M	N78 RX2)	
ANT6 (E	31 RX)	
ANT2(N	178 RX3)	
ANT5(N	178 RX4)	

Figure 38 List of DUT antenna connectors

4. For each DUT connector, pressing on + sign in the center pane opens a dialogue window to specify the Tx and Rx direction of the connector. The supported band on that antenna connector can be then added by drag and drop the band id from the list in the left pane.

Bands & Conne	ctors RF C	onnections Sim Slot 1 📋 Sim Slot 2 📋 Sim Slot 3 📋				
Bands		Connector Centric Band Centric Band Restrictions				DUT Connector
NR n25	5	Frequency Band Set		ТХ	RX	+ 🖹 🖉 Add Delete Edit
NR n26	5	 ANT1(N78 TRX) 				ANT1(N78 TRX)
NR n28	3	+	Add Direction ×			ANT3 (B1 TRX)
NR n29)					ANT4 (N78 RX2)
NR n30			TX Direction			ANT6 (B1 RX)
NK n34	+		NONE V	TXO	RXO	ANT2(N78 RX3)
NR HSt	5	+	NONE			ANT5(N78 RX4)
NR n/(,		NONE			
NR n41		• AIV1+ (N/O IO/2)	✓ Ok X Cancel			
NR n46	5	NR n78 ×		NONE	RX1	1
NR n47	7	+				
NR n48	3	ANTS (P1 PV)				
NR n50)	ANTO (BT ICK)				
NR n51		LTE FDD 1 ×		NONE	RX1	1
NR n53	3	+				
NR n65	5					
NR n66	5	ANTZINO KASJ				
NR n70)	NR n78 ×		NONE	RX2	1
NR n71		+				
NR n74	1					
NR n75	5	 ANT3(N78 RA4) 				
NR n76	5	NR n78 ×		NONE	RX3	1
NR n77		+				
NR n78	5					
NR n/s						
NR HOL						



As an example, all configured DUT connectors in connector centric view is shown in Figure 40.

≡ +	• -> 📢	R&S CMsquares	Library - CMX500 (Complete	Setup 7.0.2.10	03)				Reset Zoom Out Zoom In	Touch Reliability Home TE	Conn Help
💐 File B	xplorer	DUT Management	Frequency Dependent	Attenuation	SIM Profiles	Support Reports					-
Add	Rename Dup	icate Delete Acti	Bands & Connectors	Sim Slot 1	Sim Slot 2	Sim Slot 3 📋					
	Default DU	T Profile	Bands	Conne	ctor Centric Band	d Centric					DUT Connector
	Default DU	T Profile (2)	LTE								+ 🗎 🖉
	Default DU	T Profile (3)	▼ NR		NT: (NTO TOV)		Frequency Band Set	1X	KX		Add Delete Edit
	Default DU	T Profile (4)	Select All	• 4	NTI(N78 IKA)						ANTI(N/STRX)
	Default DU	T Profile (5)	NR n1		NR n78	×		TXO	RXD		ANTS (B1 TRX)
	Default DU	T Profile (6)	NR n2	+							AN14 (N/8 KX2)
	Demo DUT	(Y)	NR n3								ANT6 (BT RX)
	huawei Ma	te 40 Pro active	NR n5	• A	NT3 (B1 TRX)						ANT2(N/8 KX3)
			NR n7		LTE FDD 1	×		ТХО	RXO		ANT5(N78 RX4)
			NR n8								
			NR n12								
			NR n13	▼ A	NT4 (N78 RX2)						
			NR n14		NR n78	×		NONE	RX1		
			NR n18								
			NR n20	+							
			NR n24	▼ A	NT6 (B1 RX)						
			NR n25		LTE FDD 1	×		NONE	RX1		
			NR n26	1000							
			NR n28	+							
			NR n29	▼ A	NT2(N78 RX3)						
			NR n30		NR n78	×		NONE	RX2		
			NR n34	1000							
			NR n38	+							
			NR n39	▼ A	NT5(N78 RX4)						
			NR n40		NR n78	×		NONE	R/G		
			NR 045								
			NR n47	+							
			100.047								

Figure 40 Overview of DUT connector configurations in 'Connector Centric' view

Alternatively, the same configuration is represented in band centric view as shown in Figure 41.

≡ •	> 💠 R&S ® CMsquares - Libr	ary - CMX500 (Complete	Setup 7.0.2.10	3)					n Rese	t Zoom (Out Zoom In	Touch Reliability Home	TE	Conn	() Help	23
R File i	Explorer 🔲 DUT Management 🐴	Frequency Dependent A	ttenuation	SIM Profiles	🗎 Sup	port Reports										
Add	Rename Duplicate Delete Activate	Bands & Connectors	Sim Slot 1	Sim Slot 2	Sir Sir	m Slot 3 📋										
	Default DUT Profile	Bands	Conner	tor Centric Ba	nd Centric	1								DUT Co	nnector	
	Default DUT Profile (2)	LTE	^	L			Frequency Rand Set		TY			PY		+ Add	Delete	Ø Edit
	Default DUT Profile (3)	▼ NR					requercy borro acc	THE			D 1/0			ANT1/N	(78 TRX)	
	Default DUT Profile (4)	Select All		NR n78	×			1X0	ANTI(N/8 TKX)	×	KOLO	ANTI(N78 TKX)	×		TO HOU	
	Default DUT Profile (5)	NR n1									RX1	ANT4 (N78 RX2)	×	ANT3 (B	л тюд	
	Default DUT Profile (6)	NR nZ									RX2	ANT2(N78 RX3)	×	ANT4 (M	√78 RX2)	
	Demo DUT (Y)	NR n3									R/G	ANT5(N78 RX4)	×	ANT6 (B	31 RX)	
	huawei Mate 40 Pro active	NR n5		ITE EDD 1	×			TX0	ANT3 (B1 TRX)	×	RXO	ANT3 (B1 TRX)	×	ANT2(N	78 RX3)	
		NR n7		001001	^						BY1	ANTE (P1 PV)		ANT5(N	78 RX4)	
		NP nP	1.00								RAT	ANTO (BT KA)	^			
		NR no	+													
		NR HIZ														
		NK NI3														
		NR n14														

Figure 41 Overview of DUT connector configurations in 'Band Centric' view

5. The desired DUT has to be activated which then turns the DUT status to be labeled as 'active' (see Figure 42

≡ ← → 💠 R&S * CMsquares - Libra	ary - CMX500 (Complete Setup 7.0.2.10)	3)			Reset Zoom Out Zoom in Touch Reliability Home TE Conn Help
🐔 File Explorer 🔲 DUT Management 🐴	Frequency Dependent Attenuation	SIM Profiles 🗄 Support Reports			
Add Rename Duplicate Delete Activate	Bands & Connectors RF Connection	ns Sim Slot 1 📋 Sim Slot 2 📋	Sim Slot 3 📋		
Default DUT Profile	 Hide Default Connections 				
Default DUT Profile (2)	 Connections 				
Default DUT Profile (3)	🕇 🛊 Name	T 🛊 DUT Connector	Test System Connector	T 🛊 FDA MRT to DUT	T 💠 FDA DUT to MRT
Default DUT Profile (4)					
Default DUT Profile (5)					
Default DUT Profile (6)					
huawei Mate 40 Pro				No. Bours To Chann	
Demo DUT (Y) active				NO ROWS TO SHOW	
	+				
	 Connections View 				
					· · · · · · · · · · · · · · · · · · ·
	CMX	500(100144)			
	IF	U 1 Port 1			
		IFIn IPOut			
	IF	U 1 Port 2			
		IFIn IFOut			
	ir.	IFIn IFOut			
		• •	ANTIIN78 TEX		
	IF	U 2 Port 1	ANTE (B1 TEX)		
		IFIn IFOut	ANT4 (N78 RX2)		
	IF	U 2 Port 2	ANTE (B1 RX)		
		IFIn IFOut	ANT2(N78 EX3)		
			ANTSIN78 RX4		
	IF	U 2 Port 3			
		RFU 1			
	RFCom1 RFCom2 RFin1 RFI	n2 RFOut1 RFOut2 RFOut3 RFOut4			
		RELLO			
	RFCom1 RFCom2 RFIn1 RFI	n2 RFOut1 RFOut2 RFOut3 RFOut4			
		0 0 0 0			
					•

Rohde & Schwarz | Application Note Measuring Data Throughput with The CMX500 32

6. For a DUT with active status, RF connections can be defined which should reflect the physical cabling between the DUT connectors and RF connectors on CMX.

In 'RF Connection' tab, press • sign to add a new RF connection, select a DUT connector and specify the corresponding physical RF connector of the CMX, give the FDA¹¹ for both directions (MRT to DUT and DUT to MRT if this is required).

Figure 43 shows as an example all configured RF connections in the upper part and graphic representation of the RF connections in the low part of the pane.





7. DUT and its RF connections to CMX are completely defined. It is ready to be tested from now on.

3.3 Supported Test Topologies

CMX supports both direct connection and Network Address Translation (NAT)-firewall traversal connection for throughput measurement as depicted in Figure 44 and Figure 45, respectively.



¹¹ FDA = Frequency Dependent Attenuation

Figure 44 Direct connection (support of Android OS)

Network Address Translation (NAT)-firewall traversal (Tethered DUTs)



Figure 45 NAT firewall traversal (Tethered DUTs)

In this document, throughput measurement in direction connection mode is described.

3.4 Max Throughput Wizard in CMsquares

Max Throughput Wizard is a use case provided in CMsquares that performs the optimization of the cell configurations which is necessary for UE's peak throughput testing. Simply saying, it provides the user an easy entry point of the cell configurations. In the remaining of this document, the term Wizard stands for Max Throughput Wizard.

The Wizard is accessible either directly from the home page of CMsquares (see Figure 46)



Figure 46 Launch the Wizard from CMsquares home

Or, alternatively, from the CMsquares' burger menu > 'Use Cases' > 'Max. Throughput' (see Figure 47)



Figure 47 Launch the Wizard from CMsquares menu

For further readings, please refer to [13].

3.4.1 Steps in Wizard

Step 1 - Network Setup (see Figure 48)

It is highly recommended to use the DUT control of the CMsquares. Make sure that 'Use DUT Control' is checked, provided that Automation Manager is configured properly and up and running (see 3.1.2.3).

Select the frequency range, predefined network setup, e.g. LTE 4xN, NR 4xN. (see also Chapter 3.1.1 to know more about the network configuration versus hardware setup). Make sure that the selected network setup matches the actual hardware capability in your premise. Press 'Next' to proceed. It will take a little bit time for the system to start the network emulation.

Wizard - Max Throughput				×
1	2	3	4	
Network Setup	Cell Configuration	Throughput Optimization	Result	
Use DUT Control Frequency Range FR 1 Predefined Network Setup ITE 4xN, NR 4xN				×
		Previous	► Next × 0	Cancel

Figure 48 Wizard step 1 - Network Setup

Step 2 - Cell Configuration (see Figure 49)

In step 2 (cell configuration step), it is recommended to set 'Point A Location' as 'Mid', 'Low' or 'High' as shown in the upper part of Figure 49. The advantage of having these predefined frequency assignments is that CMX allocates SSB to the lower edge of the BWP as explained in Chapter 2.2.1. CMX leaves option 'User Defined' for point A position for advanced user as shown in the lower part of Figure 49. This provides extra flexibility to position the SSB in the resource grid. However, it requires the user to have deep knowledge of NR physical layer.

 Cell Configuration Trouchput Optimization Result LT Cell O (P - Cell) I' Et andvidth Steetion: Mode Books Cell Configuration Previous I' Cell O Diples Mode Diples Mode<	Wizard - Max Throughput			×
Network Strup Cell Configuration Result IT E cell (0 / cell) It cell (0 / ce	0	2		
ET call 0 v call No call If call 0 v call No call NAR call 0 v call No call No call 0 v call	Network Setup	Cell Configuration	Throughput Optimization	Result
IT Cell 0 IT Enardvikth Stection Mode MK Cell 0 Frequency Range IT Cell 0 Dubler Mode Dubler Mode Toroughput Verarer Eandvikth Dubler Mode Dubler Mode Toroughput Verarer Eandvikth Dubler Mode Dubler Mode Toroughput Verarer Eandvikth Dubler Mode NB Cell 0 Verarer Eandvikth NB Cell 0 Network Setup Cell Configuration Range Randvikth Stection Mode NR Cell 0 Trequency Range RT Cell 0 Dubler Mode NR Cell 0 Trequency Range RT Cell 0 NR Cell 0 Trequency Range RT Cell 0 Dubler Mode NR Cell 0 Trequency Range RT Cell 0 NR Cell 0 Station Frequency Range Station Frequency Range Sta				
Vervice Ver	LTE Cell 0 (P-Cell) 1 V ITE Bandwidth Selection Mode Max Bandwidth per Band ITE Cell 0 20 MHz V	NR Cell 0 Frequency Range FR 1 V Duplex Mode TDD V Frequency Band N 78 V Carrier Bandwidth 100 MHz V Point A Location Mid V		
Atwork Setup Cell Configuration Toroupput Optimization Result Frequency Band I T Cell 0 I Cel Cell I Cell Configuration I Cell Cell Configuration I Configuration I Configuration I Cell Cell Configuration I Cell Cell Configuration I Cell Cell Configuration I Cell Configuration I Configuration <th>Wizard - Max Throughput</th> <th></th> <th>< Previous</th> <th>► Next × Cancel</th>	Wizard - Max Throughput		< Previous	► Next × Cancel
Actor k Ster Cell Configuration Troughput Optimization Result FE Cell O (P-Cell) I I I	Within - Max modgiput			
Network Setup Cell Configuration Throughput Optimization Result ITE cell 0 (P-Cell) Prequency Range FR 1 Duplex Mode Duplex Mode Carrier Bandwidth Oo MHz Point A Location User Defined Sobrier Spacing Sobrier Spacing Sobrier Spacing Offset to Carrier Diffset to Point A Zo8 KS8 I8 SSB Subcarrier Spacing SolkHz Case C Previous Exect Exect<!--</td--><td>0</td><td>2</td><td>3</td><td></td>	0	2	3	
30 kHz Case C ✓ ◄ Previous ► Next ★ Cancel	LTE Cell 0 (P-Cell) 1 LTE Bandwidth 5election Mode Max Bandwidth per Band LTE Cell 0 20 MHz	NR Cell 0 Frequency Range FR 1 Duplex Mode TDD Frequency Band N 78 Carrier Bandwidth 100 MHz Point A Location User Defined Subcarrier Spacing 30 kHz Offset to Carrier 102 PRB NR ARFCN 630942 Control Resource Zero 2 Offset to Point A 208 kSSB 18 SSB Subcarrier Spacing		
		<u>1</u>	< Previous	► Next × Cancel

Figure 49 Wizard step 2 - Cell Configuration (upper: predefined Point A Location / lower: user defined Point A location)

After all the configurations are set in step 2, press 'Next' to proceed.

Step 3 - Throughput Optimization (see Figure 50)

In this step, the Wizard provides optimization measures and sets DL-MCS to boost DL throughput.

DMRS optimization

With this option, DMRS Pos0 (no additional DMRS position) is configured in RRC message. Otherwise, default Pos2 is configured. If Pos1 is desired, then set it manually in the CMsquares under NR network configuration after exit from the Wizard.

PDCCH optimization

It configures 1 symbol for PDCCH and rest of 13 symbols for PDSCH per DL slot (For more details, refer to Chapter 2.2.4).
Mixed slot activation

It enables partial slot 8 for PDSCH. This option depends on the UE capability. Only high performant UE supports this feature (see also Chapter 2.2.4).

DL-MCS

This can be individually configured depending on the actual maximum supported MCS indicated by the UE capability (see Chapter 2.2.6 for more information about MCS). Per default, it is set to max value 27.



Figure 50 Wizard step 3 - Throughput Optimization

After step 3, press 'Next' to proceed.

As a result of settings in step 3, following actions are taken in CMX

- Cells are configured with optimized parameter settings. Afterward, the cells are turned on and enter idle state
- ▶ DUT is switched on (i.e. switch off the airplane mode) via Automation Manager
- DUT enters ENDC mode

Step 4 - Result (see Figure 51)





Now, step 4 of the Wizard opens a result page as shown in Figure 51. Press 'Go to Workspace' will exit the Wizard and enter the created 'Max. Throughput' workspace in CMsquares (see details in 3.4.2).

After running through the Wizard, the NR cell parameters are set accordingly in CMsquares as shown in Figure 52. As mentioned in the beginning of this section, the Wizard provides an entry point of cell configurations optimized for max throughput testing. Based on that, it is always possible to adjust those parameters directly in CMsquares to meet individual test needs. For example, change DMRS Additional Position from Pos0 to Pos1.

General de LTE Cell 0	A NR Cell 0				Gene	eral 🔥 LTI Ce	10	NR Cell 0				General	Cell 0	A NR Cell (
	ON				_		ON							ON								
 Frequency and E 	Band				Þ	Timing Adva	nce					No. of U	L Symbols	1			before fi	rst				
Frequency Range	FR 1			~	1 +	Power						▼ UE S	cheduling				OL SIOL					
Dupley Mode	TOD			v		DM-RS						Schedu	ling Mode	Fixed				•				
Frequency Band	100				Down	link						Sched	uling Type	User Defin	ied							
Indicator	IN 70			•	Mapp	ina Type A					_	Sched	uling Type	User Defin	had							
Subcarrier Spacing	30 kHz			~	Add	litional Positi	on Pos ()			~		Uplink	Oser Denn								
	Fn	equency Cor	nfiguration.		Mapp	ing Type B							vvizaro		KI	nc						
Downlink-Uplink					Add	litional Positi	on Pos	1			~	Slot A	ssignment		Config	uration						
Carrier Bandwidth	100 MHz			•	Mapp	k ina Type A						Downlink	scheduling									
Range	Mid			~	Add	litional Positi	on Pos	2			~	IVI.	ic Padding	~								
Offset to Carrier	102			PRB	Mapp	ing Type B						Bandwi	dth Part ID	0								
Additional Spectrum Emission	0				Add	litional Positi	on Pos	2			~	Aggreg	ation Level	Level 2			```	<u> </u>				
Center Frequency	3549.990			MHz	•	PRACH						Searc	h Space ID	2								
Point A					Prei	mble Receiv	ed -92			dB	m		MCS Table	256 QAM				·				
NR ARFCN	630942				Conf	iduration Ind	ex 167					Vrb to Pr	o Mapping	Non Inter	eaved			•				
Frequency	3464.130			MHz	- Com	Power Rampi	ng a do					Uplink Sch	eduling									
Initial BWP					7	St ero Correlati	ep 4 dB				v	Bandwi	dth Part ID	0								
Location and Bandwidth	1099			RIV	-	Zo Logical Pr	ne ¹⁵					Aggreg	ation Level	Level 2				•				
 Coreset and Sea 	rch Space Zer	ro				Sequence Ind	ex 0					Searc	h Space ID	2				īl 👘				
Control Resource Zero	2					Ignore PKA Preamb	es Resp	onse Alway	s		~		MCS Table	64 OAM								
Search Space Zero	0				•	PUSCH						COL	Reporting									
▼ SSB						Precodi	ng 🗆	CP-C	DFDM			► CDR	(
kSSB	18				•	SRS						► HAR	Q									
Offset to Point A	208							SRS	Configuration	n		Char	nel Matrix									
Subcarrier Spacing	30 kHz Case	e C		~	•	TDD Commo	n					UE T	imer and Co	onstants								
Periodicity	20 ms			×	Patter	m 1 (Type III	DI Patter	<u>n)</u>				Pagi	ng Cycle									
Periodicity	201115					Periodic	ity 5 ms	(10 Slots)			~	Fadir	ng									
Absolute Frequency St	0					No. of DL Sl	ots 8															
NP APECN	633606					No. of UL Sl	ots 1															
The Aki Ch	2505.44				No	of DL Symb	ols 12			aft DL	ter last Slot											
Prequency Ream Configuration S	5000.44			MHZ	No	. of UL Symb	ols 1			be	fore first											
beam conniguration 5	30									0	SIG											
NR Cell 0 > UF Slot Sch	redulina																					×
Slot Index	0	1	2	3	4	5	6	7	8	8	9	10	11	12	13	14	15	16	17	18	18	19
	DL	DL	DL	DL	DL	DL	DL	DL	DL	UL	UL	DL	DL	DL	DL	DL	DL	DL	DL	DL	UL	UL
No. of PR	250	272	272	272	272	272	272	272	272		272	272	272	272	272	272	272	272	272	272		272
Start PP	220	0	0	0	0	0	0	0			0	0	0	0	0	0	0	0	0	0		0
Start RD	25	0	0	0	0	0		0	0	-	0	0	0	0	0	0	0	0	0	0		0
MCS - Modulation	27-25 •	27-25	27-25 •	27-25 🗸	27-25 🗸	27-25 •	27 - 25	27-25 •	27-25 🗸		10-10 •	27-25 •	27-25 🗸	27-25 •	27-25 •	27-25 •	27-25 •	27-25 •	27-25 •	27-25 •		10-16 •
modulation	230 QAM	230 QAM	230 QAM	230 GAM	250 GAM	230 GAM	2.30 QAM	230 QAM	230 GAM		TO GAM	230 QAM	250 GAM	230 QAM	230 QAM	230 QAM	230 QAM	230 GAM	230 QAM	230 QAM		TO GAM
DCI Format	DCI 11 V	DCI 11 V	DCI 11 V	DCI 11 V	DCI 11 V	DCI 11 🗸	DCI 11 🗸	UCI 11 V	DCI 11 V	-	DCI 01 V	DCI 11 V	DCI 11 V	DCI 11 V	DCI 11 V	DCI 11 V	DCI 11 🗸	UCI 11 V	DCI 11 V	DCI 11 🗸	-	DCI 01 V
MIMO Scheme	4xN 🗸	4xN 🗸	4xN 🗸	4xN 🗸	4xN ¥	4xN 🗸	4xN 🗸	4xN 🗸	4xN 🗸	1	Nx1 ¥	4xN 🗸	4xN ¥	4xN ¥	4xN ¥	4xN ¥	4xN 🗸	4xN ¥	4xN 🗸	4xN 🗸	1	Nx1 🗸
 Time Domain Alloc 																						
Start Symbol	1	1	1	1	1	1	1	1	2	-	0	1	1	1	1	1	1	1	1	2	1	0
No. of Symbols	13	13	13	13	13	13	13	13	10	-	13	13	13	13	13	13	13	13	13	10		13
Channel Mapping	TYPE A 🗸	TYPE A 🗸	TYPE A 🗸	TYPE A 🛩	TYPE A 🗸	TYPE A 🗸	TYPE A 🗸	TYPE A 🗸	TYPE A 🗸	-	TYPE A 🗸	TYPE A 🗸	TYPE A 🗸	TYPE A 🗸	TYPE A 🗸	TYPE A 🗸	TYPE A 🗸	TYPE A 🗸	TYPE A 🗸	TYPE A 🗸	-	TYPE A 🛩
Slot Offset (k0 k2)	0	0	0	0	0	0	D	0	0		2	0	0	0	0	0	0	0	0	0		2
																		🖌 Anr	olv 🖌	Apply and Clos	e ×	Cancel

Figure 52 NR cell parameter settings in CMsquares after the execution of the Wizard

3.4.2 Measurements in Maximum Throughput Workspace

A maximum throughput workspace¹² (see Figure 53) is generated after the Wizard is went through. The workspace has the collection of following service squares

¹² All service squares can be accessed in CMsquares individually independent of the Wizard execution. For more details on how to access, please refer to [13] and [21].

- ▶ Block Error Rate BLER (see 3.4.2.1)
- Ping RTT (see 3.4.2.2)
- ▶ iPerf (see 3.4.2.3)
- ► Throughput (see 3.4.2.4)



Figure 53 Overview of 'Max Throughput' workspace in CMsquares

As indicated in Figure 53, BLER measurement is accessible from 'RX Meas' service and the other measurements are accessible from 'IP Meas' service from the side-bar correspondingly.

3.4.2.1 Block Error Rate

Block Error Rate (BLER) is a quantitative measurement of quality in telecommunication. It is defined as ratio of the number of erroneous packets to the total number of transmitted packets on MAC layer. Different error ratio calculations are considered and implemented in CMsquares. Typical error rate calculation is based on the sum of non-acknowledged (NACK) and DTX packets over the entire number of transmitted packets.

It is essential to achieve good BLER result before further verification of the maximum throughput on the higher layers. Typical target BLER should be below 10%.

Select 'RX Meas' service from side-bar, select 'Continuous' mode and press key to start the BLER measurement (see Figure 54).

▶ RX Meas 1 Confi	quration		۶
Navigation Collapse Exp	and	★ Favorite	Q Search
BLER			*
			Favorite
	Off 🕨		
Repetition	Continuous	~	DUT
Samples for Moving Average	0		
Error Ratio Calculation	(NACK + DTX)/(ACK + NACK +DTX)	~	Network
Cells To Measure			- 1
Cells To Measure	CellGroup	~	General
MCG	 Image: A start of the start of		
SCG	✓		Sequencer
			Sequencer
			<mark>,</mark> ם,
			Global Services
			all
			NR FR1 TX 1
			2
			RX Meas
			<u>,</u> D,
			IP Meas
			<u>, a:</u>
			IP Tools

Figure 54 Start BLER measurement in CMsquares

In 'BLER-RX Meas' square, the scheduled DL data rate and actual measured DL BLER and data rate over different radio access technology (RAT) are presented. Example in Figure 55 shows the scheduled DL data rate has 1295.11 Mb/s over NR cell and DUT achieves 0% DL BLER. In addition to DL, UL BLER measurement, UL data throughput and scheduled UL throughput are presented there as well.

- Test E	nvironment	h Workspace	Max Throughp	ut × +								:
	🔨 BLER - RX M	leas						Ж×	➡ RX Meas 1 Confi	quration		۶
	Downlink Results	5							Navigation Collapse Ex		*	Q,
Network		Ove	rall	LTE C	ell O	NR Ce	11 0		Navigation Cottapse Ex	pand	Pavorite	Search
		Relative	Absolute	Relative	Absolute	Relative	Absolute		BLER			+
E	ACK	100.00 %	837237	100.00 %	279255	100.00 %	557982					Favorite
General	NACK	0.00 %	8	0.00 %	8	0.00 %	0			Run		
	DTX	0.00 %	0	0.00 %	0	0.00 %	0		Deservities	Continuous		
Sequencer	BLER	0.00 %		0.00 %		0.00 %			Repetition	Continuous	~	DUI
	Throughput	Relative	MBit/s	Relative	MBit/s	Relative	MBit/s		Average	0		
	Average	100.00 %	1299.06	100.00 %	3.95	100.00 %	1295.11		Error Ratio Calculation	(NACK + DTX)/(ACK + NACK +DTX)	~	Network
& Tools	Scheduled		1299.06		3.95		1295.11		Cells To Measure			
att	Streams								Cells To Measure	CellGroup	~	General
NR FR1	Uplink Results								MCG			
~		LTE G	ell O	NRG	ell O				506			
RX Meas		Relative	Absolute	Relative	Absolute				500			Sequencer
	CRC Passed	100.00 %	310100	100.00 %	61997							"0"
	CRC Failed	0.00 %	0	0.00 %	0							Global
	DIX	0.00 %	0	0.00 %	0							Services
	Throughput	Rolativo	MARIE /r	Polativo	AADit/c							all ND FD4
	CBC Passad	100.00.%	4 20	100.00.%	10.04							TX 1
5	Scheduled	100.00 %	4.59	100.00 %	10.04							~
Reset	Scheduled		4.55		10.04							RX Meas
												"o"
Multi												IP Meas
Tab												0
_												IP Tools



3.4.2.2 Round-trip Time

Round-trip time (RTT) is another fundamental performance metric of a UE which represents the time length that it takes for a data packet to travel from the sender to receiver plus the time for the acknowledgement in the reverse direction. It is measured by PING test and gives an indication of speed and reliability of the data connection.

Select 'IP Meas' service from the side-bar and choose 'Ping' measurement in CMsquares, specify the destination IP address (default: 172.22.1.100) and press ► key to start the PING measurement.



The result example shown in Figure 56 indicates the average 14.92 ms RTT of the connection.

Figure 56 Round Trip Time (RTT) measurement

3.4.2.3 iPerf

In this section, four different test scenarios using iPerf tool to verify the throughput are described. An overview of the tests is given below in Table 13.

Scenario	Section	iPerf Mode	¹³	Direction	Transport Protocol
		DUT	CMX		
1	3.4.2.3.1	Server	Client	Downlink	ТСР
2	3.4.2.3.2	Server	Client	Downlink	UDP
3	3.4.2.3.3	Client	Server	Uplink	ТСР
4	3.4.2.3.4	Client	Server	Uplink	UDP

Table 13 Overview of iPerf test scenarios

For basic information about iPerf tool, please refer to Chapter 3.1.2.2 or [12].

The main focus of this document is to show how to verify the maximum downlink throughput. Therefore, the optimizations are only done in downlink direction. But, for sake of information completeness, this section also covers iPerf measurements in uplink direction (3.4.2.3.3 and 3.4.2.3.4). In contrast to downlink, the optimizations in uplink are not performed. That means, the uplink throughputs shown in this document do not reflect DUT's maximum capacity.

In this section, the iPerf commands of the examples are issued based on following considerations:

► Without otherwise specified, default port 5001 is used on both client and server side. Therefore, iPerf -p option is omitted in the iPerf command and default port 5001 is kept in CMsquares, too.

¹³ Server = Receiver, Client = Sender

- ▶ Without otherwise configured, default DUT IP address 172.22.1.100 is used.
- ▶ Parallel iPerf option P is not in use. Because single iPerf connection is already enough to measure the maximum throughput of the used DUT.
- ▶ Default TCP window size is in use (detailed explanation, please refer to 3.4.2.3.1 and 3.4.2.3.3). That means, iPerf -w option in the iPerf command is omitted or 'Window Buffer Size' field of iPerf service square in CMsquares is set to 0 (default setting), whenever it applies.

3.4.2.3.1 Scenario 1 (Downlink, TCP)

In general, TCP receive window size is an important parameter that influence the TCP data throughput. A proper window size has to be configured at the receiver side in order to achieve optimal data throughput (see also 3.1.2.2.2).

Example shown in Figure 55 and Figure 56 deliver scheduled DL throughput 1295 Mb/s and RTT 14.92 ms, respectively. To achieve optimal throughput, a minimum TCP window size (BDP) of 2.415 Mbyte is required according to Equation 3. Since iPerf tool applies already 6 MB as default TCP window size which is larger than our calculated value here, there is no need to specify explicitly the TCP window size in iPerf command, i.e. iPerf –w option is omitted here.

 DUT
 CMX

 Mode
 Server (Receiver)
 Client (Sender)

 Protocol
 TCP
 TCP

 TCP window size
 6 MB¹⁵
 IPerf command

 iPerf command
 iPerf -s -i 1 -t 60
 Image: Server downlink

iPerf configurations of our example are shown in Table 14.

 Table 14 Example iPerf configuration of TCP for downlink

To perform the test, please follow the procedure below:

1. On DUT, enter iPerf command '-s -i 1 -t 60' in the input field of iPerf application and press 'start' key to receive TCP packets (see Figure 57).

¹⁵ iPerf default TCP window size on DUT

iPerf2 fo	or Androi	d	
ABORT	SAVE	Error: a wifi connection detected.	on cannot
-s -i 1 -t 6	0		HELP
-s i 1 -t 6 Server listeni ICP window 4 local 172 172,221,201 10] Interval 4 0,0-1.0 4 0,0-1.0 5 0,0-1.0 4 0,0-1.0 5 0,0-1	0	oort 5001 AByte (default) ort 5001 connected wilt Bandwidth Bytes 33.1 Mbits/sec Bytes 276 Mbits/sec Bytes 1.25 Gbits/sec Bytes 1.24 Gbits/sec Bytes 1.24 Gbits/sec Bytes 1.24 Gbits/sec Bytes 1.24 Gbits/sec Bytes 1.24 Gbits/sec ABytes 1.25 Gbits/sec ABytes 1.25 Gbits/sec ABytes 1.26 Gbits/sec ABytes 1.24 G	HELP
4] 26.0-27.0 4] 27.0-28.0 4] 28.0-29.0 4] 29.0-30.0) sec 149 M) sec 148 M) sec 149 M) sec 149 M	MBytes 1.25 Gbits/sec MBytes 1.24 Gbits/sec MBytes 1.25 Gbits/sec MBytes 1.24 Gbits/sec	
4] 30.0-31.0	sec 148 M	MBytes 1.24 Gbits/sec]

Figure 57 iPerf command on DUT (Server, TCP) and measurement result

2. Configure iPerf in CMsquares and press ► key to start the measurement (see Figure 58).



Figure 58 iPerf settings in CMsquares (Client, TCP) and measurement result

3. Read the measurement result in CMsquares (see Figure 58) or on DUT (see Figure 57), i.e. average DL TCP throughput in CMsquares shows 1130.54 Mbps

3.4.2.3.2 Scenario 2 (Downlink, UDP)

For throughput testing using UDP, unlike TCP case shown in 3.4.2.3.1, client sends UDP data constantly at the rate given by the iPerf command line bandwidth option '-b'. There is no acknowledgement from server. The data rate observed on the client side is constant even if server is not running. So, always check actual UDP throughput at the server side, not on the client side.

Example shown in Figure 55 gives the scheduled DL throughput 1295 Mb/s. Based on that, bandwidth parameter on the client side needs be set to a value that is no lower than the scheduled DL throughput, e.g. 1300 Mb/s, to ensure that the test condition for maximum throughput of UDP DL is met. On the server side, big enough buffer size needs also to be specified through iPerf command line option '-w'. Default UDP buffer size used by iPerf tool on DUT is 256 kB which might be too small at high data rate. 4 MB buffer size as an experience value is recommended to be used here.

	DUT	СМХ
Mode	Server (Receiver)	Client (Sender)
Protocol	UDP	UDP
Bandwidth		1300 Mbit/s
Buffer size	4 MB ¹⁶	
iPerf command	iPerf -s -u -w 4M -i 1 -t 60	

iPerf configurations of our example are shown in Table 15.

Table 15 Example iPerf configuration of UDP for downlink

To perform the test, please follow the procedure below:

1. On DUT, enter the iPerf command '-s -u -w 4M -i 1 -t 60' in the input field of iPerf application and press 'start' key to receive UDP packets (see Figure 59).

iPerf2 for Android			
ABORT SAVE Erro	r: a wifi connectio	on cannot be	
-s -u -w 4M -i 1 -t 60		HELP	
3] 22.0-23.0 sec 148 MBytes 5146/110476 (4.7%) 3] 23.0-24.0 sec 138 MBytes	1.24 Gbits/sec 1.16 Gbits/sec	0.105 ms 0.138 ms	
12019/110487 (11%) 3] 24.0-25.0 sec 127 MBytes	1.06 Gbits/sec	3.383 ms	
3] 25.0-26.0 sec 136 MBytes	1.14 Gbits/sec	1.982 ms	
3] 26.0-27.0 sec 150 MBytes 2581/109863 (2.3%)	1.26 Gbits/sec	0.008 ms	
3] 27.0-28.0 sec 145 MBytes 7162/110431 (6.5%)	1.21 Gbits/sec	0.099 ms	
3] 28.0-29.0 sec 145 MBytes 7006/110601 (6.3%)	1.22 Gbits/sec	0.034 ms	
3] 29.0-30.0 sec 155 MBytes)/110545 (0%)	1.30 Gbits/sec	0.007 ms	
3] 30.0-31.0 sec 151 MBytes 2707/110539 (2.4%)	1.27 Gbits/sec	0.009 ms	
3] 31.0-32.0 sec 126 MBytes 20312/110430 (18%) 3] 32.0-33.0 sec 146 MBytes	1.06 Gbits/sec	0.108 ms	DL UDP Throughput
3] 33.0-34.0 sec 121 MBytes	1.02 Gbits/sec	0.008 ms	
3] 34.0-35.0 sec 144 MBytes 13155/115762 (11%)	1.21 Gbits/sec	0.017 ms	
3] 35.0-36.0 sec 132 MBytes 16371/110613 (15%)	1.11 Gbits/sec	0.009 ms	
3] 36.0-37.0 sec 155 MBytes)/110611 (0%)	1.30 Gbits/sec	0.007 ms	
3] 37.0-38.0 sec 123 MBytes 22459/110314 (20%)	1.03 Gbits/sec	0.355 ms	
3] 38.0-39.0 sec 115 MBytes 28893/110680 (26%)	962 Mbits/sec	0.007 ms	
3] 39.0-40.0 sec 98.7 MBytes 33536/103958 (32%)	828 Mbits/sec	0.009 ms	
• < (]	

Figure 59 iPerf command on DUT (Server, UDP) and measurement result

¹⁶ Experience value

2. Configure iPerf in CMsquares, make sure the bandwidth is set no lower than the scheduled rate (see Rx measurement in Figure 55 to obtain the scheduled rate) and press ► key to start to send UDP packets at the configured data rate (see Figure 60).



Figure 60 iPerf settings in CMsquares (Client, UDP)

3. Read the measurement result on DUT, i.e. on receiver (see Figure 59). In our example here, UDP DL throughput measured in iPerf tool is about 1.2 Gb/s.

3.4.2.3.3 Scenario 3 (Uplink, TCP)

Same as for the DL case explained in Chapter 3.4.2.3.1, to measure throughput in an optimal way, minimum TCP window size based on BDP has to be calculated (see 3.1.2.2.2).

In our example here, scheduled UL throughput is indicated in Rx measurement in CMsquares (shown in Figure 55). It is expected to achieve 10.04 Mb/s throughput. RTT is about 14.92 ms (see Figure 56). Therefore, minimum TCP window size is 18.7 kB according to Equation 3. The default window size used by iPerf is 6 MB which is larger than our calculated window size here, therefore, the default value will still be applied. In CMsquares, the value '0' in window buffer size field in iPerf service means the default value is used.

	DUT	СМХ
Mode	Client (Sender)	Server (Receiver)
Protocol	ТСР	ТСР
Window buffer size		0
iPerf command	iPerf -c 172.22.1.201 ¹⁷ -i 1 -t 60	
Table 16 Example iPerf co	onfiguration of TCP for uplink	

iPerf configurations of our example are shown in Table 16.

To perform the test, please follow the procedure below:

1. Configure iPerf in CMsquares and press ► key to start to receive TCP packets (see Figure 61).

¹⁷ 172.22.1.201 is the default IP address of CMX DAU



Figure 61 iPerf settings in CMsquares (Server, TCP) and measurement result

2. On DUT, enter the iPerf command '-c 172.22.1.201 -i 1 -t 60' in the input field of iPerf application and press 'start' key to send TCP packets. (see Figure 62).

iPerf2 for Android	
ABORT SAVE Error: a wifi conr detected.	nection cannot be
-c 172.22.1.201 -i 1 -t 60	HELP
3) 100 17.07 acc 17.0 + 80 300 Mbits 3) 17.0 + 80 300 Mbits 900 Mbits 3) 17.0 + 80 300 Mbits 900 Mbits 3) 18.0 + 90.0 acc 11.2 Mbytes 9.28 Mbits 3) 19.0 + 20.0 acc 11.8 Mbytes 9.28 Mbits 3) 20.2 + 20.2 acc 11.2 Mbytes 9.28 Mbits 3) 20.2 - 20.3 acc 11.8 Mbytes 9.28 Mbits 3) 20.2 - 20.3 acc 11.2 Mbytes 9.28 Mbits 3) 20.2 - 20.3 acc 11.2 Mbytes 9.28 Mbits 3) 20.2 - 20.3 acc 11.2 Mbytes 9.28 Mbits 3) 20.2 - 20.3 acc 11.2 Mbytes 9.28 Mbits 3) 20.2 - 20.3 acc 11.2 Mbytes 9.38 Mbits 3) 20.2 - 20.3 acc 11.2 Mbytes 9.38 Mbits 3) 20.3 - 0.3 - 1.2 Mbytes 9.38 Mbits 9.2 - 9.38 Mbits 3) 30.3 - 40.5 acc 11.2 Mbytes 9.38 Mbits 3) 30.3 - 40.5 acc 11.2 Mbytes 9.38 Mbits 3) 30.3 - 40.5 acc 11.2 Mbytes 9.38 Mbits 3) 30.3 - 40.5 acc 11.2 Mbytes 9.38 Mbits 3) 30.3 - 40.5 ac	/ 46C /
• < 0	

Figure 62 iPerf command on DUT (Client, TCP)

 Read the measurement result in CMsquares (see Figure 61). i.e. average UL TCP throughput is 9.62 Mb/s

3.4.2.3.4 Scenario 4 (Uplink, UDP)

Same as for the DL case explained in Chapter 3.4.2.3.2, for UDP UL throughput testing, client (DUT) sends UDP data to server (CMX) at constant rate. On the client side, bandwidth (use -b option in iPerf command)

larger than the expected throughput needs to be specified. On the server side, big enough buffer size has to be specified if the default one is not sufficient.

For example, from the UL Rx measurement shown in Figure 55, we already know that the target UL throughput is about 10.04 Mb/s. For UDP UL, we can refer to this value and assign a larger value, e.g. 15 Mb/s, to iPerf bandwidth -b option. Therefore, iPerf command on client side turns to be 'iPerf -c 172.22.1.201 -u -b 15M -i 1 -t 60'.

iPerf configurations of our example are shown in Table 17.

	DUT	СМХ
Mode	Client	Server
Protocol	UDP	UDP
Window Buffer Size		0 ¹⁸
iPerf command	iPerf -c 172.22.1.201 ¹⁷ -u -b 15M -i 1 -t 60	
Table 17 Example iPerf	configuration of UDP for uplink	

To perform the test, please follow the procedure below:

1. Configure iPerf in CMsquares and press ▶ key to start to receive UDP packets (see Figure 63).



Figure 63 iPerf settings in CMsquares (Server, UDP) and measurement result

2. On DUT, enter the iPerf command '-c 172.22.1.201 -u -b 15M -i 1 -t 60' in the input field of iPerf application and press 'start' key to send UDP packets (see Figure 64).

¹⁸ Value '0' means the default UDP buffer size is used. On CMX, it is 8192 kB.

iPerf2 fo	or Androi	d	
ABORT	SAVE	Error: a wifi con detected.	nection cannot be
-c 172.22	2.1.201 -L	-b 15M -i 1 -t	60 HELP
Client connec Sending 147 adjust) UDP botter ai 3 local 172 172 22.1.201 3 0.0-10. 3 0.0-20. 3 0.0-20. 5 0	ting to 172 byte datagent ze: 256 KB .22.1.100 p port 5001 Transfer sec 1.86 M sec 1.14 M sec 1.17 M sec 1.17 M sec 1.17 M sec 1.17 M sec 1.12 M sec 1.12 M sec 1.12 M sec 1.12 M sec 1.12 M sec 1.14 M sec 1.12 M sec 1.14 M sec 1.12 M sec 1.12 M sec 1.14 M sec 1.17	22.1.201, UDP po rams, IPG target: yte (default) ort 35725 connec Bandwidth Bytes 15.6 Mbits, Bytes 9.6 Mbits, Bytes 9.6 Mbits, Bytes 9.67 Mbits, Bytes 9.67 Mbits, Bytes 9.67 Mbits, Bytes 9.67 Mbits, Bytes 9.7 Mbits, Bytes 9.24 Mbit. HBytes 9.24 Mbit. HBytes 9.24 Mbit. HBytes 9.23 Mbit. HBytes 9.23 Mbit. HBytes 9.23 Mbit. HBytes 9.24 Mbit. HBytes 9.28 Mbit. HBytes 9.15 Mbit. HBytes 9.15 Mbit.	rt 5001 747.68 us (kalman ted with (sec (sec (sec (sec (sec (sec (sec (sec
•	\triangleleft	0	

Figure 64 iPerf command on DUT (Client, UDP)

 Read the measurement result in CMsquares (see Figure 63), i.e. average UDP UL throughput is 9.78 Mb/s

3.4.2.4 Throughput

'Throughput' square in CMsquares examines the throughput in both UL and DL direction in each layer (from lower PHY layer up to the upper protocol stack layer) of each RAT, as well as the overall throughput on IP layer. Figure 65 depicts a diagram of the throughput measurements in CMsquares¹⁹. It offers an intuitive way to identify the data throughput bottleneck throughout the whole communication layers.



Figure 65 Throughput measurements in CMsquares

To perform throughput test, some preconditions have to be fulfilled. MAC padding option (see Figure 66) is enabled as per default. This is essential for throughput testing on PHY and MAC layer in both LTE and NR.

¹⁹ iPerf throughput measurement belongs to a separate service in CMsquares (refer to Chapter 3.4.2.3)

General deneral Cell 0	Cell 0		
	ON		
Stor Assignment	comgutation		
Downlink Scheduling			
MAC Padding			
Bandwidth Part ID	0		
Aggregation Level	Level 2	*	
Search Space ID	2		
MCS Table	256 QAM	~	
Vrb to Prb Mapping	Non Interleaved	~	
Uplink Scheduling			
Bandwidth Part ID	0		
Aggregation Level	Level 2	~	
Search Space ID	2		
MCS Table	64 QAM	~	

Figure 66 Enable MAC Padding in NR

To verify the throughput beyond RLC layer, additional IP data traffic needs to be generated, e.g. through traffic generator, or through iPerf session.

For ENDC mode, throughput above RLC layer can be observed on either LTE or NR, or on both depending on DRB establishment mode (either MCG, SCG or Split mode). See Chapter 2.2.9.3 for more detailed information about DRB establishment.



Figure 67 presents the throughput measurements in CMsquares.

Figure 67 Throughput measurements in CMsquares

3.5 IP Tune

IP Tune is a service that resides in CMX as a frontend for Throughput App (see 3.1.2.2). With IP Tune service, some parameters are fine tuned to explore the limit of the DUT's achievable throughput, e.g. MCS tuning, UDP and TCP tuning.

3.5.1 Preparation

Before IP Tune is started, make sure followings are prepared.

- 1. Run Max Throughput Wizard as described in 3.4.1 to optimize the cell configurations
- 2. Launch 'R&S Throughput App2' on DUT (see 3.1.2.2)
- 3. Follow the steps shown in Figure 68 to enable IP Tune service in case the service is not populated in CMsquares



Figure 68 Enable and populate IP tune service in CMsquares

4. Follow the steps shown in Figure 69 to create IP Tune workspace in CMsquares



Figure 69 Create IP Tune workspace in CMsquares

3.5.2 Tuning with IP Tune

After the preparation steps described in chapter 3.5.1, it is now ready to use IP Tune for testing with following steps:

1. As shown in Figure 70, select 'IP Tune' service, and if desired, configure IP Tune service to run the test in user defined mode in CMsquares.

In auto mode, UDP DL, TCP DL, UDP UL, TCP UL throughput will be tuned sequentially. User can define the number of the iterations for the tuning that is configured by 'maximum iteration count' parameter in CMsquares.



Figure 70 IP Tune configuration in CMsquares

2. Press ► key to start IP Tune. Optimal MCS is tuned firstly. This can be observed in event window located at the bottom of the CMsquares (Click on the status bar opens the event window). Example shown in Figure 71 indicates that DUT is tuned with MCS 27 that achieves the maximum throughput of 1882 Mbit/s on MAC layer.

T 🕈 Time Stamp	▼ \$ Tj	ype	▼	🗘 Id	Context
11-08-2022 15:34:48	0		IP-Tune: NR tuning MCS (final): 27 bitrate: 1882 MBit/s, ACK rate: 99.3889%	146	DATA
11-08-2022 15:34:48	0		TP-Tune: NR tuning report MCS: 27 bitrate: 1882 MBit/s, ACK rate: 99.3889%	145	DATA
11-08-2022 15:34:46	0		IP-Tune: NR tuning report MCS: 26 bitrate: 1813 MBit/s, ACK rate: 100%	144	DATA
11-08-2022 15:34:44			IP-Tune: NR tuning report MCS: 25 bitrate: 1754 MBit/s, ACK rate: 99.9444%	143	DATA
11-08-2022 15:34:42	0		IP-Tune: NR tuning report MCS: 24 bitrate: 1667 MBit/s, ACK rate: 100%	142	DATA
11-08-2022 15:34:40	0		IP-Tune: NR tuning report MCS: 23 bitrate: 1581 MBit/s, ACK rate: 100%	141	DATA
11-08-2022 15:34:38	0		IP-Tune: NR tuning report MCS: 22 bitrate: 1493 MBit/s, ACK rate: 100%	140	DATA
11-08-2022 15:34:36	0		IP-Tune: NR tuning report MCS: 21 bitrate: 1409 MBit/s, ACK rate: 100%	139	DATA
11-08-2022 15:34:34	0		IP-Tune: NR tuning report MCS: 20 bitrate: 1350 MBit/s, ACK rate: 100%	138	DATA
11-08-2022 15:34:32	0		IP-Tune: NR tuning report MCS: 19 bitrate: 1295 MBit/s, ACK rate: 100%	137	DATA
11-08-2022 15:34:30	0		IP-Tune: NR tuning report MC5: 18 bitrate: 1211 MBit/s, ACK rate: 100%	136	DATA
11-08-2022 15:34:28	0		IP-Tune: NR tuning report MCS: 17 bitrate: 1150 MBit/s, ACK rate: 100%	135	DATA
11-08-2022 15:34:26	0		IP-Tune: NR tuning report MCS: 16 bitrate: 1064 MBit/s, ACK rate: 99.9444%	134	DATA
11-08-2022 15:34:24	0		IP-Tune: NR tuning report MCS: 15 bitrate: 979 MBit/s, ACK rate: 100%	133	DATA
11-08-2022 15:34:22	. 0		IP-Tune: NR tuning report MCS: 14 bitrate: 919 MBit/s, ACK rate: 100%	132	DATA 🔻
11-08-2022 15:34:4	48] DATA: IF	P-Tune:	NR tuning MCS (final): 27 bitrate: 1882 MBit/s, ACK rate: 99.3889%		11-08-2022 15:44:39 (UTC) 🔺
			Click on the status har to spen the swent window		

Figure 71 MCS tuning in IP Tune

3. As long as MCS tuning is terminated, the connection status in Throughput App on DUT is changed to 'Connected' status (see Figure 72). The IP tuning is then started in CMsquares. In each iteration, the target throughput is adapting. The tuning is terminated if measured throughput converges the target or the number of iterations reaches the configured number of 'maximum iteration count'.



Figure 72 Connected status shown in RS throughput app



4. Read the tuning results. An example of results is shown in Figure 73.

Figure 73 Example of IP Tune results

3.6 Throughput Testing with XLAPI Solution

XLAPI is a scripting interface on CMX utilizing Python as a scripting language which has lean code structure in contrast to object language, e.g. C++, and its instructions are self-explanatory. Python script is created and executed in integrated development environment (IDE), e.g. PyCharm. If desired, the created script can be either executed locally on CMX or remotely from a PC that is LAN-connected to CMX. In addition, the XLAPI script can be converted to a CMsequencer script block for execution in CMsequencer (see Chapter 3.7).

It is beneficial to use XLAPI to cover versatile test needs, when user wants to have higher degree of controls over signaling procedures, L3 parameter settings and test flows.

A bunch of sample scripts are provided in XLAPI script package kf600x for various test purposes. Users can simply take those off-the-shelf sample scripts as a basis and elaborate their own ones. For example, sample scripts listed in Table 18 are suitable for NSA throughput verification that contain both DL and UL throughput measurements under various configurations.

Script	Test Purpose	Comment
nr_04_01	NSA end-to-end downlink throughput up to 1 Gbit/s	IPERF performance with NR MIMO 2x2, No additional DM-RS positions
nr_04_02	NSA end-to-end downlink throughput up to 2 Gbit/s	IPERF performance with NR MIMO 4x4, No additional DM-RS positions
nr_04_03	NSA end-to-end downlink throughput up to 942.3 Mbit/s	IPERF performance with NR MIMO 2x2, 1 additional DM-RS position
nr_04_04	NSA end-to-end downlink throughput up to 1.88 Gbit/s	IPERF performance with NR MIMO 4x4, 1 additional DM-RS position

Script	Test Purpose	Comment
nr_04_05	NSA end-to-end downlink throughput of 2.2 Gbit/s, split bearer	IPERF performance in NSA over split bearer
nr_04_06	NSA end-to-end downlink throughput of 3 Gbit/s, split bearer	IPERF performance in NSA over split bearer NR + LTE CA
nr_04_07	NSA FR2 end-to-end downlink throughput	IPERF performance in NSA with FR2 NR Cell
nr_04_07b	NSA FR2 end-to-end downlink throughput (MIMO 2x2)	IPERF performance in NSA with FR2 NR Cell (MIMO 2x2)
nr_04_07c	NSA FR2 end-to-end downlink throughput (MIMO 2x2, 256QAM)	IPERF performance in NSA with FR2 NR Cell (MIMO 2x2, 256QAM)
nr_04_07d	NSA end-to-end throughput, with FR2 and NR 4CA	
nr_04_07e	NSA end-to-end throughput, with FR2 and NR 8CA	
nr_04_08	NSA e2e uplink throughput up to 270 Mbit/s	IPERF performance of 270 Mbit/s with NR PUSCH single-layer transmission
nr_04_09	NSA e2e uplink throughput over MN & SN paths (split bearer)	Uplink performance with uplink data routed over MN and SN paths
nr_04_10	NSA e2e uplink throughput up to 250 Mbit/s, UL MIMO (64QAM)	Uplink performance of up to 250 Mbit/s with NR PUSCH dual-layer transmission
nr_04_11	NSA e2e uplink throughput up to 368 Mbit/s, UL MIMO (64QAM)	Uplink performance of up to 368 Mbit/s with NR PUSCH dual-layer transmission
nr_04_12	NSA e2e uplink throughput up to 1 Gbit/s, UL MIMO (256QAM)	Uplink performance of up to 1 Gbit/s with NR PUSCH dual-layer transmission
nr_04_20	NSA downlink throughput up to 2 Gbit/s. Parameterizable	

Table 18 NR NSA throughput performance XLAPI sample scripts (CMX-KF600X)

In this chapter, some tips are given to show how to deal with the XLAPI test scripts.

3.6.1 Preparations

Make sure followings are prepared before running the XLAPI test scripts.

- Activate the DUT and make sure the RF connections configured reflects the physical cabling on CMX (refer to 3.2 for more details)
- ▶ Install the XLAPI package via Installation Manager on CMX (see XLAPI user manual [15], Chapter 3)
- ▶ Load the installed XLAPI package as a project in PyCharm (see XLAPI user manual [15], Chapter 3.4).

Go to menu 'File' > 'Open', navigate to XLAPI version that is intended to be loaded, e.g. 10.77.3, and confirm with 'OK' button (see Figure 74)



Figure 74 Open a project in PyCharm

► Confirm with 'This Window' in the upcoming pop-up window (see Figure 75)

🖺 Open	Project				—
0	Projects can either be opened in a new window, or replace the pro How would you like to open the project?	ject in the current wind	dow, or be attached t	o the already op	ened projects.
🔲 Doi	n't ask again	This Window	New Window	Attach	Cancel

Figure 75 Confirmation window

▶ Now the actual project is loaded in PyCharm, e.g. 10.77.3. As a result, the whole project structure as shown in Figure 76 is created, including the virtual environment.



Figure 76 XLAPI project structure

Make sure that the '.venv' folder is not in red. Otherwise, it means the Python interpreter is not associated as shown in Figure 77.



Figure 77 .venv in red (missing Python interpreter)

Do following steps to associate a Python interpreter to the project

- Setup the Python interpreter in PyCharm. Go to 'File' > 'Settings' > 'Project' > 'Python Interpreter'
- Press on a next to the selection field (see Figure 78), select option 'Add ...' in the opened menu,

🖺 Settings					ſ	×
Q- Project: 10.77.3			Python Interpreter 🛛 📼			
✓ Appearance & Behavior		Python Interpreter:	<no interpreter=""></no>		- x	×.
Appearance						
Menus and Toolbars		+ - 🔺 🛛				
System Settings		Package		Latest version		
File Colors						

Figure 78 Empty Python interpreter

Choose option 'Existing environment', specify the path of the interpreter associated with the current XLAPI version if it is not automatically given in the configuration line, and then click on 'OK' to confirm (see Figure 79).



Figure 79 Specify Python interpreter

Now, the XLAPI python script packages are associated with the Python interpreter. As indication of successful association, the packages are linked with the corresponding versions as shown in Figure 80.

📓 Settings							×
Q+		Project: 10.77.3 →	Python Interpreter				Reset
 Appearance & Behavior Appearance Menus and Toolbars 		Python Interpreter:	📌 Python 3.7 (10.77.3				\$
> System Settings		Package		Version	l atest version		
File Colors		Deprecated		1,2,13	catest version		-33
Scopes		Pillow		8.4.0			
Notifications Quick Lists		PyVISA PyVISA-py PyYAML		1.11.3 0.5.2 6.0			
Path valiables		RsInstrument		1.13.0.63			
Кеутар		anytree		2.8.0			
> Editor		attrs		21.2.0			
Plugins		certifi charset-normalizer		2020.11.0			
> Version Control		cmx-kf600x		77.3.0			
 Project: 10.77.3 		cmx-kf601x		77.3.0			
Python Interpreter		cmx-kf602x		77.3.0			
Project Structure		cmx-kf603x		77.3.0			
> Build, Execution, Deployme	ent	cmx-kf604x		77.3.0			
> Languages & Frameworks		cmx-kf605m		77.3.0			
> Tools		cmx-kf606x		77.3.0			
		cmx-kfb0/x		//.3.0 77.2 0			
		cmx-kf616x		77.3.0			
		cmx-kf617x		77.3.0			
		cmx-kf619x		77.3.0			
		cmx-kf620x		77.3.0			
		cmx-kf621x		77.3.0			
		codec					
?					ОК Са	ncel Ap	ply

Figure 80 XLAPI packages associated with Python interpreter

3.6.2 Modify Sample Script

After having set up the XLAPI environment properly, XLAPI project tree structure is created as given in Figure 81.

<u>F</u> ile	<u>E</u> dit	<u>V</u> iew	<u>N</u> avigate	<u>C</u> ode	<u>R</u> efactor	R <u>u</u> n	<u>T</u> ools	VC <u>S</u>	<u>W</u> indow	<u>H</u> elp				
	10.77													
t	🔲 Pr	oject									Ð	÷	\$	
Proje	× 🖿	10.77.												
	>	🖿 .sec	quencer											
		🖿 .ver												
		🖿 app												
	> 🖿 default_config													
		~ 🖿	script_pack	ages										
			cmx-kf	500x										
> m cmx-kf601x														
	> Encrea conx-kf602x													
			cmx-kf	503x										
			cmx-kft	504x										
			cmx-kft	505m										
			cmx-kft	500x										
				515.										
			cmx-kf	516v										
			cmx-kft	517x										
			cmx-kf	519x										
			cmx-kf	520x										
			Cmx-kf	521x										
		~ 🖿	user											
			🖿 config											
			📶 read	lme.md										
			🖆 user	_default	_config_fd	d.rsxp								
			🖿 my_libr											
			🖿 my_scri	pt_pack	age									
			💑 my_	test_scri	pt.py									
			🍖 user	_nr_04_()1.py									
			🐞 user	_nsa_pe	rf.py									
		doc												
		∎ tw ≝∎ i												
			Inch Fermin	al.bat										
	> uh	Evtern	APT Help.Ini											
		Scratel	hes and Cou	nsoles										
		Sciarci	res una coi											

Figure 81 Tree structure of XLAPI project

Table 19 lists few of the important XLAPI project folders.

Project folder	Comment
appl\default_config	Original default configuration file if it is specified by the script.
appl\script_packages	Original script packages from the XLAPI installation
appl\user	This folder should contain user defined configuration files, test scripts and required libraries

Table 19 Important XLAPI project folders

It is highly recommended that user should always work on the copied version of script, library and configuration files that should be located in user folder, while keep the original ones untouched.

For example, migrate a sample XLAPI script, e.g. nr_04_01.py including its's library to user defined script either in Windows file explorer or directly within the XLAPI project structure in PyCharm.

Step 1: Copy original sample script and its library to user folder and include adaptation

The path given in the following text is relative to the XLAPI installation folder:

C:\Users\Public\Documents\Rohde-Schwarz\XLAPI\<XLAPI version>20

Copy sample script and rename it to a new name user_nr_04_01.py

Copy appl\script_packages\cmx_kf600x\nr_04_01.py

²⁰ For example, the XLAPI version 10.77.3

to appl\user\my script package\user nr 04 01.py

Copy library nsa perf.py and rename it to a new name user nsa perf.py

Copy appl\script_packages\cmx_kf600x\nsa_perf.py

to appl\user\my script package\user nsa perf.py

Adapt the included library name and location in the new script, i.e.

replace the code

from cmx_kf600x.nsa_perf import NsaDlPerfScenario

with

from appl.user.my_script_package.user_nsa_perf import NsaDlPerfScenario

Step 2: Add configuration file (optional)

Configuration file can be optionally specified in the script. If otherwise stated in the script, the default configurations are given by the XLAPI environment.

To apply customized configuration file to the script, below steps have to be followed:

- Recommended way is to copy the default configuration default_config_fdd.rsxp (a sort of configuration template file) from the folder appl\default_config\cmx_kf600x to folder appl\user\config under a new name, e.g. user default config fdd.rsxp
- Alternatively, create configuration file from a scratch. The syntax of the configuration file can be referred in 'Test Parameters' section of the XLAPI online help document as shown in Figure 90. Place the created configuration files (e.g. user default config fdd.rsxp) in folder appl\user\config.
- ▶ In both ways, make sure to add following two lines in the customized script user_nr_04_01.py to apply the configuration file. The configuration file name is given in the parentheses.

from xlapi import settings

settings.session.set_test_param_files("user_default_config_fdd.rsxp")

Hereafter the content of an example configuration file user default config fdd.rsxp is shown.



Important: make sure the LTE and NR cell name, e.g. 'LTE Cell 0' and 'NR PSCell 0', should match the cell names coded in the script so that the configurations are correlated.

3.6.3 Script Structure and Settings

In a XLAPI throughput test script, e.g. nr 04 01.py, it has the structure described in this chapter.

Scenario is an unparameterized test definition from which the user can derive concrete scenarios, e.g. NsaDlPerfScenario who inherits the attributes of basic class scenario that consists of following components:

Initialization

Specify BLER limit in NR which is checked by the BLER measurement, e.g. limit 0.1%

max_nr_bler = 0.1

When the NsaDlPerfScenario is called, object initializing with respect to the DL MIMO mode configuration, additional DMRS position and security settings is performed.

Example:

Initialize MIMO mode, enable/disable additional DMRS Position and security

```
def __init__(
    self,
    dl_mimo_mode: DownlinkMimoMode.Enum,
    additional_dmrs_pos_enabled: bool,
    security_enabled: bool = False,
):
```

Preamble

Preparations for the test. Typically, the preamble will create cells, configure the scheduler and take care of the signaling that is required to bring the DUT in the correct state to perform the test, e.g. ENDC activation in NSA case.

With below example, optimizations with respect to frequency range, TDD slot format, scheduler are performed so that DL max throughput testing in TDD mode is prepared.

Example:

Create LTE and NR cells

Cell names should match the ones specified in configuration file if it applies



Rohde & Schwarz | Application Note Measuring Data Throughput with The CMX500 59



In addition, handling of slot 0 scheduling in NR (see 2.2.4) is automatically considered by NR scheduler.

Testbody

The test purpose of the scenario. For throughput testing, it includes the BLER and iPerf measurements and deliver the verdict based on the given BLER limit (e.g. 1%) defined globally in the library.

In the testbody, DUT control is necessary either in a manual way (user interaction on DUT) or in automatic way (via Automation Manager). Refer to 3.6.4 to know more about the DUT control in conjunction with Automation Manager.

Postamble

Any cleanup that is required after the testbody has been executed, e.g. reset the network emulation, collect and close the logfiles.

Figure 82 shows the output of XLAPI throughput script where the scheduled, actual achieved throughput are presented as well as the BLER measurement after the script execution.



Figure 82 Output of XLAPI throughput script

3.6.4 DUT Control

3.6.4.1 Power On/Off

It is necessary to control DUT's power on/off status in a test script. There are two ways to bring a DUT in such a status, either through airplane mode or normal power on/off the DUT. In either way, XLAPI script communicates with Automation Manager (refer to Chapter 3.1.2.3) who is then translates the operation expression (see unique expressions in Table 20) into a corresponding action, e.g. AT command to switch on/off airplane mode etc. Important here is to make sure that Automation Manager is configured with the exact expressions as given in Table 20. Please be noted that the applied expression differs in both modes.

	Expression								
	Power On	Power Off							
Use airplane mode to control DUT	Please switch off the airplane mode.	Please switch on the airplane mode.							
Use normal mode to control DUT	Please power on the DUT.	Please power off the DUT.							
Table 20 Command expression of DLIT control in Automation Manager									

In case DUT is controlled by airplane mode using AT commands, the mapping between the applied expression and its' associated action is summarized in Table 12 on page 29. As already mentioned in chapter 3.1.2.3, the action is not only limited to AT command. Any DUT supported control commands can be defined in Automation Manager and utilized for the DUT control. An example of using batch file as defined action is shown in 3.6.4.2.

In XLAPI, functions such as DUT power on, power off and power cycle (power off followed by power on) are provided. In each function, either airplane mode or normal mode is supported.

DUT control of throughput sample scripts in Table 18 is either contained directly in the test script itself or included in the NsaDlPerfScenario class within nsa perf module.

Examples shown below use airplane mode for DUT control which is indicated by the argument airplane_mode=True when the function is called. If the argument is omitted, the normal mode will be used.

```
dut.control.power_off(airplane_mode=True)
dut.control.power_on(airplane_mode=True)
```

3.6.4.2 Control of iPerf Application

iPerf application can be handled by the Automation Manager as well.

In the following text, an example is given to show how to include the iPerf in the XLAPI script and through Automation Manager to start and stop the iPerf application on DUT.

Start iPerf

Include the iPerf configuration for CMX in XLAPI script, e.g. set the mode (client or server), protocol (UDP or TCP) and port (5001), to start iPerf.

```
# Set up iPerf on CMX side
meas.delete_all_iperfs()
perf = meas.create_iperf() perf: [IPerf] Iperf 1
perf.mode = IPerfMode.CLIENT
perf.protocol = IPerfProtocol.UDP
perf.configure_address(dut.state.pdn_connections[0])
perf.port = 5001
```

An output string based on the above settings is created that consists of indication of mode, protocol and port. In the example showing here, the output string turns to be: Start iPerf on DUT in SERVER mode for Protocol: UDP, Port: 5001



The output string is passed to Automation Manager when the function is called during the script execution, provided that DUT control in CMsquares is set to 'Automatic'. Otherwise, the output string is displayed in the pop-up message box in CMsquares and manual interaction on DUT is expected (see 3.1.2.3).

In Automation Manager, as we learn from 3.1.2.3, the command expression needs to be associated with the corresponding action. A batch file (adb_start_iperf.bat) containing ADB/ADB shell commands to execute iPerf on Android device is adopted here. Make sure that adb.exe and iperf2.1 binary for Android OS are located in the folder C:\android_adb before the batch file is called. Figure 83 presents the contents of the batch file.

In case iPerf application has already been installed on the Android DUT, line 27 to 31 of the batch file can be bypassed. Simply use the ADB shell command in line 32 to execute the iPerf application (including the full path of the iPerf binary on the DUT).



Figure 83 Batch file (adb_start_iperf.bat) to start iPerf on Andriod OS

We see the batch shown above contains the input arguments. The value of each argument is parsed in the Automation Manager using its regular expression parser feature (for more detailed information about the usage, please refer to [14]) that allows the positions marked as (.+) in the command expression to be parsed as the command line arguments (mode, protocol, port) to the batch file. This operation is shown in Figure 84.

Modify Command -	Forward Conve	rsion				? <mark>×</mark>					
Command											
Expression: (.*)Star	tiPerfon DUT in (.+) mode for Protoc	ol: (.+), Poi	rt: (,+)(,*)	🔲 Ig	nore Duplicate					
Duplicated Respons	e	$\overline{}$									
Actions											
Replacement: fi	le://C:\\Automatic										
B	efore	After	Channel								
0)	0	•	🗆 B	elease Port						
	Process Respor	nse 🔲 Prefix									
Action		Channel		Pre-Delay(ms)	Apply					
file://C:\\Automa	tion_QMICM\\	UE		0		h d d					
OK <cr><lf></lf></cr>		SIMULATOR		0		Auu					
						Remove					
					_	Move Up					
•	"				P.	Move Down					

Figure 84 Command expression and parse of the argument value to its associated action to start iPerf

Stop iPerf

To stop iPerf service, include the code line below in the XLAPI script with string 'Stop iPerf'.

dut.control.msg_box("Stop iPerf")

A batch file (adb_stop_iperf.bat) is created that contains the ADB shell command to terminate the iPerf service (see Figure 85).



Figure 85 Batch file (adb_stop_iperf.bat) to terminate iPerf on Andriod OS

In the Automation Manager, associate the command expression (Stop iPerf) that matches the string given in the XLAPI script with the batch file as the action to terminate the iPerf on DUT (see Figure 86).

Modify Command - Forward Conve	rsion		? <mark>×</mark>			
Expression: (.*)Stop iPerf(.*)			Ignore Duplicate			
Duplicated Response						
Actions						
Replacement: file://C:\\Automati	ion_QMICM\ <mark>\adb_stop_ip</mark> e	əf.bat				
Before 20000	After Chann	nel 🔽 🔽 F	Release Port			
Process Respo	nse 🔲 Prefix					
Action	Channel	Pre-Delay(ms)	Apply			
file://C:\\Automation_QMICM\\ OK <cr><lf></lf></cr>	UE SIMULATOR	20000 0	Add			
			Remove			
			Move Up			
•		+	Move Down			
Make Default Command 🔲 Rev	erse	ОК	Cancel			

Figure 86 Command expression and its associated action to terminate iPerf

3.6.5 Run the Script

Navigate to the script that intends to be run in PyCharm project tree structure and right mouse click on the script, e.g. 'user_nr_04_01.py', select drop down option 'Run user_nr_air04_01' as shown in Figure 87.

Eile	: <u>E</u>	dit	Vie	w	<u>N</u> avigate <u>C</u> ode	<u>R</u> efact	tor R <u>u</u> n	Tools	VCS	Window	<u>H</u> elp						
10								t 👌 🛃 dı									
ų.																	
Proje																	
•																	
				•													
				~ •	cmx_kf600x												
					default_confi	g_fdd.											
					default_confi	g_ims											
	default_config_ims_2cc_lte.rsxp																
	> m cmx_kf601x																
				5	cmx_krousm												
				5	cmx_kf616x												
				>	cmx kf617x												
				>	cmx kf620x												
				>	cmx_kf621x												
				í	default_config.rs												
					ims.rsxp												
					🖥 readme.md												
				s													
				1 1													
				~ •	config												
					🛃 readme.md												
					🛱 user_default_	°° 6											
				2	my_library												
				~ •	my_script_packa	ge 🗂											
					my_test_scrip	r.p											
					user_nr_04_01	-P2											
					Concination												
				fw													
			胡				Reforma				l+Δlt+I						
							Ontimiz	e Import									
							Delete				Delete						
		8				뀀	Mark as	Plain Te									
						Ē	Run 'ura	w. pr. 04	01'	Citel - Si	hift+E10						
							Debug	user or (14 01								
S,							Modify	Run Con	figura								
ruct							Onen in	Pight Sr		SPI	fte Enter						
8							Open In	night sp									
·																	
tes							Local Hi	story									
wori								TOM Disk									
ШĽ.							Compar	e With			Ctrl+D				- ·	- ·	

Figure 87 Run a XLAPI script in PyCharm

3.6.6 XLAPI References

Comprehensive XLAPI references are provided on CMX.

XLAPI interactive tutorials is highly recommended for the new comer who starts to XLAPI to do the scripting on CMX. The tutorial is assessible either from CMsquares burger menu > 'XLAPI Interactive Tutorial' or CMsquares home > select application 'XLAPI Interactive Tutorial'. Figure 88 shows the landing page of XLAPI interactive tutorials.



Figure 88 XLAPI interactive tutorials

Further reference can be obtained in XLAPI online document that covers XLAPI usage in conjunction with signaling controls, measurements etc. The online document is accessible from the shortcut 'XLAPI Help' in XLAPI installation folder 'C:\Users\Public\Documents\Rohde-Schwarz\XLAPI\<XLAPI version>²¹' (see Figure 89).

Computer + FI	RMWARE (C:) 🕨 Users 🕨 Public 🕨	Public Documents 🕨 Rohde-Schwar	z 🕨 XLAPI 🕨 10.77.3	•
Organize 🔻 Include in library	✓ Share with ✓ New folde	r		
☆ Favorites	Name	Date modified	Туре	Size
🥅 Desktop	idea .idea	4/11/2022 10:53 AM	File folder	
鷆 Downloads	.sequencer	3/22/2022 10:36 AM	File folder	
🔛 Recent Places	鷆 .venv	3/22/2022 10:37 AM	File folder	
	👪 appl	3/22/2022 10:53 AM	File folder	
🥽 Libraries	🁪 doc	3/22/2022 10:36 AM	File folder	
Documents	鷆 fav	3/22/2022 10:36 AM	File folder	
J Music	🚳 LaunchTerminal.bat	9/21/2021 10:56 AM	Windows Batch File	1 KB
Pictures	🔊 XLAPI Help	3/3/2022 4:27 PM	Shortcut	2 KB
📑 Videos				
🚛 Computer				
💒 FIRMWARE (C:)				
📷 DATA (D:)				
鷆 Install				
鷆 Rohde-Schwarz				
🍶 Temp				

Figure 89 Access to XLAPI online document

Figure 90 below presents the landing page of the XLAPI online document.

²¹ Placeholder contains the active XLAPI version, e.g. 10.77.3



Figure 90 XLAPI online document landing page

3.7 Throughput Testing in CMsequencer

CMsequencer is a sequencer tool integrated in the CMsquares. It supports test script creation, configuration and test automation with flow controls.

High level overview of the test run in CMsequencer is presented in this chapter. For more detailed information, please refer to CMsequencer user manual [16].

CMsequencer is accessible either directly from the home page of CMsquares (see Figure 91)



Figure 91 Launch CMsequencer from CMsquares home page

Or, alternatively, from the CMsquares burger menu > 'Sequencer' (see Figure 92)

visquares - workspace - civil	K500	plu	5 CM	W (csw	6.10	00.36	5.0)						
orkspace Sequencer	<u>,</u>	+												
			_	_	_	_	_	_	_	_			5.2	
E Sequence Editor													0	<u>^</u>
Y											Ω	\$		•
												Refresh		
New														
Flow Controls														
Function Blocks														
 R&S Script Packages 														
User Items														
	Sequence Sequence Sequence Editor New Flow Controls Flow Controls Function Blocks * R&S Script Packages User Items	Sequence × Sequence Editor Y New Flow Controls Function Blocks *	Sequence X + Sequence Editor Image: Constraint of the second seco	Sequencer × + Image: Sequence Editor Image: Sequence Editor Image: New Elow Controls Image: Sequence Sequence Editor Image: Flow Controls Image: Sequence Editor <tr< td=""><td>Sequencer × Image: Sequence Editor Image: Sequence Editor</td><td>Sequencer X Image: Sequence Editor Image: Sequence Editor</td><td>Sequencer X Image: Sequence Editor Image: Sequence Editor</td><td>Sequencer X + Sequence Editor Image: Constraint of the second secon</td><td>Sequencer × Esequence Editor New Flow Controls Function Blocks R&S Script Packages Vuser Items</td><td>Sequencer × + Sequence Editor V New Flow Controls Function Blocks * R&S Script Packages * User Items</td><td>Sequencer × + Image: Sequence Editor Image: Sequence Editor Image: New Editor Image: Sequence Editor Image: Flow Controls Image: Sequence Editor Image:</td><td>Sequencer X + Image: Sequence Editor Image: Sequence Editor Image: New Editor Image: Sequence Editor Image: Flow Controls Image: Sequence Editor</td><td>Sequencer × + Image: Sequence Editor Image: Sequence Editor Image: Sequence Editor <td< td=""><td>Sequencer × + Image: Sequence Editor Image: Sequence Editor Image: Sequence Editor <td< td=""></td<></td></td<></td></tr<>	Sequencer × Image: Sequence Editor Image: Sequence Editor	Sequencer X Image: Sequence Editor Image: Sequence Editor	Sequencer X Image: Sequence Editor Image: Sequence Editor	Sequencer X + Sequence Editor Image: Constraint of the second secon	Sequencer × Esequence Editor New Flow Controls Function Blocks R&S Script Packages Vuser Items	Sequencer × + Sequence Editor V New Flow Controls Function Blocks * R&S Script Packages * User Items	Sequencer × + Image: Sequence Editor Image: Sequence Editor Image: New Editor Image: Sequence Editor Image: Flow Controls Image: Sequence Editor Image:	Sequencer X + Image: Sequence Editor Image: Sequence Editor Image: New Editor Image: Sequence Editor Image: Flow Controls Image: Sequence Editor	Sequencer × + Image: Sequence Editor Image: Sequence Editor Image: Sequence Editor <td< td=""><td>Sequencer × + Image: Sequence Editor Image: Sequence Editor Image: Sequence Editor <td< td=""></td<></td></td<>	Sequencer × + Image: Sequence Editor Image: Sequence Editor Image: Sequence Editor <td< td=""></td<>

Figure 92 Launch CMsequencer from CMsquares menu

Upon selection, a workspace called 'Sequencer' is created in which the squares like 'Sequence Editor', 'Test Report', 'Recent Test Runs' are populated as shown in Figure 93. Refer to [16] for more details about CMsequencer GUI.

≡ +	🔶 🚽 🔹 R8.5 * CMsquares - Workspace - CMV500 plus CMW (CSW 6.100.44.0)									neset Zoom Out Zoom In	South Reliability Hom	e TE Help	22
- Test E	Test Environment Max Throughput x Sequence x +												+
😬 *	🔳 Sequence Editor						20 ×	Test Report				20 ×	" J
٢	Y	Q	\$	1 0		•		Subsquare Selection	**	Live Report		23	Q. Search
Network		Signaling Reset	NEITEST	JILOO NEUO	stop Eive	and obtions		Search	Q,	\$	Auto-Scroll ON	τc	
×	▶ KF600X	DUT Power off						▼ Table Group		0	Configuration		Tavorite
Services	► KF601X	Set PLMN						Select All	Show	Start	End		- 1
_ =	► KF602X	Set EPS Tracking Area								Duration	0		General
sequencer	► KF603X	Configure LTE Cell								Duration	Observation		
RX Meas	► KF604X	Set NR Scheduling											Sequencer
	► KF605M	Configure EPS Attach 🚯											
General	► KF606X	Activate LTE Cell(s)											DUT
	KF607X	Activate NR Cell(s)											٢
	▼ KF612	DUT Power on						▼ Chart Group	ß				Network
	Shuffler	Set LTE Scheduling					÷	Select All	Show				<u>, n</u>
	KE612	Set NR Cell Power A											Services
	KICIS	Activate EN-DC Mode											RX Meas
	KP014	Start IP Data Service											
	 KF015X 	Stop IP Data Service				· · · · <u>·</u>							Ping 1
C Reset View	 KF616X 	LTE Detach										m	
Ħ	► KF617X												IPerf 1
Multi	Recent Test Runs											25 ×	- Alia
CH Tab	Start Du	ration (h:m:s)						Script		Status	Verdict	Actions	IP Tune 1
	2022-02-25 23:14:40 00	:00:47 Setup Cell								Finished	V PASS	· · ·	۹
Close All	63 results	-00:49 Sotup Coll								Einlehod	TA DACC		Tput 1

Figure 93 Squares in workspace 'Sequencer'

3.7.1 Test Scripts Configuration and Execution

In general, CMsequencer test scripts can be created by drag and drop the building blocks from 'Function Blocks' area in 'Sequence Editor' square. Multiple test scripts can be included and executed in the arranged order in one test plan.

CMsequencer offers plenty of sample scripts with which user just adjusts the parameter settings of the function block of interest or modifies the sample script with minimal effort to meet the test needs. This saves the time and effort for the user to create a test script from the scratch.

As long as a user test script is created (either modified from an existing script, newly created, or converted from XLAPI etc.), it is saved and located under 'Sequencer Editor' > 'User Items' > 'Test Scripts' as shown in Figure 94.



Figure 94 Location of user defined test scripts in CMsequence

Two types of CMsequencer sample scripts are provided for throughput testing contained in R&S script packages (see Figure 95).

- XLAPI based throughput scripts package KF600X as CMsequencer script blocks (these blocks cannot be expanded on function block level, script parameterization is possible via configuration file)
- CMsequencer script package KF612, KF614 (scripts can be expanded and parameterized on function block level)



Figure 95 Script packages containing throughput sample scripts

A CMsquencer building block 'Load DUT' should be included at the start of each test script before network emulation starts. As the block name already implies, it loads the active DUT configuration by specifying the active DUT name in its parameter setting. The name should then match the one shown in the DUT configuration square as illustrated in Figure 96. For more details about how to manage DUT connections, including the activation of a DUT, please refer to 3.2.

➡ DUT Configurat	tion		۶
Navigation Collapse	C - D mand Activate Library	*, Favorite	Q,
Norrigation Cottapoe EX	spano scavele ubiery	revolte	Search
General Control	DUT Control		*
▼ DUT		A	Favorite
Name	Demo DUT (Y)		
	DUT Connectors		DUT
Runtime Parameters			
Restrict Connectors		ø	Network
 SIM Slots 			
Sim Slot 1 📋 🦉	Sim S 📋 Sim Slot 3 📋		General
IMS Supported			-
Sim Profile	P.	- 1	
Runtime Parameters	Ro		
IMEI	355988100054458		а.
PI MNs			Global Services
USIM			~
MCC	001		RX Meas
MNC	01		<u>.</u>
MSIN	0123456063		IP Meas
SUC	+		' 0'
Security Parameter			IP Tools
Authentication	XOR	~	4
Secret Key	000102030405060708090A0B0C0D0	EOF	
AME	8000		
Operator Code Tupe	Ciphered	~	
Operator Code			
Value Increments			
Sequence Number			
Enabled	ON	-	

Figure 96 Specifying DUT in 'Load DUT' CMsequencer building block

3.7.1.1 XLAPI Sample Scripts (Script package KF600X)

KF600X package in CMsequencer contains script blocks that are one to one mapped to XLAPI KF600X package containing throughput sample scripts as listed in Table 18 on page 53.

Figure 97 shows the script blocks of KF600X package in CMsequencer.

≡ +	E 🔶 -> 💠 R&S ^o CMsquares - Workspace - CMX500 plus CMW (CSW 6.110.36.0)												
- Test Er	nvironment 🔒 Work	space Max Throughput X Sequencer X +			1								
₩ *	Sequence Editor	🔀 🗙 🔳 Test Report		20 ×	4 J								
٨	T	C Refer Line Refer Store Line Store		23	Search								
Network	• территенненер	Search Q	Auto-Scroll ON	τc	-								
, u,	Network	Add all blocks Table Group	Configuration		Favorite								
Services	Power Toys	NR_01_01 - NR NSA Attach and Data Bearer Establi 🕨 Select All Show Start	End		=								
E Sequencer	Services	NR_01_02 - NR NSA Attach and Data Bearer Establi >	Observation		General								
~	 R&S Script Packages 	NR_01_03 - NR NSA Attach and Data Bearer Establi 🕨											
RX Meas	KC660	NR_01_04 - NR Frequency Division Duplexing and 1			Sequencer								
*	KC661	NR_01_05 - NR NSA 5MS over SG >			DUT								
Bluetooth	▼ KF600X	ND 01 OF ND NEA on a FDD ND call and then on a			0								
E Gaparal	▶ 10.77.3	▼ Chart Group			Network								
General	9.73.12	NR_02_01 - Initial NR Registration ► Select All			1								
	► KF601X	NR_02_02 - NR Carrier Aggregation (2CC)			Services								
	► KF602X	NR_02_03 - Demonstration of the DRX configuratio 🕨			`								
	► KF603X	NR_02_04 - NR-DC: 1CC FR1 + 1CC FR2 >			NA MIEBS								
	► KF604X	NR 03 01 - NSA BLER measurement		<u> </u>	* Bluetooth								
	► KF605M			ш	TX 1								
D Reset View	Recent Test Runs			× 23	Ping 1								
⊞	Start	Duration (hms) Script	Status Verdict	Actions	0								
Multi	2022-03-15 18:08:13	00:02:21 Modify_NSA_03_Downlink Max Throughput	Finished 🔗 PASS	:	IPerf 1								

Figure 97 KF600X XLAPI building blocks in CMsequencer

Major benefits of executing XLAPI scripts in CMsequencer are:

Automated test run

- The scripts can be freely combined with other test scripts or building blocks in the CMsequencer to form a test plan
- ► Flow control of the XLAPI execution, e.g. if, loop condition etc.

CMsequencer offers two options to parameterize the XLAPI script, by either entering the contents of configuration file .rsxp (file format with YAML²² syntax) in 'input parameters' field directly or parsing the .rsxp file including the complete path as execution argument by using --test-param-files option in 'execution parameters' field in 'Parameter' page of Sequencer Configuration. An example is given in Figure 98.



Figure 98 Parameterize XLAPI script in CMsequencer

To get more detailed information about XLAPI script parameterization, read section 'Using Parameter Files' in [15] or visit 'Test Parameters' area in the XLAPI online help document XLAPI Help (see also Chapter 3.6.6).

In principle, any XLAPI scripts can be converted into executable CMsequencer blocks via 'Send to CMsequencer' tool in PyCharm. More information about executing a XLAPI script on CMX via CMsequencer, refer to Chapter 4.6 of [15].

3.7.1.2 CMsequencer Sample Scripts (Script package KF612 and KF614)

CMsequencer sample scripts for throughput testing are included in KF612 [17] and KF614 package [18]. These can be served as an entry point to create own test script in CMsequencer environment.

Throughput relevant sample scripts of KF612 package are listed below in Table 21.

Script	Title
NSA_03	End-to-End Downlink Throughput, 700 Mbit/s

²² YAML stands for 'Yet Another Markup Language'. Like JavaScript Object Notation (JSON), it is a human readable markup language commonly used for configuration files.

Script	Title
SA_09	End-to-End UL Throughput, 350 Mbit/s with UL MIMO
SA_10	End-to-End UL Max Throughput, 950 Mbit/s with UL MIMO
Shuffler_05	ENDC with throughput with band combinations from CSV
Shuffler_06	ENDC with 4x4 Max throughput with band combinations from CSV

Table 21 CMsequencer throughput sample scripts in KF612 package

As a special remark, the scripts with shuffler function are iterated by the permutated band combinations presented in the CSV file (see Figure 99). The CSV configuration file is placed in folder

C:\Users\Public\Documents\Rohde-Schwarz\CMsequencer\conf. This function relieves the effort to explore the throughput among the various UE supported band combinations.

Signaling Reset	C						Selected Block: "Read CSV Data"
Read CSV Data	E.						 Input parameters
loop over each item in list							CSV File Name rs band comb 14 n41 low mid bigh
Signaling Reset	(\mathfrak{O})						Output Parameters
DUT Power off							Cell Combinations
Set PLMN	A						List Sband_combination
Set EPS Tracking Area	Ao						
Setup Cells	A						
Set NR Scheduling	.						
Set LTE Cell Power	A						
DUT Power on							
Check DUT Event	E,						
Set NR Cell Power	Å						
Activate EN-DC Mode							
Cellular Rx BLER	3					1	

Figure 99 Script with shuffler function and its input from CSV file

Following sample test scripts out of KF614 package given in Table 22 can be used and modified to verify the UE throughput during the handover procedure.

Script	Title							
CONN_07	NSA E2E Throughput with Handover in Loop							
CONN_08 SA E2E Throughput with Handover in Loop								
able 22 CMsequencer throughout sample scripts in KE614 package								

Table 22 CMsequencer throughput sample scripts in KF614 package

Each sample script can be expanded on function block level that can be parameterized individually. In CMsequencer, right mouse click on the selected script and choose 'Expand Block' option to see the belonging function blocks of the script (see Figure 100).



Figure 100 Expand block of CMsequencer script

In Figure 101, it shows as an example a modified script from the sample script 'NSA_03 End to End Downlink throughput 700 Mbps' and major parameter configurations of the selected function blocks for DL maximum throughput testing in TDD mode.
CMsequencer Script

		Modify_NSA_03_Downlink Max Th	rough	out	►	
		Signaling Reset	C			
		DUT Switch On Airplane Mode	\rightarrow			
		Set PLMN	Å			
		Set EPS Tracking Area	Å			
		Configure LTE Cell	Å			
ſ	1	Configure NR Cell	Å			
		Set NR Scheduling	•			
Ć	Ź	Configure EPS Attach				
		Activate LTE Cell(s)	(^(A)			
		Activate NR Cell(s)	(°Aº			
		DUT Switch Off Airplane Mode	%			
		Verify EPS Attach	P			
		Set LTE Scheduling				
	3	Set NR Cell Power	Au			
		Activate EN-DC Mode	(E ^x)			
		User Prompt				
		Start IP Data Service	0101			
		User Prompt				
		Stop IP Data Service	0101			
		Cellular Rx BLER	(~			
		LTE SCG Release	C			
		LTE Detach	(Å			

Function Block Configurations

Properties Param	eter		Properties Parame	eter	2	Properties Paramet
Selected Block: "Con	figure NR Cell"		Selected Block: "Set I	Selected Block: "Set N		
General			 General 			▼ General
 Maximum Conf 	fig (For Hw Resource Allocation)		Cell Name	NR Cell 1		Cell Name
Maximum Config (For Hw Resource Allocation)	false	\sim	Scheduling Type	User Defined Sched	ling	✓ Max. Cell Power
UL Modulation Type	16 QAM	~	PDSCH Add. DMRS	✓ true		✓ OCNG
CSI-RS Antenna	2	~	PUSCH Add. DMRS	false		PDCCH Power Offset
Ports	-	-	Position Zero Configure DL Partial		1	PDSCH Power Offset
UL Antenna Ports			Slot	V true		 Expected Uplink
Allow Fading	false	\sim	 User Defined So TDD Common 	cheduling		User Defined
 Frequency and 	Band		 TOD Common 			Max Expected RMS
Frequency Range	FR1	~	Ul-Dl Pattern 1	Disable		Power UL
Duplex Mode	TDD	~	Periodicity	5ms (10 Slots @ 30k	Hz)	~
Frequency Band	TDD N 78	~	DL slots	8		
Sub Carrier Spacing	30 kHz	~	UL slots	1		
 Downlink (Both 	n TDD and FDD)		DL Symbols	12		
Carrier Bandwidth	100 MHz	~	III Symbols	1	_	
Location	Mid Range	~	Down Link Para	meters		
Set Carrier Center	false	\sim	Maximum Cell	✓ true	1	~
Center Frequency	3549.990	MHz	Bandwidth	0	•	
NR ARECN	630942	_	Start KB	0		
-	2464420		Number RB	273	-	
Frequency	3464.130	MHZ	MCS	19		
Offset to Carrier		PRB	DCI Format	DCI 11		~
Initial DL BWP	201		Aggregation Level	Level 2		~
 Optink (Only PL Initial LIP BWP 	50)		MIMO Scheme	2 x 2		~
 TDD Common 			MCS Table	256 QAM		~
Ul-Dl Pattern 1	Enable	~	MAC Padding	✓ true		~
Periodicity	5ms (10 Slots @ 30kHz)	~	 Time Domain A 	lloc.		
DL slots	8		Start Symbol	1	1	
UL slots	1		# Symbols	13		
DL Symbols	12		Up Link Parame	ters	J	
UL Symbols	1					
 CORESET and S 	earch Space Zero					
Control Resource	2					
Zero	2					



Figure 101 CMsequencer script based on sample script 'NSA_03 End to End Downlink throughput 700 Mbps' and configurations of the selected function blocks

To run the script, press > button next to the script name as indicated in Figure 102.

\sim	Modify_NSA_03_Downlink Max Th	roughp	out	►	
	Signaling Reset	\mathbb{C}			
	DUT Switch On Airplane Mode	\rightarrow			
	Set PLMN	Å.			
	Set EPS Tracking Area	Å.			

Figure 102 Run CMsequencer script

3.7.2 Reports

As shown in Figure 103, live test report is presented in 'Test Report' square and it will be kept until the new test run reflashes the live report square.

= ←	← → 🍫 R&S * CMsquares - Workspace - CMX500 plus CMW (CSW 6.100.44.0))- (н) Ielp	23					
1) Test Environment in Workspace Sequencer × +																		
⊞ →	Test Report														ž	ξ×	••	۶
æ	Subsquare Selection	••	Live Report													- 20	C	2
Network	Search	Q,	Modify_NSA	_03_Dow	nlink Max Thr	oughput —						Au	uto-Scroll	I ON	T	C	Sea	
<u>I</u>	▼ Table Group	_	🥝 Pass	Configura	ation —	Start 2022-0	03-14 23:18:44	End 2022-03-1	4 23:21:00	Dura	ation 0.00:02:16	5.2	Ot	bservation	-		Favo	r orite
Services	 Select All 	Show	Test Item		Test Condition				Lower Limit	Upper Lim	nit Measure	Measured (rel.) Measured (ab			(abs.) Verdic			4
E			NR DTXs		n78; 630942; 10	00.0MHz; 30.0kH	+z; 64 QAM; (273@23); -:	4.8dBm			0.00 %		0				Gen	eral
Sequencer			NR BLER		n78; 630942; 10	00.0MHz; 30.0kH	lz; 64 QAM; (273@23); -	4.8dBm	0.00 %	5.00 %	1.00 %				Pass	ed		
RX Meas			NR Average Through	nput	n78; 630942; 10	00.0MHz; 30.0kH	Hz; 64 QAM; (273@23); -	4.8dBm		-	98.61 %		630.44				Seque	encer
E	NR Scheduled Throughput			ghput	n78; 630942; 100.0MHz; 30.0kHz; 64 QAM; (273@23); -2			4.8dBm			100.00 %	100.00 % 63		639.35]
General			 Overall Results 															
			Overall		Test C	ondition	Lower Limit	Upper Limit	Meas	sured (rel.)	Me	asured (ab	bs.)	v	erdict		Netv	Vork
	 Chart Group 	G	АСК						99.32	2 %	421	1		-	-			
	 Select All 	Show	NACK						0.68	%	29			-	-		Serv	ices
D Reset View			DTX						0.00	%	0			-	-			- 4
Ħ			BLER						0.68	%					-	- 1	RX N	Neas
Multi			Average Throughput	t	-				98.72	2 %	687	.51 Mbps		-	-			4
Tab			Scheduled Throughp	out	-				100.0	00 %	696	.42 Mbps		-	-		IP Tu	ine 1
Close All			📀 Cumulated Ver	dict: Pass (SCG Release succ	essfully: Passed))								Ī	Ē	Tpu	2 ut 1
[14-03-2022 22:32:50] DUT: The connection of SIM-1 to the EPS became active									1									

Figure 103 CMsequencer live test report

Test reports and logfiles of the previous test runs can be accessed easily from 'Recent Test Runs' square (see Figure 104). Click on icon in next to the test script of interest, more options are provided to enable the download of logfiles in different test report formats (.csv / .html / .pdf / .xml).

≡ +	≡ ← → 🍫 R&S * CMsquares - Workspace - CMX500 plus CMW (CSW 6.100.44.0)											ж						
Test Environment III Workspace Sequencer × +												:						
₩ ₩	, 🖻 Sequence Editor 🕅 🕅 🗶 🖉 🐨 🕅 🕅 🕅											" J						
	T		Q	Contraction Contraction	C Redo	E In	sia Onti	*			Subsquare Selectio	n 4	Live Report				- 22	Q Search
Network	New	^			ness	*	, ,				Search	Q,	Modi Max	fy_NSA_03_Do Throughput —	wnlink A	uto-Scroll	ON	*
C Services	Flow Controls	Add all blocks	hput 🕨 🥼k Max Throug	hput 🕨 🗎							Table Group Select All	ø	Pass		Configura	tion —		Favorite
	 Function Blocks 	Signaling Re Modify NSA	eset	ighput 🕨						Í	Parterna	Show	Start 2022-	03-14 23:18:44	End 2022-	03-14 23:21	:00	E General
Sequencer	Common	Modify NSA	03 Downlink Max Throu	iqhput 1 ⊳						l			Duration 0.	00:02:16.2	Observati	on —		
RX Meas	DUT	Set EPS Trac NSA 03 End	cking Area	put 700 Mbp	s Y 🕨					l			Overall	Test Lo Condition Lir	wer Upper hit Limit	Measured (rel.)	1 Me (at	Sequencer
E	Measurements				-								Throughput				Mt	
General	Network	Set NR Sche	edulina										Scheduled			100.00 %	69	001
	Power Toys	Setup Cell 🕨	Attach							н	 Chart Group 	-	Throughpu				IVIL	Network
	Services	Shuffler_05	Shuffler_05 ENDC with throughput with band combi >								lated Verdict: Pas	Verdict: Pass (SCG Release						
	 R&S Script Packages 	Test DUT Cor	ntrol > no Mode						٠				succes	sfully: Passed)				Services
	KC660	Test E2E >	rach										Cumu	lated Verdict: Pas	s (LTE detact	h successfull	ly.:	<u>م</u>
	KC661		eduling										Tasse	*)				RX Meas
	▼ KF600X		Power Å _{il}										🥑 Final	📫 Open Sigr	alling Log	Ī	۵.	<mark>ிர்</mark> IP Tune 1
5	9.73.12	-	a constant and a										-	📩 Download	l Signalling	Log	~ ~	
Reset View	E Recent lest Ruis	Duration (house)					Corint								HTML Rep	ort stien	¥ ^	Tput 1
EE Multi	2022-03-14 23-18-43	00:02:16	Modify NSA 03 Downli	nk Max Throu	iabout		benpe						Fi		Pdf Report	:	,	
rm	2022-03-14 22:50:54	00:02:35	Modify NSA 03 Downli	nk Max Throu	Jahput								Fi					
Tab	2022-03-14 19:16:43	00:11:53	NR 04 03 - NSA end-to-	end downlink	throughp	ut up to 9	42.3 Mbit	/s					Fi					
Close All	67 results												-	Download	лиц керо		•	
14-03	14-03-2022 22:32:50] DUT: The connection of SIM-1 to the EPS became active																	

Figure 104 Easy access to logfiles and test reports in 'Recent Test Runs' square

4 Summary

This application note tackles the background information of the optimization policies for verifying UE's DL maximum throughput in TDD mode for NR FR1. It includes the optimal positioning of the SSB/CORESETO, PDSCH/PDCCH/PUSCH optimization in the resource grid, MCS, HARQ scheme, DRB establishment and MIMO etc. It is all about how to increase the transmission bandwidth, reduce the control overhead, assign more resources for the data transmission in the resource grid in DL direction.

In further course of the document, R&S test and measurement (T&M) solutions based on CMX platform are presented. Table 23 summarizes the available throughput measurements in CMsquares and/or applications.

Measurement	Access of the Measurement	Typical Use Case
BLER	CMsquares (Rx Meas)	DL/UL throughput (scheduled and actual measured throughput) on MAC layer.
RTT	CMsquares (Ping)	Test the responsiveness and stability of the data connection between DUT and CMX
iPerf	CMsquares (iPerf) + iPerf on DUT	End-to-end throughput measurement on IP level in both UL and DL direction with both UDP and TCP
Throughput	CMsquares (Tput)	Throughput on different layers (PHY, MAC, RLC, PDCP etc.) in both UL and DL direction
Traffic Generator	Web application hosted on DUT running in DUT's Web browser	Quick check of the DL and UL throughput of the DUT
IP Tune	CMsquares (IP tune) + R&S Throughput App 2 on DUT	Fine tune the throughput on IP level in both UL and DL direction with both UDP and TCP including MCS tuning

Table 23 Services on CMX for throughput measurements

For ease of cell configurations tailored for max throughput testing, a max throughput wizard in CMsquares has been highlighted. Furthermore, guidelines and tips of performing max throughput by adopting XLAPI script which stands for more configuration and control flexibility, as well as the CMsequencer, a sequencer guarantees better test script management, are elaborated.

5 Literature

- [1] Rohde & Schwarz, "5G NR ebook," [Online]. Available: https://www.rohde-schwarz.com/5G-ebook.
- [2] R&S, "R&S®CMX500 Radio Communication Tester User Manual".
- [3] 3GPP, "3GPP TS38.306 V16.4.0 (2021-03); NR User Equipment (UE) radio access capabilities (Release 16)".
- [4] 3GPP, "3GPP TS38.101-1 V17.2.0 (2021-06); NR User Equipment (UE) radio transmission and reception Part1: Range 1 Standalone (Release 17)".
- [5] 3GPP, "3GPP TS38.101-2 V17.2.0 (2021-06) NR User Equipment (UE) radio transmissiion and reception Part 2: Range 2 Standalone (Release 17)".
- [6] 3GPP, "3GPP TS38.211 V16.6.0 (2021-06); NR Physical channels and modulation (Release 16)".
- [7] 3GPP TSG RAN WG1 Meeting #92, "Discussion on NR UE peak data rate," in R1-1801352.
- [8] 3GPP, "3GPP TS38.214 V16.6.0 (2021-06); NR Physical layer procedures for data (Release 16)".
- [9] 3GPP TS38.213 V16.2.0 (2020-06), "NR; Physical layer procedures for control (Release 16)".
- [10] 3GPP TS38.508-1 V16.4.0 (2020-06), "5GS; User Equipment (UE) conformance specification; Part 1: Common test environment (Release 16)".
- [11] R&S, "CMX One-Box-Tester press release," 10 Febuary 2022. [Online]. Available: https://www.rohdeschwarz.com/about/news-press/all-news/rohde-schwarz-presents-the-new-r-s-cmx500-one-box-testera-powerful-5g-test-platform-for-simplified-device-testing-press-release-detailpage_229356-1175685.html?change_c=true.
- [12] "iPerf User Manuals," [Online]. Available: https://iperf2.sourceforge.io/iperf-manpage.html.
- [13] R&S, "R&S®CMX500 Application Tests User Manual".
- [14] R&S, "R&S®CMW-KT014 Automation Manager Software Manual".
- [15] R&S, "R&S®CMX500 XLAPI Scripting Interface User Manual".
- [16] R&S, "R&S®CMsequencer User Manual".
- [17] R&S, "R&S®CMX-KF612M CMsequencer Script Package User Manual".
- [18] R&S, "R&S®CMX-KF614M CMsequencer Script Package User Manual".
- [19] 3GPP, "3GPP TS38.104 V15.11.0 (2020-09); NR Base Station (BS) radio transmission and reception (Release 15)".
- [20] R&S, "R&S®CMX-KF600X NR XLAPI Test Scripts Release Notes".
- [21] R&S, "R&S®CMX500 Signaling Applications User Manual".
- [22] "R&S®CMW500 Base Software User Manual," [Online]. Available: https://gloris.rohde-schwarz.com.

Rohde & Schwarz

The Rohde & Schwarz electronics group offers innovative solutions in the following business fields: test and measurement, broadcast and media, secure communications, cybersecurity, monitoring and network testing. Founded more than 80 years ago, the independent company which is headquartered in Munich, Germany, has an extensive sales and service network with locations in more than 70 countries.

www.rohde-schwarz.com



Rohde & Schwarz training

www.training.rohde-schwarz.com

Rohde & Schwarz customer support

www.rohde-schwarz.com/support



R&S[®] is a registered trademark of Rohde & Schwarz GmbH & Co. KG Trade names are trademarks of the owners. 1SL379 | Version 2e | 08.2022 Application Note | Measuring Data Throughput with The CMX500 Data without tolerance limits is not binding | Subject to change © 2022 Rohde & Schwarz GmbH & Co. KG | 81671 Munich, Germany www.rohde-schwarz.com