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**Physical layer procedures for control
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Contents

Intellectual Property Rights	2
Legal Notice	2
Modal verbs terminology.....	2
Foreword.....	5
1 Scope	6
2 References	6
3 Definitions, symbols and abbreviations	6
3.1 Definitions	6
3.2 Symbols.....	7
3.3 Abbreviations	7
4 Synchronization procedures	9
4.1 Cell search	9
4.2 Transmission timing adjustments	10
4.3 Timing for secondary cell activation / deactivation.....	11
5 Radio link monitoring	12
6 Link recovery procedures	13
7 Uplink Power control	14
7.1 Physical uplink shared channel	14
7.1.1 UE behaviour	15
7.2 Physical uplink control channel.....	20
7.2.1 UE behaviour	20
7.3 Sounding reference signals.....	25
7.3.1 UE behaviour	25
7.4 Physical random access channel.....	27
7.5 Prioritizations for transmission power reductions	28
7.6 Dual connectivity	28
7.6.1 EN-DC	28
7.6.1A NE-DC	29
7.6.2 NR-DC.....	30
7.7 Power headroom report	30
7.7.1 Type 1 PH report	31
7.7.2 Type 2 PH report	32
7.7.3 Type 3 PH report	32
8 Random access procedure	33
8.1 Random access preamble	33
8.2 Random access response	35
8.3 PUSCH scheduled by RAR UL grant.....	37
8.4 PDSCH with UE contention resolution identity.....	38
9 UE procedure for reporting control information	39
9.1 HARQ-ACK codebook determination	40
9.1.1 CBG-based HARQ-ACK codebook determination	40
9.1.2 Type-1 HARQ-ACK codebook determination	41
9.1.2.1 Type-1 HARQ-ACK codebook in physical uplink control channel.....	41
9.1.2.2 Type-1 HARQ-ACK codebook in physical uplink shared channel.....	46
9.1.3 Type-2 HARQ-ACK codebook determination	47
9.1.3.1 Type-2 HARQ-ACK codebook in physical uplink control channel.....	47
9.1.3.2 Type-2 HARQ-ACK codebook in physical uplink shared channel.....	52
9.2 UCI reporting in physical uplink control channel	53
9.2.1 PUCCH Resource Sets.....	53
9.2.2 PUCCH Formats for UCI transmission	55
9.2.3 UE procedure for reporting HARQ-ACK.....	56

9.2.4	UE procedure for reporting SR	59
9.2.5	UE procedure for reporting multiple UCI types	59
9.2.5.1	UE procedure for multiplexing HARQ-ACK or CSI and SR in a PUCCH	64
9.2.5.2	UE procedure for multiplexing HARQ-ACK/SR/CSI in a PUCCH	65
9.2.6	PUCCH repetition procedure	69
9.3	UCI reporting in physical uplink shared channel	70
10	UE procedure for receiving control information	74
10.1	UE procedure for determining physical downlink control channel assignment	75
10.2	PDCCH validation for DL SPS and UL grant Type 2	84
11	UE-group common signalling	85
11.1	Slot configuration	85
11.1.1	UE procedure for determining slot format	88
11.2	Interrupted transmission indication	94
11.3	Group TPC commands for PUCCH/PUSCH	95
11.4	SRS switching	96
12	Bandwidth part operation	96
13	UE procedure for monitoring Type0-PDCCH CSS sets	99
Annex A:	Change history	109
History		111

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Foreword

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1 Scope

The present document specifies and establishes the characteristics of the physical layer procedures for control operations in 5G-NR.

2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- [1] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications"
- [2] 3GPP TS 38.201: "NR; Physical Layer – General Description"
- [3] 3GPP TS 38.202: "NR; Services provided by the physical layer"
- [4] 3GPP TS 38.211: "NR; Physical channels and modulation"
- [5] 3GPP TS 38.212: "NR; Multiplexing and channel coding"
- [6] 3GPP TS 38.214: "NR; Physical layer procedures for data"
- [7] 3GPP TS 38.215: "NR; Physical layer measurements"
- [8-1] 3GPP TS 38.101-1: "NR; User Equipment (UE) radio transmission and reception; Part 1: Range 1 Standalone"
- [8-2] 3GPP TS 38.101-2: "NR; User Equipment (UE) radio transmission and reception; Part 2: Range 2 Standalone"
- [8-3] 3GPP TS 38.101-3: "NR; User Equipment (UE) radio transmission and reception; Part 3: Range 1 and Range 2 Interworking operation with other radios"
- [9] 3GPP TS 38.104: "NR; Base Station (BS) radio transmission and reception"
- [10] 3GPP TS 38.133: "NR; Requirements for support of radio resource management"
- [11] 3GPP TS 38.321: "NR; Medium Access Control (MAC) protocol specification"
- [12] 3GPP TS 38.331: "NR; Radio Resource Control (RRC); Protocol specification"
- [13] 3GPP TS 36.213: "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures"
- [14] 3GPP TS 36.321: "Evolved Universal Terrestrial Radio Access (E-UTRA); Medium Access Control (MAC) protocol specification"

3 Definitions, symbols and abbreviations

3.1 Definitions

For the purposes of the present document, the terms and definitions given in [1, TR 21.905] and the following apply. A term defined in the present document takes precedence over the definition of the same term, if any, in [1, TR 21.905]. A parameter referenced in *italics* is provided by higher layers.

3.2 Symbols

For the purposes of the present document, the following symbols apply:

3.3 Abbreviations

For the purposes of the present document, the abbreviations given in TR 21.905 [1] and the following apply. An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in [1, TR 21.905].

BPRE	Bits per resource element
BWP	Bandwidth part
CB	Code block
CBG	Code block group
CCE	Control channel element
CORESET	Control resource set
CP	Cyclic prefix
CRC	Cyclic redundancy check
CSI	Channel state information
CSS	Common search space
DAI	Downlink assignment index
DC	Dual connectivity
DCI	Downlink control information
DL	Downlink
DL-SCH	Downlink shared channel
EPRE	Energy per resource element
EN-DC	E-UTRA NR dual connectivity with MCG using E-UTRA and SCG using NR
FR1	Frequency range 1
FR2	Frequency range 2
GSCN	Global synchronization channel number
HARQ-ACK	Hybrid automatic repeat request acknowledgement
MCG	Master cell group
MCS	Modulation and coding scheme
NE-DC	E-UTRA NR dual connectivity with MCG using NR and SCG using E-UTRA
NR-DC	NR NR dual connectivity
PBCH	Physical broadcast channel
PCell	Primary cell
PDCCH	Physical downlink control channel
PDSCH	Physical downlink shared channel
PRACH	Physical random access channel
PRB	Physical resource block
PRG	Physical resource block group
PSCell	Primary secondary cell
PSS	Primary synchronization signal
PUCCH	Physical uplink control channel
PUCCH-SCell	PUCCH SCell
PUSCH	Physical uplink shared channel
QCL	Quasi co-location
RB	Resource block
RE	Resource element
RLM	Radio link monitoring
RRM	Radio resource management
RS	Reference signal
RSRP	Reference signal received power
SCG	Secondary cell group
SCS	Subcarrier spacing
SFN	System frame number
SLIV	Start and length indicator value
SPS	Semi-persistent scheduling
SR	Scheduling request
SRI	SRS resource indicator

SRS	Sounding reference signal
SSS	Secondary synchronization signal
TA	Timing advance
TAG	Timing advance group
TCI	Transmission Configuration Indicator
UCI	Uplink control information
UE	User equipment
UL	Uplink
UL-SCH	Uplink shared channel
USS	UE-specific search space

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4 Synchronization procedures

4.1 Cell search

Cell search is the procedure for a UE to acquire time and frequency synchronization with a cell and to detect the physical layer Cell ID of the cell.

A UE receives the following synchronization signals (SS) in order to perform cell search: the primary synchronization signal (PSS) and secondary synchronization signal (SSS) as defined in [4, TS 38.211].

A UE assumes that reception occasions of a physical broadcast channel (PBCH), PSS, and SSS are in consecutive symbols, as defined in [4, TS 38.211], and form a SS/PBCH block. The UE assumes that SSS, PBCH DM-RS, and PBCH data have same EPRE. The UE may assume that the ratio of PSS EPRE to SSS EPRE in a SS/PBCH block is either 0 dB or 3 dB. If the UE has not been provided dedicated higher layer parameters, the UE may assume that the ratio of PDCCH DMRS EPRE to SSS EPRE is within -8 dB and 8 dB when the UE monitors PDCCHs for a DCI format 1_0 with CRC scrambled by SI-RNTI, P-RNTI, or RA-RNTI.

For a half frame with SS/PBCH blocks, the first symbol indexes for candidate SS/PBCH blocks are determined according to the SCS of SS/PBCH blocks as follows, where index 0 corresponds to the first symbol of the first slot in a half-frame.

- Case A - 15 kHz SCS: the first symbols of the candidate SS/PBCH blocks have indexes of $\{2, 8\} + 14 \cdot n$. For carrier frequencies smaller than or equal to 3 GHz, $n=0,1$. For carrier frequencies within FR1 larger than 3 GHz, $n=0,1,2,3$.
- Case B - 30 kHz SCS: the first symbols of the candidate SS/PBCH blocks have indexes $\{4, 8, 16, 20\} + 28 \cdot n$. For carrier frequencies smaller than or equal to 3 GHz, $n=0$. For carrier frequencies within FR1 larger than 3 GHz, $n=0,1$.
- Case C - 30 kHz SCS: the first symbols of the candidate SS/PBCH blocks have indexes $\{2, 8\} + 14 \cdot n$.
 - For paired spectrum operation
 - For carrier frequencies smaller than or equal to 3 GHz, $n=0,1$. For carrier frequencies within FR1 larger than 3 GHz, $n=0,1,2,3$.
 - For unpaired spectrum operation
 - For carrier frequencies smaller than or equal to 2.4 GHz, $n=0,1$. For carrier frequencies within FR1 larger than 2.4 GHz, $n=0,1,2,3$.
- Case D - 120 kHz SCS: the first symbols of the candidate SS/PBCH blocks have indexes $\{4, 8, 16, 20\} + 28 \cdot n$. For carrier frequencies within FR2, $n=0,1,2,3,5,6,7,8,10,11,12,13,15,16,17,18$.
- Case E - 240 kHz SCS: the first symbols of the candidate SS/PBCH blocks have indexes $\{8, 12, 16, 20, 32, 36, 40, 44\} + 56 \cdot n$. For carrier frequencies within FR2, $n=0,1,2,3,5,6,7,8$.

From the above cases, if the SCS of SS/PBCH blocks is not provided by *ssbSubcarrierSpacing*, the applicable cases for a cell depend on a respective frequency band, as provided in [8-1, TS 38.101-1] and [8-2, TS 38.101-2]. A same case applies for all SS/PBCH blocks on the cell. If a 30 kHz SS/PBCH block SCS is indicated by *ssbSubcarrierSpacing*, Case B applies for frequency bands with only 15 kHz SS/PBCH block SCS as specified in [8-1, TS 38.101-1], and the case specified for 30 kHz SS/PBCH block SCS in [8-1, TS 38.101-1] applies for frequency bands with 30 kHz SS/PBCH block SCS or both 15 kHz and 30 kHz SS/PBCH block SCS as specified in [8-1, TS 38.101-1]. For a UE configured to operate with carrier aggregation over a set of cells in a frequency band of FR2 or with frequency-contiguous carrier aggregation over a set of cells in a frequency band of FR1, if the UE is provided SCS values by *ssbSubcarrierSpacing* for receptions of SS/PBCH blocks on any cells from the set of cells, the UE expects the SCS values to be same.

The candidate SS/PBCH blocks in a half frame are indexed in an ascending order in time from 0 to $L_{\max} - 1$. A UE determines the 2 LSB bits, for $L_{\max} = 4$, or the 3 LSB bits, for $L_{\max} > 4$, of a SS/PBCH block index per half frame from a one-to-one mapping with an index of the DM-RS sequence transmitted in the PBCH. For $L_{\max} = 64$, the UE determines the 3 MSB bits of the SS/PBCH block index per half frame from PBCH payload bits $\bar{a}_{\bar{A}+5}, \bar{a}_{\bar{A}+6}, \bar{a}_{\bar{A}+7}$ as described in [5, TS 38.212].

A UE can be provided per serving cell by *ssb-periodicityServingCell* a periodicity of the half frames for reception of the SS/PBCH blocks for the serving cell. If the UE is not configured a periodicity of the half frames for receptions of the SS/PBCH blocks, the UE assumes a periodicity of a half frame. A UE assumes that the periodicity is same for all SS/PBCH blocks in the serving cell.

For initial cell selection, a UE may assume that half frames with SS/PBCH blocks occur with a periodicity of 2 frames.

Upon detection of a SS/PBCH block, the UE determines from *MIB* that a CORESET for Type0-PDCCH CSS set, as described in Subclause 13, is present if $k_{\text{SSB}} \leq 23$ [4, TS 38.211] for FR1 or if $k_{\text{SSB}} \leq 11$ for FR2. The UE determines from *MIB* that a CORESET for Type0-PDCCH CSS set is not present if $k_{\text{SSB}} > 23$ for FR1 or if $k_{\text{SSB}} > 11$ for FR2; the CORESET for Type0-PDCCH CSS set may be provided by *PDCCH-ConfigCommon*.

For a serving cell without transmission of SS/PBCH blocks, a UE acquires time and frequency synchronization with the serving cell based on receptions of SS/PBCH blocks on the PCell, or on the PSCell, of the cell group for the serving cell.

4.2 Transmission timing adjustments

A UE can be provided a value $N_{\text{TA,offset}}$ of a timing advance offset for a serving cell by *n-TimingAdvanceOffset* for the serving cell. If the UE is not provided *n-TimingAdvanceOffset* for a serving cell, the UE determines a default value $N_{\text{TA,offset}}$ of the timing advance offset for the serving cell as described in [10, TS 38.133].

If a UE is configured with two UL carriers for a serving cell, a same timing advance offset value $N_{\text{TA,offset}}$ applies to both carriers.

Upon reception of a timing advance command for a TAG, the UE adjusts uplink timing for PUSCH/SRS/PUCCH transmission on all the serving cells in the TAG based on a value $N_{\text{TA,offset}}$ that the UE expects to be same for all the serving cells in the TAG and based on the received timing advance command where the uplink timing for PUSCH/SRS/PUCCH transmissions is the same for all the serving cells in the TAG.

For a band with synchronous contiguous intra-band EN-DC in a band combination with non-applicable maximum transmit timing difference requirements as described in Note 1 of Table 7.5.3-1 of [10, TS 38.133], if the UE indicates *ul-TimingAlignmentEUTRA-NR* as 'required' and uplink transmission timing based on timing adjustment indication for a TAG from MCG and a TAG from SCG are determined to be different by the UE, the UE adjusts the transmission timing for PUSCH/SRS/PUCCH transmission on all serving cells part of the band with the synchronous contiguous intra-band EN-DC based on timing adjustment indication for a TAG from a serving cell in MCG in the band. The UE is not expected to transmit a PUSCH/SRS/PUCCH in one CG when the PUSCH/SRS/PUCCH is overlapping in time, even partially, with random access preamble transmitted in another CG.

For a SCS of $2^\mu \cdot 15$ kHz, the timing advance command for a TAG indicates the change of the uplink timing relative to the current uplink timing for the TAG in multiples of $16 \cdot 64 \cdot T_c / 2^\mu$. The start timing of the random access preamble is described in [4, TS 38.211].

In case of random access response, a timing advance command [11, TS 38.321], T_A , for a TAG indicates N_{TA} values by index values of $T_A = 0, 1, 2, \dots, 3846$, where an amount of the time alignment for the TAG with SCS of $2^\mu \cdot 15$ kHz is $N_{\text{TA}} = T_A \cdot 16 \cdot 64 / 2^\mu$. N_{TA} is defined in [4, TS 38.211] and is relative to the SCS of the first uplink transmission from the UE after the reception of the random access response.

In other cases, a timing advance command [11, TS 38.321], T_A , for a TAG indicates adjustment of a current N_{TA} value, N_{TA_old} , to the new N_{TA} value, N_{TA_new} , by index values of $T_A = 0, 1, 2, \dots, 63$, where for a SCS of $2^\mu \cdot 15$ kHz, $N_{TA_new} = N_{TA_old} + (T_A - 31) \cdot 16 \cdot 64 / 2^\mu$.

If a UE has multiple active UL BWPs, as described in Subclause 12, in a same TAG, including UL BWPs in two UL carriers of a serving cell, the timing advance command value is relative to the largest SCS of the multiple active UL BWPs. The applicable N_{TA_new} value for an UL BWP with lower SCS may be rounded to align with the timing advance granularity for the UL BWP with the lower SCS while satisfying the timing advance accuracy requirements in [10, TS38.133].

Adjustment of an N_{TA} value by a positive or a negative amount indicates advancing or delaying the uplink transmission timing for the TAG by a corresponding amount, respectively.

For a timing advance command received on uplink slot n and for a transmission other than a PUSCH scheduled by a RAR UL grant as described in Subclause 8.3, the corresponding adjustment of the uplink transmission timing applies from the beginning of uplink slot $n+k+1$ where $k = \left\lceil N_{slot}^{subframe,\mu} \cdot (N_{T,1} + N_{T,2} + N_{TA,max} + 0.5) / T_{sf} \right\rceil$, $N_{T,1}$ is a time duration in msec of N_1 symbols corresponding to a PDSCH processing time for UE processing capability 1 when additional PDSCH DM-RS is configured, $N_{T,2}$ is a time duration in msec of N_2 symbols corresponding to a PUSCH preparation time for UE processing capability 1 [6, TS 38.214], $N_{TA,max}$ is the maximum timing advance value in msec that can be provided by a TA command field of 12 bits, $N_{slot}^{subframe,\mu}$ is the number of slots per subframe, and T_{sf} is the subframe duration of 1 msec. N_1 and N_2 are determined with respect to the minimum SCS among the SCSs of all configured UL BWPs for all uplink carriers in the TAG and of all configured DL BWPs for the corresponding downlink carriers. For $\mu = 0$, the UE assumes $N_{1,0} = 14$ [6, TS 38.214]. Slot n and $N_{slot}^{subframe,\mu}$ are determined with respect to the minimum SCS among the SCSs of all configured UL BWPs for all uplink carriers in the TAG. $N_{TA,max}$ is determined with respect to the minimum SCS among the SCSs of all configured UL BWPs for all uplink carriers in the TAG and for all configured initial UL BWPs provided by *initialUplinkBWP*. The uplink slot n is the last slot among uplink slot(s) overlapping with the slot(s) of PDSCH reception assuming $T_{TA} = 0$, where the PDSCH provides the timing advance command and T_{TA} is defined in [4, TS 38.211].

If a UE changes an active UL BWP between a time of a timing advance command reception and a time of applying a corresponding adjustment for the uplink transmission timing, the UE determines the timing advance command value based on the SCS of the new active UL BWP. If the UE changes an active UL BWP after applying an adjustment for the uplink transmission timing, the UE assumes a same absolute timing advance command value before and after the active UL BWP change.

If the received downlink timing changes and is not compensated or is only partly compensated by the uplink timing adjustment without timing advance command as described in [10, TS 38.133], the UE changes N_{TA} accordingly.

If two adjacent slots overlap due to a TA command, the latter slot is reduced in duration relative to the former slot.

4.3 Timing for secondary cell activation / deactivation

With reference to slots for PUCCH transmissions, when a UE receives in a PDSCH an activation command [11, TS 38.321] for a secondary cell ending in slot n , the UE applies the corresponding actions in [11, TS 38.321] no later than the minimum requirement defined in [10, TS 38.133] and no earlier than slot $n+k$, except for the following:

- the actions related to CSI reporting on a serving cell that is active in slot $n+k$
- the actions related to the *sCellDeactivationTimer* associated with the secondary cell [11, TS 38.321] that the UE applies in slot $n+k$
- the actions related to CSI reporting on a serving cell which is not active in slot $n+k$ that the UE applies in the earliest slot after $n+k$ in which the serving cell is active.

The value of k is $k_1 + 3 \cdot N_{\text{slot}}^{\text{subframe}, \mu} + 1$ where k_1 is a number of slots for a PUCCH transmission with HARQ-ACK information for the PDSCH reception and is indicated by the PDSCH-to-HARQ_feedback timing indicator field in the DCI format scheduling the PDSCH reception as described in Subclause 9.2.3 and $N_{\text{slot}}^{\text{subframe}, \mu}$ is a number of slots per subframe for the SCS configuration μ of the PUCCH transmission.

With reference to slots for PUCCH transmissions, if a UE receives a deactivation command [11, TS 38.321] for a secondary cell ending in slot n , the UE applies the corresponding actions in [11, TS 38.321] no later than the minimum requirement defined in [10, TS 38.133], except for the actions related to CSI reporting on an activated serving cell which the UE applies in slot $n+k$.

If the *sCellDeactivationTimer* associated with the secondary cell expires in slot n , the UE applies the corresponding actions in [11, TS 38.321] no later than the minimum requirement defined in [10, TS 38.133], except for the actions related to CSI reporting on an activated serving cell which the UE applies in the first slot that is after slot $n + 3 \cdot N_{\text{slot}}^{\text{subframe}, \mu}$ where μ is the SCS configuration for PDSCH reception on the secondary cell.

5 Radio link monitoring

The downlink radio link quality of the primary cell is monitored by a UE for the purpose of indicating out-of-sync/in-sync status to higher layers. The UE is not required to monitor the downlink radio link quality in DL BWPs other than the active DL BWP, as described in Subclause 12, on the primary cell. If the active DL BWP is the initial DL BWP and for SS/PBCH block and CORESET multiplexing pattern 2 or 3, as described in Subclause 13, the UE is expected to perform RLM using the associated SS/PBCH block when the associated SS/PBCH block index is provided by *RadioLinkMonitoringRS*.

If the UE is configured with a SCG, as described in [12, TS 38.331], and the parameter *rlf-TimersAndConstants* is provided by higher layers and is not set to release, the downlink radio link quality of the PSCell of the SCG is monitored by the UE for the purpose of indicating out-of-sync/in-sync status to higher layers. The UE is not required to monitor the downlink radio link quality in DL BWPs other than the active DL BWP on the PSCell.

A UE can be configured for each DL BWP of a SpCell [11, TS 38.321] with a set of resource indexes, through a corresponding set of *RadioLinkMonitoringRS*, for radio link monitoring by *failureDetectionResources*. The UE is provided either a CSI-RS resource configuration index, by *csi-RS-Index*, or a SS/PBCH block index, by *ssb-Index*. The UE can be configured with up to $N_{\text{LR-RLM}}$ *RadioLinkMonitoringRS* for link recovery procedures, as described in Subclause 6, and for radio link monitoring. From the $N_{\text{LR-RLM}}$ *RadioLinkMonitoringRS*, up to N_{RLM} *RadioLinkMonitoringRS* can be used for radio link monitoring depending on a maximum number L_{max} of candidate SS/PBCH blocks per half frame as described in Subclause 4.1, and up to two *RadioLinkMonitoringRS* can be used for link recovery procedures.

If the UE is not provided *RadioLinkMonitoringRS* and the UE is provided for PDCCH receptions TCI states that include one or more of a CSI-RS

- the UE uses for radio link monitoring the RS provided for the active TCI state for PDCCH reception if the active TCI state for PDCCH reception includes only one RS
- if the active TCI state for PDCCH reception includes two RS, the UE expects that one RS has QCL-TypeD [6, TS 38.214] and the UE uses the RS with QCL-TypeD for radio link monitoring; the UE does not expect both RS to have QCL-TypeD
- the UE is not required to use for radio link monitoring an aperiodic or semi-persistent RS
- For $L_{\text{max}} = 4$, the UE selects the N_{RLM} RS provided for active TCI states for PDCCH receptions in CORESETs associated with the search space sets in an order from the shortest monitoring periodicity. If more than one CORESETs are associated with search space sets having same monitoring periodicity, the UE determines the order of the CORESET from the highest CORESET index as described in Subclause 10.1.

A UE does not expect to use more than N_{RLM} *RadioLinkMonitoringRS* for radio link monitoring when the UE is not provided *RadioLinkMonitoringRS*.

Values of $N_{\text{LR-RLM}}$ and N_{RLM} for different values of L_{max} are given in Table 5-1.