3.5 PHYSICAL DOWNLINK CONTROL CHANNEL

★ The Physical Downlink Control Channel (PDCCH) is used to transfer Downlink Control Information (DCI). This corresponds to Physical layer signalling from layer 1, in contrast to RRC signalling from layer 3 or the use of MAC Control Elements from layer 2. 3GPP has specified a set of DCI Formats to accommodate a range of PDCCH payloads:

- DCI Format 0_0 'fallback' DCI format for uplink resource allocations on the PUSCH
- DCI Format 0_1 'standard' DCI format for uplink resource allocations on the PUSCH
- DCI Format 1_0 'fallback' DCI format for downlink resource allocations on the PDSCH
- DCI Format 1_1 'standard' DCI format for downlink resource allocations on the PDSCH
- DCI Format 2_0 provision of Slot Format Indicators (SFI)
- DCI Format 2_1 provision of Pre-emption Indications
- DCI Format 2_2 provision of closed loop power control commands applicable to the PUCCH and PUSCH
- DCI Format 2_3 provision of closed loop power control commands applicable to the SRS

The content of each DCI Format is described in sections 3.5.4 to 3.5.11

★ DCI Formats 2_0, 2_1, 2_2 and 2_3 are used to provide 'UE Group Common Signalling'. These DCI Formats are designed to address a group of UE and can accommodate payloads for each UE within the group. The payload belonging to a specific UE has a specific position within the DCI so each UE is able to extract its own information while ignoring the information intended for other UE

★ Figure 145 illustrates the general mapping of DCI onto the PDCCH physical channel. The PDCCH occupies a specific number of Resource Elements according to its aggregation level. An aggregation level is quantified in terms of the number of Control Channel Elements (CCE) that it occupies. 1 CCE is equivalent to 6 Resource Element Groups (REG) which is also equivalent to 72 Resource Elements. The link adaption algorithm within the Base Station assigns a specific aggregation level according to the size of the DCI payload and the UE coverage conditions. Small payloads can be accommodated using lower aggregation levels. UE which experience poor coverage are normally allocated higher aggregation levels to allow increased channel coding gain, i.e. higher quantities of redundancy

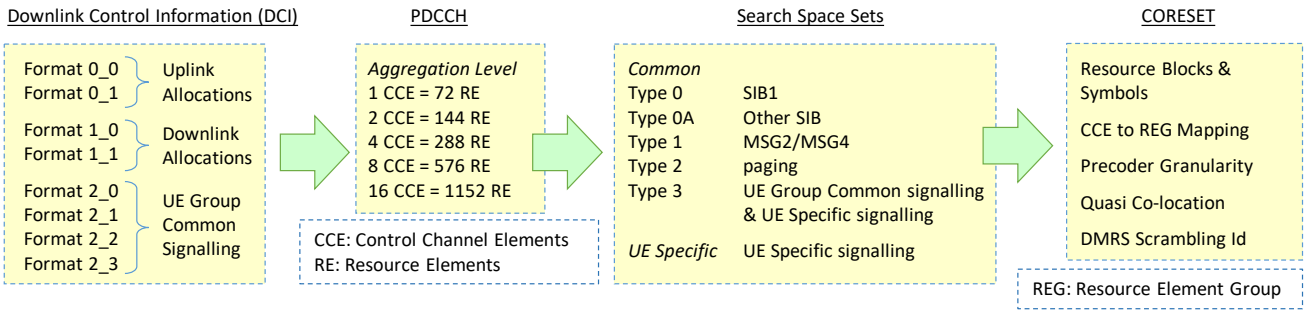

Figure 145 – Mapping of DCI Formats onto the PDCCH, Search Space Sets and Control Resource Sets

★ The PDCCH is mapped onto a specific Search Space Set according to the content of the DCI. For example, if the DCI is being used to provide a resource allocation for MSG2 during the random access procedure, then the PDCCH is mapped onto a Type 1 Common Search Space Set. Alternatively, if the DCI is being used to provide a resource allocation for the transfer of application data then the PDCCH can be mapped onto the UE Specific Search Space Set. Each Search Space Set has got a specific periodicity. This periodicity impacts latency because it determines the average waiting time for a resource allocation opportunity

★ Each Search Space Set is mapped onto a specific Control Resource Set (CORESET). The CORESET defines the set of Resource Blocks and the number of symbols available to the Search Space Set. Various other physical layer characteristics are also defined by the CORESET. These are described in the next section

★ A UE is required to deduce which DCI Format is being received at any point in time. This can be achieved using a combination of the following:

- PDCCH Search Space Set
- type of RNTI used to scramble the CRC bits which are attached to the DCI payload
- size of DCI payload
- information within the DCI payload

★ For example, if a UE is scanning a Type 2 Common Search Space Set then it knows that it should be checking for DCI Format 1_0 because DCI Format 1_0 is used to provide resource allocations for paging messages. Alternatively, if a UE is scanning a UE Specific Search Space Set then it knows that it should be checking for DCI Formats 0_0, 0_1, 1_0 and 1_1

★ Table 60 presents the set of Radio Network Temporary Identifiers (RNTI) specified by 3GPP. These RNTI are used to scramble the CRC bits which are attached to the DCI payload during Physical layer processing. This is used as a way to address either an individual UE, a group of UE or all UE. The Base Station allocates a unique C-RNTI to each UE within a cell when the UE establishes an RRC connection (either from RRC Idle mode or an incoming handover). If a UE receives a DCI Format 0_1 (for example) and obtains a successful CRC result after de-scrambling the CRC bits using its C-RNTI then the UE knows that the resource allocation is being sent to that UE rather than another UE. The Base Station can allocate a single INT-RNTI to a group of UE. All UE within that group will obtain a successful CRC result after de-scrambling the CRC bits attached to a DCI Format 2_1 payload. 3GPP has specified single fixed values for the SI-RNTI and P-RNTI. These fixed values are applicable to all UE

RNTI	DCI Format	Application	Value
SI-RNTI	1_0	PDSCH resources for System Information	FFFF
P-RNTI	1_0	PDSCH resources for Paging messages	FFFE
RA-RNTI	1_0	PDSCH resources for Random Access Response (RAR)	0001 - FFEF
TC-RNTI	0_0, 1_0	PUSCH resources for MSG3 re-transmissions, PDSCH resources for MSG4	
C-RNTI	0_0, 0_1, 1_0, 1_1	PUSCH and PDSCH resources for application data and control plane signalling	
MCS-C-RNTI	0_0, 0_1, 1_0, 1_1	Dynamic selection of low Spectral Efficiency MCS Table for PDSCH and PUSCH	
CS-RNTI	0_0, 0_1, 1_0, 1_1	Configured Grant Scheduling for PUSCH, Semi-Persistent Scheduling for PDSCH	
TPC-PUSCH-RNTI	2_2	Closed loop uplink power control commands for the PUSCH	
TPC-PUCCH-RNTI	2_2	Closed loop uplink power control commands for the PUCCH	
TPC-SRS-RNTI	2_3	Closed loop uplink power control commands for the SRS	
INT-RNTI	2_1	Interruption signalled using Pre-emption Indications	
SFI-RNTI	2_0	Dynamic changes to the slot format signalled using Slot Format Indicators (SFI)	
SP-CSI-RNTI	0_1	Trigger to activate/deactivate Semi-Persistent CSI reporting from the UE	

Table 60 – Types of Radio Network Temporary Identifiers (RNTI)

★ The size of the DCI payload can also be used to identify a specific DCI Format. The UE calculates the size of some DCI Formats based upon its configuration. For example, the UE can calculate the size of DCI Formats 0_0, 0_1, 1_0 and 1_1. DCI Formats 0_0 and 1_0 can have equal size, i.e. the pair of 'Fallback' DCI Formats. In some cases, the Base Station explicitly signals the size of a particular DCI Format, e.g. the UE is explicitly told the size of DCI Formats 2_0 and 2_1

★ Specifying multiple DCI Formats with an equal size payload reduces the number of blind decoding attempts required by the UE. For example, if DCI Format 'A' has a payload size of 30 bits and DCI Format 'B' has a payload size of 40 bits. Initially, the UE does not know which DCI Format is being received. The UE has to attempt decoding a payload size of 30 bits before checking the CRC bits to determine whether or not decoding was successful. If unsuccessful, the UE has to attempt decoding a payload size of 40 bits before checking the CRC bits. If both DCI Formats have an equal payload size, the UE only has to attempt decoding once. If the CRC bits indicate that decoding is successful then the UE has to rely upon information within the payload to differentiate between Formats 'A' and 'B', e.g. a single bit of information could be used as a flag to indicate which DCI Format is being received

★ DCI Formats 0_0 and 1_0 include a 1 bit flag to differentiate them, i.e. the flag is set to '0' to indicate an uplink resource allocation and is set to '1' to indicate a downlink resource allocation. Similarly, DCI Formats 0_1 and 1_1 also include a 1 bit uplink/downlink resource allocation flag

★ Figure 146 illustrates the Physical layer processing applied to the DCI Format payload before mapping onto the PDCCH.

★ Cyclic Redundancy Check (CRC) bits are added to allow error detection at the UE. The PDCCH does not have any mechanism which allows the UE to directly indicate successful/unsuccessful reception. Instead, the Base Station has to rely upon indirect mechanisms, e.g. if the Base Station uses the PDCCH to allocate uplink resources on the PUSCH but the Base Station does not receive a PUSCH transmission then it can deduce that the UE failed to receive the PDCCH. A set of 24 CRC bits are calculated from the PDCCH payload. These CRC bits are scrambled using the relevant RNTI. Scrambling changes some bits from '1' to '0' and other bits from '0' to '1'. The order of the bits is not changed.

★ Channel coding is applied after the CRC bits have been added. Polar coding is used as a channel coding solution for the PDCCH. The coding rate depends upon the aggregation level allocated to the PDCCH, i.e. the number of Control Channel Elements (CCE). Table 61 presents the set of aggregation levels specified by 3GPP. The number of Resource Elements shown in this table is required to accommodate both the PDCCH and the PDCCH Demodulation Reference Signal (DMRS), i.e. not all Resource Elements are available to transfer the payload

★ UE in weak coverage are likely to be allocated a higher aggregation level. This increases the number of Resource Elements which are available to transfer the PDCCH payload and allows the use of a lower coding rate (higher redundancy). UE in good coverage are likely to be allocated a lower aggregation level. This decreases the number of Resource Elements which are available to transfer the PDCCH payload and leads to a higher coding rate (lower redundancy). CCE and Resource Element Groups (REG) are described in section 3.5.1

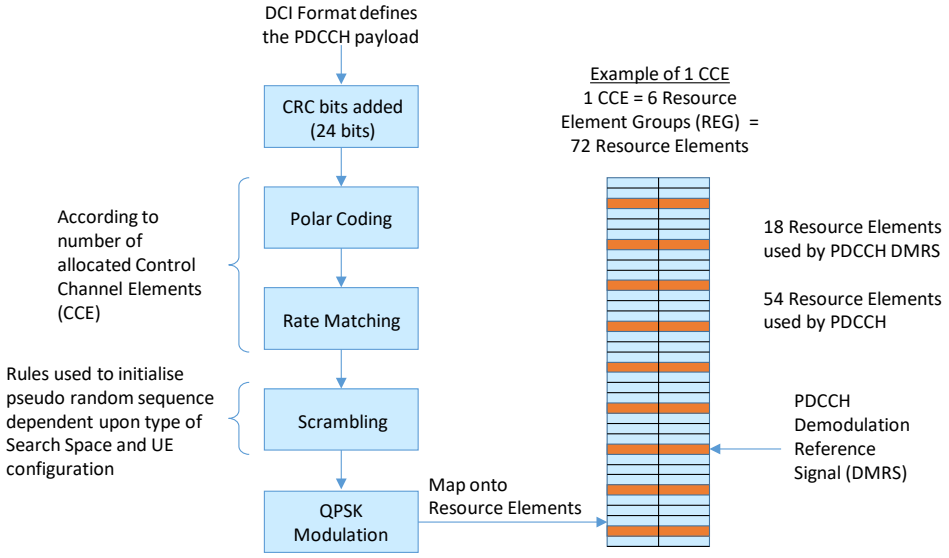

Figure 146 – Physical layer processing for the PDCCH

Aggregation Level	CCE	Resource Element Groups (REG)	Resource Elements
1	1	6	72
2	2	12	144
4	4	24	288
8	8	48	576
16	16	96	1152

Table 61 – PDCCH Aggregation Levels

- Rate Matching is applied after channel coding to ensure that the number of bits matches the capacity of the Resource Elements available to the PDCCH after accounting for the Demodulation Reference Signal (DMRS). A single CCE can accommodate 108 bits after accounting for the DMRS. Rate Matching also includes an interleaving operation to change the order of the transmitted bits
- The resultant bits are scrambled using a pseudo random sequence. Initialisation of the pseudo random sequence depends upon the type of Search Space and whether or not the UE has been configured with a *pdcch-DMRS-ScramblingID*. If a Common Search Space is used then the pseudo random sequence is always initialised using the PCI which has been allocated to the cell. If a UE Specific Search Space is used and the UE has been configured with a *pdcch-DMRS-ScramblingID* then the pseudo random sequence is initialised using a combination of the C-RNTI and the *pdcch-DMRS-ScramblingID*. If a UE Specific Search Space is used but the UE has not been configured with a *pdcch-DMRS-ScramblingID* then the pseudo random sequence is initialised using the PCI which has been allocated to the cell
- QPSK modulation is applied to generate the set of modulation symbols which are mapped onto the allocated Resource Elements. There are 54 Resource Elements available per CCE after accounting for the DMRS
- The PDCCH and DMRS are transmitted using a single antenna port, i.e. antenna port 2000. Beamforming can be applied to improve downlink coverage. If using a Common Search Space to allocate resources for a paging message or the broadcast of system information then it will be necessary to repeat the PDCCH transmission using multiple beams to ensure that the PDCCH is transmitted across the whole cell. In other cases, the PDCCH can be transmitted using a single beam, e.g. when using a UE Specific Search Space
- The PDCCH can be transmitted with or without transmit diversity. 3GPP has not specified the precoding for PDCCH transmit diversity but network vendors can implement solutions which are transparent to the UE. The same precoding is applied to both the PDCCH and the DMRS so the UE can use the DMRS to estimate the composite propagation channel (including precoding). The Base Station may apply the same precoding to all Resource Blocks used by the PDCCH, or may apply different precoding to different Resource Blocks. At least some information regarding the precoder granularity in the frequency domain can be provided as part of the Control Resource Set (CORESET) configuration (*precoderGranularity* information element within Table 62, section 3.5.1).
- 3GPP References: TS 38.211, TS 38.212, TS 38.213, TS 38.321