

9.2 DOWNLINK BEAM REFINEMENT

- ★ Once a UE has entered RRC Connected mode, it is possible to initiate Beam Refinement procedures. These procedures can be used to select beams which are more directional and have higher gain. More directional beams can improve the link budget but are also likely to require more frequent switching between beams
- ★ The CSI Reference Signal can be used to support Beam Refinement procedures. For example, a set of 4 CSI Reference Signal resources can be associated with each SS/PBCH Block, i.e. a total of 32 CSI Reference Signal resources would be configured when using the maximum of 8 SS/PBCH Blocks in Frequency Range 1. The Base Station can apply a different set of beamforming coefficients to each CSI Reference Signal resource to generate 4 directional beams per SS/PBCH Block
- ★ Each set of 4 CSI Reference Signals can be time multiplexed across 4 symbols, and frequency multiplexed with the associated SS/PBCH Block. Figure 318 illustrates a set of 4 CSI Reference Signals that use the Resource Blocks above an SS/PBCH Block. This example assumes that the CSI Reference Signal resources use a density of 3 Resource Elements per Resource Block (alternatively, a density of 1 or 0.5 could be configured). It is assumed that all CSI Reference Signal resources use the same subcarriers because they are time multiplexed and there is no need for frequency co-ordination within a specific cell. Neighbouring cells can be configured to use different subcarriers to avoid interference between CSI Reference Signal transmissions. Section 16.8 discusses frequency co-ordination between neighbouring cells

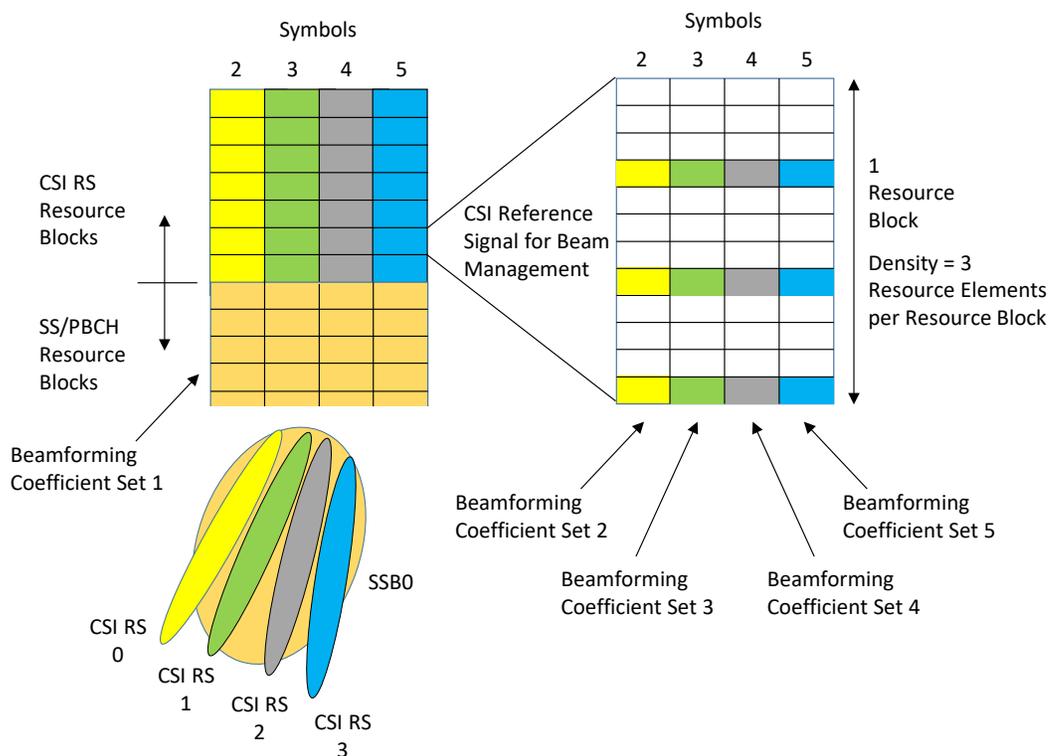


Figure 318 – Beam Refinement using CSI Reference Signals

- ★ The Base Station applies a different set of beamforming coefficients to each transmission: the beamforming coefficients applied to the Resource Blocks belonging to the SS/PBCH generate a relatively wide beam; the beamforming coefficients applied to the Resource Blocks belonging to each CSI Reference Signal generate 4 directional beams within the envelope of the wider SS/PBCH beam
- ★ The layout of the refined beams within the envelope of the wider SS/PBCH beam has a dependence upon the antenna configuration. If the antenna uses a single row of transceivers then beamforming is restricted to the azimuth direction and the set of refined beams will be arranged in a single horizontal row. If the antenna uses multiple rows of transceivers then beamforming can be completed in both the azimuth and elevation directions. This allows the refined beams to be arranged in multiple horizontal rows. Figure 319 illustrates two example refined beam layouts for these two categories of antenna configuration
- ★ Each CSI Reference Signal resource can be configured to use a single logical antenna port. The Base Station may apply the beamforming coefficients to a single polarisation and transmit the CSI Reference Signal using a single polarisation beam. Alternatively, the Base Station could apply the beamforming coefficients to both polarisations and transmit the CSI Reference Signal using the resultant pair of polarisation beams. In both cases, the precise transmission scheme would be transparent to the UE which would expect to receive a single downlink transmission on a single logical antenna port
- ★ Alternatively, the CSI Reference Signal resource can be configured to use 2 logical antenna ports. The Base Station can then transmit one port from each polarisation and the UE generates a linear average of the 2 RSRP measurements

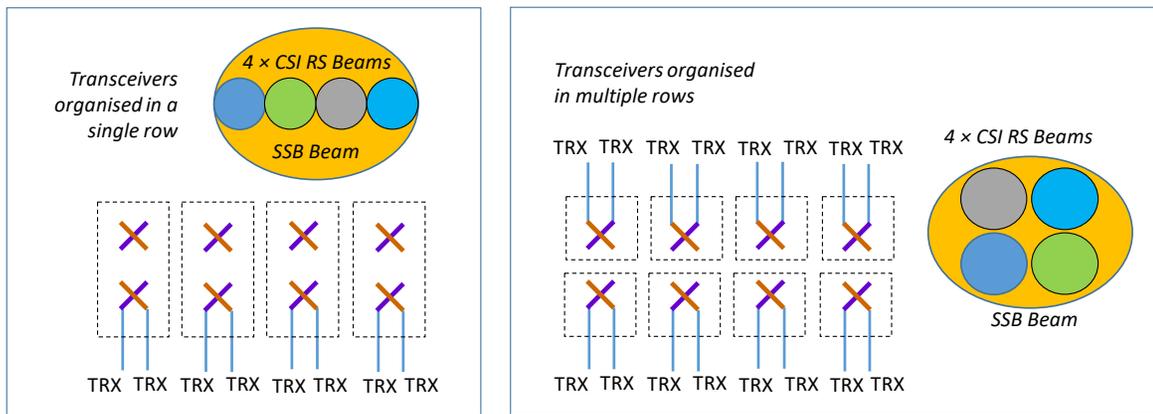


Figure 319 – Example CSI Reference Signal refined beams for different antenna layouts

- ★ The Base Station can instruct the UE to identify and report the best CSI Reference Signal. This is done using the CSI reporting framework which allows the Base Station to configure a CSI report with the *reportQuantity* set to ‘cri-RSRP’. This means that the UE generates CSI reports which include a CSI Reference Signal Resource Indicator (CRI) to identify the strongest CSI Reference Signal, i.e. the UE identifies and reports the best downlink refined beam. The UE also reports the Layer 1 RSRP which has been measured from the strongest CSI Reference Signal
- ★ The refined beam can be used for both PDCCH and PDSCH transmissions. Alternatively, the Base Station may decide to use the refined beam for the PDSCH, while using the wider SS/PBCH beam for the PDCCH. This approach allows the PDSCH to benefit from the higher gain, directional beam, while the PDCCH benefits from the wider beam which is less likely to require frequent switching between beams
- ★ In the case of 2×2 MIMO, the two polarisations can be used to generate the two beams which transmit the 2 PDSCH logical antenna ports. In the case of higher order MIMO, it is necessary to use an increased number of beams to match the increased number of PDSCH logical antenna ports. For example, 4×4 MIMO requires the transmission of 4 PDSCH logical antenna ports. This can be done using a combination of 2 polarisations and 2 refined beams, i.e. the UE is required to report the best 2 CSI Reference Signal beams rather than only the best CSI Reference Signal beam. Rank 4 transmission will rely upon reflections and scattering to generate a downlink propagation channel which allows the UE to receive all 4 layers with sufficient quality but also with low correlation
- ★ Downlink beam refinement can also be used to optimise beam selection at the UE. This is primarily applicable to Frequency Range 2, in which case the UE is more likely to use one or more antenna panels to provide a beamforming capability. CSI Reference Signal repetition can be used to generate multiple transmissions of the same CSI Reference Signal beam. The UE can use these repetitions to evaluate each of its beam positions and thus identify the best beam for downlink reception, i.e. the UE completes its own beam sweep while the Base Station repeats the CSI Reference Signal transmission. The CSI Reference Signal transmissions are time multiplexed rather than frequency multiplexed because analogue beamforming is applicable to Frequency Range 2 and in this case, the UE can generate only one of its beam positions at any point in time
- ★ Figure 320 illustrates the concepts of downlink beam refinement at both the Base Station and UE. The Base Station does not require knowledge of the beam generated by the UE so the CSI report is configured with *reportQuantity* set to ‘none’. The CSI Reference Signal is described in greater detail within section 3.7.4, whereas CSI reporting is described in greater detail within section 13.6

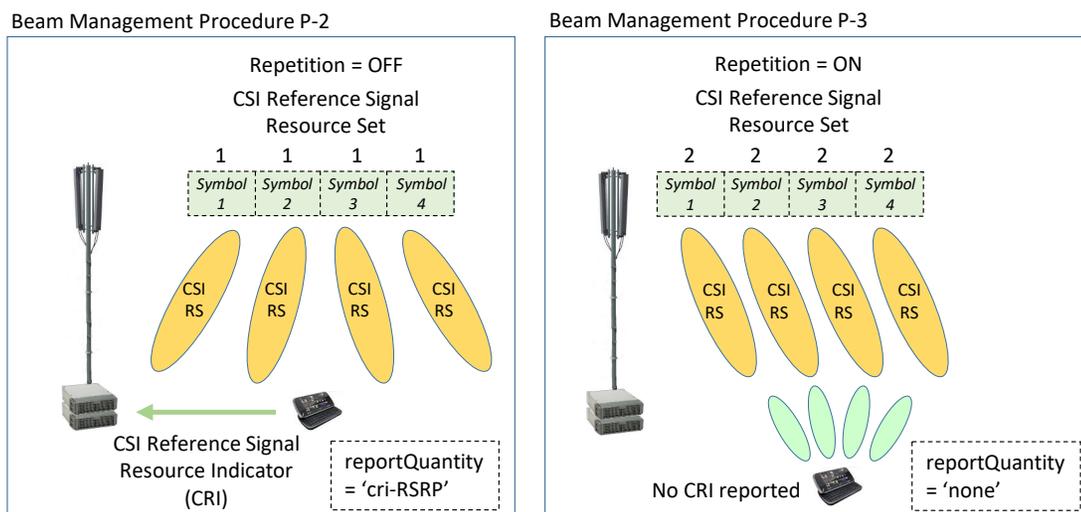


Figure 320 – Downlink beam refinement for both Base Station and UE beams

- ★ Beam refinement based upon the CSI Reference Signal has a dependence upon the UE capability. Table 236 presents the *beamManagementSSB-CSI-RS* parameter set which belongs to the *MIMO-ParametersPerBand* UE capability information. This parameter set specifies the UE capability in terms of the number of Reference Signals supported for Beam Management. For example, the *maxNumberCSI-RS-Resource* information element specifies the maximum number of CSI Reference Signal resources supported by the UE (within the context of Beam Management). 3GPP TS 38.306 specifies that a UE must support at least 8 CSI Reference Signal resources when using an operating band within Frequency Range 1

9.3 UPLINK BEAM REFINEMENT

- ★ Uplink beam refinement is not necessary if there is ‘Beam Correspondence’ between the uplink and downlink, i.e. the Base Station and UE can use the same beams for both directions
- ★ A connection can benefit from uplink beam refinement if ‘Beam Correspondence’ does not exist. In contrast to downlink beam refinement which relies upon the downlink CSI Reference Signal, uplink beam refinement relies upon the uplink Sounding Reference Signal (SRS)
- ★ The use of the SRS for uplink beam refinement is described in section 7.5.3.1. The fundamental procedure involves the UE transmitting the SRS in each beam position which allows the Base Station to select both the best UE transmit beam and the best Base Station receive beam

9.4 MOBILITY

- ★ Both the Base Station and UE must be capable of changing beams as the radio conditions change as a function of time. Intra-cell mobility involves beam switching which requires layer 1 and layer 2 procedures. Inter-cell mobility involves a handover which requires layer 3 procedures. These two categories of mobility are illustrated in Figure 321

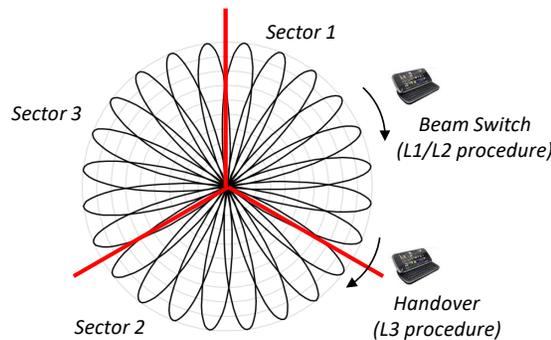


Figure 321 – Handover and Beam Switching scenarios

- ★ Intra-cell beam switching can be both transparent and seamless from the UE perspective. The UE can be instructed to generate periodic CSI reports with the *reportQuantity* set to ‘cri-RSRP’ if mobility is required between CSI Reference Signal beams, or with the *reportQuantity* set to ‘ssb-Index-RSRP’ if mobility is required between SS/PBCH beams. Assuming the former, the UE monitors the set of CSI Reference Signal beams and periodically reports the identity of the best beam in combination with an RSRP measurement
- ★ The Base Station can use this information to switch between beams without informing the UE. This is done by changing the set of beamforming weights which are applied to the Resource Blocks allocated to the PDCCH and PDSCH. The UE continues to receive the downlink transmissions without knowing that the beamforming weights have been changed. This basic beam switching scenario is illustrated in Figure 322
- ★ The basic beam switching scenario can be enhanced using a set of Transmission Configuration Indicator (TCI) States to specify Quasi Co-Location (QCL) relationships between the PDCCH and a downlink Reference Signal, and between the PDSCH and a downlink Reference Signal. 3GPP introduced the concept of QCL to help the UE with its channel estimation, frequency offset estimation and synchronisation procedures. For example, if two antenna ports are categorised as being QCL in terms of Delay Spread then the UE can determine the delay spread for one antenna port and then apply the result to both antenna ports. This avoids the UE having to determine the delay spread separately for each antenna port
- ★ A TCI State is used to define a specific QCL relationship for either the PDCCH or the PDSCH. 3GPP has specified four categories of QCL relationship which are labelled A, B, C and D. These QCL categories are described in section 2.6. For example, TCI State ‘1’ could define a QCL Type ‘A’ relationship between the PDSCH and CSI Reference Signal ‘1’. This indicates that the PDSCH and CSI Reference Signal share the same characteristics in terms of { Doppler Shift; Doppler Spread; Average Delay, Delay Spread }