

Source: Texas Instruments

Title: CSI-RS Patterns for LTE-Advanced

Agenda Item: 6.3.2.1

Document for: Discussion and Decision

1. Introduction

In RAN1 #61, the following agreements were made regarding CSI-RS pattern design for LTE-Advanced:

- *CSI RS port multiplexing is based on CDM for each pair of CSI RS port*
 - *Avoidance of port 5 of the same cell should be addressed.*
- *A nested structure among 2, 4, 8 CSI-RS ports simplifies the implementation*
 - *The pattern with smaller number of CSI-RS port is a subset of the pattern with larger number of CSI-RS port*
- *Study a single and multiple patterns in terms of achievable reuse factor and signaling overhead.*
- *A time-invariant time/frequency shift is used in a cell*

It was further agreed for each company to present their CSI-RS patterns for normal cyclic prefix (CP) and extended CP transmission. In this contribution, we further elaborate Texas Instruments' views on our proposed CDM-T based intra-cell and inter-cell CSI-RS patterns and provide the reuse factor achieved for different numbers of antenna ports (APs). We conclude the discussion by presenting link-level simulation results for evaluating performance of the proposed patterns.

2. Background

CSI-RS transmission is required for performing channel estimation at the UE since Rel-8 CRS is available only up to 4 antenna ports. The general principles behind newly added Rel-10 reference symbols (RS) are that the Rel-10 precoded UE-RS will be used for data demodulation for up to 8 layer transmission, while non-precoded cell-specific CSI-RS is used for link adaptation. Existing Rel-8 CRS will be used for control and measurement purposes and providing backwards compatibility for channel estimation at Rel-8 UEs.

In parallel with DL RS pattern design, RAN1 is evaluating muting aspects on PDSCH REs for inter-cell CSI channel estimation for DL CoMP. Several companies have proposed utilizing inter-cell CSI-RS for estimating channels from non-serving cells to the UE of interest after muting appropriately chosen PDSCH REs from its serving cell. One foreseeable problem with this approach is the likely deterioration in Rel-8 LTE UE performance especially when PDSCH muting on inter-cell CSI-RS occurs in a different subframe relative to the subframe carrying intra-cell CSI-RS. Our view [2], on the other hand, is that PDSCH muting over inter-cell CRS (for 2/4 AP eNodeBs) provides compelling benefits in terms of its higher RE density within each subframe. Moreover, unlike CSI-RS which will occur with a low duty cycle (e.g. one subframe every 10 ms), Rel-8 CRS occurs every subframe, which will help channel tracking.

We identify the following high-level design guidelines for converging to the final CSI-RS pattern:

1. **Minimize Rel-8 UE performance degradation.** Because Rel-8 LTE UEs are oblivious to CSI-RS puncturing of their PDSCH REs, such UEs will experience throughput degradation and BLER floor at high SNR, especially when they are scheduled with higher-order MCS. Computer simulation results corroborating the deteriorated Rel-8 UE performance have been given in [3]. To offset impact on Rel-8 LTE UEs – for example, by appropriate eNodeB scheduling of such UEs on non CSI-RS subframes – we suggest minimizing the CSI-RS footprint across subframes to the maximum extent possible. Alternative possibilities include MCS downscaling (e.g. QPSK-1/2) whenever Rel-8 UEs are scheduled in CSI-RS subframes.
2. **Subframe indices in FDD systems.** It is important that CSI-RS transmissions do not occur in PBCH/SCH/Paging channel carrying subframes in order to avoid causing problems with cell-search and initial acquisition.
3. **Channel estimator complexity.** For minimizing UE channel estimator complexity, we suggest the following:
 - CSI-RS pattern should be completely specified with just one resource block (that is, stay shift-invariant across frequency domain).
 - *Nested property* whenever number of eNodeB APs < 8.
 - CSI-RS RE locations for AP $i > 0$ should be implicitly determined by the OFDM symbol and resource element position of AP 0.
 - For ease of channel estimation, all APs corresponding to CSI-RS in a given cell should be transmitted within a single subframe.
4. **Interference avoidance on PDCCH.** For avoiding collision with PDCCH irrespective of the control region size, it is desirable that CSI-RS is not carried on OFDM symbols 0 through 2. For higher re-use and considering the limited availability of “real-estate”, we suggest that OFDM symbol 3 should be transmitting CSI-RS as long as the operational bandwidth is greater than 1.4 MHz.
5. **Interference avoidance on CRS.** For ensuring that Rel-8 UE can receive CRS *at least* on APs 0 & 1, it is essential that CSI-RS transmissions do not occur on OFDM symbols {0, 4, 7, 11} in normal CP operation and OFDM symbols {0,3,6,9} in extended CP operation.
6. **Interference Avoidance on UE-RS.** Since Rel-10 UEs will use UE-RS for data demodulation, CSI-RS transmissions should not occur on REs positions intended for Rel-10 UE-RS transmissions takes place.
7. **Interference Avoidance on Rel-8 DM-RS.** For accurate channel estimation over Rel-8 DM-RS (AP5) at UEs – configured for transmission mode 7 – it is desirable that CSI-RS transmissions do not puncture out DM-RS REs. RAN1 has not yet decided whether or not CSI-RS transmissions can reuse REs on DM-RS positions whenever there is no UE configured for TM7. This leads to the following alternatives:
 - **Option 1:** eNodeB avoids AP5 by picking a reuse pattern located outside of the AP5 OFDM symbol

Comments: Although eNodeB avoids collision with AP5, Option 1 may result in smaller reuse factor, especially when RS corresponding to APs 2, 3 and 5 are transmitted in a CSI-RS subframe.
 - **Option 2:** eNodeB avoids AP5 by picking a reuse pattern for a given cell specific Rel-8 DM-RS shift, if possible.

Comments: We support Option 2 because it avoids causing interference on AP5, while ensuring a reuse factor which is at least as large as those obtained using Option 1.
 - **Option 3:** avoidance of AP5 by scheduling, i.e. AP 5 can never be sent in a subframe with CSI-RS. In this case, the AP5 and CSI-RS should not be shown in the same subframe.

Comments: Option 3 increases eNodeB scheduler complexity because it cannot configure a Rel-8 UE for TM7 in CSI-RS subframes.

- **Option 4:** eNodeB transmits AP5 RS and CSI-RS by superposition on the same RE.
- **Option 5:** Either AP 5 RS or 1 CSI-RS is transmitted, while the other one is punctured.

Comments: Since CSI-RS is transparent to Rel-8 UEs configured for TM7, superposition/puncturing techniques may result in inferior channel estimation quality at such UEs, which can affect data demodulation procedure. Further, RB selective transmission of CSI-RS, as implied in Option 5, may deteriorate intra-cell channel estimate, considering the already low PRB density of CSI-RS (1 RE /PRB/port).

- **Option 6:** CSI-RS REs avoid RE positions corresponding to AP5 if TM7 is enabled in a CSI-RS carrying subframe. If TM7 is not enabled (no UE is configured for TM7), then CSI-RS may reuse RE positions corresponding to AP5.

Comments: Option 6 requires one-bit signalling from eNodeB to Rel-10 UEs informing them whether or not TM7 is enabled in that CSI-RS subframe. This results in increased specification complexity. Additionally, whether or not TM7 is enabled may vary from one subframe to the next, implying significant signalling overhead during transmitting the one bit message.

On balance, we prefer Option 2 because it has minimizes specification impact and does not affect performance of Rel-8 UEs which rely on AP5 for their data demodulation.

Based on the above discussion, we make the following proposals:

Proposal 1: *Intra-cell CSI-RS transmissions for all APs occur within a single subframe in each frame.*

Proposal 2: *Avoid CSI-RS pattern collisions with AP5 REs, whether or not TM7 is enabled. The eNodeB avoids interference on AP5 by picking a reuse pattern for a given cell specific Rel-8 DM-RS shift, if possible.*

Proposal 3: *To avoid collision with PBCH, sync and paging channels, the unicast subframe index on which CSI-RS transmissions occur is chosen from the set {1, 2, 3, 6, 7, 8}.*

Proposal 4: *For normal CP operation, CSI-RS transmissions may occur on OFDM symbol 3 whenever system bandwidth is 3 MHz or higher. CSI-RS transmissions can occur on OFDM symbol 8 (resp. OFDM symbol 7) in normal CP operation (resp. extended CP operation) if and only if the cell is configured for $i \leq 2$ CRS antenna ports.*

3. CSI-RS Patterns

We support **CDM-T multiplexing** for CSI-RS. We note that CDM-T is well adapted towards low mobility environments, which is anyway the scenario for which closed-loop MIMO operation is intended. Alternative multiplexing schemes such as CDM-F may either suffer from loss in orthogonality due to frequency selectivity [4], or increase channel estimator complexity (CSM multiplexing). An additional motivation for CDM-T multiplexing is its use – on conjunction with orthogonal cover codes (OCC) – for Rel-10 UE-RS transmission. Our proposed CSI-RS patterns use pair-wise CDM-T multiplexing of CSI-RS APs with orthogonal cover code (OCC2).

Proposal 5: *CSI-RS subframes utilize **CDMT multiplexing with length-2 OCC** for both normal CP and extended CP transmissions.*

3.1. Proposed CSI-RS Patterns for Normal CP Transmission

Figs. 1-3 present our proposed 8-TX CSI-RS patterns corresponding to cell ID modulo 3 values of 0, 1 and 2. The S patterns for 2 TX and 4 TX eNodeBs – refer email discussion summary – are not presented in this contribution because the CSI-RS patterns for 4 TX AP (resp. 2 TX AP) are *nested* within the corresponding 8 TX AP [resp. 4 TX AP] CSI-RS pattern.

The patterns are designed such that the CSI-RS pilots shall accommodate and avoid collisions with existing and newly introduced RS, taking into account their cell-id dependent pattern shifts [e.g. for Rel-8 CRS, the pattern shift in REs = Cell ID modulo 6; for Rel-8 DM-RS, the corresponding pattern shift in Res $v_{\text{shift}} = \text{Cell ID modulo } 3$]. In all cases, the patterns do not puncture or transmit on REs corresponding to AP5. When CRS ports 2 & 3 are disabled, the patterns additionally use OFDM symbols 3 & 8 for transmitting CSI-RS pilots.

Proposal 5: The CSI-RS patterns are designed with a time-invariant time- and frequency shift per cell. Location of AP 0 for CSI-RS pilots is determined by the serving Cell-ID, system bandwidth and whether or not CRS ports 2 & 3 are enabled. Time and frequency resource location of AP $i > 0$ is implicitly derived given the location of AP 0.

Table 1 shows the obtainable reuse factors with normal CP transmission.

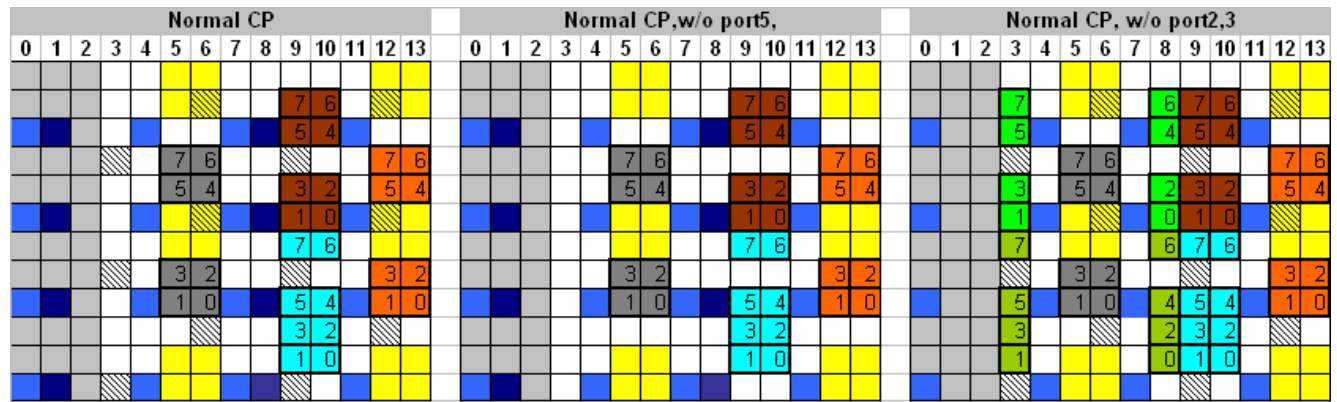


Figure 1: 8 TX Antennas, $N_{ID}^{cell} = 0 \bmod 3$

Table 1: Reuse factors for different number of CSI-RS ports and normal CP transmission

Configuration	2 CSI-RS ports	4 CSI-RS ports	8 CSI-RS ports
With Port 5	19	8	4
Without Port 5	19	8	4
Without Ports 2/3	28	12	6

Table 2 : Mapping from physical cell-id to resources for Antenna Port 0 within CSI-RS subframe

OFDM symbols carrying AP 0	Potential RE indices for AP 0 (Cell-ID = 0 mod 3)	Potential RE indices for AP 0 (Cell-ID = 1 mod 3)	Potential RE indices for AP 0 (Cell-ID = 2 mod 3)	Applicability
(12, 13) and (5, 6)	3	4	2	Co-exists with CRS APs 2 & 3 and Rel-8 DM-RS on AP 5.
(9, 10)	1 or 6	2 or 7	3 or 8	Co-exists with CRS APs 2 & 3 and Rel-8 DM-RS on AP 5.
(3, 8)	1 or 6	2 or 7	3 or 8	CRS APs 2 & 3 are disabled. System bandwidth is 3 MHz or higher.

We describe an illustrative example for assigning a CSI-RS pattern to a LTE-A UE given the Cell-ID of their serving cell, the number of transmission antenna ports and whether or not APs 2 and 3 are configured.

Step 1: The UEs determine the cell group (that is Cell-ID modulo 3) from which to pick their CSI-RS pattern. For example, if their serving cell-id mod 3 = 1, the corresponding CSI-RS pattern shall be picked from Figure 2.

Step 2: For choosing the appropriate OFDM symbol pair on which to transmit CDM-T multiplexed CSI-RS pilots, the UE can once again map their cell-ID to an element in the set of candidate OFDM symbol pairs. See column 1 in Table 2 for the set of candidate OFDM symbol pairs carrying AP0.

Step 3: Once the OFDM symbol locations for AP0 are determined, the corresponding RE offset of AP0 can be determined once again from a one-to-one mapping from the cell-ID to one of columns 2,3 and 4 in Table 2.

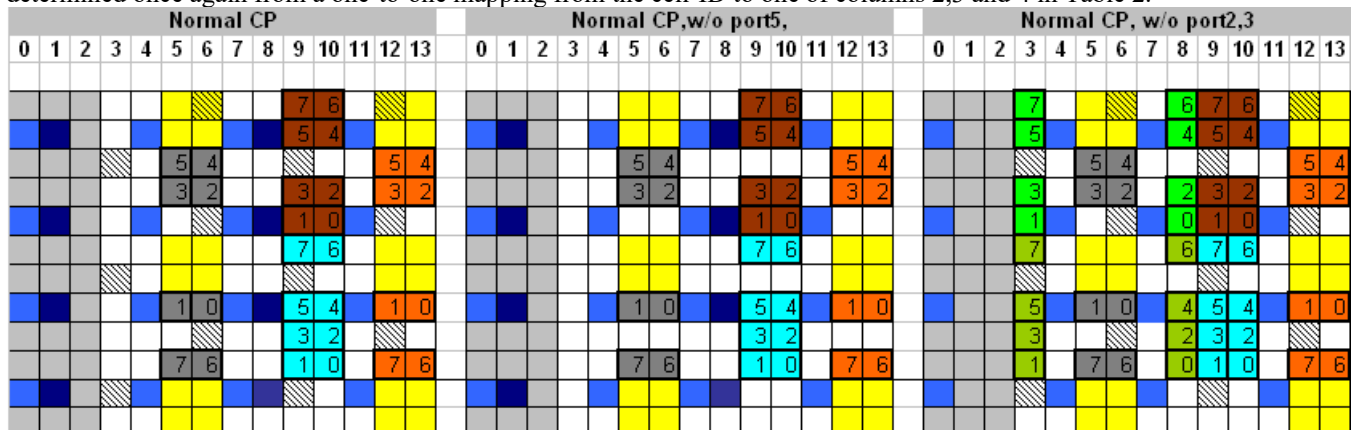


Figure 2: 8 TX Antennas, $N_{ID}^{cell} = 1 \bmod 3$

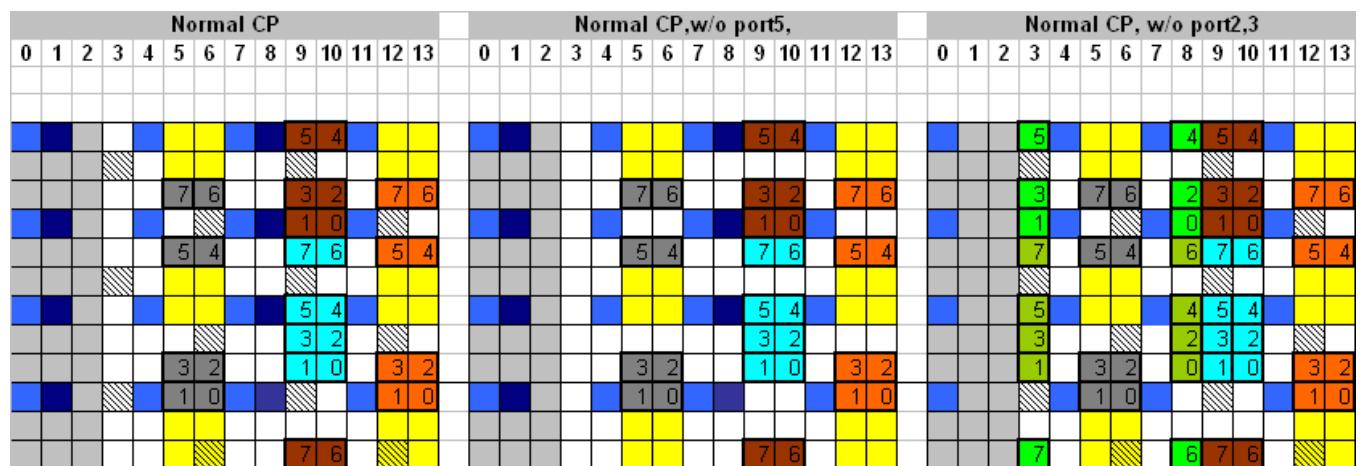


Figure 3: 8 TX Antennas, $N_{ID}^{cell} = 2 \bmod 3$

3.2. Extended CP Transmission

In Figs. 4 through 6, we present the 8 TX AP CSI-RS patterns for extended CP transmission. Most of the salient features of the patterns regarding interference avoidance on APs 2, 3 and 5 carry over from the preceding discussion in Section 3.1. Before presenting the achievable reuse factor, we shall briefly detour to discuss the (yet to be resolved) Rel-10 UE-RS patterns for extended CP transmission.

3.2.1. Rel-10 UE RS for Extended CP

As of RAN1 #61, RAN1 has not finalized UE-RS transmission patterns for extended CP transmission. Significant number of companies (9 companies) have co-sourced a way-forward agreement [6] which proposes a staggered UE-RS pattern for extended CP with transmission ranks lesser than or equal to 2. At the same time, concerns have been expressed in Nokia-NSN's contribution [5] regarding the applicability of transmission rank > 2 , especially since the typical use case priority for extended CP transmission is to maximize coverage in large cells, rather than increasing the peak throughput.

We share Nokia-NSN's proposal to restrict transmission rank to less than 2 for extended CP operation. We support [6] and focus on CSI-RS design for extended CP (given below), assuming a staggered UE-RS pattern.

3.2.2. Proposed CSI-RS Patterns for Extended CP

Mindful of the preceding discussion in 3.2.1, our proposed CSI-RS patterns (shown below) for extended CP are forward compatible with the staggered UE-RS pattern given in [5] and assume that the transmission ranks are restricted to less than or equal to 2.

For maximizing the achievable reuse factor, a distinguishing aspect of our proposed CSI-RS pattern is that we expand the OFDM symbol set depending on the eNodeB antenna port configuration.

Specifically,

- If APs 2 & 3 are **enabled**, the OFDM symbol pair carrying the CDM-T multiplexed CSI-RS pattern is chosen from the set $\{(5, 8), (10, 11)\}$.
- If APs 2 & 3 are **disabled**, the set of OFDM symbol pair carrying the CDM-T multiplexed CSI-RS is chosen from the set $\{(4, 5), (5, 7), (7, 8), (10, 11)\}$.

Table 3 shows the obtained reuse factors with our proposed CSI-RS patterns. Table 4 provides guidelines on how the UE can be assigned its CSI-RS pattern, given the serving cell-id and the antenna port configuration at its serving eNodeB.

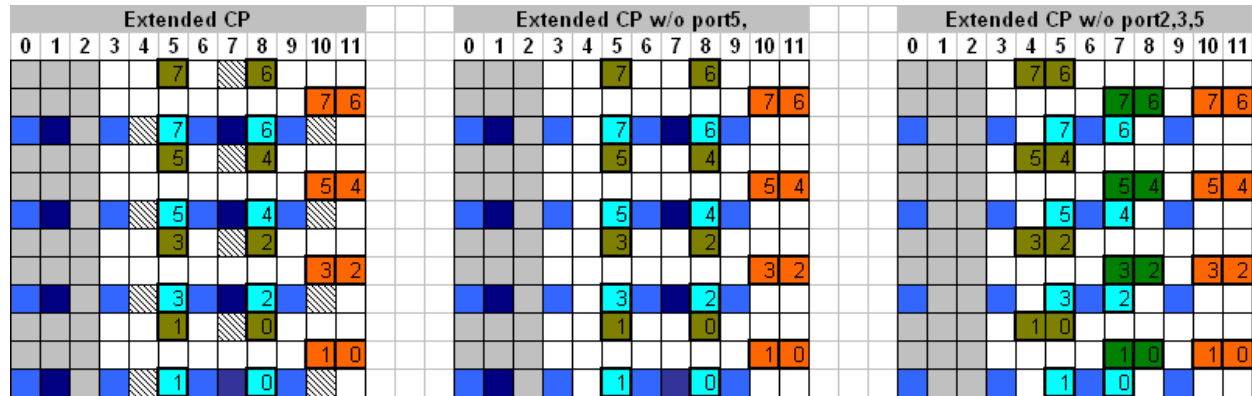


Figure 4: 8 TX Antennas, $N_{ID}^{cell} = 0 \bmod 3$

Table 3: Reuse factors for different number of CSI-RS ports and extended CP transmission

Configuration	2 CSI-RS ports	4 CSI-RS ports	8 CSI-RS ports
With Port 5	12	6	3
Without Port 5	12	6	3
Without Ports 2/3	16	8	4

Table 4 : Mapping from physical cell-id to resources for Antenna Port 0 within CSI-RS subframe

OFDM symbols carrying AP 0	Potential RE indices for AP 0 (Cell-ID = 0 mod 3)	Potential RE indices for AP 0 (Cell-ID = 1 mod 3)	Potential RE indices for AP 0 (Cell-ID = 2 mod 3)	Applicability
(10, 11)	1	0	3	Co-exists with CRS APs 2 & 3 and Rel-8 DM-RS on AP 5.
(5, 8)	0 or 2	3 or 5	6 or 8	Co-exists with CRS APs 2 & 3 and Rel-8 DM-RS on AP 5.
(4, 5)	2	5	8	CRS APs 2 & 3 are disabled
(7, 8)	1	4	7	CRS APs 2 & 3 are disabled
(5, 7)	0	3	6	CRS APs 2 & 3 are disabled

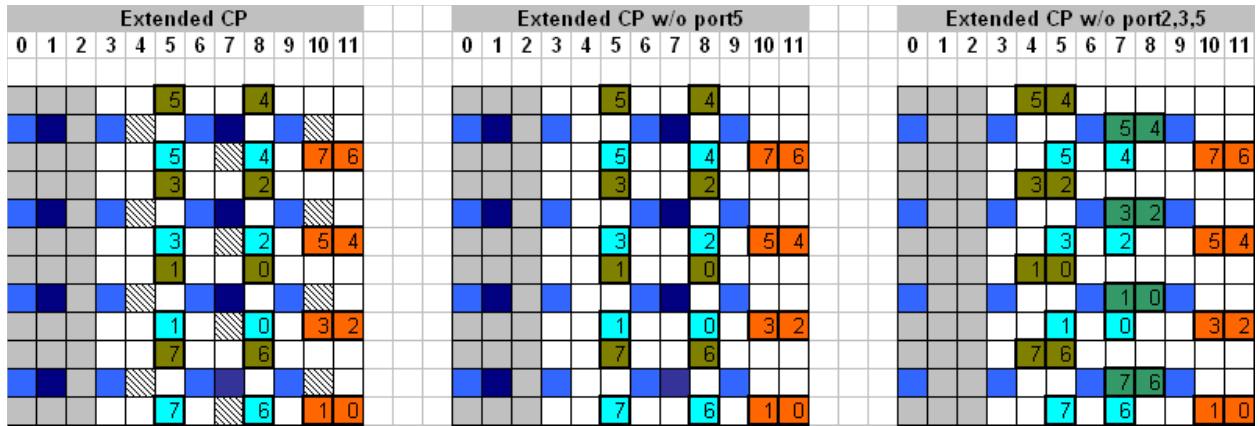


Figure 5: 8 TX Antennas, $N_{ID}^{cell} = 1 \bmod 3$

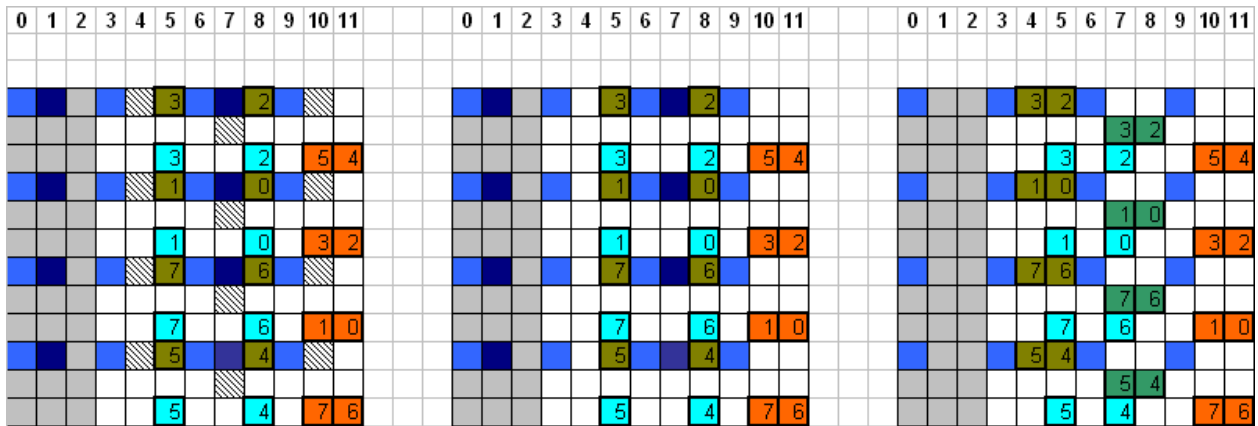


Figure 6: 8 TX Antennas, $N_{ID}^{cell} = 2 \bmod 3$

4. Simulation Results

This section discusses computer simulation results obtained using typical simulation parameters as given in Table 6. The CDM-T multiplexed CSI-RS pilots are carried over consecutive OFDM symbols (9 & 10, see Figs. 1-3). In the simulations, normal CP transmission was assumed. Figure 6 shows the corresponding PDSCH throughputs, accounting for CSI-RS overhead.

The PDSCH throughputs are averaged over 50000 subframes. The results show PDSCH throughputs with CSI-RS transmission with transmit precoder adaptation using CSI-RS transmissions with 8 transmit antenna ports. The throughputs with transmit precoder adaptation are compared against a baseline scenario without transmit precoder adaptation. For purposes of this evaluation, the channel estimation for demodulation is assumed as ideal. The MCS is held fixed for the entire simulation duration. Rank-1 transmission was assumed (no rank adaptation), considering 8 transmit and 2 receive antennas.

As expected, the maximum PDSCH throughputs with precoder adaptation using CSI-RS derived channel estimates converge to the theoretical maximum as given in Table 5 and derived in Appendix 8.

Table 5: Maximum PDSCH throughput assuming rank-1 transmission (CRS APs 2 & 3 are disabled)

MCS	Number of scheduled RBs	Number of available PDSCH RES with/without CSIRS	Maximum Rank-1 PDSCH throughput (Mbps)
QPSK-1/2	4	432/400	0.4048
16QAM-1/2	4	432/400	0.8336

64QAM-2/3	4	432/400	1.691
-----------	---	---------	-------

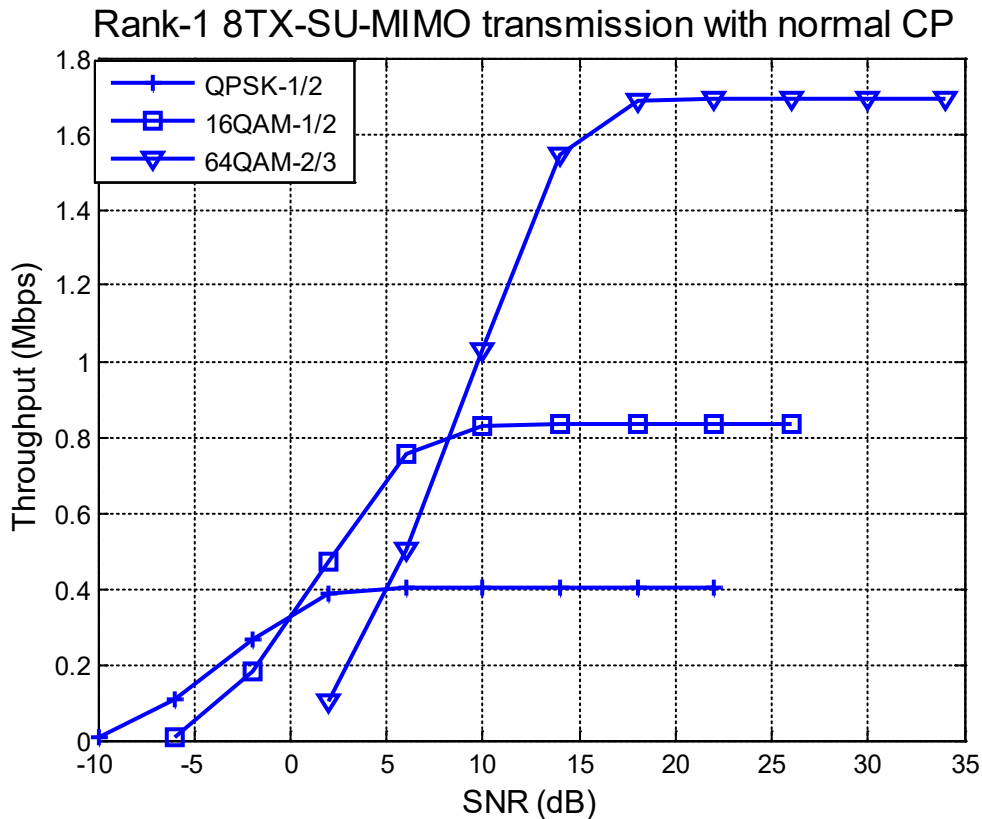


Figure 7: Single cell 8tx CDM-T multiplexed CSI-RS pattern (on symbols 9 & 10) in 3GPP-TU, 3 Kmph.

5. Conclusions

In this contribution, we have presented design guidelines outlining our preferences for CSI-RS pilot patterns in LTE-A. We have also presented a set of candidate pilot patterns for different cell-ID modulo 3 values and presented their achievable re-use factors taking into account the antenna port configuration at the serving cell.

We reiterate the following proposals in this contribution:

Proposal 1: CSI-RS subframes utilize **CDMT multiplexing with length-2 OCC** for both normal CP and extended CP transmissions.

Proposal 2: Intra-cell CSI-RS transmissions occur within a single subframe in each frame.

Proposal 3: Avoid CSI-RS pattern collisions with AP5 REs, whether or not TM7 is enabled. The eNodeB avoids interference on AP5 by picking a CSI-RS reuse pattern for a given cell specific Rel-8 DM-RS shift, if possible.

Proposal 4: To avoid collision with PBCH, sync and paging channels, the unicast subframe index on which CSI-RS transmissions occur is chosen from the set {1, 2, 3, 6, 7, 8}.

Proposal 5: For normal CP operation, CSI-RS transmissions may occur on OFDM symbol 3 whenever system bandwidth is 3 MHz or higher. CSI-RS transmissions can occur on OFDM symbol 8 (resp. OFDM symbol 7) in normal CP operation (resp. extended CP operation) if and only if the cell is configured for $i \leq 2$ CRS antenna ports

Proposal 6: The CSI-RS patterns are designed with a time-invariant time- and frequency shift per cell. Location of AP 0 for CSI-RS pilots is determined by the serving Cell-ID, system bandwidth and whether or not CRS ports 2 & 3 are enabled. Time and frequency resource location of AP $i > 0$ is implicitly derived given the location of AP 0.

6. References

1. Report of 3GPP TSG RAN WG1 #61 (Montreal, Canada, 10th-14th May, 2010).
2. R1-103698, "PDSCH Muting: N-MSE for Inter-cell CSI Estimation, Texas Instruments.
3. R1-103697, "PDSCH muting for inter-cell CSI estimation: Rel-8 UE performance", Texas Instruments.
4. R1-102956, "Intra-cell CSI-RS design", Nokia, Nokia Siemens Networks.
5. R1-102954, "DM-RS views on extended CP", Nokia, Nokia Siemens Networks.
6. R1-103383, "Way-forward on DM-RS pattern for extended CP".

7. Appendix: Simulation Parameters

Table 6: Simulation parameters and their description/value.

Simulation Parameter	Value
Carrier frequency	2 GHz
Transmission bandwidth	5 MHz (25 RBs)
eNodeB antenna configuration	8 Tx uncorrelated.
UE antenna configuration	2 RX uncorrelated.
Channel model	3GPP-TU
UE velocity	3 Kmph
PDCCH/PDSCH configuration	3/11 OFDMA symbols per subframe.
Scheduling in time	Scheduling in every downlink subframe.
Channel coding (PDSCH)	Rel-8 turbo coding.
Number of allocated PRB	4 PRBs (RBs 4,5,6,7)
CSI-RS reference pattern	CDM-T multiplexing on OFDM symbols 9 & 10. CSI-RS for AP0 is transmitted on RE index 1
MCS, HARQ and link adaptation	Separate MCS (QPSK-1/2, 16QAM-1/2, 64QAM-2/3)
PDSCH Demodulation	MRC
Precoding/Feedback granularity	4 PRB granularity for PMI feedback
Transmit Precoding	16 entries for rank 1
Transmission rank	1
CSI-RS allocation	Full bandwidth in active CSI-RS subframe
CSI-RS duty cycle configuration	Once every 10 ms (duty cycle factor = 0.1)
CSI-RS density	1 RE/PRB/Port
CQI/PMI reporting delay modelling	Delay equals 5 subframes (5 ms) between time of computation at UE and use for precoding at eNodeB.
Channel estimation for demodulation	Idealized channel estimation
Channel estimation for PMI adaptation over CSI-RS	LS estimation over CSI-RS pilot locations and DFT frequency domain interpolation across entire bandwidth.
Simulation output	PDSCH throughput (Mbps) versus SNR (dB) accounting for CSI-RS overhead

8. Appendix: PDSCH Availability Given CSI-RS

Table 7: CSI-RS overhead calculation.

Symbol	Description	Value
N_{syms}	# OFDMA symbols/subframe	14

N_{PDCCH}	#Control symbols/subframe	3
$N_{tonesperRB}$	Resource Elements per RB	12
N_{RB}	Number of scheduled PDSCH RBs	4
$N_{CSIRSports}$	Number of CSIRS ports	8
$N_{DMRSREperRB}$	Number of DMRS REs per subframe	24
N_{CRSRE}	Number of CRS REs outside PDCCH region per subframe	12
$DutyCycle_{CSIRS}$	Fraction of subframes in which CSI-RS is transmitted	0.1

Ignoring SCH and BCH resource elements (REs), assume a PDSCH allocation of N_{RB} resource blocks. The CSI-RS specific parameter is given by $M_{CSIRSperport}$ (units of REs/PRB/port). Define the parameter $N_{DMRSREperRB}$ which denotes the total number of DMRS symbols in each RB. See Table 7 for detailed description of different parameters used in the ensuing CSI-RS overhead calculations.

The number of available data (PDSCH) REs when CSI-RS is present is therefore given as

$$N_{data} = N_{RB} \times [(N_{syms} - N_{PDCCH}) \times N_{tonesperRB} - M_{CSIRSperport} \times N_{CSIRSports} - N_{CRSRE} - N_{DMRSREperRB}].$$

Using typical values given in Table 7, the total available number of PDSCH REs (N_{data}) equals 400 REs.