3GPP TSG RAN Rel.-18 Workshop **RWS-210319**
Online, June 28 – July 2, 2021

Agenda item: 4.1 eMBB-driven Functional Evolution

Source: Fraunhofer IIS, Fraunhofer HHI

Title: MIMO Enhancements for Rel.-18

Document for: Discussion

1 Motivation

The demand for seamless connectivity and high-capacity links in scenarios with moving UEs is growing rapidly. In such cases, adequate CSI feedback schemes used for link adaption are of major importance. However, the current Rel. 15/16 type-II CSI feedback schemes lack performance in scenarios where UEs move even at moderate speeds (10 to 30 km/h). This issue was already addressed during the preparatory phase of Rel.-17 MIMO where operators as well as companies from the vertical industries expressed high interest on CSI enhancements for the following applications:

- Industrial scenarios with moving UEs such as robots,
- Automotive scenarios with moving UEs (30-100 km/h),
- Highway scenarios up to 250 km/h,
- High-speed trains up to 500 km/h,
- Scenarios with moving UEs up to 30 km/h.

Figure 1 shows simulation results for the Rel. 15/16 type-II CSI feedback schemes and the performance loss when a UE is moving at 30 km/h compared to a non-moving static UE. A performance loss up to 30% can be observed.

Observation 1: For the Rel. 15/16 type-II CSI feedback schemes a performance loss is observed when UEs move already at moderate speeds of 30 km/h.

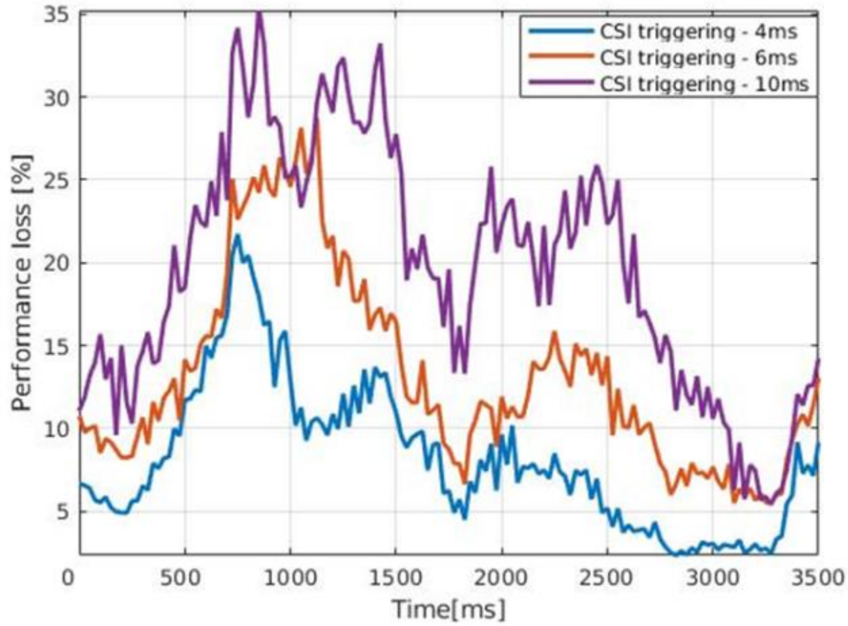
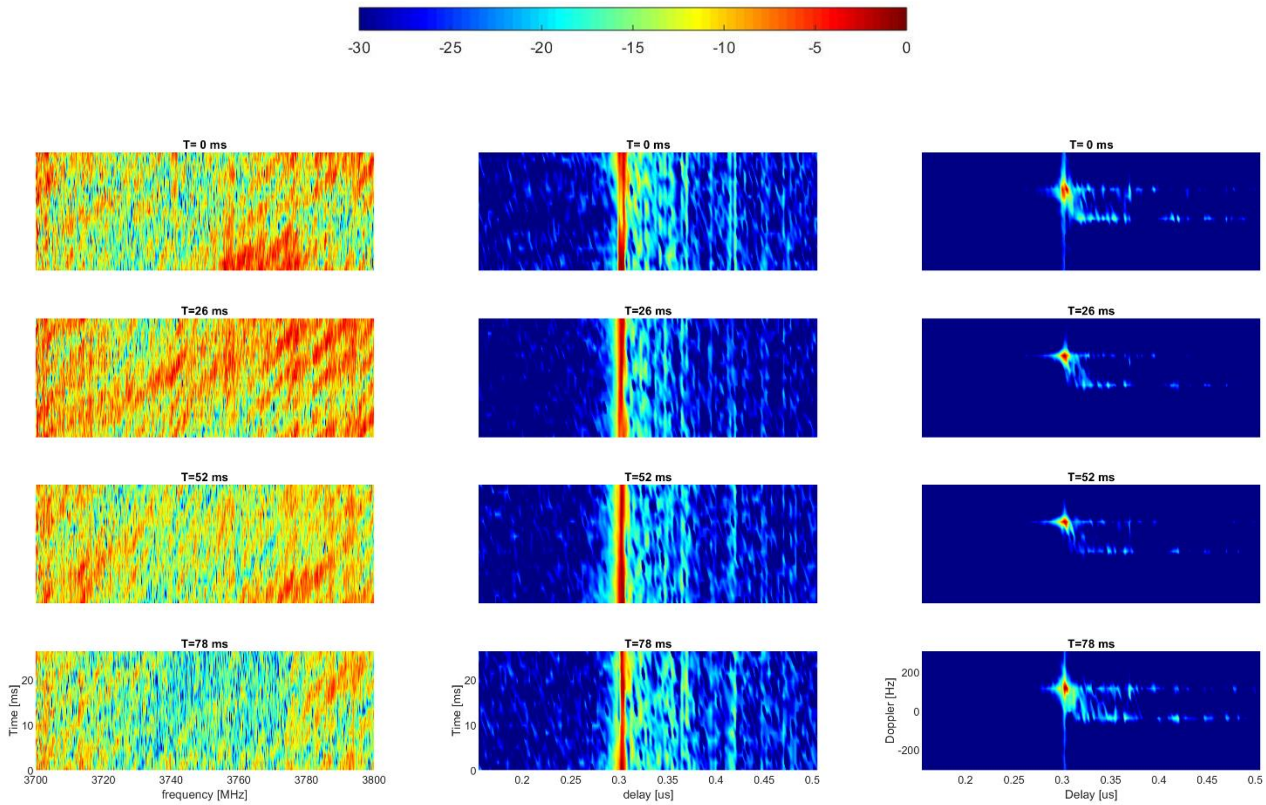


Figure 1: Performance loss of a moving UE (30 km/h) compared to a static UE for different CSI feedback rates at 4 GHz.

For the current Rel. 15/16 type-II codebooks a performance loss is observed when the CSI update rate of the PMI measurements is not sufficiently high with respect to the channel variation rate. This is mainly caused by the Doppler spread of the channel. The Doppler spread leads to significant time-variations and potential deep fades of the channel over time as shown in Figure 2 (see first and second column of Figure 2) for an urban scenario with low UE mobility (up to 20 km/h). In order to cope with these channel variations (and hence PMI variations), the network may trigger more frequent CSI measurements to accurately track the channel. Obviously, a higher CSI update rate comes at the cost of higher UE battery consumption and increased use of UL/DL resources.

Observation 2: For the current Rel. 15/16 type-II codebooks, the following is observed in UE mobility scenarios:

- ***Large performance loss is obtained when channel variations are fast and CSI measurement and update rate is not sufficient high,***
- ***A high CSI update rate is needed to handle fast channel variations even for UEs with low mobility,***
- ***Increased use of UL/DL resources due to frequent PMI measurements and CSI feedback, and***
- ***Increased UE battery consumption.***



Power spectrum [dB] at different measurement times.

Power delay profile [dB] at different measurement times.

Doppler-delay spectrum [dB] at different measurement times.

Figure 2: Power spectrum [dB] (left), power delay profile [dB] (middle), and Doppler-delay spectrum [dB] (right) over 104ms at measurement times $T = T_{ref} + \Delta T,\ T_{ref} = 30$ s, $\Delta T = 26$ ms for an urban scenario, average speed of approx. 20 km/h, center frequency 3.75 GHz.

In current NR systems, the CSI measurement and reporting rate depends on the channel coherence time that defines the time duration over which the amplitude and phase change imposed by the propagation conditions is considered to be constant. Moreover, the CSI report contains only information on the current channel state. Consequently, a high CSI (CQI and/or PMI) update rate is required in UE-mobility scenarios, where the channel variations are fast, and the channel coherence time is small.

Observation 3: The CSI update rate depends on the fast-fading channel variations and a high CSI update rate is required in UE-mobility scenarios where the channel variations are fast, and the channel coherence time is small.

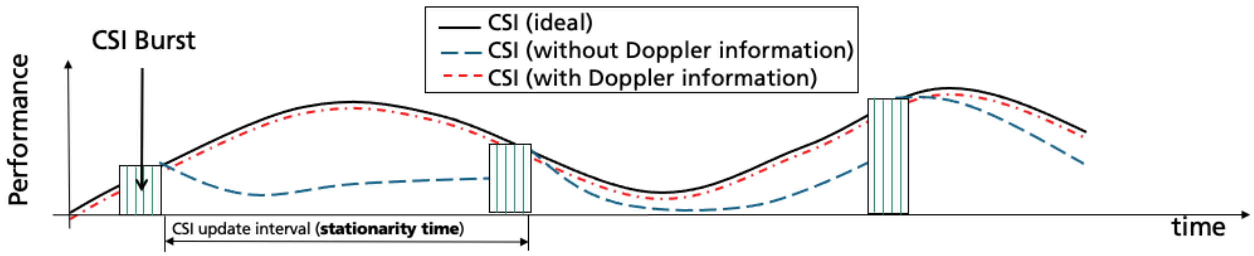


Figure 3: Performance with and without Doppler-spread-related information.

In order to overcome this drawback and to decouple the CSI feedback rate from the channel coherence time, the CSI report should contain information on the fast-fading channel variations in the form of a Doppler or Doppler-delay spectrum-related information. The Doppler or Doppler-delay spectrum-related information can be measured on a burst of CSI-RS resources as shown in Figure 3 to characterize the channel variations over the so-called channel stationarity time, where the CSI-RS bursts are triggered with a large CSI update interval. The channel stationarity time is the time over which the channel is static (with respect to the Doppler-delay spectrum) and remains identical, and large-scale parameters such as path loss and shadow fading do not change, and channel variations are only related to small-scale fading. The Doppler or Doppler-delay spectrum-related information can be represented in the form of a precoder (PMI) in the CSI report. With such a representation the channel fast-fading process can be covered in a compressed manner. An example of the Doppler-delay spectrum is shown in Figure 2 (right).

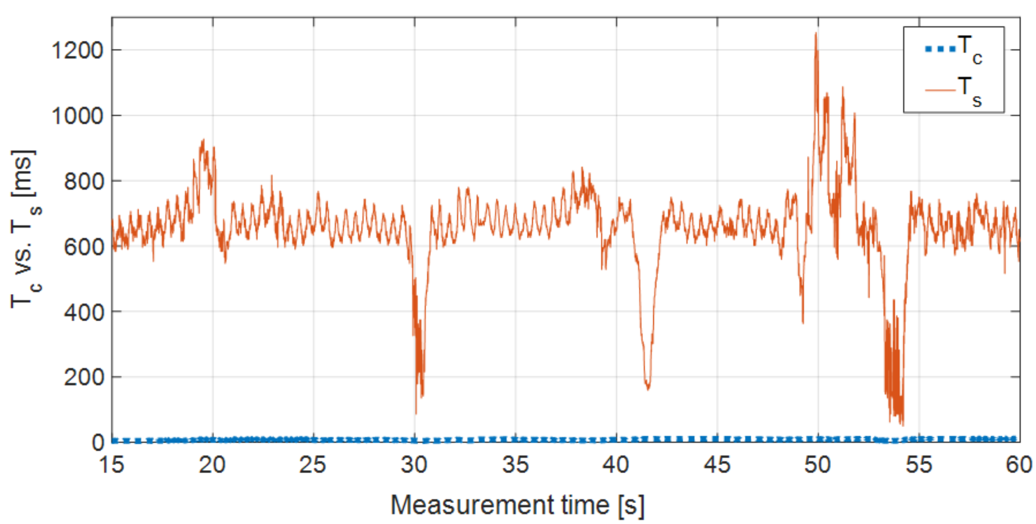


Figure 4: CSI update rate based on channel coherence time (T_c) versus CSI update rate based on stationarity time (T_s) for a V2X highway measurement scenario.

Figure 4 compares the CSI feedback rate based on the channel coherence time (T_c) and the channel stationarity time (T_s) for a V2X highway measurement scenario at 2.53 GHz and 20 MHz system bandwidth. It can be observed that the stationarity time is significantly larger than the coherence time over the whole measurement time along the measurement track. While the mean value of T_c is approx. 8 ms, the average T_s is about 656 ms which is more than 80 times larger.

Observation 4: To drastically reduce the CSI feedback rate, the CSI report should contain Doppler or Doppler-delay spectrum-related information of the channel.

The simulation results presented in Figure 1 are based on the 3GPP channel model of TR 38.901. In [1] it was shown that the Doppler spread is a serious issue and cannot be neglected in real-world scenarios such as:

1. High-speed train scenario (100-130 km/h),
2. Urban scenario 1 (average speed 20 km/h),
3. Urban scenario 2 (average speed 20 km/h),
4. Highway scenario (average speed 100 km/h),
5. Side-link highway scenario (average speed 100 km/h).

Furthermore, for the above UE mobility scenarios, it was observed in [2] that the stationarity time of the channel is significantly larger than the coherence time. A stationarity-time-based CSI reporting would drastically reduce the UE complexity for CSI calculation and reporting in mobility scenarios. Moreover, due to reduced CSI feedback rate, less UL/DL resources are required for CSI measurements and reporting.

Observation 5: When the CSI report contains Doppler or Doppler-delay spectrum-related information, the gNB can perform precoding in the time-domain to compensate for the fast-fading variations of the channel, and

- ***less UL/DL resources are required for CSI measurements and reporting,***
- ***UE complexity and UE battery consumption are reduced, and***
- ***improved performance is expected in fast-fading channels.***

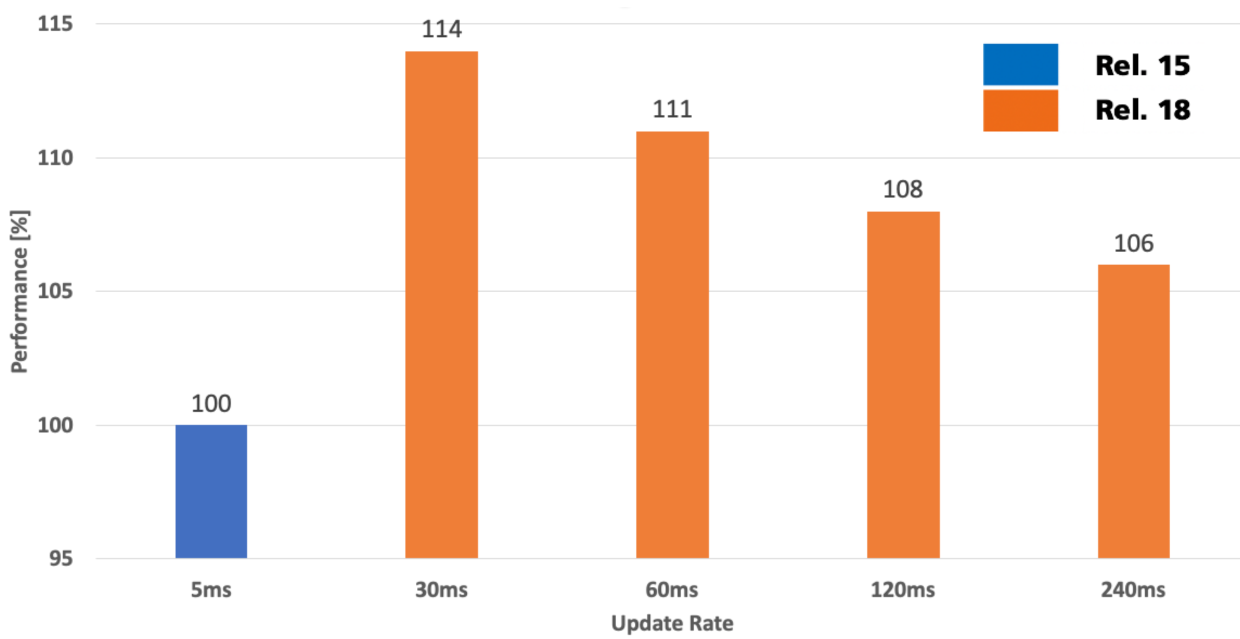


Figure 5: Performance of the Doppler-delay precoder over the Rel. 15 precoder for CSI update rates 30ms, 60ms, 120ms and 240ms. Reference is the Rel. 15 precoder with CSI update rate of 5ms.

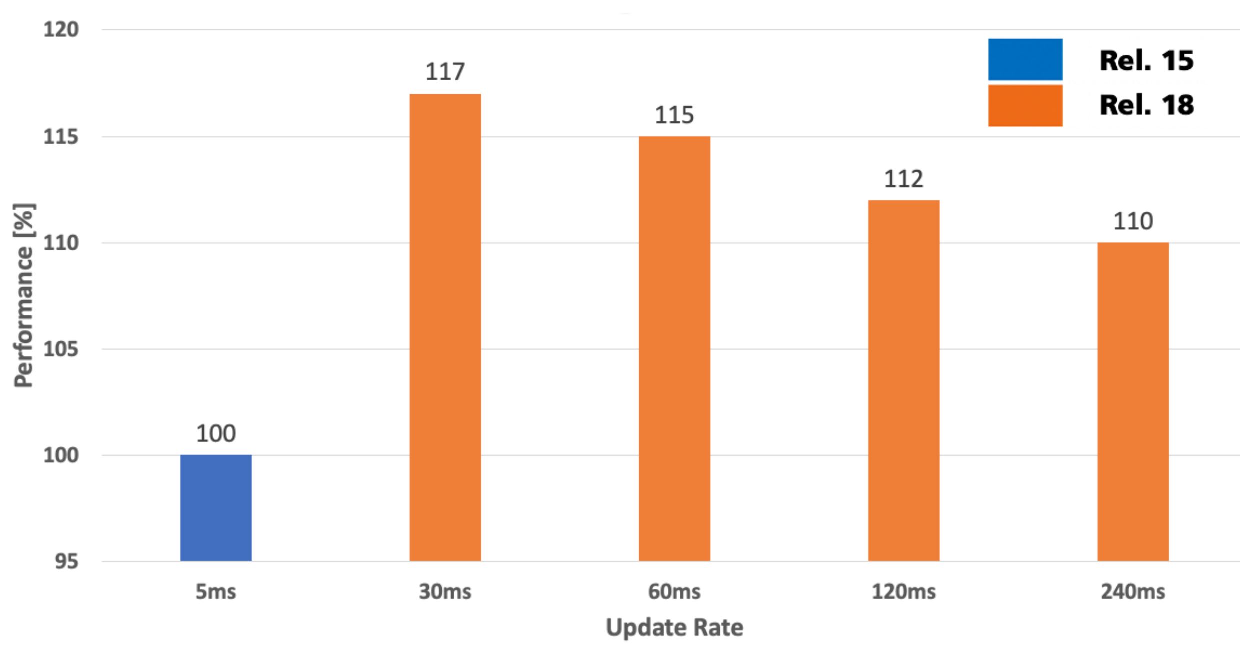


Figure 6: Performance of the Doppler-delay precoder over the Rel. 15 precoder for CSI update rates 30ms, 60ms, 120ms and 240ms. Reference is the Rel. 15 precoder with CSI update rate of 10ms.

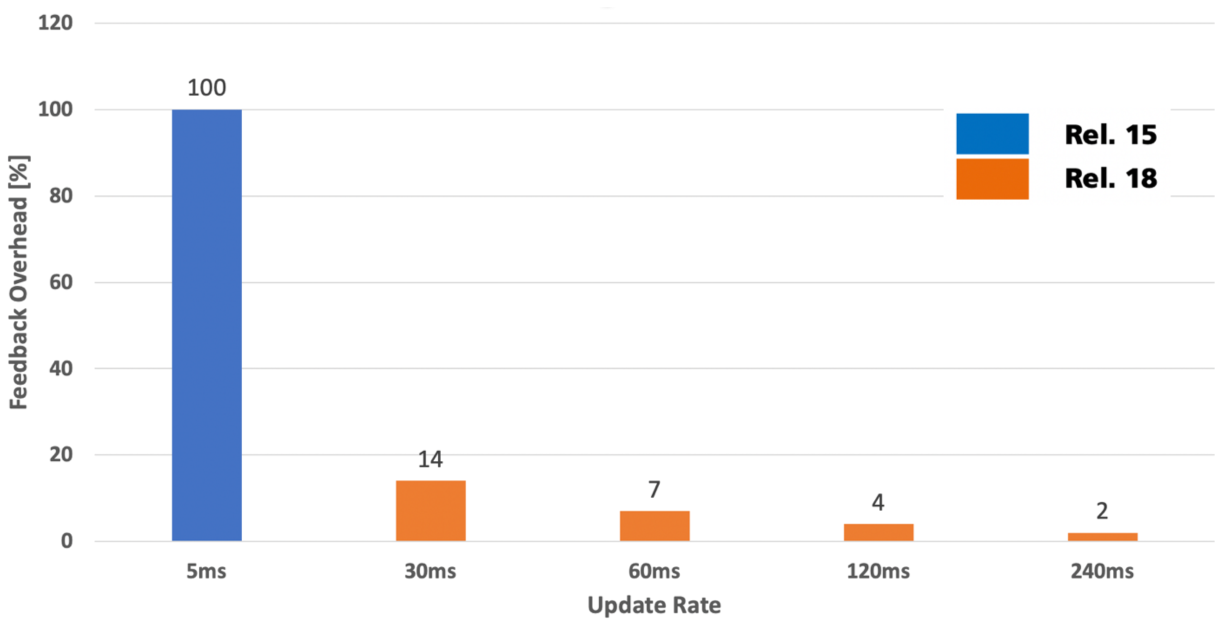


Figure 7: Feedback overhead of the Doppler-delay precoder over the Rel. 15 precoder for CSI update rates 30ms, 60ms, 120ms and 240ms. Reference is the Rel. 15 precoder with CSI update rate of 5ms.

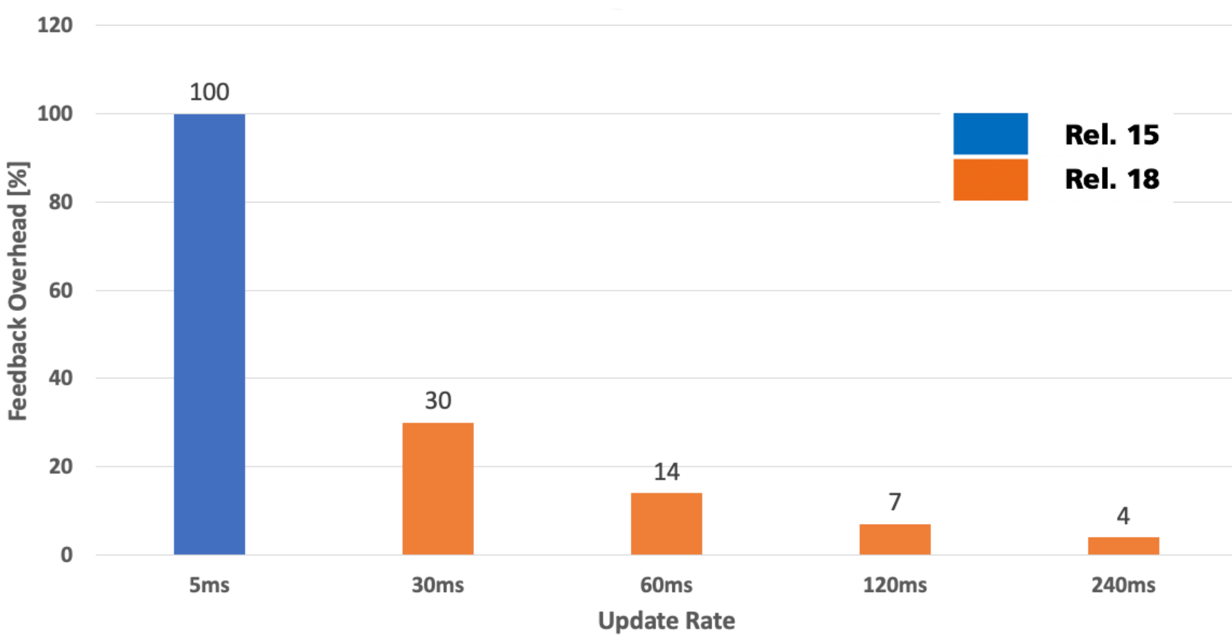


Figure 8: Feedback overhead of the Doppler-delay precoder over the Rel. 15 precoder for CSI update rates 30ms, 60ms, 120ms and 240ms. Reference is the Rel. 15 precoder with CSI update rate of 10ms.

2 Simulation results

Figures 5 to 8 show preliminary simulation results for a Doppler-delay-based CSI reporting scheme. Similar to Rel. 15 and 16, it was assumed that the precoder is based on a linear combination of L spatial beam vectors per polarization. Compared to the Rel. 16 enhanced type-II codebook where the precoder is determined in the delay domain (FD components), the Doppler-delay precoder is calculated in the Doppler-delay domain such that each precoder coefficient is associated with a beam and a Doppler-delay pair. A burst of $N = 4$ CSI-RS resources (see Fig. 3) was used to properly determine the Doppler components of the precoder. For the simulations, a scenario was considered where UEs move with approximatively 20 km/h on a track radial to the base station. Figure 6 shows the performance (rank-1 only) of a Doppler-delay precoder for different CSI update rates (30ms, 60ms, 120ms, 240ms) compared to the Rel. 15 precoder with a CSI update rate of 5ms. The corresponding feedback overhead is shown in Figure 6. Similarly, Figure 7 shows the performance (rank-1 only) of the Doppler-delay precoder for different CSI update rates (30ms, 60ms, 120ms, 240ms) compared to the Rel. 15 precoder with an assumed CSI update rate of 10ms and the corresponding feedback overhead is shown in Figure 8. Here, a CSI update rate of X ms means that the UE calculates and reports the CSI for every X ms. For the Doppler-delay precoder, a total of 8 spatial beams ($L = 4$ per polarization) and 3 precoder coefficients per beam are used resulting in a total of 24 precoder coefficients. From the Figures 6 and 7, it can be observed that the Doppler-delay precoder achieves a significant performance gain compared to the Rel. 15 precoder at a significantly reduced CSI update rate. Moreover, we also clearly see that the feedback overhead is drastically reduced compared to Rel. 15 Type II CSI.

Observation 6: A significant performance gain is observed by Doppler-delay-based CSI reporting over the Rel. 15 type-II CSI reporting with significantly lower CSI update rates.

Observation 7: Doppler-delay precoder needs significantly lower feedback overhead compared to the Rel. 15 precoder.

Based on the above observations, we propose the following.

Proposal 1: Study and specify time-domain CSI compression for Release 18 MIMO.

Time-domain CSI compression for UE mobility scenarios should be considered in Rel. 18 MIMO. The detailed objective is as follows.

- Consider reporting mechanism(s) for CSI overhead reduction and for tackling CSI aging assuming moderate to high speed UEs, mainly targeting FR1

3 Conclusion

Based on the above discussion, we have the following observations and proposals.

Observation 1: For the Rel. 15/16 type-II CSI feedback schemes a performance loss is observed when UEs move already at moderate speeds of 30 km/h.

Observation 2: For the current Rel. 15/16 type-II codebooks, the following is observed in UE mobility scenarios:

- ***Large performance loss is obtained when channel variations are fast and CSI measurement and update rate is not sufficient high,***
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- ***Increased use of UL/DL resources due to frequent PMI measurements and CSI feedback, and***
- ***Increased UE battery consumption.***

Observation 3: The CSI update rate depends on the fast-fading channel variations and a high CSI update rate is required in UE-mobility scenarios where the channel variations are fast, and the channel coherence time is small.

Observation 4: To drastically reduce the CSI feedback rate, the CSI report should contain Doppler or Doppler-delay spectrum-related information of the channel.

Observation 5: When the CSI report contains Doppler or Doppler-delay spectrum-related information, the gNB can perform precoding in the time-domain to compensate for the fast-fading variations of the channel, and

- ***less UL/DL resources are required for CSI measurements and reporting,***
- ***UE complexity and UE battery consumption are reduced, and***
- ***improved performance is expected in fast-fading channels.***

Observation 6: A significant performance gain is observed by Doppler-delay-based CSI reporting over the Rel. 15 type-II CSI reporting with significantly lower CSI update rates.

Observation 7: Doppler-delay precoder needs significantly lower feedback overhead compared to the Rel. 15 precoder.

Proposal 1: Study and specify time-domain CSI compression for Release 18 MIMO.

4 References

[1]. RP-193072, Measurement results on Doppler spectrum for various UE mobility environments and related CSI enhancements, Fraunhofer IIS, Fraunhofer HHI, 3GPP TSG RAN WG#86, Sitges, ES, 09th – 12th December 2019

[2]. RP-191951, Mobility Enhancements for MIMO, Fraunhofer IIS, Fraunhofer HHI, Newport Beach California, USA, September 16 – 19, 2019

[3]. S. Jaeckel, L. Raschkowski, K. Börner, L. Thiele, F. Burkhardt and E. Eberlein, QuaDRiGa – Quasi Deterministic Radio Channel Generator, User Manual and Documentation, Fraunhofer Heinrich Hertz Institute, tech. Rep. v2.4.0, 2020.

Table 1: Simulation parameters

Parameter	Value
Duplex, Waveform	FDD, OFDM
Multiple access	OFDMA
Channel model, and scenario	BERLIN Urban Macro NLOS [3]
Frequency Range and BW	2.6 GHz, 10 MHz
Inter-BS distance	200m
Antenna setup and port layouts at gNB	32 ports: (8,8,2,1,1,2,8), (dH, dV) = (0.5λ, 0.8λ)
BS Tx power	44dBm
BS antenna height	25m
UE antenna height & gain	Follow TS38-901
UE receiver noise figure	9dB
Feedback Delay	4ms