A Preview on MIMO Systems in 5G New Radio

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Abstract. With 3GPP 5G new radio (NR), proposals are already being discussed. Although participants offer various suggestions for the first 5G standardization, common ideas can already be identified. The purpose of the paper is to anticipate, in the context of massive multiple input multiple output (MIMO) systems, the main directions the standard would focus on; for example, a unified transmission scheme, multi-level channel state information (CSI), and non-linear precoding (NLP). The latter, an alternative to linear precoding employed in Long Term Evolution (LTE), is analyzed in detail in the paper.

Keywords: 3GPP · NR · MIMO · CSI-RS · DM-RS · NLP · MRT ZF · THP

1 Introduction

With the approval of the service requirements for the 5G [1], the work for the first 3GPP 5G New Radio (NR) release is now at full speed. To finalize a first version of the standard by March 2018, a major decision was taken in Radio Access Network (RAN) group on the 5G NR workplan (Fig. 1), to have an intermediate non-standalone (NSA) 5G NR mode for the enhanced Mobile Broadband (eMBB) use-case. For NSA-NR, the connection is anchored in Long Term Evolution LTE, while 5G NR carriers are used to boost data-rates and reduce latency. The Standalone (SA) 5G NR mode is estimated in September 2018.

Several scenarios require the support of very high data rates or traffic densities of the 5G system, as part of eMBB use case. They address different service areas, including massive gatherings, broadcast, residential, and high-speed vehicles. As such the focus on multiple input multiple output (MIMO) systems (with a higher number of antennas - massive) to deliver high data rate services, in an energy efficient way with a manageable implementation complexity, is still under full investigation in 5G NR.

When talking about the NR MIMO, the main concepts can be clustered in Unified transmission mode, DM-RS and CSI-RS based transmission schemes, and Non-linear precoding directions.

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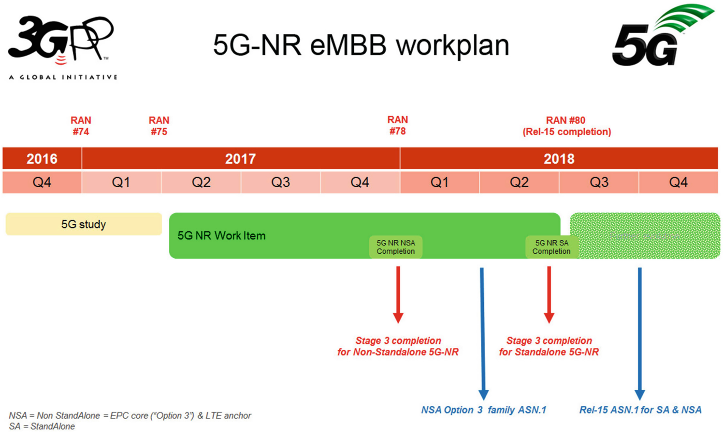

Fig. 1. 3GPP 5G NR workplan.

To address various MIMO proposal for 5G NR, the remainder of this paper is organized into the following sections. Section 2 describes the concepts and motivations behind using a unified MIMO transmission scheme for 5G NR. Section 3 addresses the possibility of using transmission schemes that only require channel estimation with demodulation reference signals (DM-RS) or channel state information reference signals (CSI-RS) in the context of massive number of antennas. Section 4 deals with a proposal of changing the precoding technique to a non-linear one, and as such to address use cases of ill-conditioned channels and correlated inter-user interference. Finally, Sect. 5 presents the research directions for the future work.

2 Unified Transmission Mode

In every release the downlink MIMO has evolved. Due to system design constraints and backward compatibility, each release added just a small enhancement on top of previous specifications. The motivation to design one single transmission mode is to simplify the system design and increase the flexibility to fit different application scenarios. Since the NR shall meet the requirement of diverse use cases and scenarios, one unified and scalable MIMO mode is required [2].

Avoiding of transmission mode handover for different scenarios, reducing standardization efforts, simplifying user equipment (UE) behaviors and related test cases, as well as providing performance benefits over legacy transmission mode, are reasons for designing one unified downlink MIMO framework. The main challenges of a unified transmission mode are the possibility to cover multiple legacy transmission schemes, the enabling transmission scheme switching, the use of DM-RS and setting up the relationship between transmission scheme and type of CSI report.

In legacy LTE system, one transmission mode corresponds to one transmission scheme, hence dynamic switching between some transmission schemes in different transmission modes, like open loop (OL)-MIMO and closed loop (CL)-MIMO), has not been supported.

Although fully dynamic switching within all MIMO transmission schemes may provide scheduling flexibility at the base station (BS) scheduler, it may increase blind decoding complexity and/or control signaling overhead. Therefore, to enable fast transmission scheme switching, it is necessary to specify one mode integrating multiple transmission schemes, to balance between the scheduling flexibility and receiver complexity.

3 DM-RS Based Transmission Schemes

There has been a proposal to design NR MIMO transmission schemes based on DM-RS for a more flexible transmitter design as well as minimizing always-on RS, like common (CRS) [3,4]. To some extent, it is beneficial to design all NR MIMO transmission schemes with DM-RS as it allows tailored DM-RS patterns for each MIMO transmission scheme and for each channel condition. On the other hand, the channel estimation performance is worse than a CRS.

DM-RS will enable the BS to apply different precoding operation transparent to the UE. It will be beneficial to support flexible transmission scheme utilization within one unified MIMO mode, as with DM-RS, UE will be aware of rank indication without additional identification to real signal transmission format. From UE point of view, it will simplify the receiver complexity.

There have been mainly two categories of DM-RS based transmission schemes discussed - transmit diversity and spatial multiplexing.

3.1 Transmit Diversity

DM-RS based transmit diversity is specifically designed for reliable transmission. DM-RS could be UE-specific or shared for transmit diversity. The DM-RS advantages include the use of non-precoded or beamformed DM-RS, both being transparent to UE, or adaptively adjusting beam width and beam direction of DM-RS coverage optimization.

3.2 Spatial Multiplexing

Among the techniques to improve spectral efficiency, the most known one is spatial multiplexing (SM), which includes OL/semi-OL SM scheme and CL spatial multiplexing scheme [5].

To facilitate various use cases such as a wide range of UE speeds, a two-tier precoding-based framework is proposed. Dynamic precoding is analogous to LTE CL MIMO, while semi-dynamic precoding is analogous to OL/semi-OL MIMO proposed in release 14 enhanced full duplex (eFD) MIMO [4].

Semi-dynamic Precoding. denotes a spatial multiplexing scheme that uses cyclic delay diversity or precoder/beam cycling to achieve SM and an extra spatial diversity gain. It is especially applicable when CSI quality is outdated at the base station (for instance, high UE speeds and poor cell isolation, which causes bursty inter-cell interference). In this case, it is more advantageous for the BS to transmit data through a group of directional beams since the UE can only indicate an approximate directional information. For this purpose, precoder (beam) cycling within a group of beams in frequency domain can be employed. This approximate directional information can be reported via Precoding Matrix Indicator (PMI) or other precoding-related feedback, which includes only long-term precoding information.

Dynamic Precoding. is the most effective scheme to improve spectral efficiency, essential to NR data channel transmission. It is applicable when accurate CSI is available at the base station. In this case, the base station can transmit data through a narrow directional beam since accurate directional information is available in the CSI report. This directional information can be reported via PMI or other precoding-related feedback, which includes both long-term and short-term precoding information. It is worth noting that long-term CSI is beneficial to reduce the channel spatial dimension for CL spatial multiplexing transmission, thereby reducing CSI-RS and reporting overhead for massive MIMO transmission in NR. Analogous to LTE, short-term precoding information can be reported as a wideband or sub-band CSI parameter. This facilitates frequency-selective precoding.

Unified CSI Reporting. In legacy LTE system, different transmission modes use a different CSI feedback mode. The NR MIMO operation needs to be more flexible, for example, one transmission mode could operate with multiple feedback modes corresponding to different transmission schemes.

Each CSI mode could corresponds to one channel quality indicator (CQI) hypothesis and one CSI feedback accuracy. In order to simplify the design, for an unified CSI report, different CSIs will share the same feedback framework, with specific parameters configuration. For example, depending on the use case, a UE may be configured to measure CSI of a broader (uncompressed) or narrower (compressed) propagating channel. OL transmission required robust CQI feedback and rough CSI acquisition.

A first CSI type, coverage CSI-RS is proposed, where each resource corresponds to a the static macro (coverage) beam. The use cases of coverage CSI-RS are the combination of use cases of release 13 non-precoded CSI-RS and cell-specific beamformed (BF)CSI-RS. In CL transmission, the UE zooms into a smaller part of the channel. As such, the BS can increase CSI-RS penetration by beamforming and generate CSI-RS with a much smaller number of ports. The second type of CSI-RS, analogous to release 13 UE-specific BF CSI-RS, is named UE-specific CSI-RS [6,7].

4 Non-linear Precoding

Linear precoding (LP) scheme is a conventional approach to realize multi-user (MU) MIMO. Block diagonalization (BD) is a well-known technique to create prescribed nulls for UEs except for the target UE and to mitigate inter-user interference (IUI). BD works well in a spatially-uncorrelated scenario and simplifies receiver designs. However, by consuming degrees of freedom in MIMO systems to cancel interference, a tradeoff between interference mitigation and achievable spatial diversity arises. Moreover, IUI mitigation performance of LP degrades considerably in ill-conditioned or spatially-correlated channels, resulting limited throughput [8].

Figure 2 shows how the spatial correlation and imperfect CSI limits the downlink throughput performance of the linear precoded TDD systems, assuming 80% of resources used for downlink. In case of the imperfect CSI feedback, Additive White Gaussian Noise (AWGN) with –20dB power is added to CSI. The equations that model the simulated system can be found in [9].

Alternatively, non-linear precoding (NLP) achieves near-capacity and establishes robust links over MU-MIMO donwlink transmission even in spatially-correlated or ill-conditioned channels. On the other hand, thanks to interference removal at the transmitter (TX), NLP yields throughput gain even with imperfect CSI feedback [10].

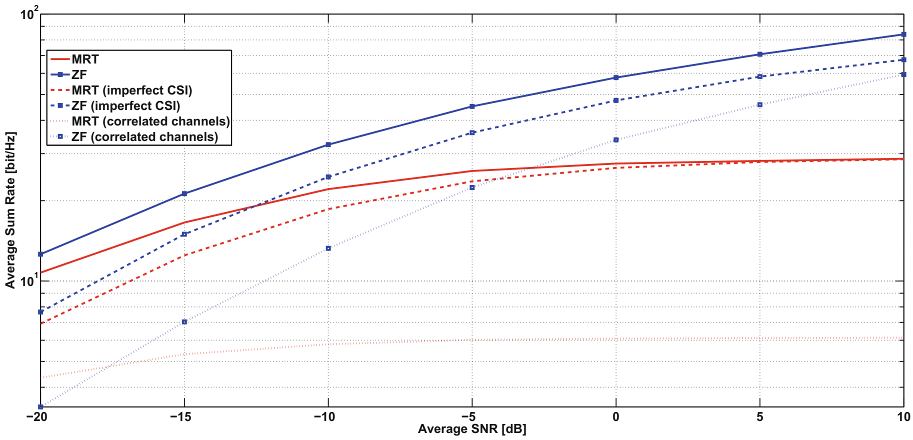

Fig. 2. MU-MIMO Maximum Ratio Transmitter (MRT) and Zero Forcing (ZF) linear precoders performance with 100 TX Antennas and 10 users.

In a typical NLP scheme, a combination of feedforward and feedback functionalities at TX is required, where the former is LP, and the latter is realized by IUI-precancellation (PC). Unitary matrix based LP can easily be realized by block triangulation (BT) [11,12]. Subsequently, NLP can be used to cancel IUI in the processed signal. Using a combination of LP and NLP spatial diversity, a IUI-free signal can be obtained simultaneously.

To realize low peak-to-average-power-ratio (PAPR) IUI cancellation at TX, a modulo operation is a well-known method to compress signal constellation at IUI-PC output. This configuration is generally known as Tomlinson-Harashima precoding (THP) [13,14].

5 Conclusion and Future Work

Although the two 5G NR directions are quite challenging, the non-linear precoding attracted particularly our attention. In the perspective of the massive MU-MIMO approach, the challenges would be to limit the computational burden as well as the overhead required for the channel estimation, in time division duplex (TDD) and frequency division duplex (FDD) systems, and CSI feedback (FDD).

To reduce the complexity of the precoding operations, hybrid non-linear precoding schemes, where non-linear IUI is canceled within the same group, are possible alternatives. How to optimize the user-grouping, to balance between performance loss and complexity reduction, requires further investigation.

In terms of reducing the CSI feedback and the overhead of the reference signals, it turns out that the performance of both LP and NLP schemes is affected by imperfect CSI estimation. This can be caused by rapid changing channel conditions, an insufficient resolution of reference signals or CSI feedback inaccuracy. Reducing the reference signals and feedback information is an essential approach in massive MIMO context.

The last aspect of NLP are the design of the reference signals used to estimate the channel in FDD [in TDD the BS estimates the channel trough reciprocity using the uplink sounding reference signals (SRS); both long and short term CSI can be obtained through SRS]. Although it was previously suggested to rely on DM-RS, as the precoding operation was transparent to the UE and interference for other UEs could have been estimated trough DM-RS assigned to different ports, it turns out that the NLP is not transparent for the UE. Using NLP signals, estimation of the channel or interference is not straightforward. Modulo operation is needed at the receiver for optimal demodulation of NLP signals, so the transmitter needs to signal the precoding type to UE.

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