Unified Beam Management

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Ofinno • ofinno.com • September 2021

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Abstract
Beam management has been one of the key enabling technologies employed in 5G new radio (NR) systems. This article discusses how the beam management mechanisms in 5G NR have been evolved, the current paradigm shift toward unified/common beam management, and other application scenarios jointly, to be optimized with the common beam management technology in Rel-17 and beyond.

Introduction

Frequency range 2 (FR2), as shown in FIG. 1, is where the beam management is generally regarded as an essential technology in 5G NR systems, while FR1 has similar spectrum bands as 4G long-term evolution (LTE) in most operation scenarios which may not use the beam management mechanisms.

In 4G LTE systems and similarly for FR1 in NR, a spatial domain control for efficient communications between a base station (BS) and a user equipment (UE) has been mainly based on digital-domain precoding techniques. A DL/UL codebook may be used in selecting a preferred precoding matrix from the codebook, which is applied to transmission of a signal having a directivity to a certain intended direction. This directivity can be efficiently managed by the BS thanks to its digital-domain processing before transmission of the signal, which is often managed by dynamic signaling via DCI and/or MAC-CE. The directivity can be toward any direction among an omni-directional spatial area depending on the transmitter's antenna structure.

In 5G FR2, however, due to its channel characteristics including a severe path loss that a transmitted signal experiences, more focused spatial domain control and narrower spatial domain area formed by the transmitter have been necessary. One efficient technology that has been regarded as utilizing analog-domain beam control techniques which is often referred to as the beam management employed in 5G NR systems. In general, the analog-domain beam control is based on phase shifters, which may be employed at both the BS and the UE. The digital-domain precoding matrix may be also used, which is known as a hybrid beamforming technique when combined with the analog-domain beam management, as illustrated in FIG. 2 [2].

Per-Channel Individual Beam Indication Framework

The beam management in 5G DL has been employing a so-called transmission configuration indication (TCI) signaling framework where a beam for a target channel/signal (e.g., PDSCH, PDCCH, CSI-RS) to be received by the UE can be indicated by a TCI. The TCI consists of a source reference signal (RS) and an intended quasi co-location (QCL) type to be applied. For example, the BS can signal a DCI scheduling a PDSCH to the UE, where the DCI can select a TCI to

Frequency range designation	Corresponding frequency range
FR1	410 MHz – 7125 MHz
FR2	24250 MHz – 52600 MHz

FIG. 1: Definition of frequency ranges in 5G NR [1].

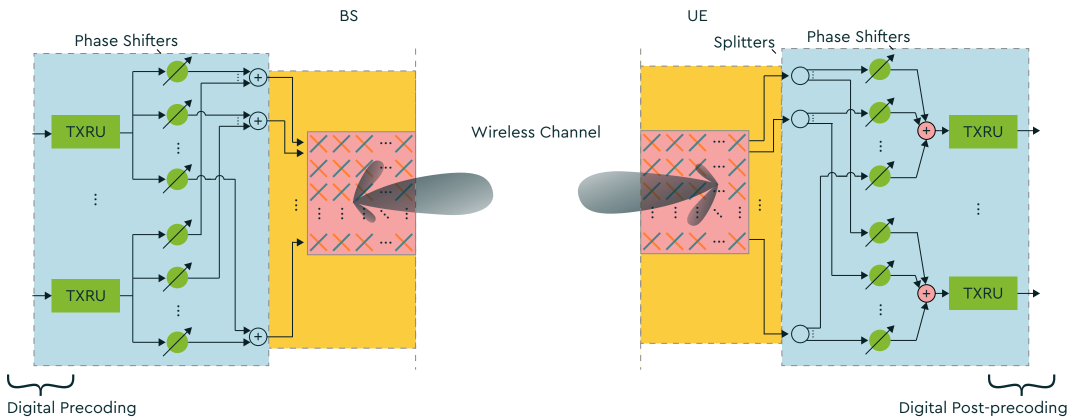

FIG. 2: An illustration on hybrid beam-forming system in 5G [2].

be used for reception of the PDSCH. Then, the UE can set its analog beamforming coefficients based on the indicated TCI for receiving the PDSCH. Since the indicated TCI is intended only for the PDSCH reception in this case, it can be regarded as the individual TCI framework. For PDCCH (or CSI-RS), a separate signaling is defined and used for such a beam indication, independently of the case of PDSCH.

FIG. 3 shows illustrations on how to construct per-channel individual TCI framework [3]. The PDSCH can be a target channel to be received by the UE, where a TCI can be indicated and contains a source RS as the CSI-RS (CSI) and a QCL type as Doppler shift/spread and Delay avg/spread, illustrated by an arrow in FIG. 3. It is assumed the CSI-RS (CSI) has been already measured by the UE, where another TCI configured for the measurement of the CSI-RS (CSI) may also be separately given to the UE to help the measurement efficiently. The source RS in this case can be the CSI-RS (TRS) and a QCL type can also be selected, as either Type A or Type B, depending on the BS's efficient operational strategy.

This individual per-channel beam indication framework has been a consistent design basis even for cases of UL. For example, the BS can signal a DCI scheduling a PUSCH to the UE, where the DCI can select a sounding reference signal resource indicator (SRI) to be used for transmission of the PUSCH. Then, the UE can set its analog beamforming coefficients based on the indicated SRI for transmitting the

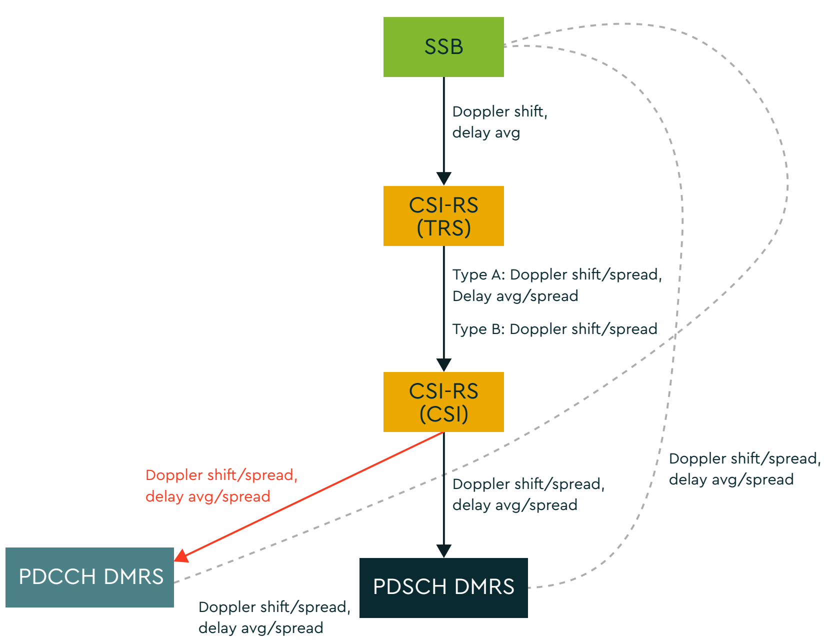

FIG. 3: Illustrations on how to construct per-channel individual TCI framework [3].

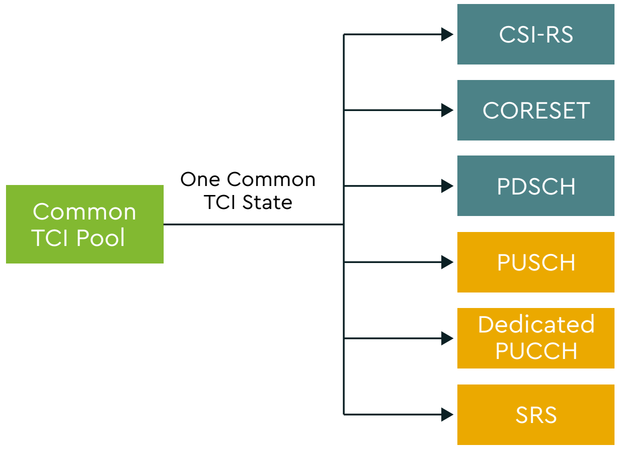

FIG. 4: Unified/Common beam associations in Rel-17 [5].

PUSCH. For PUCCH, a separate signaling based on a parameter of spatial-relation-info is defined and used for such a beam indication, independently of the case of PUSCH.

Unified/Common Beam Management Technology

Although the individual per-channel beam indication framework has been regarded as being efficient and flexible as the BS can set and signal any independent beam reference per channel, the overall signaling overhead to control every target channel with a proper beam indication could be unnecessarily large in some cases. In a practical FR2 operation scenario, for example, the BS may utilize one or a few beam directions to efficiently communicate with the UE. Even for such a case, the BS has to set all individual communication channels, each with a beam indication referring mostly to the same beam reference. To overcome this drawback, Rel-17 WI on MIMO [4] includes a topic for enhancements on multi-beam operation employing so-called "common beam" for data and control transmission/reception for DL and UL.

Common beam indication applicable to multiple DL/UL channels: It is presented that a common beam may be associated with multiple channels/signals in Rel-17 [5]. In FIG. 4, it is illustrated that a common beam (a.k.a. TCI state) can be indicated among one unified common TCI pool pre-configured by a higher-layer signaling. Once a common TCI state is indicated to be used, it can be used for not a particular channel, but for multiple channels/signals simultaneously, which significantly reduces the signal overhead and latency. For example, the common TCI state may be commonly applied for a CSI-RS, a CORESET, and a PDSCH. The common beam may also be applied for uplink channels/signals, e.g., a PUSCH, a dedicated PUCCH, and an SRS, depending on the BS's pre-configuration on the applicable list of channels/signals.

Joint TCI state pool or separate TCI state pool: The BS may configure a joint TCI state pool by RRC signaling, in which a common TCI state can be indicated to be applied for multiple DL/UL channels jointly as shown in FIG. 4. Or, a common TCI state may only be applicable to either DL channels or UL channels, if the BS configures separated DL TCI

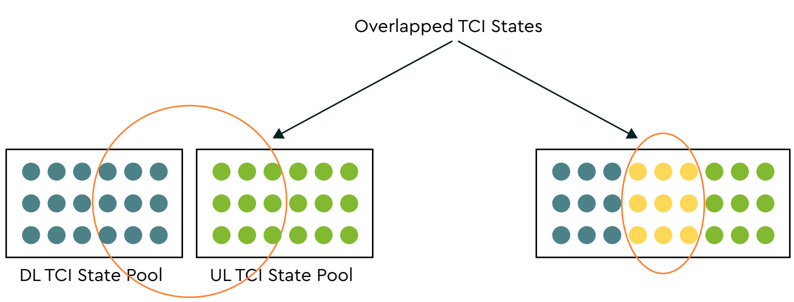

FIG. 5: Illustration of separate and joint TCI state pools for DL and UL [6].

state pool and UL TCI state pool, as illustrated in FIG. 5 [6]. Rel-17 supports both the joint TCI state pool mechanism and the separate TCI state pool mechanism. The joint TCI state pool mechanism has benefits in efficiency of the common beam management especially when there are overlapped TCI states to be intended for use of both DL and UL, as shown in FIG. 5. The separate TCI state pool mechanism has benefits to simplify UE behaviors in that only TCI states in the UL TCI state pool can be further associated with additional parameters for UL such as power control parameters, and the UE can only be tracking the power control process regarding TCI states only in the UL TCI state pool.

Simultaneous common beam update across CCs: BS may configure to apply an indicated common beam to multiple CCs/BWPs simultaneously to further reduce the signaling overhead. The BS may configure TCI state pool(s) for each CC/BWP independently. Then, once the common beam with a TCI state ID indicated via a CC/BWP, the same TCI state ID is regarded as being indicated as well for other CCs/BWPs, which reduces the signaling overhead for the other CCs/BWPs. In another mechanism, the BS may only configure TCI state pool(s) for a reference CC/BWP, and may not configure TCI state pool(s) for other CCs/BWPs. When a common beam is indicated for a CC/BWP which is not the reference CC/BWP, the common beam referred from the reference CC/BWP is to be applied simultaneously for multiple CCs/BWPs including the reference CC/BWP. This can further reduce the signaling overhead by skipping configuration of TCI state pool(s) for CCs/BWPs other than the reference CC/BWP.

Further Use Cases With The Common Beam Management

Application to multi-TRP scenarios: As discussed above, unified/common beam management technology can significantly reduce signaling overhead and latency in multi-beam operations. However, if the indicated common beam is indeed blocked by an obstacle, a.k.a. beam blockage event, a large performance reduction may occur, depending on wireless channel conditions. If multi-TRP scenario is taken into account together, the common beam management mechanism may well work more efficiently and reliably. FIG. 6 shows illustration of the beam blockage issue in multi-TRP scenario [7].

TRP 1 and TRP 2 may employ unified/common beam management, where beam k1 from TRP 1 for UE1 may be indicated as a common beam to be applied for multiple channels/signals, instead of using other beams from TRP 1. At the same time, beam k2 from TRP 2 for UE1 may be indicated as a common beam to be applied for multiple channels/signals, instead of using other beams from TRP 2, assuming the beam k2 is not currently blocked by the obstacle. When the beam k2 is being blocked by the building as UE1 moves, the beam k1 from TRP1 may still be alive as the common beam used by TRP 1, and the communication link between TRP 1 and UE1 may still work, while TRP 2 changes its common beam to a different beam. This benefit in terms of reliability

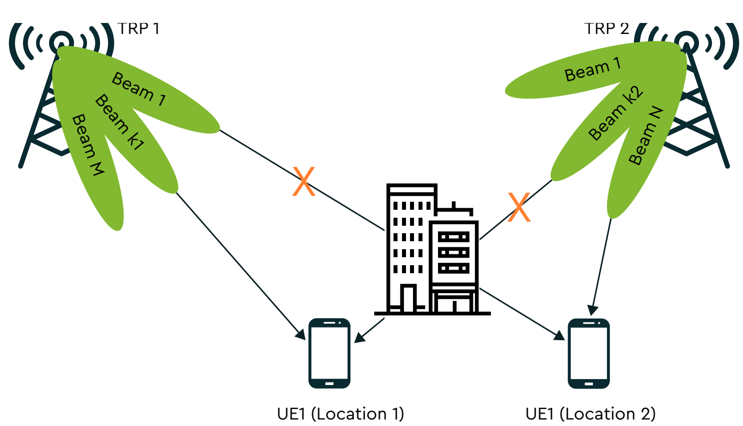

FIG. 6: Illustration of beam blocking issue in multi-TRP scenario [7].

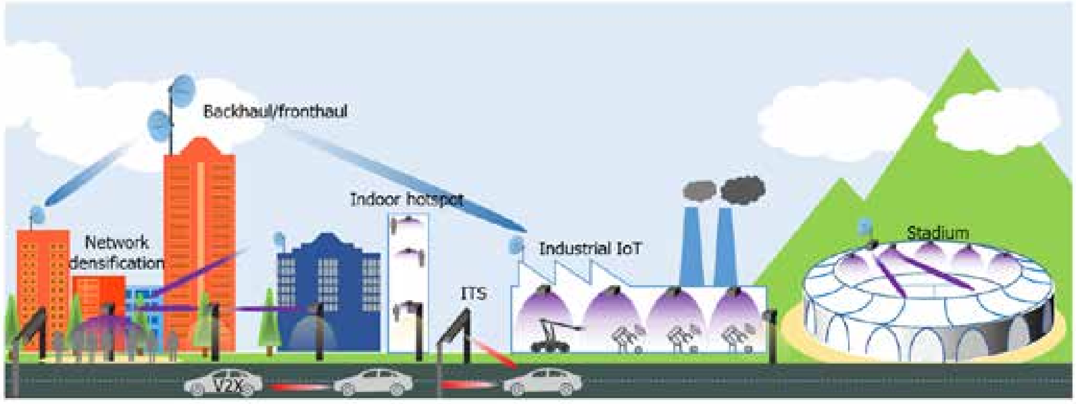

FIG. 7: Use cases for NR above 52.6 GHz [9].

comes from the multi-TRP operation, also with reduced control signaling overhead based on the common beam management mechanism.

Application to higher frequency band: As another ongoing WI on extending current NR operation to 71 GHz in Rel-17 [8], frequencies above 52.6 GHz to 71 GHz are faced with more challenges, such as higher phase noise, larger propagation loss due to high atmospheric absorption, lower power amplifier efficiency, and strong power spectral density regulatory requirements in unlicensed bands, compared to lower frequency bands. Additionally, the frequency ranges above 52.6 GHz potentially contain larger spectrum allocations and larger bandwidths that are not available for bands lower than 52.6 GHz. The potential use cases identified include high data rate enhanced mobile broadband (eMBB), mobile data offloading, short-range high-data rate D2D communications, broadband distribution networks, integrated access backhaul (IAB), factory automation, industrial IoT, wireless display transfer, AR/VR wearables, intelligent transport systems (ITS), vehicle-to-everything (V2X), data center inter-rack connectivity, smart grid automation, private networks, and support of high positioning accuracy [9].

The use cases span over several deployment scenarios, including indoor hotspot, dense urban, urban micro, urban macro, rural, Hall factor, and indoor D2D scenarios. As this WI aims to extend current NR operation, it is critical how to efficiently accommodate beam management aspects into such a high frequency above 52.6 GHz. Considering many use cases requiring low complexity and simplified controlling mechanisms, the unified/common beam management technology needs to be applicable in these scenarios, which have been identified during discussions under the WI and will be further discussed after stabilizing the common beam mechanism details.

Conclusion

Rel-15/16 NR employs per-channel individual beam management framework, which provides sufficient benefits in terms of beam control flexibility. BS can manage its beam control with high-granularity for each target channel/signal for DL and UL, based on separated beam indication mechanism with various different beam control parameters. Rel-17 WI on MIMO considers enhancements toward unified beam management mechanism using a common beam indication across multiple channels/signals for DL and/or UL. Both approaches of joint TCI state pool and separate TCI state pool have been agreed to be supported as either one of them has a pros and cons in terms of flexibility and complexity. The unified/common beam management technology brings significant overhead reduction in beam management and it is to be further applicable to other technical areas such as multi-TRP scenarios and various use cases in higher frequency bands above 52.6 GHz.

Acronym List

3GPP	3rd Generation Partnership Project
4G	Fourth Generation
5G	Fifth Generation
LTE	Long Term Evolution
NR	New Radio
FR	Frequency Range
BS	Base Station
UE	User Equipment
DL	Downlink
UL	Uplink
DCI	Downlink Control Information
MAC-CE	Medium Access Control – Control Element
TXRU	Transceiver Unit
TCI	Transmission Configuration Indication
PDSCH	Physical Downlink Shared Channel
PDCCH	Physical Downlink Control Channel
CSI-RS	Channel State Information – Reference Signal
QCL	Quasi Co-Location
SSB	Synchronization Signal Block
TRS	Tracking Reference Signal
DMRS	De-Modulation Reference Signal
PUSCH	Physical Uplink Shared Channel
PUCCH	Physical Uplink Control Channel
SRI	Sounding Reference Signal Resource Indicator
WI	Work Item
MIMO	Multiple Input Multiple Output
CORESET	Control Resource Set
SRS	Sounding Reference Signal
CC	Component Carrier
BWP	Bandwidth Part
RP	Transmission and Reception Point
GHz	Gigahertz
eMBB	Enhanced Mobile Broadband
D2D	Device-to-Device
IAB	Integrated Access Backhaul
IoT	Internet of Things
AR	Augmented Reality
VR	Virtual Reality
ITS	Intelligent Transport Systems
V2X	Vehicle-to-Everything

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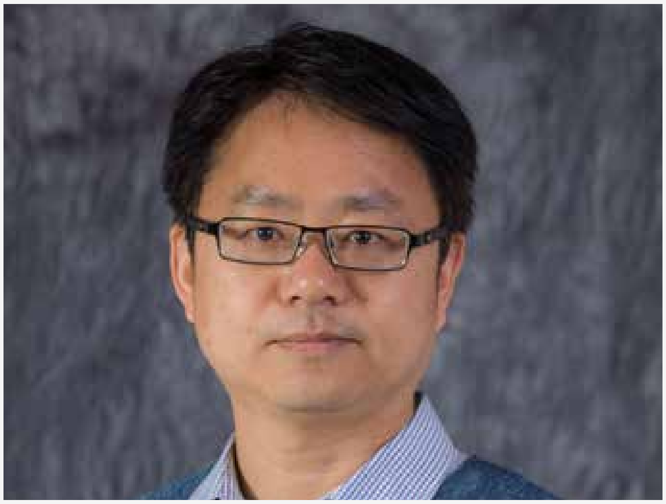

About the Author:

Hua's research areas cover radio access network technologies/ procedures for IEEE 802.16, LTE Advanced, LTE Advanced Pro, and New Radio for 5G. Prior to working for Ofinno, he held a research expert position at Fujitsu and participated in IEEE and 3GPP standardization activities. He is an inventor of more than 300 US patents on wireless communications. He received his Ph.D. in communication and information systems from Beijing University of Posts and Telecommunications.

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