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Source: **Ericsson**
Title: **On spatial QCL definition**
Agenda Item: **5.1.2.3.5**
Document for: **Discussion and Decision**

1 Introduction

With respect to QCL definitions, there has been some agreements the last two meeting, where the highlights are listed here

- QCL is defined as follows:
  - Two antenna ports are said to be quasi co-located if properties of the channel over which a symbol on one antenna port is conveyed can be inferred from the channel over which a symbol on the other antenna port is conveyed.

- All physical channels and reference signals in NR are transmitted using antenna ports
- All QCL assumptions that a UE is allowed to make among antenna ports should be identified and explicitly specified

- Parameters for antenna port QCL in NR includes at least (if QCL is supported)
  - Average gain, average delay, delay spread, Doppler shift and Doppler spread (same as in LTE)
- QCL framework in NR is extended with new spatial QCL parameter(s) to support UE side beamforming/receiving procedure
  - FFS details (e.g., receive angle of arrival, transmit angle of departure, spatial correlation of receiver antennas, Rx/Tx beamforming, etc.)
- For DM-RS antenna ports, NR supports:
  - All ports are QCL-ed
  - Not all ports are QCL-ed
- Flexible configuration/indication of the QCL assumption should be studied in NR:
  - Possible grouping of the QCL parameters should be studied:
    - e.g., average gain, average delay
    - e.g., angle of arrival/ departure, delay spread, Doppler spread

Working assumption:

- Spatial parameter(s) for QCL in NR describes the spatial channel properties of the RS antenna ports observed at the receiver.
- FFS: Spatial parameter(s) in NR also describes the spatial channel properties of the antenna ports at transmitter(s).
  - Support UE reporting for related information, if necessary

In this contribution we elaborate on the QCL definition in NR and we have a related contribution on port coherency regions in [3]. Then we continue with a discussion on possible improvements/extensions to quasi co-location assumptions in NR.

2 Discussion

2.1 On QCL in NR

Following the discussion on port definitions in [3], the notion of quasi co-location in NR should also capture the effects of precoded or beamformed signals. Two antenna ports are said to be quasi co-located (QCL) if large scale

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properties of the channel over which a symbol on one antenna port is conveyed can be inferred from the channel over which a symbol on the other antenna port is conveyed.

Often, QCL does not apply to antenna ports mapping to different TRPs. Possible exceptions to this rule are SFN type of transmissions. Considering beam based operation it is also not possible to assume QCL per default even when antenna ports map to the same TRP, as effective channels in different beam spaces may look very different. Beamforming may for example impact the average gain or delay spread of an effective channel.

Observation 1 Antenna ports mapping to the same transmission points are not necessarily QCL.

Similarly, as the precoder of a precoded antenna port may change on a port coherency transition event, an antenna port is not necessarily QCL with itself across different port coherency regions, but two sets of antenna ports may have port coherency regions that are mutually QCL, for instance if the precoder of the ports in the two coherency regions match.

Observation 2 An antenna port is not necessarily QCL with itself across different port coherency regions.

Observation 3 A port coherency region for one antenna port can be QCL with another port coherency region for another antenna port.

With these observations it becomes evident that QCL is not something that can be assumed per default, it is a relation between port coherency regions that must be signaled to the receiving node or known a-priori through specification.

Proposal 1 Refine the definition of QCL to capture the effects of port coherency regions.

This proposal is needed since it is evident that antenna ports alone is not sufficient to describe QCL relations**.**

2.2 QCL properties for NR

Beam management includes various forms of beam sweeping. A transmitter may repeatedly transmit a precoded reference signal to facilitate a receiving node to sweep and identify an optimal receiver beam. The UE can then use the optimized receiver beam for a later reception of a signal transmitted with the same precoder. For this to work, a mechanism and a specification language is needed to indicate to a UE that two reference signals are transmitted with the same precoder, i.e. beamformed 'in the same way'.

Observation 4 The receiver may use the information that two different signals are transmitted from the same TRP with similar precoding to improve receiver processing, especially for analog reception.

Quasi co-location is a natural way to describe the relation between the two different signals originating from the same TRP and using the same precoder. The piece that is missing is a channel property that can be used by the receiver to allow for improved receiver processing. Clearly the channel property must capture some sort of spatial distribution as it will be used for spatial receiver filtering. As an example, the UE should be able to assume it can use the same analog receive beam when receiving the two different signals using this property. This was a common understanding among companies at meeting #86bis and it lead to the agreement:

- *QCL framework in NR is extended with new spatial QCL parameter(s) to support UE side beamforming/receiving procedure*
    - *FFS details (e.g., receive angle of arrival, transmit angle of departure, spatial correlation of receiver antennas, Rx/Tx beamforming, etc.)*

In a way forward [1], two options were presented on how to capture the spatial QCL properties:

- Option A: Receive angle of arrival (exact wording is FFS)
- Option B: Spatial correlation

While in another way forward [2], a proposal similar to Option A was proposed

- Angle of arrival/departure, angular spread

First order moments of channel realizations, such as amplitude and phase, are most likely too detailed and unpredictable to be used as QCL parameters. Parameters describing angle of arrival distribution parameters such as

mean angle and angle spread are also not suitable as non-straightforward estimation algorithms capturing arbitrary receiver antenna arrays and multi-path would be needed to accompany such QCL parameters.

In non-LOS channels with multiple scattering clusters with comparable strength there will by multiple angle of arrivals, and there is not a unique definition of angle of arrival. For instance, how do you measure angle of arrival in the case of two well separated, equally strong multipath components? Is it the average of the angles? Does it make sense to point a receive beam in that direction?

Moreover, in the case of non-ULA/non-Uniform Planar Array antennas, which will be the case for terminals with multiple receive antennas, how to define the beams forming main-lobes in angles and with specific spread in this case? These are problems associated with the angle of arrival definition for QCL.

One may argue that 3GPP will not need to define such estimation algorithm anyway since it will not be specified and we have not defined corresponding algorithms for the other parameters. However, our view is that we should not base QCL framework on parameters that is not obvious and that we don't understand how to estimate in principle. For the other parameters (average gain, average delay, delay spread, Doppler shift and Doppler spread) there is an established method for these estimators.

Moreover, angle of arrival is a fast fading property, and some averaging is needed.

Observation 5 Angle of arrival and angular spread are unsuitable as spatial QCL parameters

On the other hand, second order statistics between antenna ports are simple and straightforward to estimate. The method to estimate a spatial correlation matrix is well known and the method is independent of how antennas are placed relative to each other. The same estimation algorithm is used irrespectively of whether the channel is LOS with a dominant path or rich scattering around the UE with many different simultaneous angle of arrivals.

For receiver purposes it is often sufficient to use QCL assumption with respect to receiver side correlation of the channel. Using such second order statistics automatically includes the averaging, by definition.

Observation 6 Second order channel statistics is a well suited candidate for spatial QCL properties

Proposal 2 Support QCL with respect to receiver side channel correlation to the list of QCL parameters

QCL with respect to channel correlation can also be useful for applications where the UE is expected to estimate a channel based on a reference signal with many ports, e.g., a non-precoded CSI-RS type of reference signal. Assuming the UE knows that a non-precoded CSI-RS is QCL with respect to channel correlation to a previously transmitted non-precoded CSI-RS (possibly with a higher pilot density), then it may use spatial channel correlations obtained from the previously transmitted CSI-RS to acquire spatial processing gain.

Proposal 3 Consider adding QCL with respect to transmitter side channel correlation, or QCL with respect to spatial channel correlation in general.

2.3 Reciprocal QCL

For nodes that have reciprocity-calibrated transmitter and receiver chains it may be useful to know when a signal that will be received is the reciprocal response to another signal that was transmitted earlier. That is, assuming a node with analog beamforming is transmitting a sounding reference signal with some analog beam. When receiving a response to the sounding it could expect the response to arrive through the reciprocal channel, for which the receiver beam could favorably be the same beam as was used for the reciprocal transmission.

The QCL framework could be extended to also cover the use case of reciprocal responses for analog beamforming by defining the received signal to be *reciprocally quasi co-located* with the transmitted signal.

Proposal 4 Consider introducing the notion of reciprocally quasi co-located signals to handle the case of reception of reciprocal responses to previous sounding for analog beamforming.

2.4 QCL and Sidelink

Differently from LTE, NR is expected to provide native support for sidelink (SL). Another difference compared to LTE is that MIMO capabilities are expected to be relevant also for SL in NR. The transmitter/receiver spatial

processing used for sidelink is expected to be similar if not identical to the one used for the cellular interface, therefore we believe that the QCL framework should include SL ports.

A notable difference is that some devices may synchronize to a non-3GPP synchronization source (e.g., GNSS), which is a likely scenario, e.g., for V2X. In this case it is useful to enable configurable QCL at least with respect to received timing and Doppler shift between NR ports and GNSS.

A further observation (which does not necessarily have impact in specifications) is that sidelink ports are not necessarily associated to a "UE ID". Consider for example sidelink reference signals (SLSS in LTE) and associated broadcast control channel transmissions (PSBCH in LTE) which are broadcasted in SFN fashion by multiple UEs. In this case the QCL assumptions would refer to certain antenna ports which are not associated to unique UE ID and possibly not even to a cell ID.

Proposal 5 **Sidelink antenna ports are included in the QCL framework.**

Proposal 6 **Consider including external synchronization references such as GNSS for QCL with respect to timing and frequency shift.**

3 Conclusions

In this contribution we made the following observations:

Observation 1 **Antenna ports mapping to the same transmission points are not necessarily QCL.**

Observation 2 **An antenna port is not necessarily QCL with itself across different port coherency regions.**

Observation 3 **A port coherency region for one antenna port can be QCL with another port coherency region for another antenna port.**

Observation 4 **The receiver may use the information that two different signals are transmitted from the same TRP with similar precoding to improve receiver processing, especially for analog reception.**

Observation 5 **Angle of arrival and angular spread are unsuitable as spatial QCL parameters**

Observation 6 **Second order channel statistics is a well suited candidate for spatial QCL properties**

Based on the discussion in this contribution we propose the following:

Proposal 1 **Refine the definition of QCL to capture the effects of port coherency regions.**

Proposal 2 **Support QCL with respect to receiver side channel correlation to the list of QCL parameters**

Proposal 3 **Consider adding QCL with respect to transmitter side channel correlation, or QCL with respect to spatial channel correlation in general.**

Proposal 4 **Consider introducing the notion of reciprocally quasi co-located signals to handle the case of reception of reciprocal responses to previous sounding for analog beamforming.**

Proposal 5 **Sidelink antenna ports are included in the QCL framework.**

Proposal 6 **Consider including external synchronization references such as GNSS for QCL with respect to timing and frequency shift.**

4 References

[1] R1-1610520, "WF on the QCL for NR" , Intel, LGE, Ericsson, NTT DOCOMO, Samsung

[2] R1-1610513,"Way Forward on QCL for NR", ZTE Corporation, ZTE Microelectronics, Qualcomm
[3] R1-1700852, "Introducing port coherency regions", Ericsson