List of Abbreviations

OFDMA	Orthogonal Frequency Division Multiple Access
PRB	Physical Resource Block
RB	Resource Block
SE	Spectral Efficiency
SRS	Sounding Reference Signal

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Literature Review

Contents

1.1 5G Physical layer

The length of the RB in time is called the Transmission Time Interval (TTI). It is also considered to be the minimum division to perform operations.

5G uses Orthogonal Frequency Division Multiple Access (OFDMA) to multiplex access to different UEs simultaneously. OFDMA works by. . . 12 subcarriers, 14 symbols. The symbol duration is inversely *equal* to the subcarrier spacing. But some guard time is used too, so that is not completely the case. In table REF are the different numerologies, or subcarrier spacings/bandwidths, and respective symbol and slot durations in 5G. A slot always has 14 symbols and we call a Physical Resource Block (PRB) to 12 subcarriers used for a slot's duration.

put table with numerologies, symbol and slot time

1/B = symbol time = slot time =

What spectrum bands? What are frequency ranges, and the numerologies allowed in them...

The codebook-based beamforming mentioned in Section **??** is CSI-RS-based.

The non-codebook-based beamforming SRS-based.

1.1.1 Why mmWave?

30 GHz (1cm) to 300 GHz(1mm), but 20-30 in a loose sense is included too.

- Spectrum available: Hundreds of MHz below 6 GHz vs Tens of GHz in mmWaves;

1.1.2 Massive MIMO

When the small-scale fading between antenna elements is sufficiently uncorrelated, which is the case when AEs in arrays are separated more than half-wavelength, then the channel will tend to a deterministic state as the number of AEs increases in BSs or terminals. This happens because the more diversity there is in the channel, the less relevant the big oscillations become because all oscillations average out . This effect is called channel hardening [1].

One is associated with SRS and the other with CSI-RS-based operation.

Massive MIMO assumes 10x more antennas than users because that way, statistically speaking, it is possible to have independent paths to all users simultaneously. However, that may not lead to the best Spectral Efficiency (SE) [2], proving the relevance of modelling real scenarios. This is especially true when deriving realizable metrics for an application.

Increasing the number of antennas in the UE will provide considerably more flexibility, although making the SRS approach quickly impractical.

Multi-layer transmission

Also in this area 3GPP has left room for interpretation providing more flexibility for manufacturers' implementation.

It is important to understand how orthogonal data streams (or layers, the terms will be used interchangeably) can be transmitted with no significant interference between them. This mechanism is fundamentally different in implicit and explicit beamforming.

When the beams are not previously defined (implicit beamforming), the precoders are computed from the channel matrix H, through, essentially, matrix operations (See Appendix **??** for examples). This leads to an implicit treatment of different propagation paths and distinct polarisations. Not only one can't proceed this way with a codebook-based approach, but also there are gains to be had when a explicit polarisation separation is done on the BS side.

The antennas in a BS are cross-polarised [3] which means the BS is capable of transmitting orthogonal polarisations. This offers a degree of freedom and does not limit the number of layers to two. In order to send multiple streams it is necessary to use either different polarisations or choose distinct paths. Note that when we refer to polarisations, we are referring to all elements oriented the same way in the antenna array. Figure 1.1 differentiates the single polarised in two colours: all elements making +45°with the vertical are in red, and all elements making -45 °with the vertical are in blue.

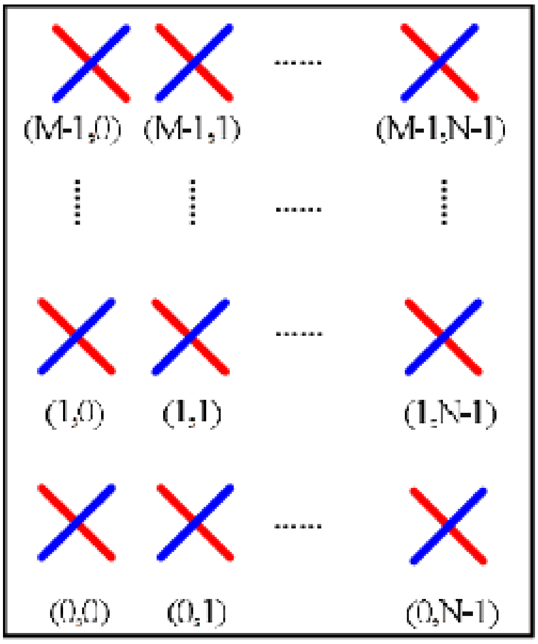

Figure 1.1: Replace this with high quality image, still with indexes starting in the top corner and be consistent with the appendix A(do in powerpoint?)

Thus, in summary, the mechanism to orthogonality can be polarisations or all together independent paths. When using a GoBs there is a constraint that it is not present in free-format beamforming which is the discretisation of beams. This leads to two major differences when using a GoB as opposed to the implicit variant: i) in order to consider different paths, one has to code reference signals in different beams explicitly and await feedback; and ii) if each polarisations in the BS has a similar response to either polarisation in the UE, then they would interfere significantly, because they can only be transmitted in the beam.

To achieve both degrees of freedom in orthogonality to the UE, the polarisation mechanism in the GoB needs to separate transmissions on a polarisation basis. This means that one must assess the quality of the channel for a single polarisation before considering a transmission on that polarisation.

A maximum of two layers between each UE and each BS is supported in the MU-MIMO codebook [4]. But, since UEs do not necessarily beamform codebook-based, each UE may receive/transmit from/to several BSs simultaneously, up to a maximum of eight layers, since this is the the maximum number of layers in the SU-MIMO codebook [4].

Therefore, both in GoB operation and in implicit beamforming, this provides the optimal way of proceeding with regards to layer separation, assuming constant total transmit power (i.e. using half the antennas, double the power per antenna can be used).

Contrast between access beams and fine tuned beams and assumption that we are connected and only managing beam alignment

mention the usage of TDD, because the mmWave bands only have TDD and because allows UL-DL reciprocity. The concept that UL beams can be determined based on DL measurement, and vice-versa, is called beam correspondence [https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=8947954] and results in overhead reduction. Since beamforming and Massive MIMO have gained popularity in the community (cite emil stuffs), TDD has become increasingly favoured because it allows such reduction in beam management procedures. Thus, also here TDD operation is favoured.

To form adequately oriented beams-pairs the most recent and precise channel state information is needed. There are two main ways of obtaining precise channel state information in 5G: the UL of a SRS, or the DL transmission of a CSI-RS. Naturally, since the approaches are based on different reference signals they involve different procedures, effectively resulting in different beams.

Acquiring CSI via the uplink of a Sounding Reference Signal (SRS) allows the BS to have information on up to four distinct channels to the UE, because up to four orthogonal SRS sequences are available per UE [5]. Therefore, the UE may use only up to four antenna ports, each antenna port mapping an SRS sequence to a set of physical antennas. In essence, this means that if the UE has four or less antennas, it can send a different SRS per physical antenna and the BS may extrapolate the channel to every single antenna of the UE. However, when the number of antennas on the UE is greater than four, it will not be possible for the BS to know the transformation that occurred between each UE antenna and each of its antennas. Many authors [6] have the misconception that an infinite amount of orthogonal SRSs are available to be sent by the UE, and that is possible to obtain the channel to each antenna on the UE. However, when there is a limited amount of orthogonal sequences allowed per UE is the spatial filter applied to map one SRS to several physical antennas will be part of the transformation on the SRS, and the BS will only be capable of inverting the complete transformation that occurred on the reference signal.

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When UEs only had one or two antennas, this was no issue. But with the increase in popularity of mmWave frequencies, UEs may have hundreds of antenna elements. Therefore, the gain in CSI precision using SRSs will be marginal or even inferior to the gain using CSI-RSs, since CSI-RSs transmitted per UE may have 32 different ports, allowing for far more resolution.

check nokia slides to
sure...

these 2 papers:
ieeexplore.ieee.org/document/7803878
ieeexplore.ieee.org/document/8250021

But, in

This comes with advantages, such as the possibility of performing a transmission optimised for that UE by targeting the antenna that has the highest potential for coherent constructive interference. But also disadvantages, e.g. considerable feedback overhead. This drawback is significant and thus not desirable in practice.

The CSI-RS-based feedback option is more flexible in terms of what information can be derived from that reference signal. Actually, even when acquiring CSI from SRSs, CSI-RSs are still used to derive other CSI like interference levels. The overhead burden of this option depends on the periodicity and the Resource Blocks (RBs) assigned to CSI-RS measurements. The most relevant contrast with the previous option is that different CSI-RSs are transmitted in different beams, instead of each antenna. Therefore, in order to derive suitable beam-pairs the UE reports the beam that contains the strongest CSI-RS (and may even feedback the strengths of the next strongest beams). Although the beams created by the BS to transmit the CSI-RSs don't need to be pre-defined, i.e. based on a pre-existent GoB, given the feedback possibilities, pre-defined beams is the most likely approach.

In [4] 3GPP standardises a GoB based on the two codebooks. The codebook of Type I supports until 8 layers per UE but has lower resolution/flexibility, making it a good fit for SU-MIMO operation. Codebook Type II fits MU-MIMO better, supporting 2 layers per UE and allowing further beam-steering precision. Nevertheless, in Section **??** we propose a simpler and more manageable grid as a first approach. The need for a more elaborate implementations should be carefully assessed since the scenarios, where our SXR meetings happen (indoors), and where the codebook-based precoders were meant to operate (outdoors), are significantly different.

Bibliography

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