Synthesis of Link Optimization Considerations for 5G and Beyond Wireless Communications

Francesco Di Stasio

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1 Synthesis

The dramatic increase in data demand over the mobile networks has brought the research community to a significant change in how to address wireless communications. In this work we discuss some of the main novel physical level techniques for 5G and beyond that have emerged from this research effort and we try to address some potential issues.
Chapter 1 offers a comprehensive review of the history of mobile communications, beginning with the first communication standard introduced in conjunction with the second generation cellular system, GSM, which is still active today. The first breakthrough in the mobile world has been introduced in the GPRS system, the first scheme able to offer to the mobile stations the capability of data connection. Since the immediate heirs of GPRS are the third generation standards like UMTS and HSPA, we discuss their behavior and performance, with particular focus on the WCDMA concept. The advent of 4G LTE has brought a new concept of mobile network, a full packet-switched domain network for both data and voice communications. After that, the discussion moves to the 5G New Radio networks, with particular attention to the role of 3GPP and ITU in the standardization process and in the requirements phase. Essentially, 5G aims to improve the LTE performances in terms of, among others, data rate, spectral efficiency and latency. To meet those goals many innovations have been proposed at each level of the transmission stack, such as massive MIMO, mmWave communications, new radio access technologies, software defined networking and so far. In this thesis we deal with few of these enabling technologies. In Chapter 2 we focus on the channel modeling problem for the mmWave frequency range. The availability of reliable channel models allows to perform numerical simulations throughout the standardization process in order to validate analytic models and preview the system performances before the field tests. A proper channel model is therefore necessary for reliable and valid simulation results. We show the main channel models present in the literature such as METIS, WINNER II, NYUSIM and so on. We focus on the channel model proposed by 3GPP in TR 38.901, valid for frequency range $0.5 - 100\,GHz$. It is a 3D channel model in which all the scatterers are grouped into clusters, and we treat it as a single scatterer. More specifically, for each link BS (Base Station) - UE (User Equipment), we will have a certain number N of clusters, from each cluster we have M rays going towards the receiver. The generation of a channel model is divided in many step, we divide it in three macro areas as follows:

1. *General parameters*: Here we set the scenario (we choose to focus only on UMi (Urban Micro-area) and UMa (Urban Macro-area)), we select the array (multi panel planar arrays for both

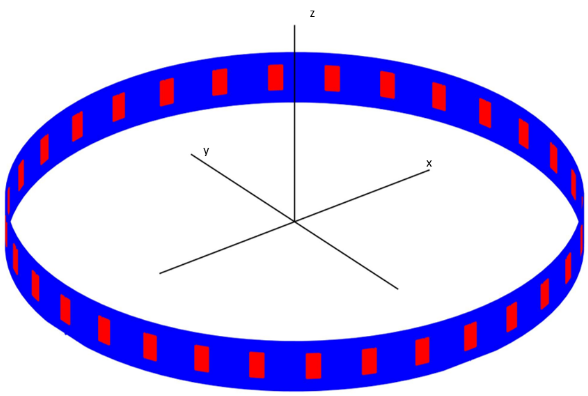
transmitter and receiver) parameters such as the number of elements in transmission and reception and so on. Furthermore, user are placed in the considered circular cell, and indoor users are taken into account. Finally, propagation condition (LOS/NLOS) are assigned by computing the LOS probability through the formulas provided by 3GPP in the report. Those formulas depend on the carrier frequency and the distance between the BS and the considered user.

2. *Large scale parameters*: Here we evaluate all the per-link parameters useful to describe the link behavior between transmitter and receiver. We have 7 parameters: angular spread of arrival for azimuth and zenith, angle spread of departure for azimuth and zenith, delay spread, shadowing fading and Ricean K-factor (only for LOS links). Those parameters are log-normally distributed with means and variances provided by the 3GPP report. We further discuss the correlation among the parameters, which can be intra-UE and inter-UE. Finally, we generate the number of clusers per link and the number of rays per cluster.

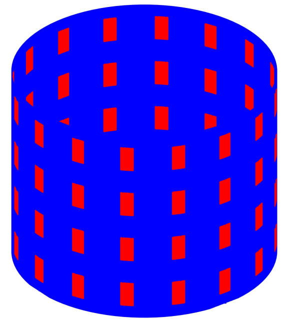
3. *Small scale parameters*: these are all the parameters regarding the propagation between transmitter and receiver. In particular each parameter is related to each cluster-ray and not to a single user. Here we evaluate cluster powers, we choose a threshold of power ($-25\,dBm$ with respect to the maximum power) and discard all the cluster below it. Moreover, angle of departure and arrival for both azimuth and zenith are evaluated ray per ray.

Finally, we show how to generate the channel coefficients in the flat-fading scenario.
In chapter 3 we point out one of the most promising technologies for 5G new radio: massive MIMO. The usage of a huge number of antennas at the base station, and potentially on the devices, is necessary to overcome the high path loss issues intrinsic in the use of the mmWave range of spectrum. Indeed, thanks to innovative techniques like beamforming, we are able to improve the array gain proportionally with the number of elements present in the array. Throughout the chapter, we introduce the concept of steering array and we show how to evaluate it for linear array, planar array, circular array and cylindrical array. The last two types of array, are the so called conformal arrays (figure 1). In the LTE scenario, the most common base station (BS) equipment foresees a trisectorized framework (120 degrees per sector). This suffers from beam broadening and pattern degradation as the beam is steered toward azimuths or elevations angles far from broadside. On the other hand, conformal arrays, such as circular or cylindrical ones, have almost isotropic behavior, i.e., the beam can be scanned in discrete steps through an arc while maintaining a constant pattern [144]. Moreover, conformal arrays do not present pattern degradation due to beam broadering and there is no need of cell sectorization. We study their behavior in the uplink of a massive MIMO mmWave system by considering both isotropic and directive elements with two strategies of beamforming: conventional beamforming and Capon (MVDR). Results are provided in terms of average achievable per user rate with different system configurations in figure 2, where we can notice that in our scenario best performance occurs when all antennas are arranged in a a single circular array.

In chapter 4 an in-depth analysis has been carried out about OFDM and their relatives OFDMA, SC-FDE and SC-FDMA. We put our focus on the drawbacks of OFDM like high PAPR, tight time/frequency synchronization requirements and high Out Of Band (OOB) emissions. The last one is mainly due to the frequency tails from the sinc-shaped subcarriers and from the rough transition in the time domain between one symbol and the successive one. We then discuss the desired waveforms for 5G systems, which foresees a variety of services so that the radio access



(a) Circular



(b) Cylindrical

Figure 1: Array configurations

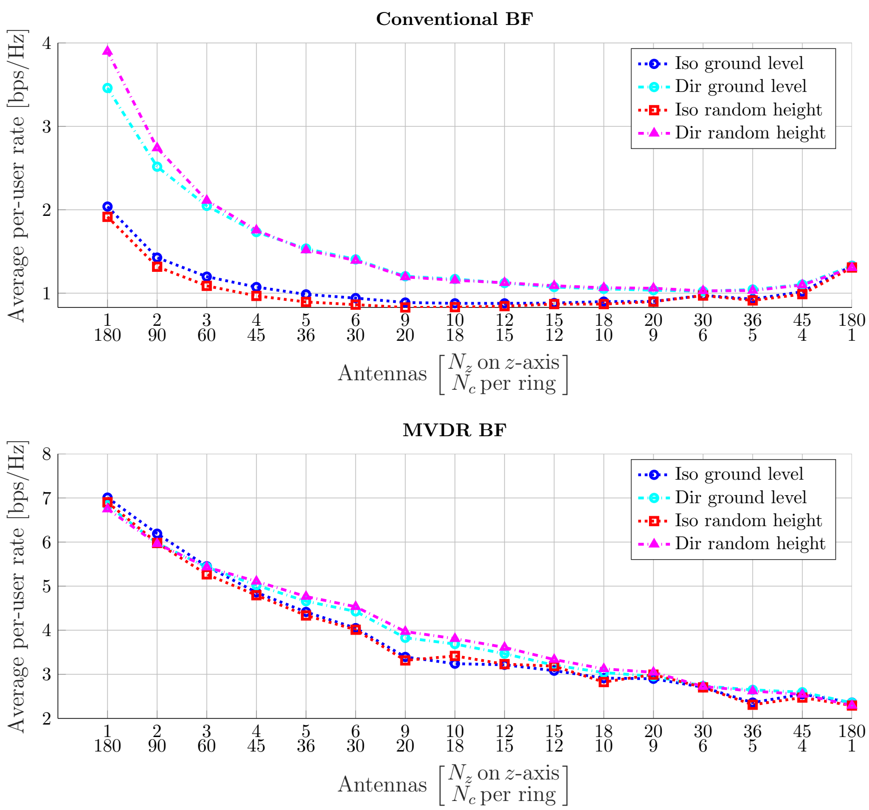


Figure 2: Average per user rate

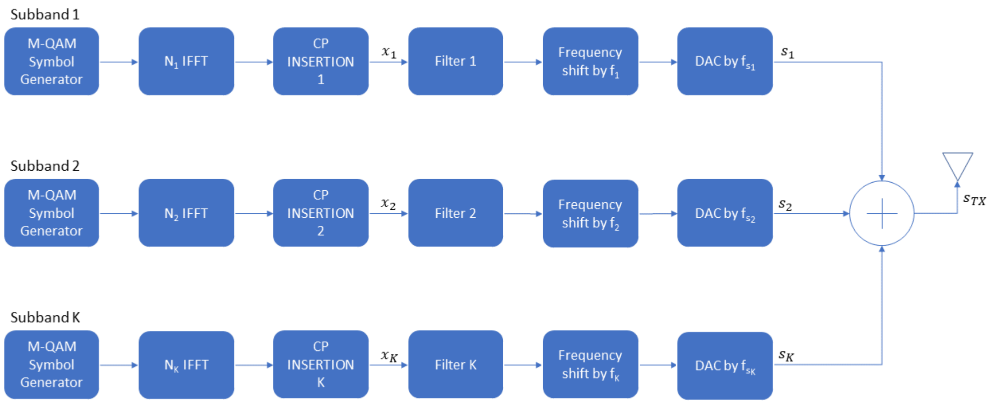
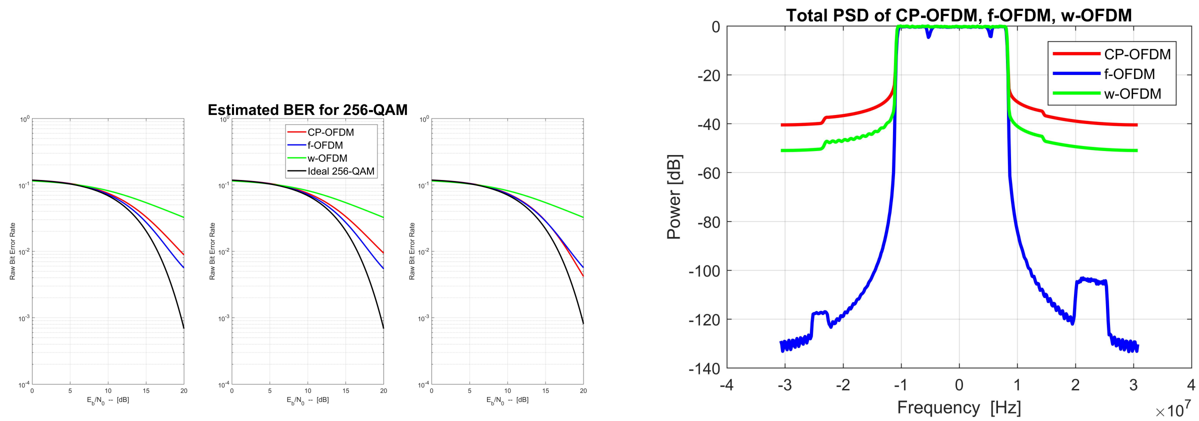


Figure 3: Filterd OFDM transmitter



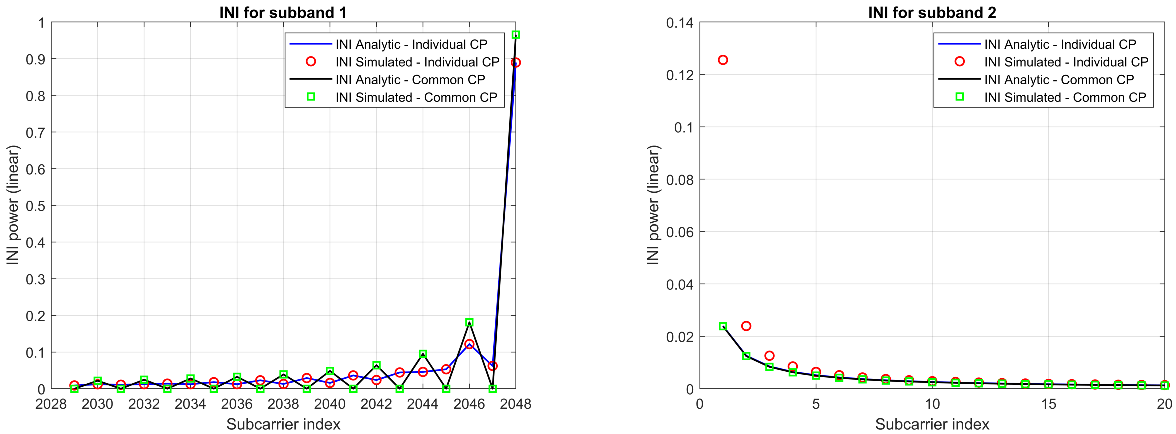
(a) BER

(b) PSD

Figure 4: Performance comparison

technique needs to be flexible and able to satisfy these different requirements. A solution can be a multi-numerology system, in which we divide our available bandwidth in subbands and each subband has a proper numerology. A numerology is defined as the set of parameters specific for transmission such as symbol duration, FFT sizes, CP duration and subcarrier spacing. We propose three schemes: CP-OFDM, filtered-OFDM and windowed-OFDM.

Figure 3 shows the proposed transmitter for filtered OFDM, which is basically a multi-branch OFDM with an additional filter aiming at reducing the OOB emissions. The transmitter of w-OFDM is very similar, but instead of filtering we adopt a time domain window in order to smooth the transitions between adjacent symbols. In this case we do not add a classic CP but instead we adopt a suffix and prefix configuration to extend the time duration of the signal. Finally, CP-OFDM is a multi-numerology version of a classical OFDM without any OOB rejection technique. Results are presented in terms of BER and PSD for a 3-subband systems in figure 4. Among these three schemes, f-OFDM offers the best performance in term of OOB emission suppression, but the filer adds additional delay in the transmission chain and adds computational complexity. Moreover, the additional filter is not suitable for uplink applications, since the device could result overloaded.



(a) Subband 1 (b) Subband 2

Figure 5: Performance comparison

Finally, in chapter 5, we give further details about flexibility in 5G waveforms and on the multi-numerology concept and we focus on a particular source of OOB emissions, the so called inter-numerology interference (INI). Since subcarriers are sinc(.) shaped in the frequency domain, they generate frequency tails which can cause interference for adjacent subbands. This phenomena is due to the fact the the adjacent subbands are using a different subcarrier spacing, so they are not orthogonal respect to the tails of the adjacent channels interference. In this chapter we developed an analytic model for evaluation of INI in two CP configuration: classic individual CP and common CP. Common CP has gained interest in the research world thanks to the concept of multi-symbol encapsulated OFDM. The large subcarrier spacings envisioned by 3GPP could bring to a very short CP duration, so that the CP addition is not anymore protective for inter-symbol interference.

Figure 5 shows the simulated results together with the analytic results of our model. As we can imagine, INI is higher on the subband edges, particularly for subband 1 which has a smaller subcarrier spacing. Moreover, the Common CP configuration presents similar results as the individual CP case and simulated results are very close to the analytic ones.

Finally, figure 6 shows the influence of the subcarrier spacing of the interfering signal (subband 2) on the victim (subband 1). As expected, interfering signals with high subcarrier spacing present thicker sinc-lobes and so more important INI contributions.

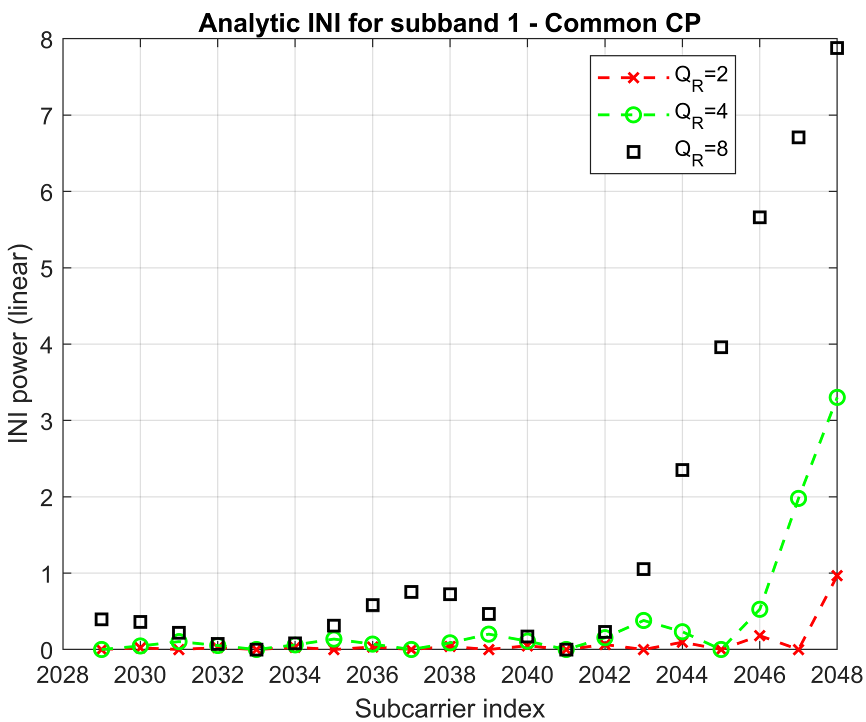


Figure 6: INI for different subcarrier spacing

2 Corrections

After the first revision:

- For a more coherent exposition Chapter 1 has been split in two chapters: Introduction to mobile network systems and A simplified 3GPP channel model for 5G networks.
- Typos have been fixed throughout the thesis.
- On Chapter 4, ex Chapter 3, more clarifications have been introduced about figures. Comments about the role of the transition bands (Figure 4.9) have been added. The section of numerical results have been enriched with more comments and figures. The ex Figure 3.15, now 4.15, about the BER performance in QPSK scenario have been corrected and motivated with more comments an example of constellation of received samples (Figure 4.16). The same happens for performance for 256 QAM. Moreover, performance for 16-QAM and 64-QAM have been introduced (Figure 4.17).
- On Chapter 5, ex Chapter 4, more comments have been introduced about Figure 5.7 (previously Figure 4.7).