Measurements of Beamforming Performance in Commercial 5G Deployments

Bruno Benedetti
Universidad de la República
Montevideo, Uruguay
bbenedetti@fing.edu.uy

Claudina Rattaro
Universidad de la República
Montevideo, Uruguay
crattaro@fing.edu.uy

Benigno Rodríguez
Universidad de la República
Montevideo, Uruguay
benigno@fing.edu.uy

***Abstract*—This paper presents field measurements of different beamforming mechanisms using a commercial 5G network. Beamforming enhances signal quality and capacity through directional transmission, and its effectiveness depends on factors like user position and feedback. We analyze Sounding Reference Signal (SRS)-based and codebook-based beamforming under real-world conditions. Results show SRS-based beamforming excels in mid-cell areas, while codebook-based performs better at the cell edge.**

***Index Terms*—mMIMO, beamforming, in-situ measurements**

I. Introduction

5G is designed to support a wide range of services by introducing a more flexible and scalable network architecture [1], [2]. One of its most impactful innovations on the RAN side is beamforming, implemented through Massive MIMO (mMIMO) antenna arrays. By steering energy toward specific directions, beamforming improves link quality, extends coverage, reduces interference, and enables MU-MIMO, thereby increasing spectral efficiency. It is also essential for the operation of millimeter-wave bands, where high propagation losses make directional transmission indispensable.

5G New Radio supports two main downlink beamforming mechanisms: codebook-based and SRS-based selection, each with distinct advantages in commercial deployments. In codebook-based beamforming, the Next-Generation NodeB (gNB) transmits CSI-RS on multiple ports and the User Equipment (UE) reports the preferred precoding matrix from a standardized codebook, enabling efficient beam selection without relying on channel reciprocity and allowing use in both FDD and TDD bands, as well as in carrier-aggregation scenarios where uplink may not be available. Conversely, SRS-based beamforming is entirely gNB-driven: the UE transmits Sounding Reference Signals in the uplink, enabling the gNB to directly estimate the channel and compute arbitrary beams beyond the constraints of predefined codebooks. While this offers greater flexibility, it requires orthogonal uplink resources, depends on TDD reciprocity, and may suffer from low SRS SINR, particularly at the cell edge due to UE power limitations. Both mechanisms therefore represent complementary strategies for dynamic beam adaptation in real 5G networks, with deployment suitability driven by spectrum configuration, uplink capacity, and vendor-specific algorithms.

Although beamforming has been widely studied through simulations (e.g., [3], [4]), there are relatively few works based on real-world measurements in commercial 5G deployments. Some experimental studies exist, such as [5], which evaluates digital beamforming in multi-site mMIMO using real channel measurements for optimization. Others, like [6] and [7], use Software Defined Radio-based prototypes to explore practical challenges and testbed evaluations, rather than commercial hardware. This article contributes to closing that gap by presenting a practical study based on field measurements in a live commercial 5G network, using only commercial equipment.

II. Field Tests and Results

The field tests were conducted on a commercial 5G Non-Standalone (NSA) network operated by a local provider in Uruguay. A 32-TRX, 128-antenna-element Massive MIMO radio was deployed on the gNB side. The tests used band n78 at 3500 MHz with a subcarrier spacing (SCS) of 30 kHz and a total bandwidth of 100 MHz (273 PRBs). The TDD frame followed a 10 ms slot pattern of 7D:1S:2U—specifically, DDDDD DDSUU—where the special slot (S) was configured to avoid downlink transmission. The system supported up to four downlink layers and used 256-QAM as the maximum modulation scheme. Throughout the test sessions, the only parameter modified on the gNB was the beamforming mechanism under evaluation. With this configuration the maximum achievable throughput can be estimated at around 1.4 Gbps, considering only traffic contribution from 5G n78 band in use. This bitrate, though, is on optimal radio conditions which are rarely achieved. The network is generally configured to accept around 10% block error rate when choosing a modulation and coding rate. Logging was done with XCAL software from Accuver, which was set up on a Windows laptop connected to the mobile device through USB ports. A GPS was also connected to the PC to gather location information during testing. Fig. 1 shows the actual setup on the field. It is important to note that all logs are taken at the user side, and therefore there will not be more information available than what the user can know during these tests.

During the comparative tests conducted under identical conditions, the SRS-based beamforming operated in a Grid of Beams (GoB) mode, selecting the best beam from a predefined set, as no beam synthesis was enabled. While both Codebook

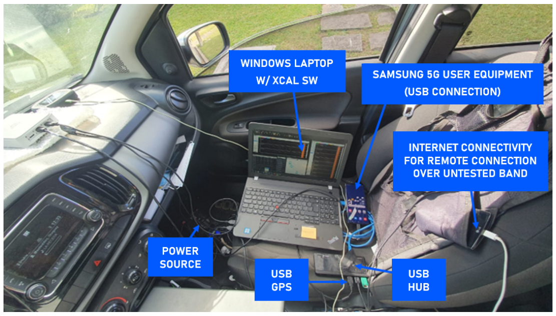

Fig. 1. Test setup.

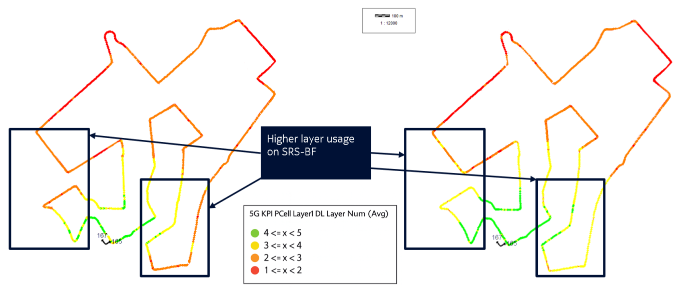

Fig. 2. DL Layers transmitted using Codebook-based (left) and SRS-based (right) Beamforming. More layers enable higher potential bitrate.

and SRS options in this case use a GoB mode, SRS is not limited to pre-defined codebook and allows for much more flexible beams to choose from when compared to its codebook counterpart. A single gNB was configured for the measurements, with all other nearby gNBs kept offline. The experiments used a Samsung S22+ running full-buffer UDP downlink traffic generated with iPerf3 from a Linux server.

SRS-based beamforming allows a clear gain on DL layers being used, there is much more usage of 3 and 4 layers during the drivetest route with SRS-based beamforming being used on near/mid cell areas. This is exemplified on Fig. 2. This leads to better throughput values, which can be seen on Fig. 3. This image presents the DL MAC layer throughput obtained on each drivetest. However, upon closer inspection it is also seen that on the cell-edge codebook-based beamforming outperforms SRS-based beamforming. These tests show that SRS-based beamforming provides strong performance at near and mid-cell ranges, even when operating in GoB mode, but its accuracy degrades at the cell edge due to limited UE transmit power and weaker SRS reception. Codebook-based beamforming, relying on higher-power gNB-transmitted CSI-RS, offered more robust beam selection in challenging coverage conditions and remains suitable for FDD operation.

A. Real-Time Beamforming: Key Observations from Field Measurements

We conducted additional experiments with Real-Time Beamforming (RT BF). For users with high traffic demand and strong SRS reception, the gNB dynamically switches to Wide-Band SRS (WB-SRS), allowing full-band channel estimation

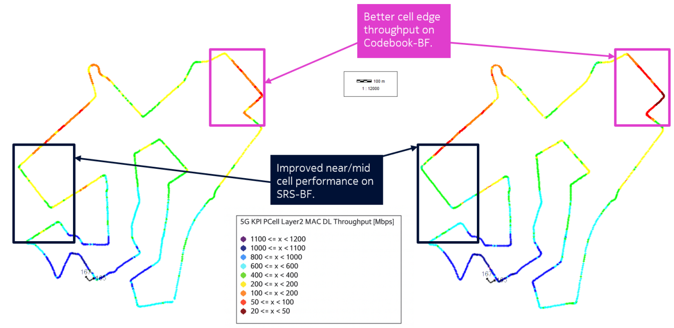

Fig. 3. DL MAC Throughput with Codebook-based (left) and SRS-based (right) Beamforming.

in a single SRS occasion and enabling RT BF. Unlike SRS BF setup from previous setup, with RT BF beams are dynamically synthesized. Field tests using a Samsung S23 show that RT BF provides limited gains when the user moves quickly (at driving pace), but delivers a clear throughput improvement, up to around 30%, for static and low-mobility users located near the gNB.

III. Conclusions

This study compared SRS-based and codebook-based beamforming using field measurements on a commercial 5G network. SRS-based beamforming demonstrated clear advantages for users located closer to the gNB, benefiting from SB-SRS multiplexing, while codebook-based beamforming achieved more stable performance across the entire cell, particularly at the edge. Beyond these results, we also explored the applicability of RT beamforming, which enables highly customized beams but is inherently constrained to near-cell users because its reference signals are also power-limited. A more comprehensive evaluation of RT beamforming—including scenarios with beam synthesis and wider SRS configurations—remains an important direction for future work

References

[1] ITU-R, "Recommendation ITU-R M.2083-0: Imt vision – framework and overall objectives of the future development of imt for 2020 and beyond," https://www.itu.int/rec/R-REC-M.2083, 2015, accessed: 2025-05-06.

[2] E. Dahlman, S. Parkvall, and J. Sköld, *5G NR: The Next Generation Wireless Access Technology*. Cambridge, MA: Academic Press, 2018.

[3] G. Barb and M. Otesteanu, "Digital GoB-based beamforming for 5G communication systems," in *2020 International Symposium on Antennas and Propagation (ISAP)*, 2021, pp. 469–470.

[4] Y. Wang, C. Chen, and X. Chu, "Performance analysis for hybrid sub-6GHz-mmwave-THz networks with downlink and uplink decoupled cell association," *IEEE Transactions on Wireless Communications*, pp. 1–1, 2025.

[5] T. Okuyama, S. Suyama, J. Mashino, S. Yoshioka, Y. Okumura, K. Yamazaki, D. Nose, and Y. Maruta, "Experimental evaluation of 5G multi-site massive MIMO," in *2017 20th International Symposium on Wireless Personal Multimedia Communications (WPMC)*, 2017, pp. 476–480.

[6] N. R. Dusari and M. Rawat, "Practical implementation challenges in MIMO beamforming and its applications," *IEEE Microwave Magazine*, vol. 26, no. 4, pp. 59–75, 2025.

[7] L. Bisulli, D. Scazzoli, F. Linsalata, M. Magarini, M. Mizmizi, C. Mazzucco, and U. Spagnolini, "Real-time beamforming testbed and tracking relay for mmwave applications," in *2024 IEEE 30th International Conference on Embedded and Real-Time Computing Systems and Applications (RTCSA)*, 2024, pp. 114–119.