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(Article begins on next page)

22 September 2026

Electromagnetic Interference from Consumer Electronics on GNSS Performance in Smartphones

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***Abstract*—This paper explores the impact of electromagnetic interference (EMI) from consumer electronics and common household appliance on the performance of GNSS receivers in smartphones. As GNSS signals are weak and susceptible to external noise, consumer appliances can introduce spurious emissions near GNSS frequency bands, leading to signal degradation. To investigate this, we conducted a series of controlled experiments simulating typical smartphone usage in proximity to different sources of EMI among household appliances and consumer electronics (a microwave oven, a Wi-Fi router, and Bluetooth accessories such as gimbal and earphones). Our analysis reveals that the microwave oven can induce severe GNSS signal degradation, with substantial AGC and C/N$_0$ drops and significant satellite availability loss, particularly in close-range configurations. Additionally, Wi-Fi interference resulted in moderate reductions in signal quality and limited—but non-negligible—inaccuracies in position estimates. In contrast, Bluetooth exhibited negligible effects under tested conditions. These findings suggest potential implications for indoor navigation applications and underscore the importance of further improvements in interference mitigation for consumer GNSS devices.**

***Index Terms*—GNSS, Satellite Navigation, Electromagnetic Interference, Smartphone, Android.**

I. Introduction

Global Navigation Satellite System (GNSS) receivers embedded in smartphones play a pivotal role in navigation, location-based services, and time synchronization [1]. Their widespread adoption has made precise positioning a key enabler for applications ranging from turn-by-turn navigation to emergency response [2] and autonomous systems. However, despite significant advancements in GNSS receiver design, smartphone-based GNSS remains highly susceptible to electromagnetic interference (EMI), particularly in indoor and semi-indoor environments. Since smartphone GNSS receivers operate with signals received at extremely low power levels—typically around -130 dBm or lower at Earth's surface—external noise sources can significantly degrade their performance [3], [4].

The consequences of EMI on GNSS receivers can range from minor disturbances to complete signal loss. In severe cases, the interference can lead to the loss of satellite signals, causing navigation and timing outages. Even brief periods of interference may result in position, velocity, and time (PVT) errors, with position jumps or inaccurate velocity readings being particularly problematic in dynamic environments.

Previous studies have extensively examined intentional interference sources such as jammers and spoofers [5], [6], also from a smartphone perspective [7]–[10], but unintentional EMI from common household appliances and consumer electronics—and, more generally, from RF-emitting devices which operate near GNSS frequency bands—remains less explored [11]. Many of these potential EMI sources are ubiquitous in residential, commercial, and industrial settings, yet their potential to interfere with GNSS signals in smartphones has received limited attention. Given the increasing reliance on GNSS-based services indoors and in transition zones (e.g., building entrances), understanding the impact of these interference sources is crucial for improving GNSS receiver resilience.

Although GNSS usage is limited indoors, many emerging applications leverage hybrid positioning systems (e.g., combining GNSS with Wi-Fi, Bluetooth, or inertial sensors) to support location-based services in large indoor areas such as malls, airports, or warehouses [12]–[14]. In these cases, even weak GNSS signals can contribute to the overall positioning solution. Unintentional EMI in these contexts could degrade the performance of GNSS-based services, causing intermittent errors in location tracking, particularly in moments where GNSS still has a role in the positioning process.

Microwave ovens are one of the most powerful household sources of RF radiation, operating at 2.45 GHz within the Industrial, Scientific, and Medical (ISM) band [15]. While this frequency does not directly overlap with GNSS bands such as L1 (1.57542 GHz) or L2 (1.2276 GHz) [16], microwave ovens are not perfectly shielded, leading to leakage of spurious emissions that can extend into adjacent frequencies. The potential for interference is exacerbated by the significant disparity in signal power between GNSS signals and microwave oven emissions, which operate in the range of hundreds of watts [3]. This leakage can introduce RF noise and phase distortions in nearby GNSS receivers, leading to signal tracking errors. The effects of microwave interference are particularly concerning for Doppler measurements, which rely on precise frequency tracking to estimate velocity.

Wi-Fi routers and Bluetooth devices also operate within the 2.4 GHz ISM band, overlapping with microwave oven emissions and producing RF interference in crowded environments [17], [18]. Smartphones are frequently used near high-density wireless networks, where multiple Wi-Fi access points and Bluetooth accessories compete for spectrum. This creates a scenario where co-channel interference, intermodulation distortions, and spurious emissions can contribute to

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GNSS signal degradation [19]. As a result, Wi-Fi routers can generate harmonic emissions that extend beyond 2.4 GHz, potentially affecting GNSS bands, particularly in environments with multiple active devices. Moreover, Bluetooth gimbals and earphones continuously transmit data in short bursts, which may introduce localized interference patterns affecting GNSS tracking. Given the increasing integration of smartphones with IoT ecosystems, these interference sources must be accounted for when assessing GNSS performance in real-world conditions.

To systematically evaluate the impact of consumer electronics on smartphone GNSS receivers, this study conducted a series of controlled experiments replicating real-world usage scenarios and analyzing the impact of a microwave oven, a Wi-Fi router, and Bluetooth accessories (gimbal and earphones). The goal is to measure the impact at three distinct levels: (*i*) the signal level, (*ii*) the measurement level, and (*iii*) the state estimation level. The adopted figures of merit (FoMs) are therefore designed to provide a comprehensive understanding of how interference affects the receiver's performance, from the impact on the AGC, to the measured C/N_0, and PVT solution. Additionally, the metrics are aggregated using averages and root mean square error (RMSE) to facilitate comparison across different experiments, interference sources, and device configurations.

The results provide insights into the relative severity of interference across different consumer electronics, highlighting which devices pose the greatest risk to GNSS accuracy in smartphones. By characterizing these effects, this study contributes to the broader goal of improving interference mitigation techniques in smartphone GNSS receivers.

The remainder of the paper is organized as follows: Section II describes the methodology, Section III presents the results, and Section IV discusses conclusions and future work.

II. Methodology

This study involved controlled experiments designed to simulate typical smartphone usage in three different scenarios. The first scenario considers proximity to a microwave oven. The second scenario involves the use of a wireless router, differentiating between open-sky conditions and low-elevation blockage. Finally, the third scenario examines interference from Bluetooth devices, specifically headphones and a gimbal.

All tested devices, since sold in Europe are CE-certified. As such, they comply with the applicable electromagnetic compatibility (EMC) requirements under Directive 2014/30/EU [20]. These devices also conform to the following relevant technical standards: ETSI EN 300 328, ETSI EN 301 908 series, ETSI EN 55011 / CISPR 11.

Outdoor experiments were conducted using different smartphone models (Oppo Reno 11F 5G (CPH2603), Oneplus 8 IN2013, Motorola Razr 40) to examine the impact of microwave radiation on the smartphones' GNSS chipset. The phones were not connected to the internet during the whole duration of the experiments to favor the genuineness of raw GNSS measurements, limiting external aiding or corrections. Given that the smartphones had been powered on for several hours prior to the measurements, the GNSS receivers were operating under a hot start condition.

Notably, in each scenario, the duration of the EMI phase was strictly set to 3 minutes for all cases, except for the Wi-Fi case, where it was extended to 4 minutes to facilitate setup and account for the modem power-up transient. This ensured a comparable common ground without distinctions. For the sake of completeness, all parameters shared across the various experiments and scenarios are presented in Tab. I.

TABLE I: Experimental Scenario. Common Settings.

Parameter	***Value***
Experiment Duration	10 min
Interference Duration	3 (from t_0+5 to t_0+8) min[a]
Location	$45.0627°$N, $7.6622°$E
Receiver's dynamic conditions	Static
Data collection start time	t_0

[a] Exception made for the Wi-Fi case: 4 (from t_0+4 to t_0+8) min.

Data were collected using the GNSS Logger app [21], developed by Google, and analyzed with a custom Matlab script. This script reads the output files from the GNSS Logger and calculates parameters such as pseudorange, C/No, and PVT solution using the weighted least squares (WLS) method. Python scripts were employed to derive the FoMs discussed in the introductory section, specifically to aggregate all results and present them in a compact form using heatmaps.

A. Figures of merit

The following metrics compare data collected before EMI and data affected by EMI (denoted with $\sim$), with post-interference data excluded to avoid transient behaviors. A study on the lasting effects after interference is planned for future work.

- Average drop of the Automatic Gain Control (AGC): determined by computing the average AGC before (α) and during interference ($\tilde{\alpha}$) for each constellation i and then averaging the results across all of them, yielding

$$\Delta\mathrm{AGC} = \frac{1}{M}\sum_{i=1}^{M}(\alpha_i - \tilde{\alpha}_i) \ .$$

- Average drop of the Carrier-to-Noise Density (C/N_0): calculated by comparing the mean C/N_0 before (γ) and during the interference phase ($\tilde{\gamma}$) for each satellite, followed by an average across all the persistently observed satellites ($\bar{N}$), resulting in

$$\Delta\mathrm{C/N0} = \frac{1}{\bar{N}}\sum_{i=1}^{\bar{N}}(\gamma_i - \tilde{\gamma}_i) \ .$$

- Position Root Mean Square Error (RMSE) drop: it's computed by determining, at each time step, the 3D position error distance from the median, calculating the RMSE before (ϵ) and during interference ($\tilde{\epsilon}$), and then computing their difference through

$$\mathrm{RMSE\ drop} = \tilde{\epsilon} - \epsilon \ .$$

- Availability of satellites: assessed by the average number of tracked satellites in both interference-free (N) and EMI conditions ($\tilde{N}$), measuring the relative decrease, and representing it as a percentage so that

$$\text{Lost Satellites} = \left(1 - \frac{\tilde{N}}{N}\right) \cdot 100\% \; .$$

It is worth highlighting that the AGC metric in Android devices presents certain limitations and inconsistencies that should be considered when interpreting results. Specifically, the response of AGC to EMI varies across devices, with some showing an increase and others a decrease under similar conditions. Additionally, AGC values are typically reported on a relative scale, undergoing periodic re-scaling, which can obscure long-term trends. Another limitation is that AGC measurements are only available when GNSS signals are received, preventing its use for distinguishing between interference and signal attenuation in cases where no GNSS data is logged. These factors impact the reliability of AGC for certain applications, such as interference detection. For a more detailed discussion, refer to [7].

B. Household Appliances Interference

The experiment was conducted in an open courtyard of a residential building in downtown Turin, characterized by the presence of surrounding buildings on all four sides while maintaining an unobstructed line of sight to the sky. A foldable table was positioned at the center of the courtyard, and a microwave oven was placed on top to investigate the effects of microwave interference on GNSS signal reception.

Three experimental configurations were employed, with the relative positioning of the mobile devices varied while ensuring that the microwave oven remained stationary throughout the tests. The experimental configurations consisted of mobile devices positioned in direct proximity to the microwave oven: against the lower front panel of the microwave door (Fig. 1a); on the upper surface at its approximate center (Fig. 1b); in contact with the lower left side of the appliance (Fig. 1c).

Baseline GNSS measurements were recorded for five minutes before the microwave interference. Each experimental run lasted ten minutes, with the microwave oven activated at the five-minute mark, operating at 900W for three minutes. After the baseline phase, the microwave oven Whirlpool Cook30 was powered on to induce interference and disconnected at the eight-minute mark to cease operation. Throughout the experiment, the microwave oven remained closed and was unplugged except during the interference phase.

C. Wi-Fi Interference

Two experiments were conducted to analyze the impact of Wi-Fi-induced interference on GNSS performance under different environmental conditions. The two experiments aim to compare open-sky conditions (first experiment) with low-elevation blockage scenarios (second experiment). The first experiment took place in the courtyard of a residential building in central Turin, while the second experiment was conducted in the underground courtyard of Politecnico di Torino, in Fig. 2b.

In the first experiment, the router was placed on a foldable table at the center of a residential courtyard in downtown Turin, as in Fig. 2a. The smartphones were positioned directly on top of the modem router (TP-Link TD-W8961N). At the fourth-minute mark, the router was connected to a power source and at the fifth minute, the Motorola smartphone was connected to the router's network and began generating web traffic. The router was powered off at the eighth minute, after which GNSS measurements continued for the final two minutes.

The setup of the second experiment was identical to that of the first. At the fourth minute, the router was powered on, and two iPads Air 4th Gen (Wi-Fi) connected to the network. Using a ping application [22], the iPads generated network traffic by pinging each others. The router was powered off at the eighth minute to stop the interference.

(a) Front setup (b) Over setup (c) Side setup

Fig. 1: Microwave oven case experimental configurations.

(a) Experimental setup (b) Campus courtyard

Fig. 2: Wi-Fi case experimental configurations.

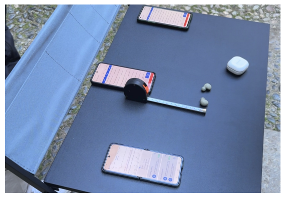
D. Bluetooth Interference

Two experiments were conducted to analyze Bluetooth interference in different environments. The first, performed in the underground courtyard of Politecnico di Torino, examined interference from a DJI Osmo Mobile 6 gimbal. The second, conducted in a residential courtyard in downtown Turin, focused on interference from Samsung Galaxy Buds 2 headphones.

In the first experiment (Fig. 3a), Bluetooth interference was induced by placing a DJI Osmo Mobile 6 gimbal on a cement table, with the Oppo Reno F11 5G mounted on it and the OnePlus 8 beside it. At the five-minute mark, the Gimbal was paired with an iPhone 14 Pro Max, and moved its arm for 3 minutes. Then, it was then turned off, and the phones were monitored for the remaining 2 minutes.

For the second experiment, the setup is shown in Fig. 3b. The Bluetooth headphones and phones were placed on the table, and the distance between them was varied (10 cm, 1 m, 3 m and 15 m). The experiment lasted for 10 minutes, during which, at the five-minute mark, the Samsung Galaxy Buds 2 were connected to the Oppo phone, and music started playing. The interference lasted for 3 minutes, after which the Bluetooth connection on the Oppo was disabled. Meanwhile, throughout the entire experiment, the other two smartphones continued performing stationary measurements.

(a) Phones and Gimbal



(b) Phones and headphones

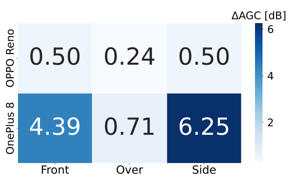
Fig. 3: Bluetooth case experimental configurations

III. Results and Discussion

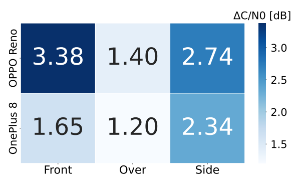
This section presents and analyzes aggregated experimental results to evaluate the impact of interference in each scenario.

A. Household Appliances Interference

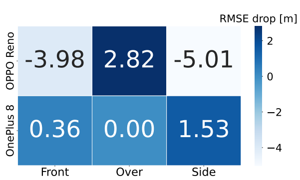
Fig. 4 presents aggregated heatmaps of all FoMs for each smartphone and scenario.



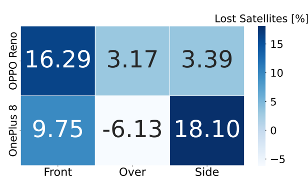
(a) Average AGC drop



(b) Average C/N_0 drop



(c) Position RMSE drop

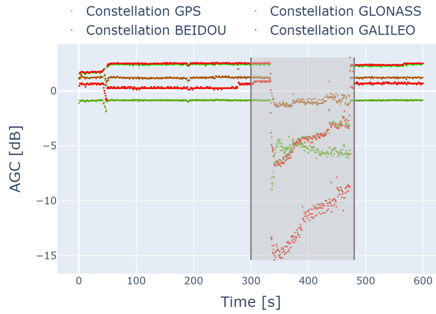


(d) Satellite availability

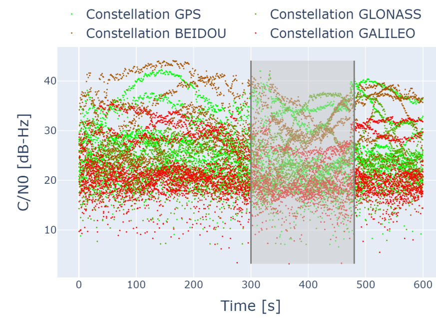
Fig. 4: FoMs Microwave experiments

The "side" case, as shown in Fig. 4a and Fig. 4b, exhibited the most notable AGC and C/N_0 drops, prompting a detailed analysis with point-wise graphs in Fig. 5. Notably, the grey area represents the phase of the experiment during which EMI was present.

The significant AGC and C/N_0 reductions suggest strong interference, potentially affecting localization and navigation. This aligns with Manfredini et al. [23], where simultaneous AGC and C/N_0 drops indicate possible jamming. Moreover, the "front" configuration exhibits similar drops, in contrast to the "over" position, which shows a less pronounced impact.



(a) AGC trend over time during the experiment



(b) C/N_0 trend over time during the experiment

Fig. 5: AGC and C/N_0 in microwave "side" case

Furthermore, Fig. 4d illustrates a greater loss in satellite availability for front and side configurations, confirming the disruptive effect of EMI on signal acquisition and tracking.

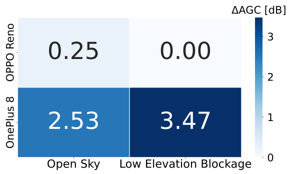
Device-specific analysis highlights differential susceptibility to interference. The OPPO Reno F11 5G demonstrates a lower AGC drop compared to the OnePlus 8, whereas the OnePlus 8 experiences a smaller decline in C/N_0. This discrepancy is likely due to hardware differences, as reported in the official manufacturer specifications of the devices [24], [25]. The positioning performance remains relatively stable, likely due to the integration of auxiliary positioning technologies such as Assisted GPS (A-GPS) and, in the case of the OPPO phone, additional support from WLAN and cellular network positioning, which help mitigate the impact of GNSS signal degradation.

These findings highlight the varying susceptibility of GNSS receivers to external microwave interference, emphasizing the role of hardware design and supplementary positioning technologies in mitigating signal degradation.

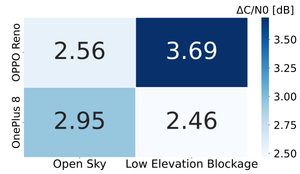
B. Wi-Fi Interference

This section presents the experimental results for the Wi-Fi case. In particular, the result of both open-sky and low-elevation blockage cases, are reported in Fig. 6.

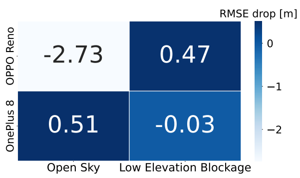
The analysis of the interference effects induced by the Wi-Fi router modem on GNSS signals reveals critical insights into signal degradation and satellite availability. A comparison between the two experiments, indicates that the results from the



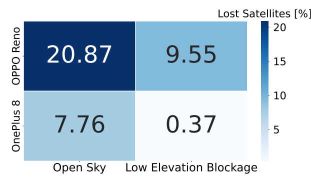
(a) Average AGC drop



(b) Average C/N_0 drop



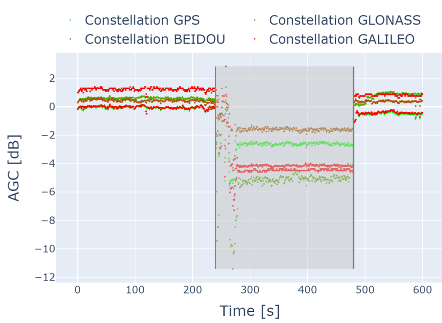
(c) Position RMSE drop



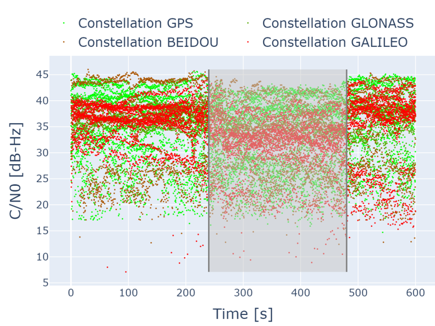
(d) Satellite availability

Fig. 6: FoMs Wi-Fi experiments

low-elevation blockage experiment exhibit a more pronounced degradation of the GNSS signal. Therefore, for this scenario the point-wise graphs of AGC and C/N_0 are provided in Fig. 7.



(a) AGC trend over time during the experiment



(b) C/N_0 trend over time during the experiment

Fig. 7: AGC and C/N_0 in Wi-Fi low-elevation blockage case

However, this degradation is accompanied by a comparatively lower loss in satellite availability, with respect to the open-sky case. This suggests that while signal quality is significantly impacted, the overall tracking capability of the GNSS receiver is less severely affected. Moreover, the AGC graph for the OnePlus 8, presented in Fig. 7a, further illustrates these findings. Specifically, the period during which the modem was intentionally used to generate interference corresponds to a considerable drop in AGC levels across all satellite constellations. Notably, the initial pairing phase of devices to the freshly powered modem shows that the GLONASS and Galileo constellations experience the most substantial impact. This observation suggets a higher susceptibility of these constellations to EMI during critical connectivity operations.

Device	**avgAGC (dB)**	**C/N_0 (dB)**	**Pos. RMSE (m)**	**Avail. Loss (%)**
OPPO Reno F11 5G	0.21429	0.88398	-0.265	2.14
OnePlus 8	0.14623	0.90734	-0.337	0.33

TABLE II: FoMs for Bluetooth Interference on Gimbal

C. Bluetooth Interference

This section presents the results of the two experiments conducted to evaluate Bluetooth interference. The results of the first experiment, which includes interference from the gimbal, are presented in Tab. II. Remarkably, the gimbal induces significantly lower AGC and C/N_0 drops compared to the other experiments, such as microwave and Wi-Fi cases. The impact on Position RMSE is minimal, and the satellite availability loss remains negligible. While there is a moderate drop in C/N_0, suggesting some level of Bluetooth interference, its effect on GNSS signal quality is noticeable but negligible.

Conversely, the FoMs for the second experiment, which involves Bluetooth headphones, are presented in Fig. 8.

Comparing Fig. 8a and Fig. 4a it's possible to notice that the Bluetooth generates a smaller AGC drop with respect to the microwave oven, suggesting that Bluetooth has a lesser impact on the GNSS receivers.

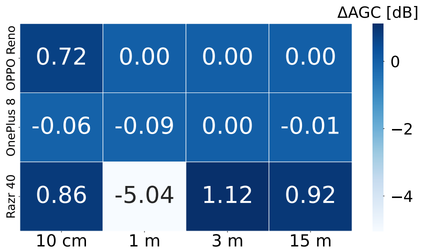
Moreover, Fig. 8b shows that as the distance of the Bluetooth headphones increases, leading to a corresponding increase in Bluetooth signal power, the C/N_0 drop does not proportionally increase. Instead, a gain is observed. This behavior is characteristic of Bluetooth transmitters, which dynamically adjust their power output as the distance to the receiver increases.

Furthermore, as shown in Fig. 8d, the satellite loss between EMI-free and EMI-affected periods remains negligible across all analyzed position ranges. This provides further evidence that the interference generated by Bluetooth headphones has a minimal impact on GNSS signal integrity.

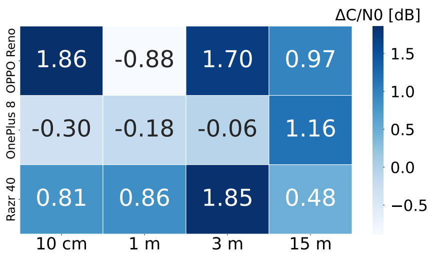
In summary, although the second experiment with Bluetooth headphones yielded higher performance degradations compared to the first experiment with the Gimbal, the interference generated by both Bluetooth accessories does not significantly impact GNSS performance in terms of signal strength, positioning accuracy, or satellite tracking.

D. Comparative Analysis

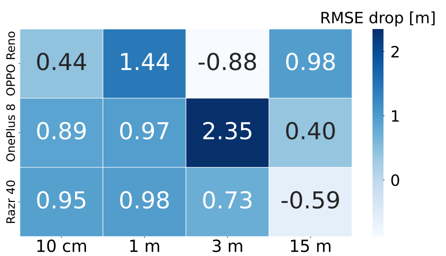
The comparative analysis of GNSS signal degradation across the tested devices—microwave oven, Wi-Fi router, and Bluetooth—reveals distinct interference patterns and levels of



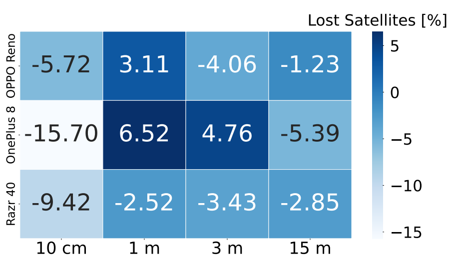
(a) Average AGC drop



(b) Average C/N_0 drop



(c) Position' RMSE drop



(d) Satellite availability drop

Fig. 8: FoMs for Bluetooth Interference on Headphones

impact. Among the three, the microwave oven exhibits the most severe effects, with significant drops in both AGC and C/N_0 values, particularly in the side and front configurations, as shown in Fig. 4a and Fig. 4b. This pronounced degradation, accompanied by a substantial loss in satellite availability, underscores the disruptive nature of microwave-induced EMI, aligning with previous findings.

In contrast, the Wi-Fi router shows a more mitigated impact. While the low-elevation blockage scenario results in greater signal degradation than the open-sky case (Fig. 6), the corresponding availability loss remains comparatively low. This suggests that although Wi-Fi interference affects signal quality, it does not critically impair the GNSS receiver's tracking capability. Notably, the GLONASS and Galileo constellations appear more susceptible to interference during the initial device pairing phases (Fig. 7a), indicating potential constellation-dependent vulnerabilities.

Instead, for what concerns Bluetooth interference, it exhibited the least impact on GNSS performance. The experiments demonstrate minimal AGC and C/N_0 drops, with no clear correlation between signal power and degradation, as shown in Fig. 8a and Fig. 8b. However, given the rapid expansion of Bluetooth-enabled IoT devices, potential cumulative interference effects in dense urban environments require further investigation.

Device-specific analyses also reveal interesting disparities. The OPPO phone generally experiences lower AGC drops but higher C/N_0 reductions compared to the OnePlus 8. These differences likely stem from variations in hardware design and the use of auxiliary positioning technologies such as A-GPS and WLAN-based positioning, which can mitigate GNSS signal degradation.

Overall, the microwave oven poses the highest interference threat to GNSS performance, followed by Wi-Fi, with Bluetooth showing negligible effects under the tested conditions.

IV. Conclusion

The outcomes presented in this paper demonstrate that unintentional EMI from common household devices can induce notable degradations in GNSS signal reception on smartphones. Among the tested devices, the microwave oven produced the most significant interference with GNSS performance, while Wi-Fi exhibited a noticeable but comparatively lesser impact on the overall tracking capability of the GNSS receiver. Instead Bluetooth experiments yielded negligible effects under the examined conditions.

While household appliances and consumer electronics may not pose a significant threat to GNSS receivers in urban environments, and despite the distinct impacts of each analyzed device on GNSS performance, the overall implication is that GNSS receivers are inherently vulnerable to various forms of localized EMI and require appropriate protective measures — especially as the density of potential EMI sources is expected to increase in urban environments.

Finally, variations in interference susceptibility across different smartphone models highlight the need for standardized testing frameworks that account for diverse chipset architectures and auxiliary positioning methods. Future research should investigate the cumulative and synergistic effects of multiple coexisting EMI sources, along with potential mitigation strategies designed to address the evolving landscape of consumer electronics. Moreover, extending the experimental campaign to a broader and more diverse range of device models and brands could help strengthen the generalizability of the conclusions, and is suggested as an avenue for future work. By integrating these insights into both receiver design and regulatory guidelines, the resilience and accuracy of GNSS-based applications can be more effectively safeguarded in rapidly changing electromagnetic environments.

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