WHITEPAPER

Wireless Power Measurements From First Principles

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Executive summary

Accurate and objective wireless power measurement is a deceptively complicated task to perform since any measurement of the wireless environment is implicitly filtered by antenna design and orientation relative to a signal's direction of propagation. This antenna filtering effect has two primary consequences. First, power measurements taken from different devices with different antennas and/or orientations will not match, making comparison of measurements impracticable. Second, the complicated multipath channel in which wireless measurements are often made makes accounting for the antenna nearly impossible. Therefore, using a traditional approach to wireless power measurement results in measurements that are heavily influenced by the measurement device manufacturer and orientation. To address this problem, Aurora Insight conducts measurement with a standardized equipment deployment, ensuring consistency in measurements and repeatability across measurement campaigns even in the toughest multipath environments. Our engineers architect all of our measurement processes from the ground up as opposed to outsourcing it to custom silicon, making our approach to wireless power measurement principled, transparent, accurate, and explainable, resulting in data that is more representative of how users will experience the network regardless of the type of equipment in use.

1 Introduction

In today's wireless environment, the radio frequency (RF) spectrum is more crowded than ever, which is increasing pressure on operators to deploy wireless networks with maximum efficiency. A foundational pillar of network analysis is wireless power measurement. Oftentimes, this metric is misunderstood and oversimplified by the test and measurement community. In this whitepaper, we approach the familiar metric of power from first principles and demonstrate how Aurora Insight can provide superior solutions to wireless power measurement.

2 First principles

Radio frequency (RF) energy is typically generated by an alternating current in a radio and is radiated into free space by an antenna. This energy is distributed across the surface of the wavefront according to the radiation pattern associated with the antenna. In order to better visualize the power distribution across this expanding sphere, it is sometimes scaled according to the density of the power on its surface as illustrated in Figure 1. As the wavefront moves farther away from the emitter, this finite energy is necessarily spread farther and farther across the surface of the spherical wavefront. The finite energy and expanding surface area of the wavefront lends itself to the concept of power flux density, usually measured in watts per square meter. Thus, when discussing RF power in the context of a wireless network without regard for a specific receiver antenna, what we are really discussing is power flux density.

3 Challenges to power measurement

Any observation of an RF wavefront is accomplished with a transducer, such as an antenna, through which the expanding sphere of emitted power can be measured. This receiving antenna provides a filtered view of the RF environment via an abstraction called effective aperture. Effective aperture is a way of characterizing an antenna's ability to absorb the latent RF energy as a function of angle of arrival (AoA) and frequency, and is expressed in square meters, thus providing a convenient means to translate power flux density to watts received at the antenna port.

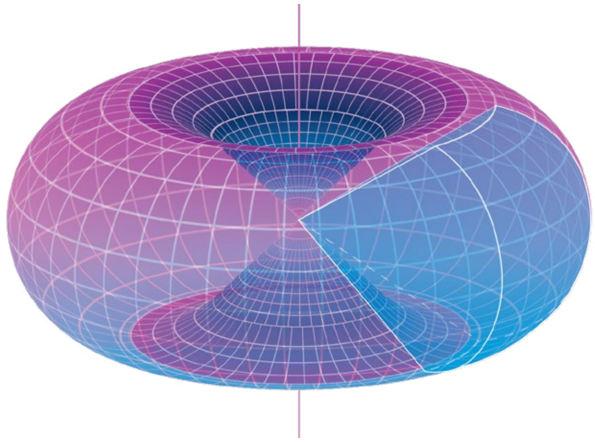

FIGURE 1

Although the phenomenon of RF propagation in free space is strictly spherical, radiation patterns are sometimes scaled according to the density of power on the sphere. For the case of a dipole antenna, the sphere is then transformed to the shape shown here. Effective aperture as a result of the AoA can then be easily visualized.

Because of the filtering effect of the antenna, two measurement devices with different antennas and/or in different orientations are likely to present two different power measurements despite being at the same approximate location relative to the receiver. In an ideal scenario in which the only medium is free space and the AoA is accurately known, one should be able to remove the filtering effect of the antenna and estimate the latent power flux density as the ground truth. This would enable a comparison of power measurements between any two measurement devices regardless of antenna orientation.

However, most communications environments are not so idealized as free space. Consider a typical urban scenario in which user equipment (UE) is traveling in a vehicle while connected to a stationary base station. When either the UE or base station transmits information, the transmission reflects off of urban clutter such as buildings and vehicles regardless of whether or not there is a line-of-sight component in the channel. These reflections are then superimposed at the receiver (along with the line-of-sight signal if there is one). However, each reflection has a random AoA, magnitude, phase offset, frequency offset, and delay. This presents in the frequency domain as frequency-selective fading. Frequency-selective fading results in power loss, which is occasionally catastrophic (called “deep fades”), at random frequencies in the overall band of interest.

The problem of estimating power flux density in a multipath environment is exacerbated when considering modern antenna solutions. Wireless endpoint devices sometimes have complex and proprietary antenna patterns that complicate third-party evaluation and verification. At best, an antenna can be approximately corrected for via stochastic or computationally intensive processes like ray-tracing, but even this approximate correction does not yield an accurate small-scale view of the power at a particular frequency, space, and time.

Antenna patterns can only be accurately compensated for with precise knowledge of both the signal AoA and the beam pattern. Since beam patterns are complicated and sometimes obscured, and the AoAs of each multipath reflection cannot accurately be estimated, no single piece of test equipment is able to lay claim to an objective measure of the latent ground truth.

4 Case study: 5G power measurements

To better describe the difficulty associated with RF power measurement, we present a case study that aims to provide an accurate measure of signal strength in an urban 5G channel. We first begin with the 3rd Generation Partnership Project (3GPP) definition of power that is used in 5G and then demonstrate the sensitivity of these power measurements to measurement methodology with real-world examples.

4.1 — THE 3GPP DEFINITION OF SIGNAL POWER

Although 3GPP defines several measures of power, our focus is specifically on reference-signal-received power (RSRP). RSRP measures the signal power on a subset of the total number of symbols in a transmission. The subset used depends on the type of RSRP that is measured. Among others, 3GPP defines versions of RSRP that are calculated over just the portion of the signal used for synchronization or, alternatively, channel-state information. As these different symbol portions are not required to be the same power, the choice or RSRP type could significantly impact the measured power. Regardless of the RSRP type, a linear average over an undefined time-frequency window of this subset is used for power calculation.[1] This time-frequency window is presumably left unspecified in order to allow for provider-specific implementations. Additionally, the 3GPP stipulates the antenna port as the reference for measuring RSRP; thus, by definition, when measuring RSRP with two different antennas, the measurements should not necessarily be expected to match, even if they are the same type of RSRP. Therefore, any new measurement campaign will face the fundamental difficulties of a relativistic (measurement at the antenna port and type-specific measurements) and vague (no time-frequency window definition for the average) definition.

[1] 3GPP TS 38.215 “Physical layer measurements.”

4.2 — UE VS. AURORA DATA

To understand the nuances of an RSRP-focused measurement campaign, we present time-series data collected simultaneously by a Samsung Galaxy S21 (termed hereafter "UE") and an Aurora Insight sensor. Over the course of the experiment, both the UE and Aurora Insight sensor were stationary and measured the RSRP of a single 5G cell. The Aurora Insight sensor measured RSRP based on the portion of the downlink signal used for synchronization. RSRP values were reported for every synchronization block of the 5G downlink. The UE utilized a different portion of the downlink signal used for channel state estimation, although the time-frequency window and rate at which RSRP was reported by the UE is unknown, as these parameters are typically implemented at a very low level in the UE silicon. Every 10 minutes, the UE orientation was changed to demonstrate the sensitivity associated with the deployment of measurement equipment. In a traditional measurement campaign, UEs may be placed inside a vehicle. In contrast, Aurora Insight deploys antennas outside the vehicle, which dramatically improves signal consistency.

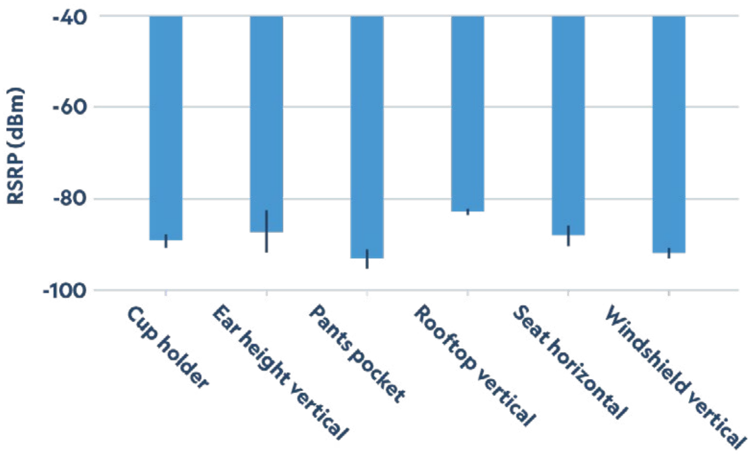

FIGURE 2

Stationary UE measurements of the same 5G cell RSRP for different UE orientations

FIGURE 3

Comparison of stationary Aurora Insight sensor RSRP measurements vs. stationary UE RSRP measurements for the horizontal seat UE orientation

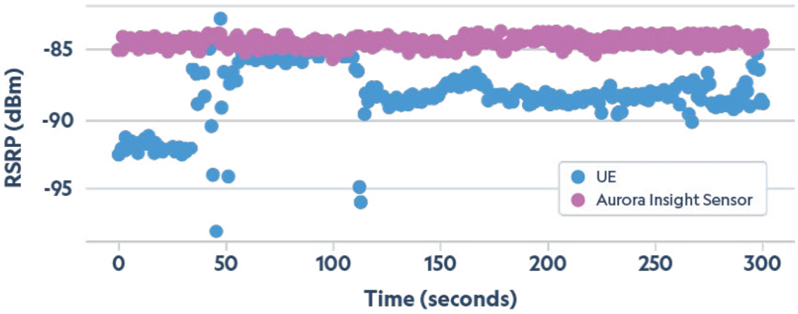

Figure 2 illustrates the results of these measurements. Each bar and whisker in the histogram corresponds to the mean and standard deviation of measurements taken by the UE in a particular orientation. The data shows large variation in the UE measurements as its orientation is changed. Further, the UE data mean is dependent on orientation and location of the UE relative to its environment. Even with the UE in a stationary position, minor orientation changes can have a major impact on reported RSRP.

Figure 3 depicts time-series measurements taken concurrently by the Aurora Insight sensor and the UE in the horizontal seat orientation. The results clearly show that even when the UE is stationary and in a fixed orientation, the Aurora Insight sensor provides a more consistent RSRP measurement over time. It can be assumed that this consistency is a direct result of careful antenna presentation outside the vehicle.

5 Modern precision power measurement solutions

Most endpoints (such as a UE in the cellular ecosystem) not only make uncorrected power measurements at the antenna port after spatially filtering the impinging signal with the antenna, but also apply other more opaque filters such as time-frequency averaging that are not available for adjustment or observation (as in the above example). Additionally, complex protocols allow power to differ over the course of a single transmission. Therefore, it is important to clearly define and understand exactly what is being measured. This is further complicated by the compact form factors used by some test equipment that allow for the introduction of variability associated with antenna orientation change across and during sensing campaigns. The potential for variability in UE measurements across both time and manufacturer make the UE-derived measurement a less attractive solution for network analysis. Despite the fact that a network serves UE endpoints, a network operator will derive deeper insight into its wireless environment with a measurement tool that is more consistent, provides a basis for comparison across campaigns, and provides measurements that are truly representative of the network instead of specific equipment. Only with this type of measurement can manufacturer-agnostic network performance and network change over measurement campaigns be accurately inferred.

Aurora Insight performs data collection using a standardized equipment deployment, ensuring the same antenna presentation relative to the environment during every campaign. Our engineers perform all physical-layer processing from the ground up, ensuring our measurement process is reliable, explainable, and transparent. By architecting all of our own signal processing, we avoid outsourcing to custom silicon and offer the possibility to answer unlimited questions about the RF environment, unlike other proprietary software or user interfaces that provide limited insights.

Aurora Insight's first principles approach to RF solutions affords an unparalleled level of precision, sophistication, and flexibility for measuring the wireless environment.

To learn more about how Aurora Insight measures spectrum and wireless networks, contact us at **sales@aurorainsight.com**.

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Aurora Insight empowers wireless-centric decision-makers with actionable insights by accurately and impartially decoding the vast wireless spectrum.

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