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Experimental Assessment of Wireless Performance Under an Elevated Noise Floor

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ABSTRACT

Debugging wireless communication problems in a field installation is difficult, disruptive, and costly. Roaming problems reported after the installation of wireless access points are hard to reproduce since the radio-frequency (RF) environment at an end-user facility such as a data center, hospital, industrial environment, etc. can be uncontrolled, dependent on the radio traffic, the time of day, the location of potentially mobile scatterers, etc. This disclosure describes techniques to reproduce the RF environment found in a given real-life scenario in a controlled RF environment such as a semi-anechoic chamber or a reverberation chamber. Experiments can be easily conducted in order to determine the root cause of failures and to develop and test = solutions.

KEYWORDS

- Anechoic chamber
- Reverberation chamber
- Test and measurement
- Radio frequency noise
- Radio-frequency interference
- In-band noise
- Received signal strength indicator (RSSI)
- Signal-to-noise ratio (SNR)
- Access point
- WiFi
- Zigbee
- Internet-of-things (IoT)
- Root cause analysis

BACKGROUND

Parameters that influence the quality of a wireless communication service include received signal strength indicator (RSSI), radio-frequency (RF) background noise, etc. RF noise, also known as in-band noise or interference, is generated by other client devices on the same wireless channel. Examples of multiple client devices that use common wireless channels include mobile devices such as tablets, laptops, smartphones, etc. that communicate over WiFi or cellular bands; mobile machines such as automated guided vehicles, robots, etc. that use wireless for telemetry and control; Internet-of-Things (IoT) devices such as cameras, sensors, etc. that communicate over Zigbee or Bluetooth; etc.

The ratio of RSSI to background noise is known as the signal-to-noise ratio (SNR). Wireless communication improves in capacity (measured in bits per second) with SNR. A wireless communication network can cover a large area by having multiple, geographically distributed access points (APs) that client devices can connect to as they move through the area. A client device moving from one AP to another is said to be roaming.

Some wireless environments, e.g., data centers, hospitals, industrial buildings, etc., are challenging due to saturation with in-band noise. High levels of in-band noise are typically found in unlicensed spectra (currently 2.4 and 5 GHz, and possibly 6, 7, and other below-12 GHz frequencies in the near future). Access points attempt to compensate for elevated in-band noise by increasing their transmitted powers to achieve an increased RSSI and SNR at the client device. However, increased transmit power makes roaming difficult, because roaming algorithms assume a low level of RF noise and don’t search for another AP if the RSSI is high. High RSSI intended to offset high in-band noise can thus cause client devices to latch to suboptimal APs, e.g., APs with the highest available RSSI but low (negative dB) SNR. Roaming becomes slow, unreliable, and, in some cases, wireless communication can stop completely.

APs use RF measurements made at their location to take decision branches within wireless protocols. However, client devices may sometimes be located far away from APs. RF conditions at the client and the AP rapidly de-correlate with distance. Consequently, real-time traversing of protocol branches or modification of radio settings that are not based on radio conditions at the client device can generate suboptimal or inadequate wireless and roaming performance.

Most wireless interfaces (e.g., network cards) found in client devices and APs are not designed to operate in high-noise RF environments. As mentioned earlier, roaming algorithms assume a suitably low level of RF noise. Client devices generally do not measure the received level of RF noise, and, if they do, they do not communicate their measurements to APs. As a result, when the RF noise is high (low SNR) and comparable to the wireless communication signal strength (RSSI), the quality of wireless communication can degrade significantly or stop entirely, and yet, client devices may not search for a different AP unless the RSSI (as opposed to SNR, a truer measure of channel quality) drops below a preset value, usually around -70 dBm. It is not uncommon to find client devices not using APs with the highest available SNR.

Debugging these types of wireless communication problems in a field installation is difficult, disruptive, and costly. Roaming problems reported after the installation of APs, while serious, are often hard to reproduce, as the RF environment at an end-user facility such as a data center, hospital, etc. can be uncontrolled, dependent on traffic, time of day, location of potentially mobile scatterers, etc.

DESCRIPTION

This disclosure describes techniques to reproduce the RF environment found in a given real-life scenario such as in a data center, hospital, industrial environment, etc. in a controlled RF environment such as a semi-anechoic chamber or a reverberation chamber. Experiments can be conducted easily to determine the root cause of failures, and to develop and validate appropriate solutions. A proposed solution can be tested in the lab before being ported into the field, without risking the functionality or productivity of the real-life environment that is being reproduced.

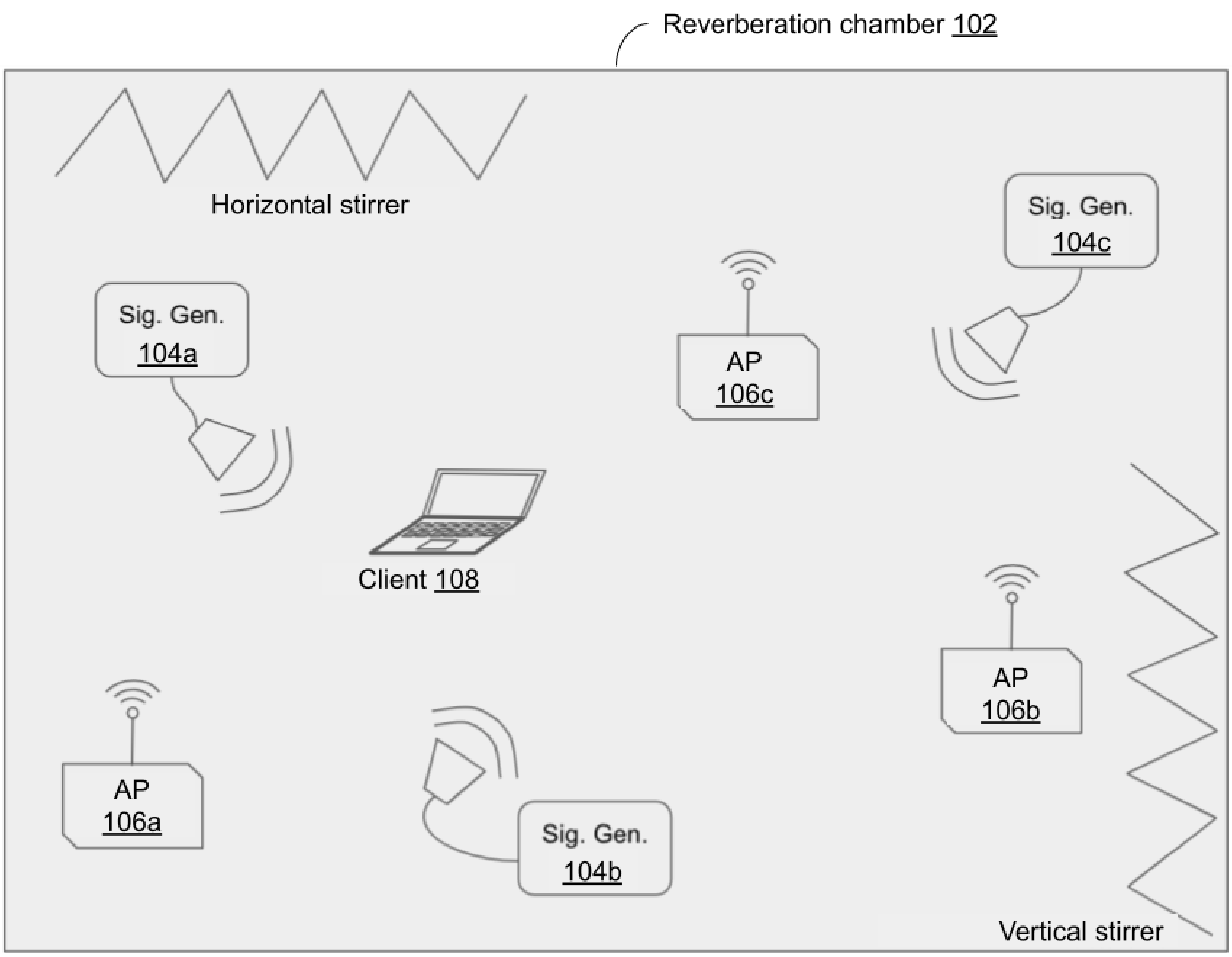

Fig. 1: Example configuration of client devices, signal generators acting as noise sources, and access points inside a reverberation chamber

Fig. 1 illustrates an example collection of a client (108), multiple signal generators (104a-c) acting as noise sources, and access points (106a-c) inside a reverberation chamber (102), configured for the purposes of testing performance under a close simulation of a real-life scenario with high in-band noise. The signal generators simulate competing client devices (or other emissions in unlicensed bands) by emitting in-band noise. The client devices and the access points can be variously configured for protocol settings, radio settings, channel-selection procedures, etc. to test for performance.

The noise sources can be configured for noise level, bandwidth, spectral shape, time variation, etc., to closely simulate the real-life scenario being reproduced. The numbers and locations of RF noise sources, access points, and client devices can be selected based on the goals of the experiment. The various components of the experimental setup can be controlled remotely by an experimenter over a general-purpose interface bus, and are described in greater detail below.

- A shielded room, a semi-anechoic chamber, or a reverberation chamber (102) where APs and RF noise sources are placed. The shielded room, the semi-anechoic chamber, or the reverberation chamber serve the purpose of preventing the entry of RF noise external to the experimental setup, e.g., external APs, intentional radiators, etc., which can pollute the ambient environment of the experiment. Internal to itself, a reverberation chamber can reproduce noise coming from all possible directions at the same time.
- One or more controlled noise sources that can generate the same (or similar) RF noise characteristics at frequencies measured (or expected) in the real-life scenario being reproduced. As illustrated, an RF noise source includes an antenna connected to a signal generator (104a-c) and to a power amplifier as necessary. The signal generator can be programmed to generate the same RF characteristics as the noise measured in the field.

The noise level can be changed as necessary. For test robustness, the noise level can be adjusted to a level higher than what is realistically expected in the field.

- One or more APs (106a-c) to test wireless communication performance and roaming capabilities. The AP settings can be programmed to reproduce a given scenario that is similar to a real-life case. The APs can also be manipulated to study the effects of different settings, roaming protocols, RSSI levels, etc.
- One or more wireless communication client devices (108) of different types (e.g., smartphone, laptop, IoT device) to test or reproduce performance characteristics and abilities of the client devices under given RF conditions and AP settings (RSSI, roaming protocols, selected channels, etc.).

Roaming between different APs can be reproduced by moving the client devices closer or further away from one of the APs, by reducing the RSSI of the AP to which the client is presently connected to, etc. Reducing the RSSI forces the client to search for another AP with a stronger RSSI. RSSI reduction can be achieved by changing the AP settings, by placing an RF attenuator just before the AP antenna, by partially shielding an AP to reduce its signal strength as received by a client, etc.

Setting different APs to use the same channel simulates co-channel interference between the APs, which enables a study of the response of client devices to co-channel interference. RF interference can be reproduced by programming the signal generators to generate RF noise in the channel used by the wireless client. RF noise can be broadband or narrowband depending on the type of noise characteristics being reproduced. Different types of RF interference, e.g., additive white Gaussian noise (AWGN), interference with the spectra of common RF signals such as Bluetooth, 5G, intentional radio, etc., can be used based on the goals of the experiment.

The signal generators can also be configured to generate noise that is not strictly in-band but still can interfere with client devices. For example, a strong out-of-band RF signal in close proximity to the client can saturate the power amplifier of the wireless card, thereby creating interference). Broadband interference can be generated by configuring the signal generator to simultaneously produce noise in multiple adjacent channels. The output power level of the signal generator can be adjusted according to the target noise level at the client device.

The described techniques can advantageously be used to study and optimize the wireless performance of client devices in a variety of industrial, corporate, or residential settings. In particular, the techniques can be used to:

- Design and improve wireless infrastructure; optimize AP and radio settings; optimize AP density; quantify the robustness of proposed wireless solutions; define RF noise specifications, study de-sense and co-channel interference effects on wireless client devices; select the most appropriate wireless client devices for a given application; test client devices in different RF conditions; develop next-generation wireless devices and protocols; etc.
- Assess the wireless connectivity and performance of different client devices in the presence of elevated RF noise levels (e.g., manufacturer A versus manufacturer B).
- Develop or adjust wireless communication protocols robust to real-life noise and interference conditions.
- Reproduce roaming conditions typically found in specific environments such as data centers, industrial buildings, hospitals, offices, airports, stadiums, etc.
- Establish RF noise limits for various products and assess the risk associated with differing levels of RF noise.

- Experiment with AP settings, handoff, and roaming algorithms.
- Use direction-of-encounter (DoE) to improve the roaming, robustness, and reliability of wireless communication.
- Experiment with and validate the expected performance of new wireless technologies prior to costly field deployment.

CONCLUSION

Debugging wireless communication problems in a field installation is difficult, disruptive, and costly. Roaming problems reported after the installation of wireless access points are hard to reproduce since the radio-frequency (RF) environment at an end-user facility such as a data center, hospital, industrial environment, etc. can be uncontrolled, dependent on the radio traffic, the time of day, the location of potentially mobile scatterers, etc. This disclosure describes techniques to reproduce the RF environment found in a given real-life scenario in a controlled RF environment such as a semi-anechoic chamber or a reverberation chamber. Experiments can be easily conducted in order to determine the root cause of failures and to develop and test solutions.