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Simplified and reliable channel modeling for Aerospace, Defence and 5G

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Abstract:
Currently, a lot of new, high performance communication radio links are being developed and implemented. In the military and in safety-critical missions mesh radios are used in the VHF and UHF region. In the civilian domain new mobile phone frequencies and transmission technology are being developed such as 5 G, which is going to be used in safety critical applications such as autonomous driving. These safety critical applications require new and better test approaches, than have been available so far. In addition, there are more and more satellite communication links for ground-satellite and satellite ground communication. Creating a robust RF test plan for tactical and other mission critical radio systems requires specialized techniques. The standard RF channel modeling used in typical cellular and Wi-Fi tests can fall short. Mission critical devices encounter higher Doppler, lower frequency ranges, multiple device-to-device paths and other challenges that make standard channel models and test approaches unsuitable. This paper will examine the unique aspects of tactical and other mission critical mesh radio systems and their impacts on propagation.

Key words: satellite communication, 5G, channel modeling, fading

Introduction

In recent years, there has been more and more communication traffic wirelessly transmitted on different Radio Frequency bands. Both the number of services and the data volume have increased. Mobile phone usage and diversity of apps have exploded, and new technologies are being developed all the time both in the military and in the civilian domain. More and more small satellites are being launched to Low Earth Orbit LEO, contributing to an ever increasing RF communication data stream from ground-to-satellite and from satellite-to-ground. In the satellite case challenges are high Doppler shifts due to high velocity of satellites and sometimes significant signal delays due to long distance of signal propagation. In the military domain, lower RF frequencies are used in mesh networks, to enable communication between multiple participants on the ground, from ground-to-flight, and from coast to marine vessels and back. Challenges are safety and robustness, interference mitigation and obscuration, e.g. when using hand-held radios in uneven terrain, behind rocks and in forests, or near buildings.

Nowadays the military is also looking at 5-G in C5ISR Command, Control, Computers, Communication, Cyber, Intelligence, Surveillance, Reconnaissance, Systems, for discovering, selecting, organizing, filtering and sharing information to achieve ultimate situational awareness during field operations.

In summary, this means, that data transmission via radio channels at different frequencies and especially at 5G is becoming increasingly important, and in many cases human lives depend on it. Thus, it needs to be robust and reliable for safe, secure and trustworthy operations and data transmission. This can be ensured and improved with proper testing before deployment in the field.

Radio Channels

Signal propagation takes place between the transmitter and the receiver over the air or over parts of space outside the atmosphere and the air and thus always needs to cross the atmosphere. On its path, it is subject to many atmospheric effects and disturbing factors, that will impact and attenuate the signals. "The signal propagation over the radio channel is affected by free-space loss, ionosphere, troposphere, fading, multi-path, shadowing and interference" [2]. In the atmosphere, radio signals will be delayed, attenuated and phase-shifted, e.g. by charged ions in the ionosphere [1,2]. Distance plays a major role, as "every doubling of the distance cuts the received power by a factor of four". [3] Radio signals can and will interact with each other, resulting in constructive and destructive interference, and sometimes create signal energy at frequencies

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other than the original frequency, leading to new peaks in other bands, different from the original transmission frequencies. “Sources on different frequencies could be creating harmonics or spurious noise that appear in our band”[3] Such effects are called intermodulation effects.[7] Anything in the environment can cause reflections. The reflections “typically arrive with different delays and power levels and from various angles of arrival. Even in the simplest case, where we have an unobstructed line of sight, there are still ground reflections that arrive at the receiving antenna in-phase or out-of-phase with the primary signal and thereby cause higher or lower received power levels. Some obstructions may block signals entirely, while others may partially absorb RF energy. Barriers, such as structures, weapon systems and armored vehicles have a wide variety of reflectivity and absorption characteristics, which may also vary considerably depending on frequency” [3].

RF Signals can and will also be affected by Interference and noise. There are many different potential sources. Another radio system may be operating on a nearby frequency, such as WiFi routers or IoT devices. [3]. Non-wireless electronic devices in the area can create RF emissions, such as computers, on-boards devices or weapon systems.[3]

“Movement also causes highly variable fading: even at low speeds and over short distances, a receiver experiences widely fluctuating power levels as the phasing of reflections add up constructively or destructively. When endpoints are moving at higher speeds, Doppler effects come into play and shift the frequency of the received signals” [3,4].

Testing

Since, there are all these different effects, which delay, attenuate, and degrade the propagated radio signals, it is essential to properly test the devices against radio channels before installation and operation in the field. These tests can be performed in the laboratory in a repeatable and controlled way, with automation, enabling much faster and less expensive radio channel validation and thus leading to greater reliability and quality of the communication later in the field. In this paper, we will describe some use cases, which are demonstrating these advantages.

Bench Testing with Basic Channel fading

“Two of the most fundamental characteristics of RF channels that transceivers must cope with are the wide change in received power levels, as the distance increases, and the multitude of multi-path signals as a result of reflection, refraction and scattering. Both conditions can be modeled easily and inexpensively with a tapped delay line.” Multi-path propagation, for instance, “results in numerous copies of the original signal, each arriving at the receiving antenna at slightly different times and with different power levels. The tapped delay line starts with the original signal, and then adds some delay and phase offsets with attenuation to create a second copy of the signal, simulating a reflection. By adding successive stages of delay and attenuation, a power delay profile is created that mimics multipath behavior.” [3]

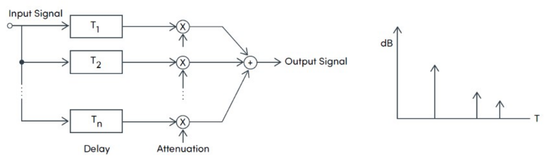

Fig. 1. A tapped delay line uses stages of delay and attenuation to model Multi-path reflections [3].

“The tapped delay line can be built from readily available components and at a relatively small cost. By simulating distance vs. power effects and simple multi-path effects,” it is possible to ”test the basic sensitivity and range of” the receiver and establish the best-case link throughput data rate. The setup gives a way to rapidly iterate on a design, as it is highly repeatable and easily available.” [3] However there is also a drawback, as the test set-up is not realistic. It does not represent all error conditions and environmental effects and is not able to “meet the complexity of modern systems such as 5G that use many (dozens or more) RF channels simultaneously.” [3]

Bench Testing with Channel Modeling and Emulation

To move beyond simple channel power and delay characteristics, requires complex mathematical models. “Channel models are mathematical descriptions of radio signal propagation”. [3] They cannot be described in a deterministic way, as this would involve solving the Maxwell equations in a non-ambiguous way, which is not possible. Another way of dealing with the effects described above, is by representing them as a series of impulse responses. “Channel modeling can be used to describe” signal propagation in time, frequency and space. Modern channel models can use antenna embedding, i.e. 3 D radiation patterns can be included in spatial characterization of the propagation. These effects can be

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combined to create complete scenarios, such as urban and rural models." [3]

A channel emulator will execute these models. "at its simplest, a channel emulator takes in an RF signal, uses digital signal processing to implement the mathematics of a channel model and applies it to the input signal, and outputs the resulting signal." [3] The signals are not interpreted or decoded. Thus, the channel emulator is agnostic to codes and modulation and can deal with any signal in the specified frequency range.

In the last few years, the mathematical modeling of conditions and scenarios has gotten more sophisticated. "Frequency dependent fading, complex multi-antenna-element phasing for beam forming and beam tracking, and arbitrarily complex motion paths can all be modeled mathematically." In addition, "the power of the channel emulator hardware has vastly improved. Today's channel emulators can operate over a broad range of radio frequencies (from VHF Very High Frequencies to millimeter wave), employ state of the art DSP (Digital Signal Processing) and FPGAs to implement complex channel models, and can support large numbers of connections to simulate multiple endpoint scenarios. " [3]

Fig. 2. A channel emulator creates a simulation environment for real RF signals [3].

"A benchtop setup with state-of-the-art channel emulator is a hardware-in-the-loop-environment for modern radio systems. It is capable of emulating urban, rural, indoor and custom propagation model. It can model ground-to-ground RF channels as well as ground-to-air and air-to-air-channels. It allows the user to simulate macro-cell (large radius, high power) and micro-cell (small radius, low power) architectures, with antenna placements at arbitrary heights. It can implement frequency dependent fading effects that are especially important in wide bandwidth and frequency hopping channels. It can simulate the Doppler effects of high speed motion, with user-defined motion paths for transmitters, receivers and reflectors. And it can handle peer-to-peer and mesh network scenarios, where a dozen or more endpoints are communicating with each other, each with a different propagation model comprising" all sorts of different effects, as described above. [3]

VERTEX Channel emulator

Here, we present an example for a channel emulator, the Spirent VERTEX Channel emulator, executing the radio channel emulation in a wide range of frequencies of 30 MHz to 5925 MHZ. This frequency range can be extended to higher frequencies from 6 GHz up to 47.5 GHz with a High frequency converter. Thus, it can operate in mm Wave range, and support military and public safety bands and bandwidth, for instance 5G, LTE, WiFi and military mesh network communication links. It is a modular and scalable system with 2-32 RF Outputs and up to 256 internal digital links. Radio channel bandwidth is 200 MHz. There is the option to concatenate several channels to achieve 1 GHz bandwidth or more. The VERTEX channel emulator enables real-time and I/Q playback channel emulation and is provided with Extensive channel model and connection setup libraries. Channel models can also be modified and defined by the user. Field measured channel models can be loaded and applied [8].

Fig. 3. VERTEX channel emulator

To facilitate scenario creation including movement of receivers and transmitters there is an Advanced Channel Modeling Software (ACM). It supports circular, linear, orbital and static motion. After input of the user settings, it automatically "creates and downloads channel samples to the VERTEX Channel emulator." [5] With a Plugin "Array Modeling Tool" it is possible to visualize antenna array theoretical performance. [6] Virtual Drive Test (VDT) solutions allow field measurement conversions and dynamic emulation engine (DEE) enables dynamic scenarios.

The following conditions can be modeled:

* Urban, long-distance, indoor and custom propagation models
* ground-to-ground, ground-to-air, air-to-air..

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* Antenna heights and ground effects
* Angle spread clusters and 3 D geometry
* Phased Array antennas for MIMO
 and beamforming
* High-speed device motion
* complex motion paths
* Blockers and moving blockers
* Multiple nodes and each with distinct models

A channel emulator can support the following major types of tests

- Conformance Tests to check if a user device conforms to a certain standard such as 3-GPP standards (3-GPP: Third Generation Partnership Program) [12]
- Performance Tests
- Field to Lab: to find out how well does a user device operate in different environments

And it supports simulated drive fly routes for development, performance tuning, trouble shooting and regression and manufacturing parametric validation.

Use Cases

A great variety of 5G civilian use cases can be tested and supported: such as acceleration of 5G development and replacement of field testing for 5G Cellular Vehicle-to-Everything (V2X) chipset validation. A North American OEM used Vertex for assuring 5G chipset performance, and enabling early 5G launch by fast validation of mm Wave communication in an Over the Air Test Setup. In all these cases, a VERTEX test setup has been successfully used to accelerate testing and thus save time.

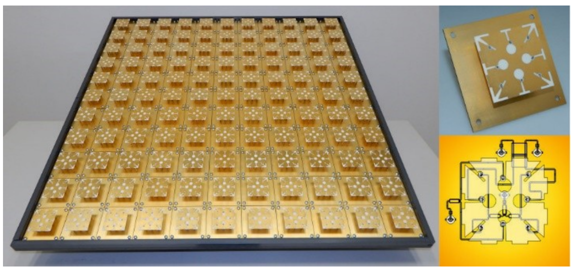

Fig. 4. Multi Mode Massive MIMO Antena Array, by www.hft.uni-hannover.de

Other challenging 5 G use cases, which can be addressed with this technology, are MIMO (Multiple Input, multiple Output) over the Air Testing, massive MIMO with a large amount of antenna elements, mm Wave for fast video communication with high throughput of data, and beamforming [9,10,11].

The spatial channel models of the VERTEX channel emulator were validated in 2021 for 3GPP FR2 (upper Frequency Range of 24.25 GHz – 40 GHz) MIMO Over the Air Tests, for metrics such as Doppler Autocorrelation, Power Delay profile, Vertical to Horizontal Power Ratio and Power Angular Spectrum Similarity Percentage [13].

A test setup for conductive MIMO testing for a network equipment manufacturer was implemented comprising four VERTEX units connected to each other, each with 18 I/O Ports and a sum of 72 I/O Ports. In addition there is a VERTEX Baseband Synchronizer. This complex system was delivered to one of the world's largest network equipment manufacturers.

One major oil and gas company managed to successfully test their own network base station and their high-powered devices before installation in the field with a VERTEX RF channel emulation platform, and thus assured Device Connectivity for specialized Devices and Spectrum.

5G is also considered by the military for applications such as Smart Command Centers, Enhanced Intelligence, Surveillance and Reconnaissance, unmanned operations, smart warehouse and logistics and health and supply monitoring. In every case, controlled and repeatable testing will make a big difference in reliability and quality and robustness of communication in field operation under real conditions.

Traditional military use cases are usually characterized by lower frequencies, higher velocity, mesh networks and complex ground-to-air radio channels. Some Examples: Testing has been performed for handheld radios in the field with obscuration by rocks and forests and also for verification of mesh network design with testing multiple radios simultaneously under a variety of channels, network configurations and implementations. [15]

In the Aircraft field, a Military contractor needed to simulate high-speed beamforming scenarios for several flight to ground applications, where a beam from the base station needed to track the flight. They were able to test their beamforming performance with a VERTEX system plus a Live Streaming Dynamic Environment Emulation. [15]

Satellite-to-ground and ground to satellite radio channels can suffer from long delays of up to 1-2 seconds and a very high Doppler shift, due to the high speed of satellites in orbit. The above test system was used to simulate satellite to ground connectivity with dynamic scenarios including moving vehicles. [13]

Conclusion

Data transmission via radio channels at different frequencies and especially at 5G is increasingly important, and needs to be robust and reliable for safe, secure and trustworthy operations, in all sorts of communication applications, both military and civilian, ground-to-ground as well as air-to-ground, satellite-to-ground and vice versa, and many more.

Radio channel modeling is a way to represent environmental conditions, fading, attenuation and different types of potential errors.

Here we present a versatile tool to test all sorts of communication signals' fading, by applying channel models to them, across a very wide frequency range. The signals are not interpreted or decoded, which results in the possibility to test fading with any type of signal.

We have also shown a wide range of use cases, in 5G communication, in aircraft and satellite communication and in the military domain, where this type of testing has been successfully implemented and used.

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