Design and characterization of cost effective planar antennas with steerable beams: Gap waveguides, SMT and Random-LOS (Part II)

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Abstract: In order to characterize the OTA (Over-The-Air) system performance of wireless devices, such as smart phones or base stations, we need to consider various factors. For example, the type of propagation channel in which they are expected to operate, the type of communications standard, system parameters (e.g., coding and modulation), the frequencies and bandwidths of operation, the number of transmit/receive antennas, as well as the actual transmit/receive algorithms used to produce single or multiple data bit streams.

Knowing the most representative propagation channel behavior for your specific application is not a minor undertaking. For handheld devices and small base stations it was early shown that the spatial behavior of the impinging waves at these devices could be approximated by the so-called RIMP (Rich Isotropic MultiPath) environment. If properly designed, a reverberation chamber can be used to emulate the RIMP channel with high accuracy. It has been shown that antenna diversity and MIMO performance can be determined for multi-port arrays in reverberation chambers, with well-defined diversity gains [1]. The standard deviation of the measurement errors obtained in RIMP is typically within 0.5 dB or smaller. At higher frequencies, e.g., up to 30, 60 GHz or higher the multipath waves (i.e., the RIMP contribution to the total receive signal fluctuation) will be weaker as compared to the direct line-of-sight (LOS) wave. The LOS component behaves randomly in real life. This randomness appears due to the randomness induced by the orientation and/or position of the wireless device, often at the user end. Hence, in addition to the well-known RIMP propagation channel, the Random-LOS environment is proposed as a new complementing reference propagation scenario [2]. The RIMP and the Random-LOS provide two idealized yet well-defined edge propagation channels for this purpose. While the RIMP can be emulated in reverberation chambers, the Random-LOS is emulated in anechoic or rather in semi-anechoic chambers [3].

In OTA characterization of active and passive devices, system related parameters are often fixed by the standards. Therefore, good system models are needed. The ideal threshold receiver model devised in [4] has been shown to work well for current LTE/LTE-A and WiFi communications standards. The model makes it easy to incorporate system specific parameters and receive/transmit algorithms over the whole bandwidth of operation of the device as well as the use of multiple antennas at both ends of the communication link. The probability of detection
(PoD) of single or multiple bit streams is used as a measure of system performance in terms of relative data bit stream throughput. Excellent agreement has been achieved between theory and experiment [5]. In 5G systems, both the RIMP and the LOS propagation channels provide favorable propagation conditions for communications systems employing massive MIMO array antennas. The development, testing and characterization of new wireless technologies will heavily depend on OTA techniques. Especially, given the practical constraints by the huge number of antenna elements and the lack of a testing port at the mm-waves frequencies.

The combination of the ideal threshold receiver model with the two limiting environments RIMP and Random-LOS are linked together by a real-life hypothesis: “If a wireless device is tested with good performance in both pure-LOS and RIMP environments, it will also perform well in real-life environments and situations, in a statistical sense” [2].

**Keywords:** 5G, Over-The-Air (OTA) characterization, active and passive OTA measurements, Random Line-Of-Sight (Random-LOS), Rich Isotropic Multipath (RIMP), system performance, array antenna, wireless device, automotive.

**References:**
Andrés Alayón Glazunov (SM 2011) was born in Havana, Cuba, in 1969. He obtained the M.Sc. (Engineer-Researcher) degree in Physical Engineering from Peter the Great St. Petersburg Polytechnic University, Russia, and the Ph.D. degree in Electrical Engineering from Lund University, Sweden, during 1988-1994 and 2006-2009, respectively. From 1996 to 2001, he was a member of the Research Staff at Ericsson Research, Ericsson AB in Kista, Sweden, where he conducted research in the areas of advanced receiver performance evaluation for UMTS, applied electromagnetic wave propagation and stochastic channel modelling for wireless communications systems. During this period he also contributed to the European COST Action 259 project in the directional channel modelling working group. In 2001, Alayón Glazunov joined Telia Research, Sweden, as a Senior Research Engineer. Later, starting 2003, he held a position as a Senior Specialist in Antenna Systems and Propagation at the newly formed TeliaSonera Sweden, where he pursued research in smart antennas and MIMO, network optimization and Over-The-Air (OTA) performance evaluation of handsets and their impact on wireless network performance. From 2001 to 2005 he was the Swedish delegate to the European COST Action 273 and was active in the handset antenna working group. He has been one of the pioneers in establishing OTA measurement techniques. He has contributed to the EVEREST and NEWCOM European research projects as well as to the 3GPP and the ITU standardization bodies. During 2009 and 2010, Alayón Glazunov held a Marie Curie Senior Research Fellowship at the Centre for Wireless Network Design (CWiND), University of Bedfordshire, UK. From 2010 to 2014 he was a post-doc at the Electromagnetic Engineering Lab, KTH-The Royal Institute of Technology, Stockholm, Sweden. Alayón Glazunov is currently an Assistant Professor at the Division of Antenna Systems at the Department of Signals and Systems, Chalmers University of Technology, Gothenburg, Sweden.

Andrés Alayón Glazunov is the author of various scientific and technical publications. He is the co-author and co-editor of LTE-Advanced and Next Generation Wireless Networks (Wiley 2012). His current research interests include, but are not limited to, statistical signal processing, electromagnetic theory, fundamental limitations on antenna-channel interactions, RF propagation channel measurements, modelling and simulations for network optimization, and OTA testing of wireless devices.

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What is the focus?

- **Over-The-Air (OTA) performance characterization** of wireless devices and antennas.

- OTA characterization focuses on system performance, e.g., bit stream throughput.
- Requires system modelling.
- Communications systems (e.g., LTE/LTE-A and 5G) are complex!
OTA

- Over-The-Air characterization means that the testing is performed for signals that go through the radio propagation channel.
- Not through cables connected to a testing port!
OTA Characterization

• Over-The-Air characterization means that the testing is performed for signals that go through the radio propagation channel
• Hence, antenna impact on system performance must be taken into account too.
Why OTA Characterization?

- 5G systems may increase the number of antennas at the base station by a factor 10 or 100 (massive MIMO).
Why OTA Characterization?

• In the Internet-of-Things (IoT) paradigm everything radiates.
Why OTA characterization?

• In 5G and beyond systems mmW and even THz frequencies will be used. Components’ sizes will become very small; most likely devices will have no testing port.

• Hence, potentially, the performance of 100s of small antennas in a device must be characterized.

• *Individual characterization of antenna elements integrated in a system will not be feasible!* 

• *OTA-aided antenna design will become crucial!*
Radio Propagation Channel

- It is the set of all objects between the transmit and the receive antenna ports that have an impact on the propagation of the transmission and reception of electromagnetic signals (e.g., radio waves: 3 kHz – 300 GHz)
- Radio Propagation Channels Are Very Complex to model to fully cover all possible relevant scenarios!
Short Summary

• Detailed characterization of
  — Throughput (as well as any other relevant figures of merit)
  — in Realistic Propagation Channels
    is in general a very complex task!

• Testing systems become too expensive!

• End users can’t afford the expenses!
What to do?

• We need simple yet accurate enough models!

• Proposed approach:
  — System model: The ideal threshold receiver model
  — Propagation model: Two edge propagation environments
    • Rich Isotropic MultiPath (RIMP)
    • Random-Line-Of-Sight (RLOS)
2 limiting environments
Two Limiting Propagation Channels

**RIMP:** Rich Isotropic MultiPath

**PLOS:** Pure Line of Sight

- **PLOS-PLOS**
- **PLOS-RIMP/RIMP-PLOS**
- **RIMP-RIMP**
The Kildal Conjecture

• If a wireless device works well both in the RIMP and in the Random-LOS environments, it will also work well in real-life environments.
How to realize the two extreme reference environments

<table>
<thead>
<tr>
<th>Environment</th>
<th>Equivalent measurement method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free space (pure-LOS)</td>
<td>Anechoic chamber</td>
</tr>
<tr>
<td>Real-life environments</td>
<td>Expensive drive tests</td>
</tr>
<tr>
<td>Rich isotropic multipath (RIMP)</td>
<td>Reverberation chamber</td>
</tr>
</tbody>
</table>

**Kildal Conjecture**: If a wireless device works well both in the RIMP and in the random pure-LOS environments, it will also work well in real-life environments.
Ideal Threshold Receiver

For example: This is the threshold $P_{th}$ (or sensitivity) of the receiver in LTE mobile terminal.

“Conducted Throughput” determines the “threshold of the receiver” OR “sensitivity of the receiver”
OTA Throughput and MIMO efficiency

- The 95% throughput level is typically of interest in MIMO Systems.
- MIMO efficiency defined as:
  \[
  \eta_{\text{MIMO}} = \frac{\text{PoD}_{\text{ref}}^{-1}(0.95)}{\text{PoD}_{\text{ref}}^{-1}(0.95)}
  \]
- The MIMO efficiency describes the amount of additional transmit power (or receiver sensitivity) required to achieve the desired relative throughput in at least 95% of cases.
Applications

- RIMP has been successfully implemented and commercialized by the Chalmers’ spin-off company Bluetest.

- Random-LOS is currently being developed, especially with focus on the automotive industry.
• The automotive (3G+4G) Random-LOS concept has been already verified together with Volvo
Random-LOS OTA-aided bowtie designs, 2-port realization

First  Second  Third

MIMO multiplexing efficiency in Random-LOS within hemispherical coverage
2-bitstream MIMO throughput Coverage in Random-LOS

f = 1.7GHz

f = 2.2GHz

f = 2.7GHz
The effect of the channel gain on 2-bitstream MIMO throughput Coverage in Random-LOS

- $f = 1.7$GHz
- $f = 2.2$GHz
- $f = 2.7$GHz
The effect of the orthogonality on 2-bitstream MIMO throughput
Coverage in Random-LOS

\[ f = 1.7\text{GHz} \]

\[ f = 2.2\text{GHz} \]

\[ f = 2.7\text{GHz} \]
Summary

• RIMP and Random-LOS characterization provide relevant insights and concrete performance measures of the OTA system performance of wireless devices and antennas.

• OTA characterization of antenna systems and wireless devices will be essential for the development of new wireless technologies, e.g., for 5G and beyond systems as well as the IoT society.

• OTA-aided antenna system design following the Kildal conjecture is an enabler of.
Essentially, all models are wrong, but some are useful.

(George E. P. Box)

“Everything should be made as simple as possible, but not simpler.”

Albert Einstein

MANY THANKS FOR LISTENING!

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