Measurement Procedures for Design and Enforcement of Harm Claim Thresholds

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Overview

• Harm claim thresholds (HCTs) are expressed in terms of measurable criteria on interference, e.g. in terms of field strength

• HCTs enable regulators to specify the interference environment in which a wireless system is expected to operate

• Observations (modeling and/or measurements) play a critical role for enforcement and initial design of HCTs

• In this work we make a first comprehensive proposal for how spectrum measurements should be treated for these purposes
Harm Claim Thresholds (HCTs) in Brief

• Answer to: “Is there harmful interference, and who should fix it?”

• Explicit, up-front statement of the interference that systems need to tolerate before operators can bring a harmful interference claim
  – Engineering proxy for the legal construct “harmful interference”

• Incorporates receivers into regulation without using receiver standards
HCT in practice

1. 50 dB(μV/m) per MHz
2. Exceeded at ≤ 5% of locations (95th percentile)
3. At the 95% confidence level

- Make observations (measurements or modeling)
- Construct confidence interval for the given confidence level
- Decide whether to declare HCT violation or not

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- **C.L.**
- **Confidence level**
- **Exceedance percentile**
- **Confidence interval**
- **Band to be protected**
Design Objectives

• **Straightforward to specify** at a high level in rules, e.g. a small number of technology- and service-neutral parameters

• Relatively easy to **accommodate new technologies**, e.g. by updating regulatory bulletins not changing rules

• **Easy to understand and apply**, and in particular should not require sophisticated knowledge of statistics
  – Contain as few parameters as possible
  – Based on ex ante stratification distances rather than estimates derived in the course of a continuous drive test
  – Enable simple estimation and planning of measurements
Motivation – Pitfalls of Naïve Analysis

- Let’s consider a test drive in a 10 km x 10 km square as shown on the right.

- Naïve analysis would take all the 7266 data, compute the percentile, and find high statistical confidence
  - C.I. length < 1 dB

- But **how reliable** are the obtained conclusions?
Motivation – Pitfalls of Naïve Analysis

- The stated statistical confidence is grossly overestimated, caused by treating all 7266 measurements as independent samples.

- However, nearby drive test measurements are always heavily correlated, significantly reducing the amount of information they convey about the underlying field strength.

- Therefore the “true” number of measurements is much lower.

- Further, the measurements are not representative is what an interfered user would be likely to see, as they are obtained in a rural highway environment with low population density.

- Overall, in our example these effects result in close to 10 dB error.
Our Proposal

• To remedy these problems we suggest to use two well-known statistical techniques when analyzing drive test data

• *Stratification* is used to remove correlated measurement points, enabling fair estimation of statistical confidence

• *Weighting* helps to ensure representativeness of measurements, giving more value to samples collected from where users are expected to be

• Results in a substantially simpler scheme than state-of-the-art statistical approaches, at the cost of fewer usable data
Revisiting the Drive Test Data

- When applied to the example data set, stratification reduces the number of sample to 67
  - Details follow

- This is too small number for the results to have any statistical confidence
  - Formally, the confidence interval has infinite length

- Weighting also slightly changes the estimate, but the results are meaningless in any case
Application to a Denser Drive

- When a denser segment of the test drive is considered, very reasonable results are obtained.

- Stratification results in 260 remaining samples from a 10 km x 10 km region.

- Percentile estimate within 1 dB of ground truth obtained from 4+ million samples.

- Population density used as weights, resulting in 3 dB increase in the estimated field strength percentile.
Implementing Stratification

- In the paper we discuss several algorithms for implementing stratification
- Simplest approach is the grid based one, illustrated on the right
- Here *stratification distance* defines the grid length, and just one measurement per square is used
- We use 500 meters
Choosing the Stratification Distance, $d_S$

- **Selection of $d_S$ a crucial choice**
  - Too small $\rightarrow$ spurious conclusions
  - Too large distance $\rightarrow$ drives uneconomical

- **We use a simple similarity measure**
  - Calculate semivariogram $\gamma(r)$ for all pairs in bins $r \pm \Delta$
  - Fit parametric model
  - Choose $d_S \sim$ how close to asymptote

- **Could be derived run-time from data; we recommend fixing in advance**
Considerations on Weighting

• Population density including working time effects (e.g. the ORNL LandScan database) seems like the natural candidate for many wireless services

• However, for services such as aeronautical radars, emergency and military radios, etc. this should be replaced with corresponding receiver density estimates

• Again, choice of weighting should be part of the regulations, and clear for all involved stakeholders
Stratification as Prerequisite for Weighting

- Applying weighting becomes complex if original data are not uniform in space
- Stratification turns the data back to roughly uniform, making weighting easy
- Drive tests often have lots of samples collected at intersections, which needs to be compensated for
Trade-Offs in HCT Parameter Choices

- We also studied in detail the interplay between
  - The chosen HCT percentile ($p$)
  - Desired statistical confidence (C.L.)
  - Number of measurements (after stratification)

1. 50 dB(μV/m) per MHz
2. Exceeded at ≤ 5% of locations (95th percentile)
3. At the 95% confidence level
Trade-Offs in HCT Parameter Choices

• For given $n$, generated 100 samples of $n$ measurements; plot one-sided C.I. length

• HCT percentile
  – Assume $n=260$ measurements
  – Increasing HCT percentile from the 90th or 95th to 99th or higher vastly increases the amount of data needed for enforcement

• Number of measurements
  – Assume 95th percentile
  – 200-300 measurements typically yields estimates accurate to 5 dB or better

\[ n = 260 \]
Determining HCT Thresholds from Measurements

- Key issue is representativeness of measurements: avoid underweighted regions that under-estimate field strengths
- So: add lowest allowable sum weight as additional criterion for admissibility of a test drive
  - Probably not needed for enforcement as bias is downwards
## What the Regulator Needs to Specify

<table>
<thead>
<tr>
<th>Category</th>
<th>Parameters</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>HCT policy</td>
<td>Frequency band</td>
<td>2 GHz</td>
</tr>
<tr>
<td></td>
<td>Percentile of field strength</td>
<td>95th</td>
</tr>
<tr>
<td></td>
<td>Field strength threshold</td>
<td>50 dB(μV/m) per MHz</td>
</tr>
<tr>
<td></td>
<td>Confidence level</td>
<td>95% ( (\alpha = 0.05) )</td>
</tr>
<tr>
<td>Measurement procedure</td>
<td>Stratification procedure</td>
<td>Grid-based</td>
</tr>
<tr>
<td></td>
<td>Weighting method</td>
<td>Population weighting</td>
</tr>
<tr>
<td></td>
<td>Submission of drive data</td>
<td>Complete without gaps</td>
</tr>
<tr>
<td></td>
<td>Responsibility for processing</td>
<td>Claimant</td>
</tr>
<tr>
<td></td>
<td>Requirements on equipment</td>
<td>Standard drive test</td>
</tr>
<tr>
<td>Derivation of ( d_S )</td>
<td>Allowed methodologies</td>
<td>Measurements or data from planning tools</td>
</tr>
<tr>
<td></td>
<td>Threshold semivariance / autocorrelation</td>
<td>Half of saturation value ( (or \ \text{correlation} \leq 0.5) )</td>
</tr>
<tr>
<td></td>
<td>Flexibility in model choice</td>
<td>Exponential only</td>
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</tbody>
</table>
What the Regulator Needs to Specify

• Regulator may wish to separate parameter families
  – high-level, unchanging requirements, e.g. broad policy requirements like field strength, percentile and C.L.
  – more detailed and dynamic low-level specifications, e.g. stratification distances, measurement methodologies

• High-level parameters in regulation

• Low-level parameters in guidance documents
  – From regulator (e.g. FCC OET Bulletins, cf. E911)
  – Delegated to standards bodies (e.g. ETSI guidance on implementing EU Radio Equipment Directive)

• Parties could seek waivers, e.g. to reduce stratification distance when cell densification occurs
Summary and Conclusions

• **Measurements play a critical role** for enforcement of HCTs, and also for their initial design

• We propose a *simple but effective method* for processing measurement data to avoid pitfalls of naïve statistical analysis

• Key ingredients in our approach are *stratification* and *weighting* to ensure fair estimation of statistical confidence and representativeness of the measurements

• Same method can be applied *beyond HCT enforcement*, e.g. for processing of drive test data from cellular networks
Backup Slides
Questions for the Audience

• Other cases where measuring RF environment rather than device behavior might be useful?

• Are there other regulatory measurement problems where our pragmatic simplification could be applied?
  – Could this help in SAS-managed bands, e.g. enforcing Reception Limits on PALs in 3.5 GHz?

• How could this measurement protocol be gamed?
Field Strength CCDF – Naïve Statistical Approach
Field Strength CCDF – Our Method

Field strength [dB(uV/m)/MHz]

Probability of exceedance

HCT violation

56.5

0.05

0.00

20 40 60

Field strength [dB(uV/m)/MHz]