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?”

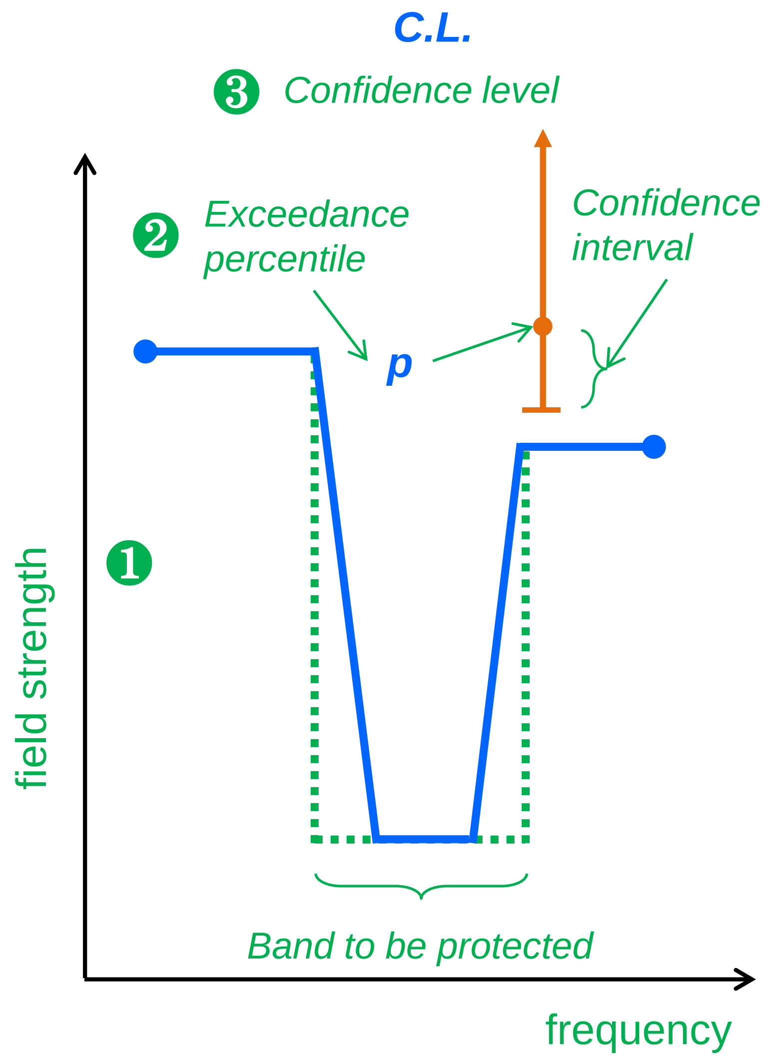
- Explicit, up-front statement of the interference that systems need to tolerate before operators can bring a harmful interference claim
  - Engineering proxy for the legal construct “harmful interference”

- 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

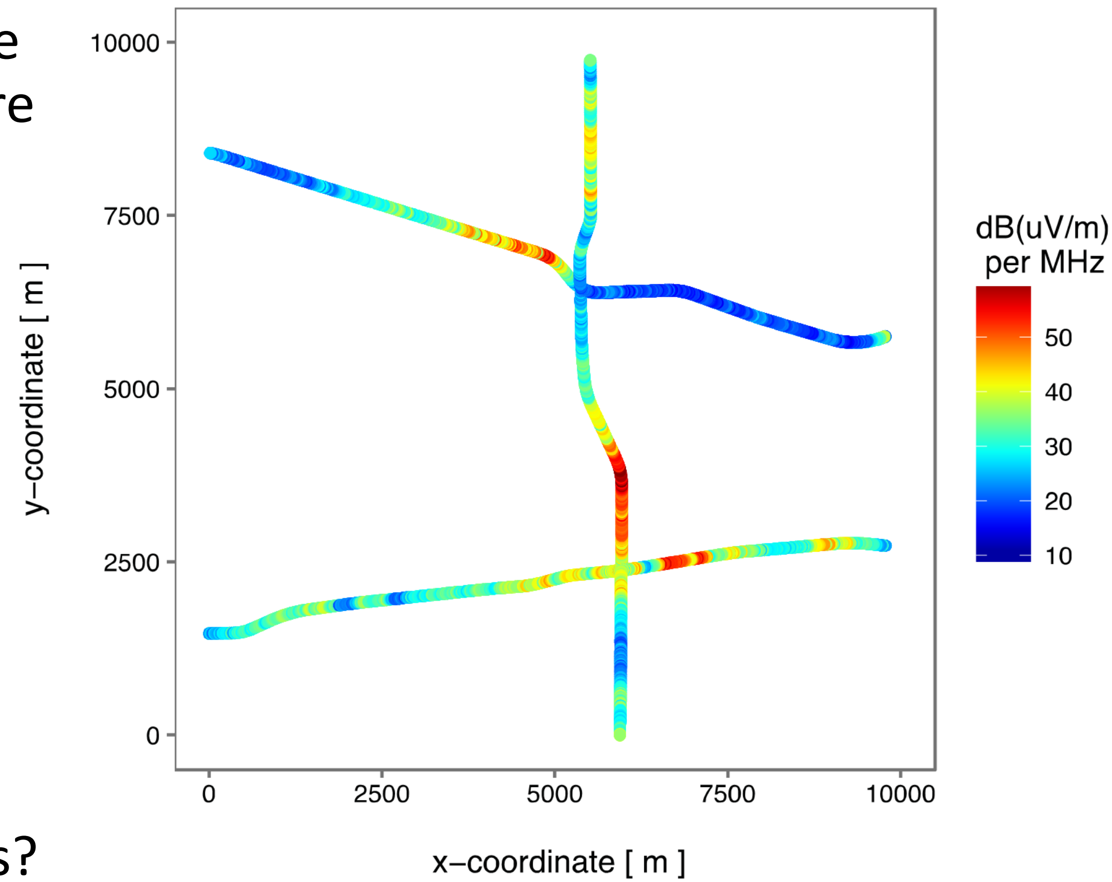


Design Objectives

- ***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?



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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

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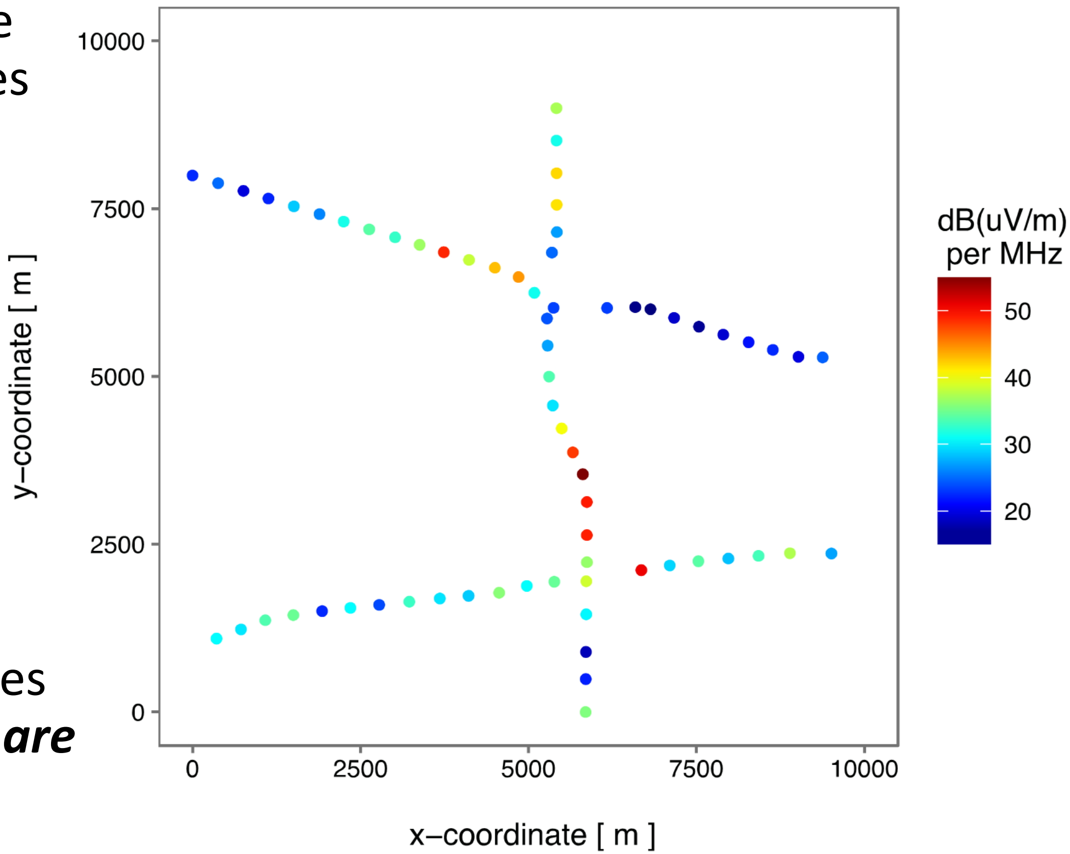
Our Proposal

- 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

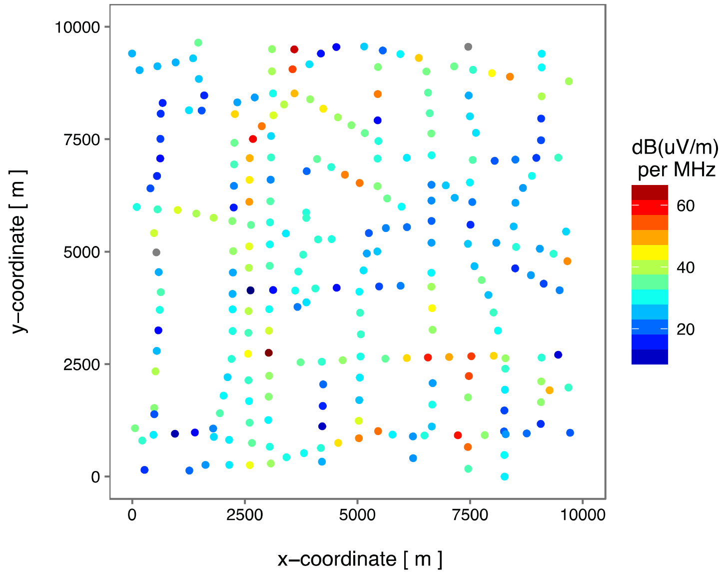
Revisiting the Drive Test Data

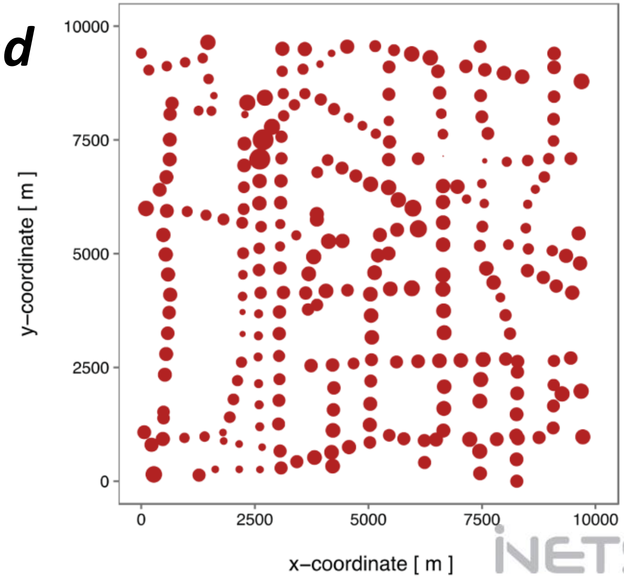
- When applied to the example data set, stratification reduces the number of sample to 67
  - Details follow
- This is too small number for the results to have any statistical confidence
  - Formally, the confidence interval has infinite length
- Weighting also slightly changes the estimate, but the ***results are meaningless*** in any case



Application to a Denser Drive

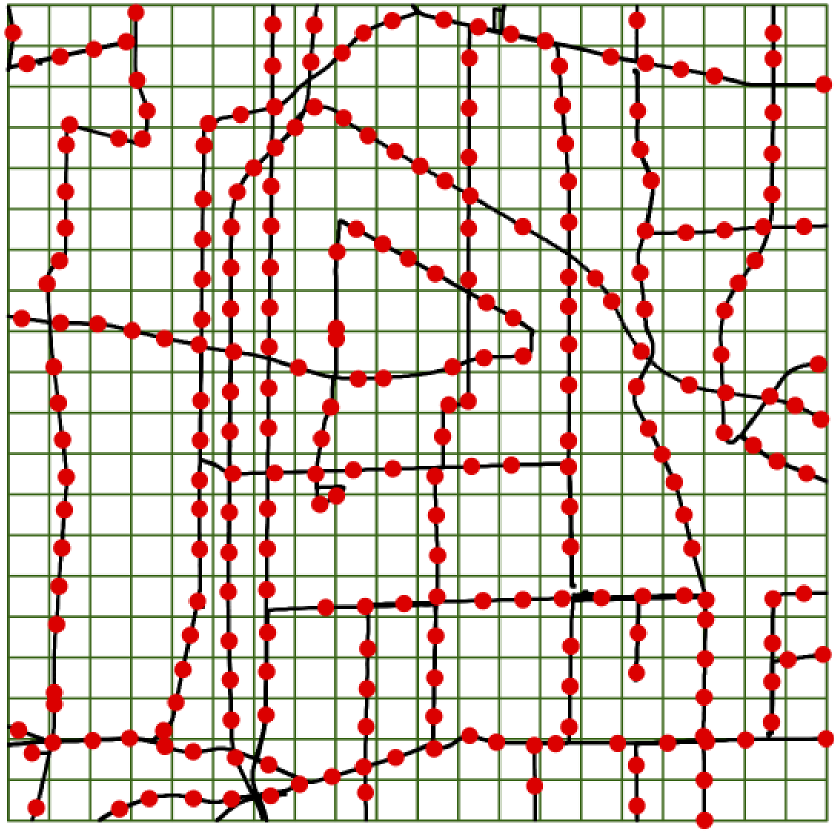
- When a denser segment of the test drive is considered, ***very reasonable results*** are obtained
- Stratification results in 260 remaining samples from a 10 km x 10 km region
- Percentile estimate ***within 1 dB of ground truth*** obtained from 4+ million samples
- Population density used as weights, resulting in 3 dB increase in the estimated field strength percentile





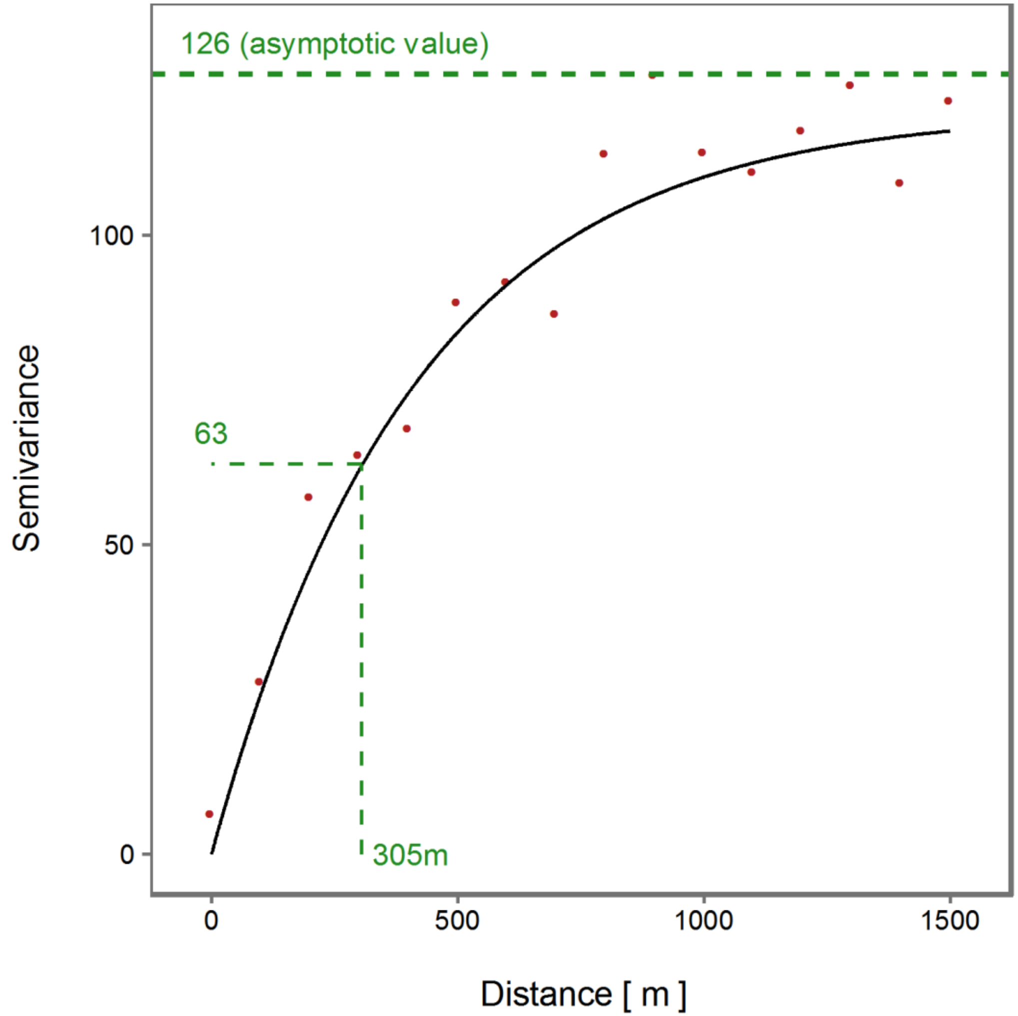
Implementing Stratification

- 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 → spurious conclusions
  - Too large distance → 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 ~ how close to asymptote
- Could be derived run-time from data; we recommend fixing in advance



Considerations on Weighting

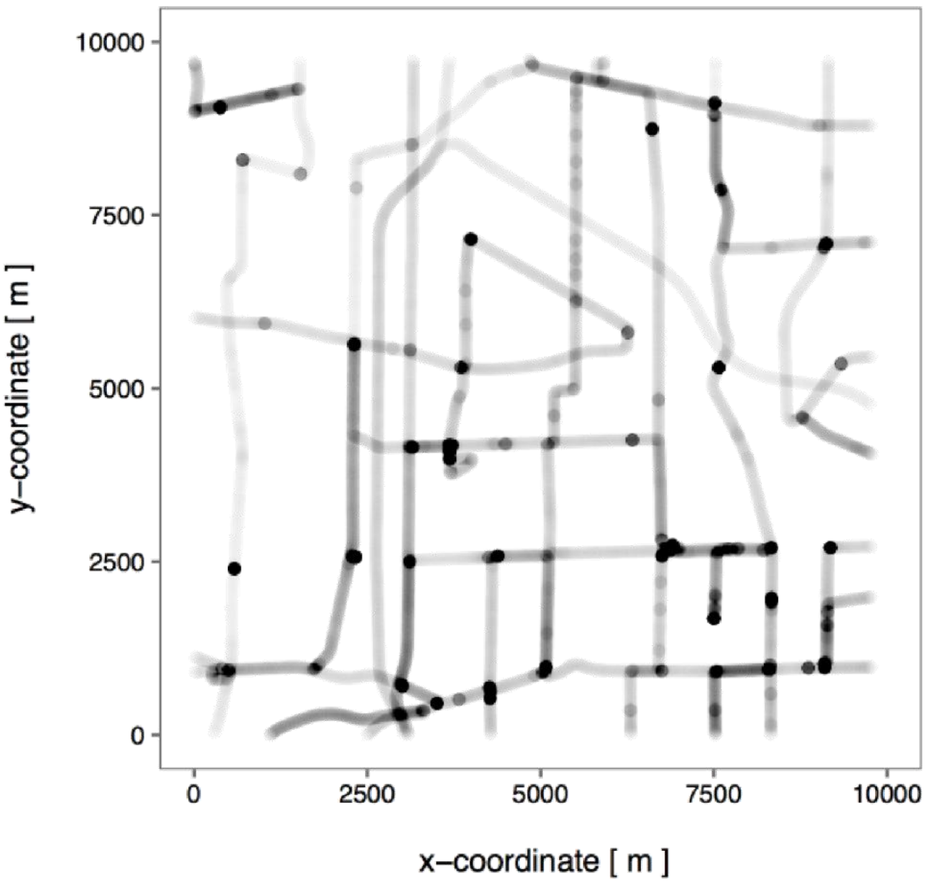
- Population density including working time effects (e.g. the ORNL LandScan database) seems like the natural candidate for many wireless services

- 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)

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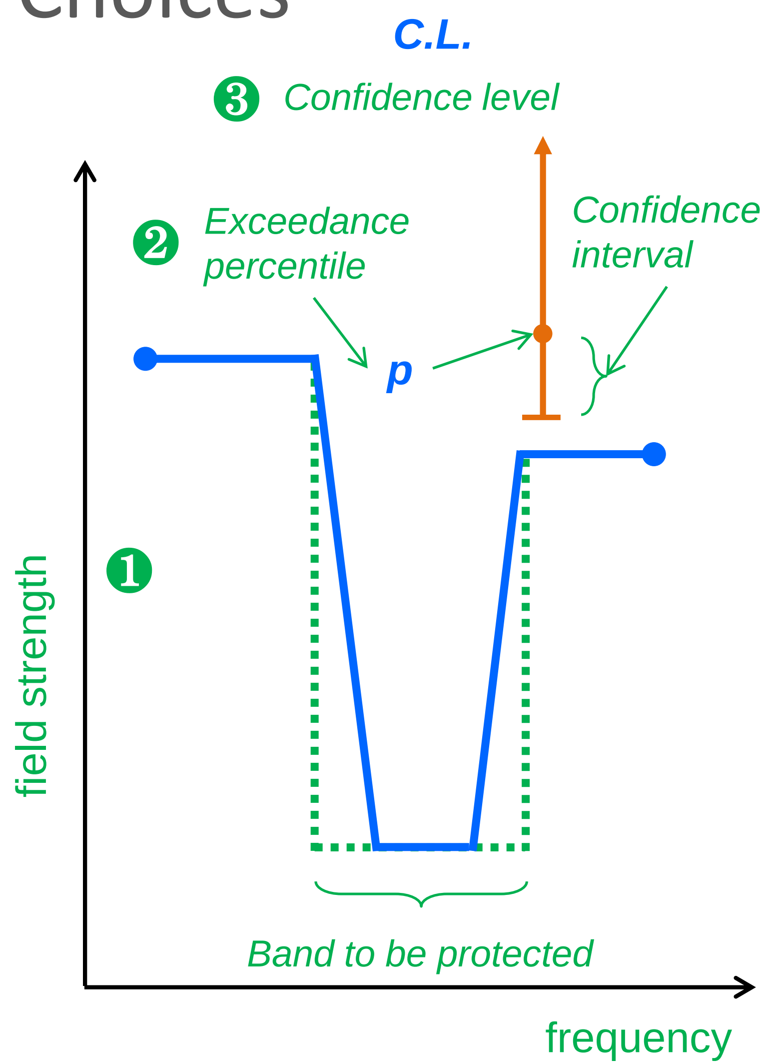
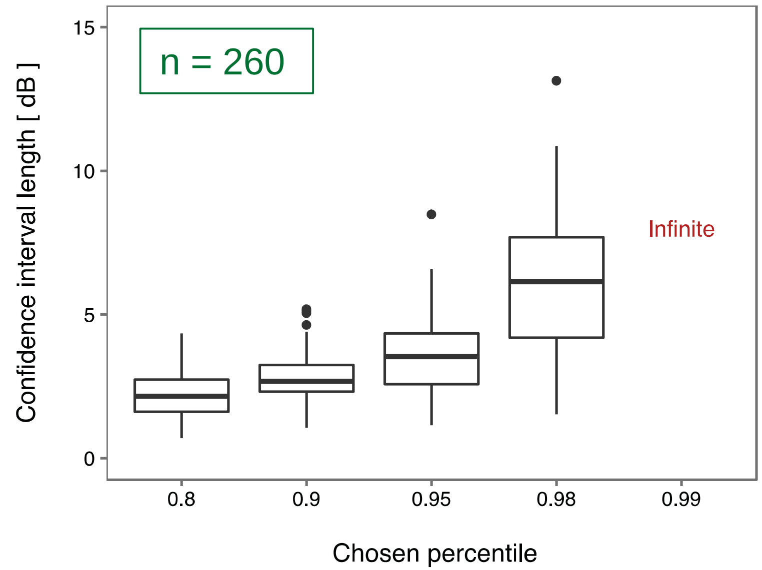
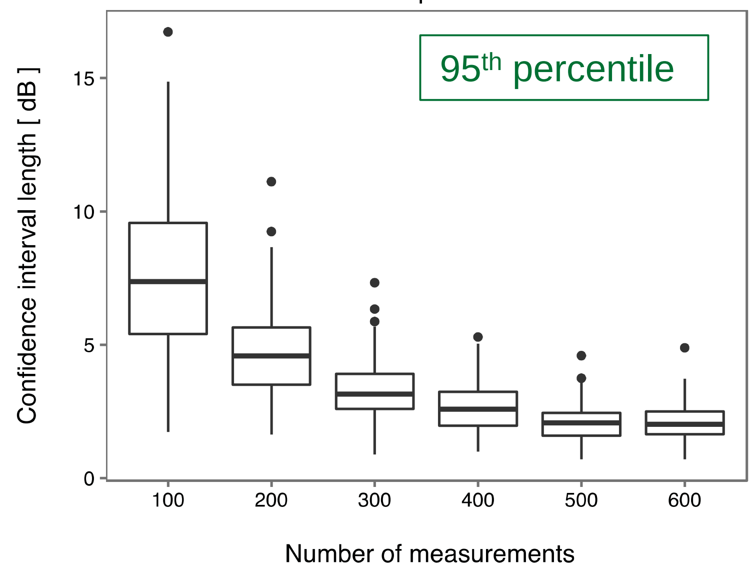


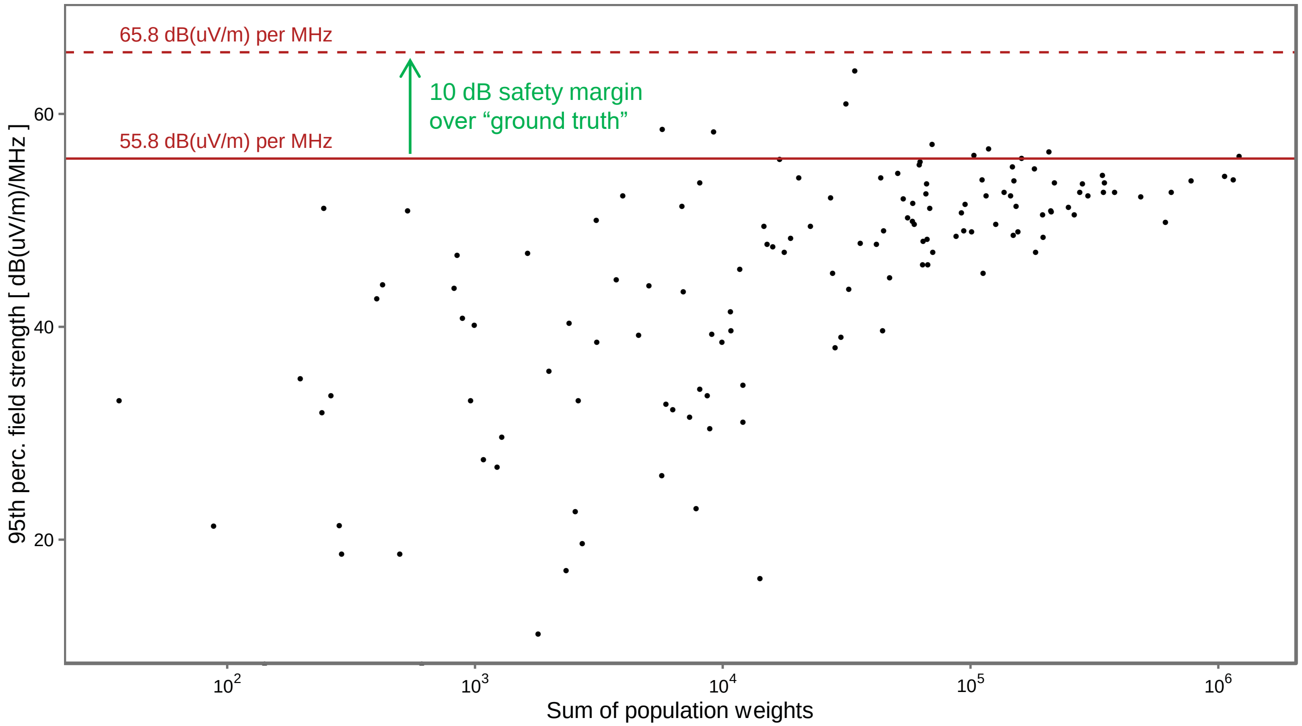
Trade-Offs in HCT Parameter Choices

- 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





Determining HCT Thresholds from Measurements



Measured 95th percentile of field strength
x
Total weights

… for all distinct 10 km x 10 km regions in data

- 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

Category	*Parameters*	*Examples*
HCT policy	Frequency band Percentile of field strength Field strength threshold Confidence level	2 GHz 95th 50 dB(uV/m) per MHz 95% ($\alpha = 0.05$)
Measurement procedure	Stratification procedure Weighting method Submission of drive data Responsibility for processing Requirements on equipment	Grid-based Population weighting Complete without gaps Claimant Standard drive test
Derivation of d_S	Allowed methodologies Threshold semivariance / autocorrelation Flexibility in model choice	Measurements or data from planning tools Half of saturation value (or correlation ≤ 0.5) Exponential only

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

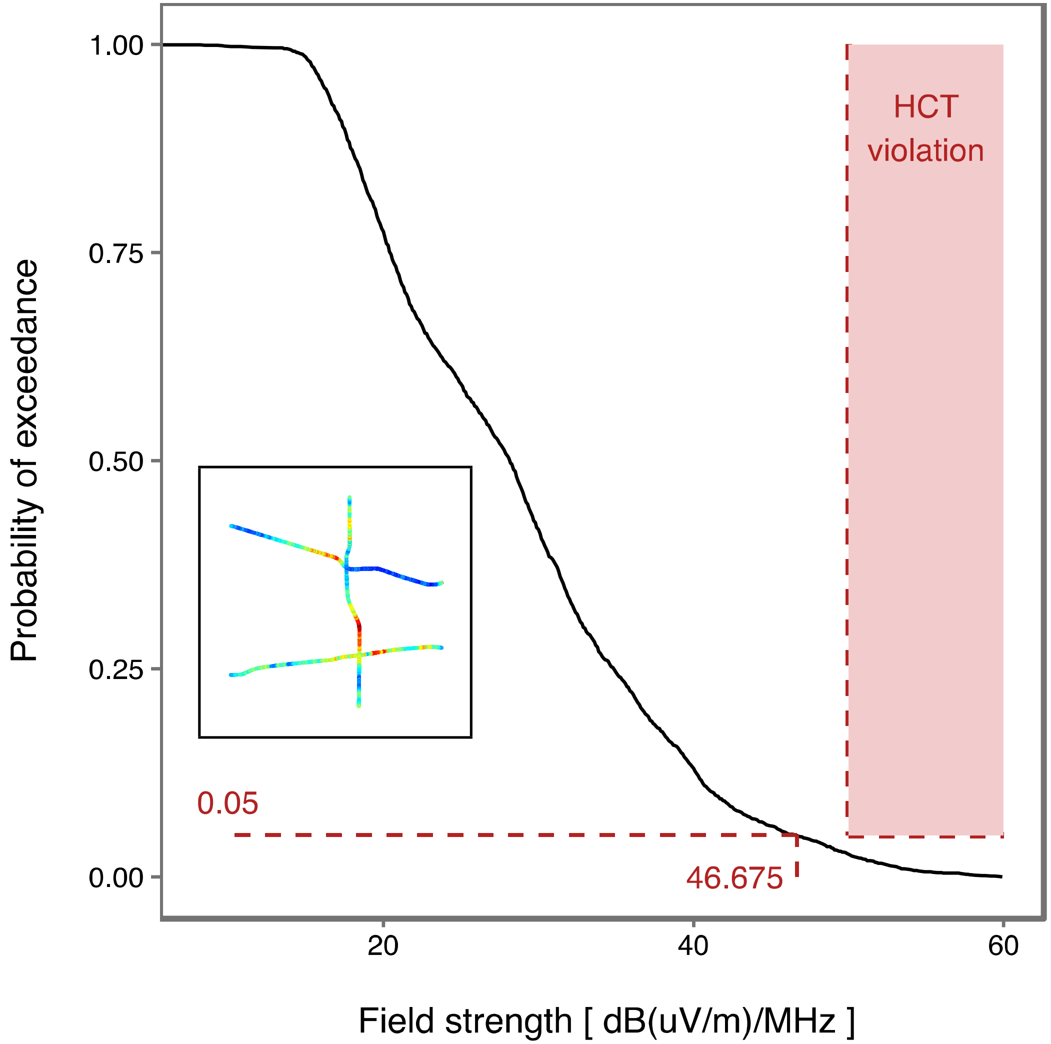
- ***Measurements play a critical role*** for enforcement of HCTs, and also for their initial design
- We propose a ***simple but effective method*** for processing measurement data to avoid pitfalls of naïve statistical analysis
- Key ingredients in our approach are ***stratification*** and ***weighting*** 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