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How to Conduct a Drive Test Survey

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Outline

- Reasons for Conducting a Survey
- Collecting the Measurements
- Analyzing the Measurements
- Uplink (Talk Back) Measurements
- Measurements at the Repeater Site
- Case Study: Newport News, Virginia

Why Conduct a Survey?

Reasons for the Survey

- Prove Coverage Meets Contract Requirement
- Identify Problem Areas in Existing System
  - Is it weak signals or interference?
- Test Prospective Repeater Sites
  - To improve coverage of existing system
- Find 800 MHz Interference
- Verify Equivalent Coverage
  - E.g., for 800 MHz rebanding

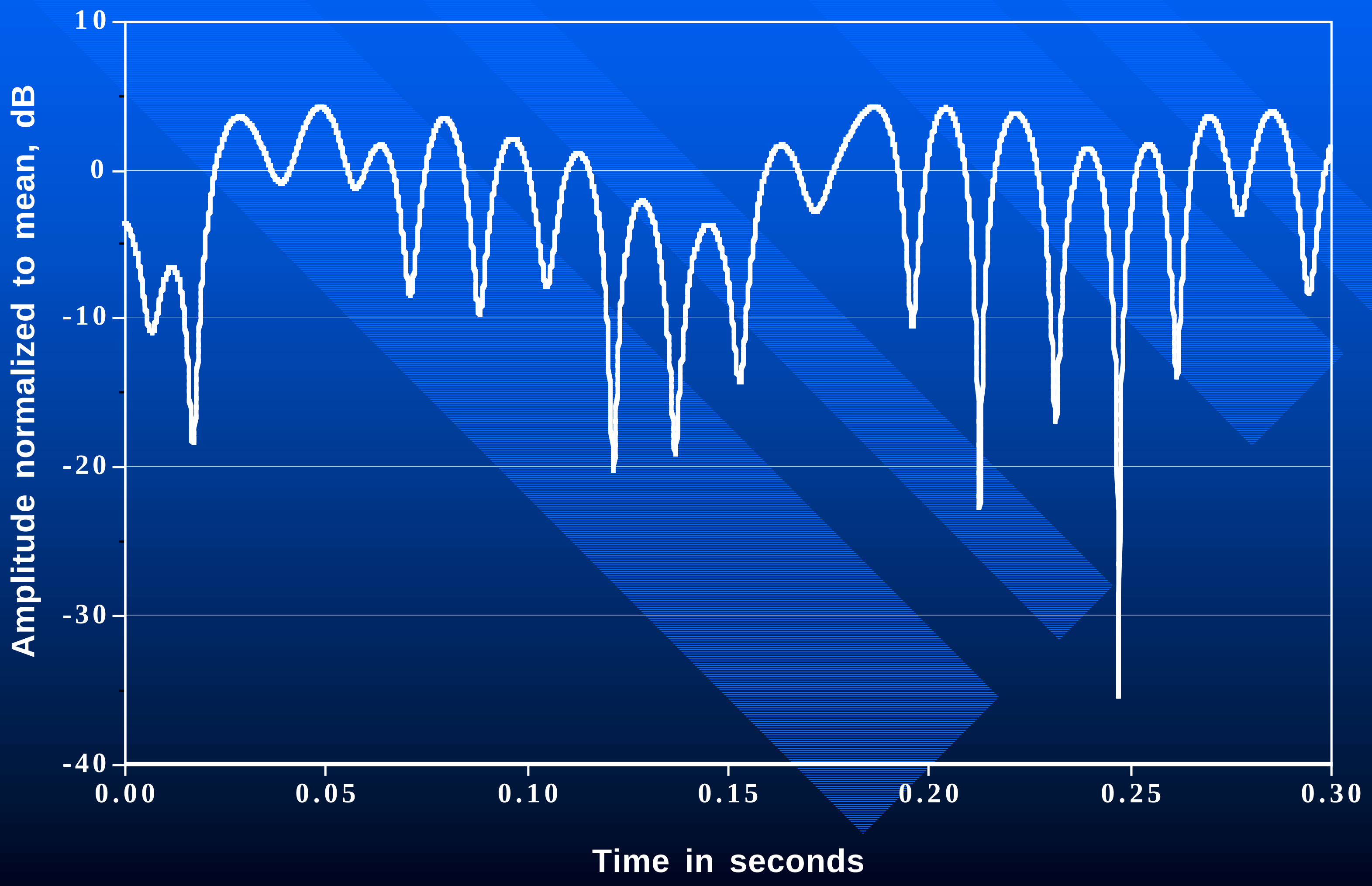
Collecting the Data

Characteristics of the Signal

- Multipath Fading Dominates the Mobile Radio Channel
  - Fade rate is a function of the doppler frequency, V/λ
  - E.g., for 860 MHz at 60 mph, fade rate is roughly 75 Hz
  - Amplitude is assumed to be Rayleigh-distributed
- Radio Specifications are Typically for Mean Signal
  - Corresponds to a particular delivered audio quality (DAQ)
  - Additional margin is needed to operate in fading
- E.g., Analog FM Radio:
  - 25 kHz channel
  - 5 kHz peak deviation
  - Static sensitivity = -118 dBm (12 dB SINAD)
  - Sensitivity in fading = -102 dBm (DAQ = 3.4)

Rayleigh Fading

(*V* = 30 mph, *f* = 850 MHz)

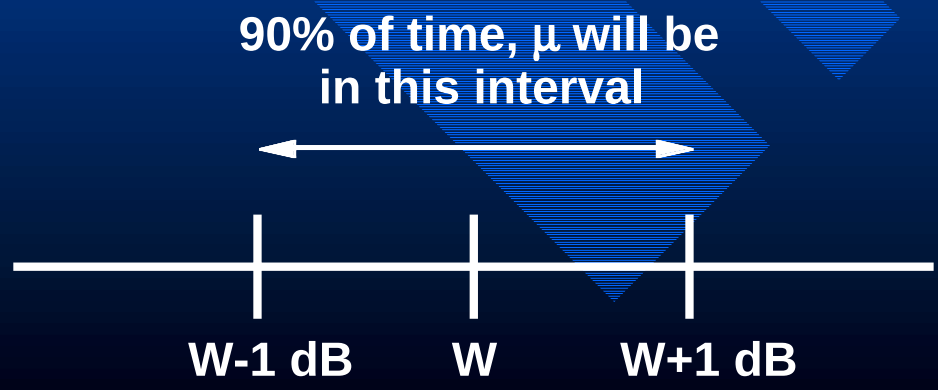


Estimating the Mean

- This is a Statistics Problem:
  - Find an unbiased estimator for the mean of a Rayleigh signal
- The typical estimator is the arithmetic average
- But a point estimate is only part of the story
- We want to know how accurate is this estimate
- We quantify accuracy by using the confidence level and the confidence interval

Confidence Intervals

- **Definitions:**
  - **The value *p* is the probability that the interval +/- *d*, about the estimate contains the true value, μ. The value +/- *d* is the confidence interval and the probability *p* is the confidence level.**
  - **For example, if the confidence level is 90% and the confidence interval is +/- 1 dB, then the probability that the interval of +/- 1 dB about the estimate contains the actual value, μ, is 90%.**



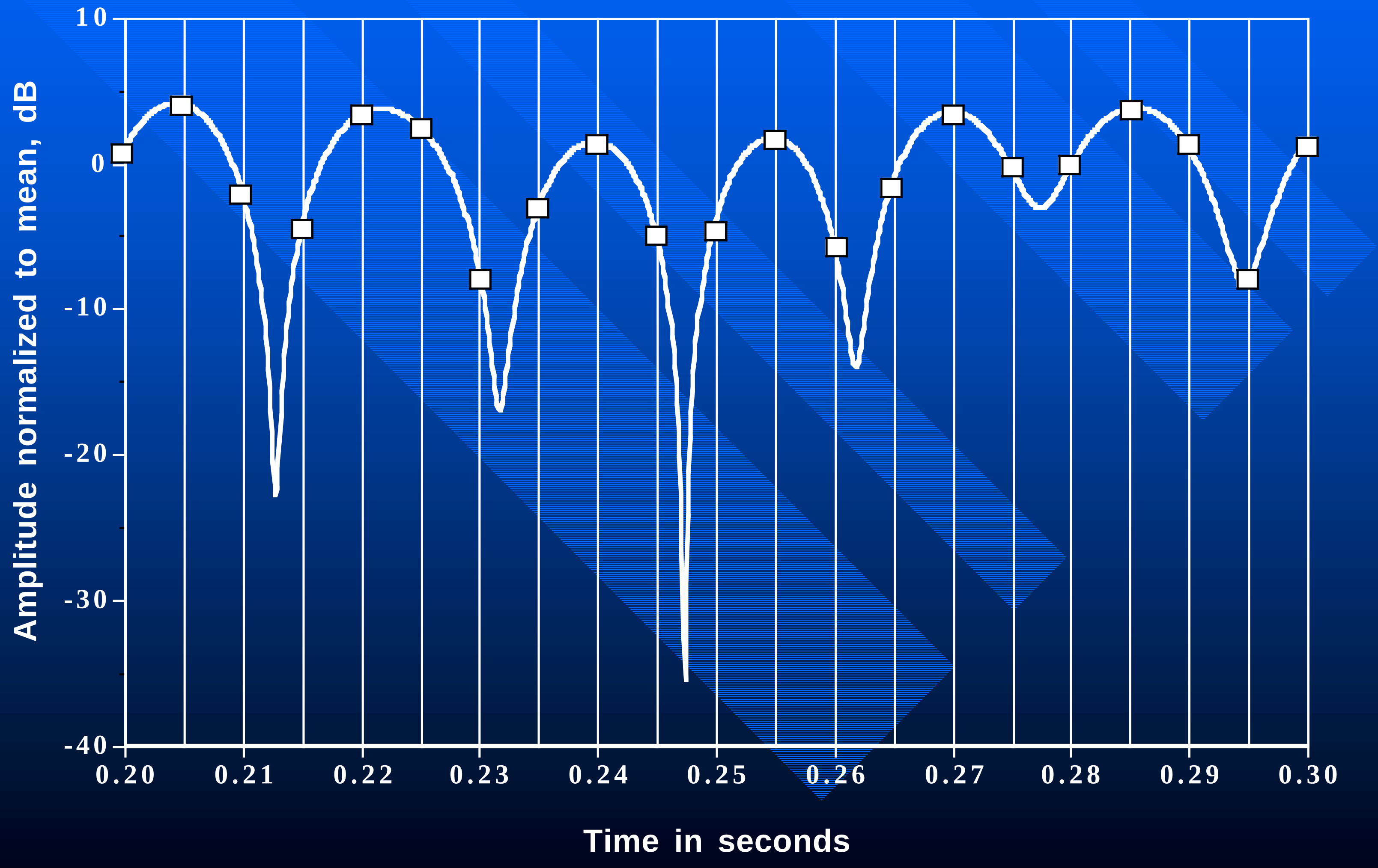
Estimating the Mean

- **Our estimator is the arithmetic average, also called the sample mean:**

$$W = \overline{X} = \sum_{i=1}^{n} x_i$$

- **How many samples, *n*, are required to ensure a small confidence interval?**

Sampling Rayleigh Signal



Sampling Rayleigh Signal

- Usually, receiver samples at a uniform rate
- One sample every 10 ms is typical
- I.e., 100 samples per second
- For mathematical convenience, the expressions for confidence level assume independent samples, which is not strictly true.
- However, common sense tells us more samples are better as long as we see a minimum number of wavelengths.

Subsamples Required

- From Lee [2]:

$$CI\left(\frac{\overline{X}}{\mu}\right)=\left(1-\frac{z_{\alpha/2}}{\sqrt{n}}\sqrt{\frac{4-\pi}{\pi}},\ 1+\frac{z_{\alpha/2}}{\sqrt{n}}\sqrt{\frac{4-\pi}{\pi}}\ \right)$$

- Where μ is the mean value we are estimating and $z_{\alpha/2}$ is the argument of the unit normal distribution for a confidence level of 1-α. Values of $z_{\alpha/2}$ = 1.65, 1.96, 2.58 for 90%, 95%, and 99%, respectively.

Subsamples Required

Full Confidence Interval	Confidence Level		
	90%	95%	99%
1.5 dB	91	129	222
1.75 dB	67	95	164
2.0 dB	52	73	126
2.5 dB	33	47	81
3.0 dB	23	33	56

Minimum Wavelengths

- Previous Expression Assumed Independent Samples
- In reality, Consecutive Samples are Correlated
- To Correctly Sample the Signal, a Minimum Number of Fades Must be Observed
- Minimum Fades Correspond to Minimum Wavelengths
- From Lee [2], Minimum Wavelengths = 40
  - At 150 MHz, 40 wavelengths = 262 feet
  - At 450 MHz, 40 wavelengths = 87 feet
  - At 850 MHz, 40 wavelengths = 46 feet
  - At 4.9 GHz, 40 wavelenghts = 8 feet

Linear vs. Log Average

- Say we want at least 50 subsamples averaged over 40 λ
  - Will give us 90% confidence interval of +/- 1 dB
  - Assumes Rayleigh-distributed amplitude
- Receiver Typically Records Levels in dBm
- Do we average the log values or linear (anti-log) values?
- Log Average Creates -2.5 dB error*
  - Assuming amplitude is Rayleigh-distributed
- Conclusion: Use Linear Average

*Ie., it is a biased estimator. See Hess [4], page 100.

Mean vs. Median

- Some Prefer the Median over the Mean
- Why?
  - Weak signals below the noise floor of the receiver will skew the mean to a higher level than reality
- Problems with the Median
  - More difficult to compute
  - Confidence intervals unknown
  - Radios are specified for a mean level in Rayleigh fading
  - Mean and median are not the same value in Rayleigh fading
- Practical Advice
  - For levels of -106 dBm and above, error is small if receiver noise floor is below -120 dBm
  - I.e., error is < 0.2 dB

Other Collection Issues

- **Where to Drive?**
  - Everywhere the user drives
  - Do not limit survey to the highways
  - Significant signal loss occurs on the side streets (more clutter)
- **When to Drive?**
  - For contract compliance, in the summer (foliage loss)
- **How Much to Drive?**
  - More is better
  - Nominal grid size driven should match analytical grid size

Characteristics of Receiver

- Relatively fast (e.g., 100 samples per second)
- Good sensitivity (e.g., -118 dBm, match user radio)
- Accuracy: +/- 1.5 dB
- Good adjacent channel and intermod. rejection
- Computer-Controlled
- GPS compatible
- Linear averaging of at least *n* samples over 40 wavelengths

Analyzing the Data

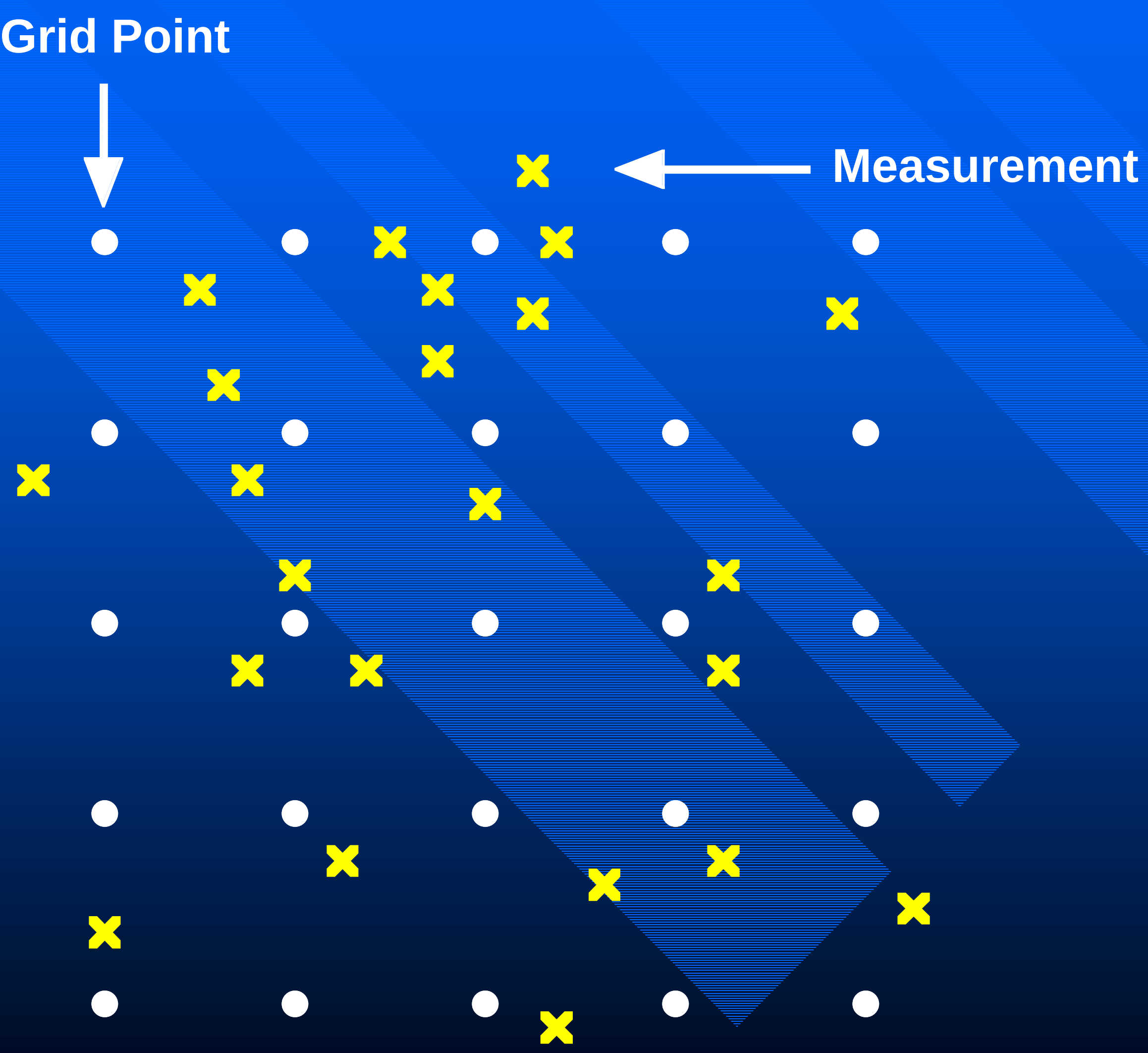
Analysis Tasks

- **Remove Spatial Bias From Measurements**
- **Compute Service Area Reliability**
- **Compare Service Area Reliability to Contract Reqt.**
- **For Rebanding Surveys:**
  - **Create intersection set**
  - **Compare pre and post service area reliabilities**
  - **Draw conclusion on equivalent coverage**

Gridding

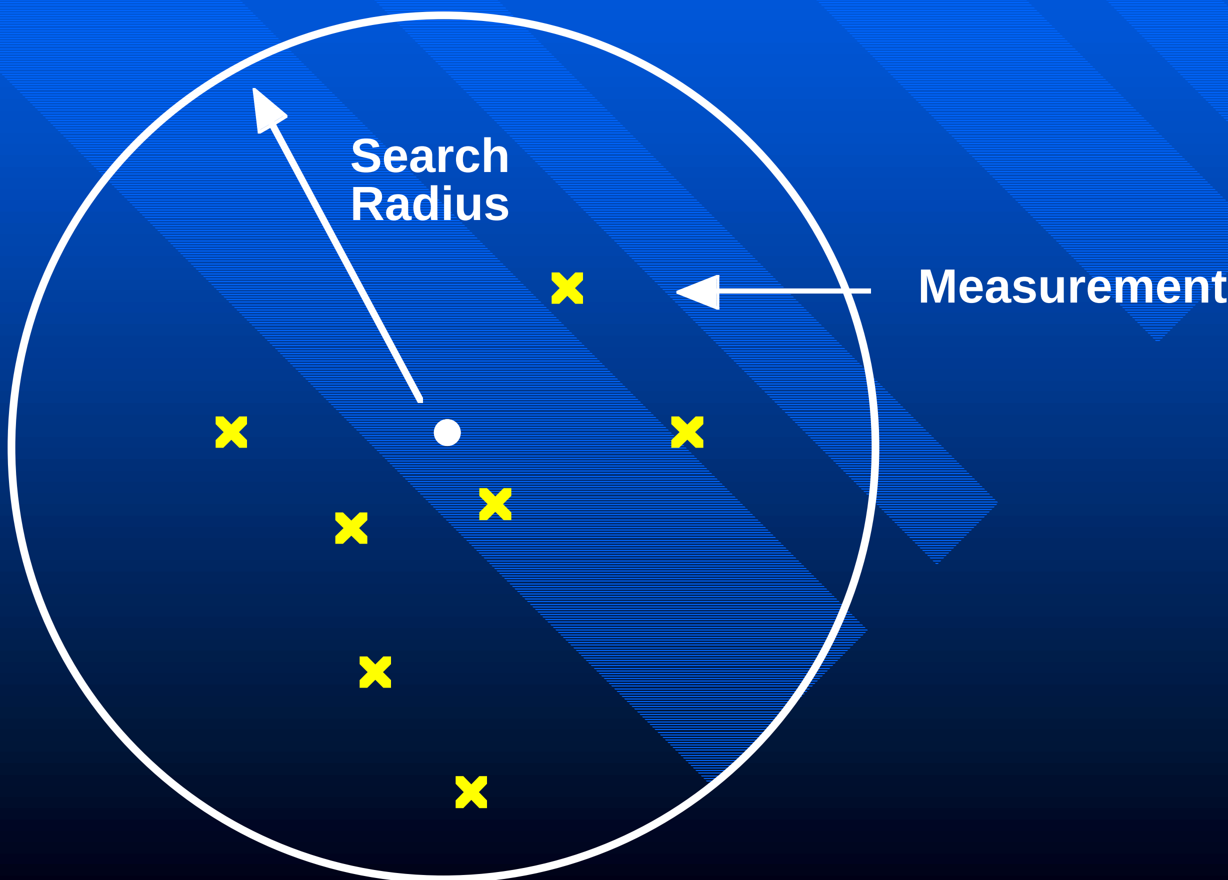
- In Practice, Uniform Spatial Sampling is Difficult
  - I.e., some spatial bias exists in the data
- Gridding Solves This Problem
- What is Gridding?
  - Gridding interpolates randomly distributed data to a uniform, two-dimensional grid
- SAR Computed from Gridded Data

Gridding



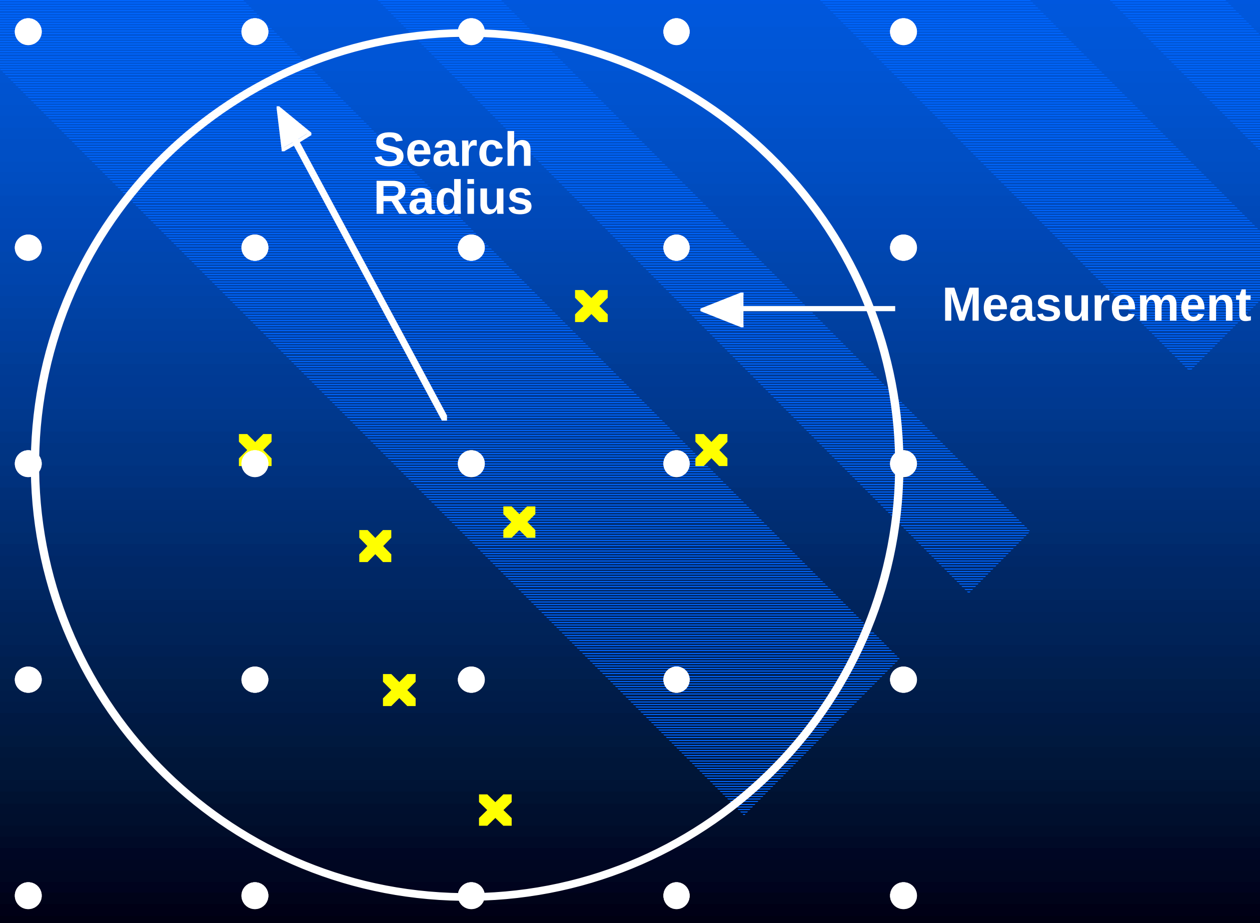
Gridding

- Gridding is 2-D Interpolation
  - Key elements are search radius and interpolation algorithm



Search Radius

- Search Radius Should Be Relatively Small
  - Twice the nominal collection grid size is appropriate



Interpolation Algorithm

- Weight by Distance
- Nearby Measurements Weighted More Heavily
- Inverse-Distance-Squared is One Algorithm
- No Universally Accepted Algorithm

A Word About Independence

- Mathematical Models Usually Assume Independence
- Measurements Collected Close in Time or Space are Likely to be Somewhat Correlated.
- Some Suggest that Data be Purged to Approximate Independence.
- Is this a Good Idea?
  - Generally, no because the purged data are still good data
- Advantage of interpolation is that all data within the search radius is used to estimate the signal level inside that tile.

Service Area Reliability (SAR)

- **Definition:**

"Service area reliability is the probability that a point, selected at random inside the service area, has a measured level above the service level."

- **For Mathematical Convenience, Each Sample of the Service Area is Assumed to be an Independent Trial.**
- **With This Assumption, the SAR is the Parameter, *p*, for a Binomial Random Variable**
- **Typical Contract SAR is 95%**

Estimate for SAR

(From Drive Test Survey)

$$SAR(\%) = \frac{T_p}{T_t} 100\%$$

where

T_p *is the number of tiles passed*

T_t *is the total number of tiles*

How Accurate is the Estimate?

(More Confidence Intervals)

$$n = \frac{z_{\alpha/2}^{2} p(1-p)}{d^{2}}$$

Where *p* is the value of the SAR, $z_{\alpha}/2$ is the argument of the unit normal distribution for a confidence of $1-\alpha$ and *d* is one-half of the confidence interval [5]. For example, for 90% confidence, $z_{\alpha}/2 = 1.65$.

Worst Case

(p = 1/2)

$$n = \frac{z_{\alpha/2}^{2}}{4\,d^{2}}$$

Confidence Level	$z_{\alpha/2}$	d	n
90%	1.65	+/- .02	1,702
95%	1.96	+/- .02	2,401
99%	2.58	+/- .02	4,160

Proving Equivalent Coverage

- Attention to Detail is Paramount
  - Use the same receiver,vehicle, antenna, coaxial cable, drive route, time of day, day of the week, season, etc.

- Despite Best Efforts, Before & After will Vary
  - Some variation is normal
  - Systems may still be equivalent

Equivalent Coverage Rule

"If the post-rebanding service area reliability estimate falls inside a range equal to twice the 90% confidence interval of the pre-rebanding service area reliability estimate, the two systems have equivalent coverage."

Equivalent Coverage Example

- Test Parameters:
  - 1750 gridded samples
  - 90% confidence interval = +/- .02
  - Pre-rebanding SAR = 97%
  - Post-rebanding SAR = 93%
  - Actual SAR = 95% (known only to the omnicient)
- Pass or Fail?
  - Pass because the range is less than twice the confidence interval

Uplink Drive Tests

Uplink vs. Downlink

- Drive Test Surveys are Usually Downlink (Talk Out)
- Should We Measure Uplink (Talk Back) Also?
- Maybe
  - Antenna reciprocity means we can deduce uplink from downlink
  - But only if same antennas are used
  - Frequency separation effects usually negligible
- Example:
  - Four-site simulcast system with voting receivers
  - Transmit antennas are directional
  - Receive antennas are omnidirectional
  - Antenna reciprocity does not apply to talk out/talk back

Uplink From Downlink

- **Antenna Reciprocity May Apply, But**
  - Transmit power levels are different
  - Sensitivities are different
  - Amplifiers on uplink amplify noise and signal

- **For These Reasons, Must Compare on Basis of Common Metric Such as Signal-to-Noise Ratio**

Uplink Measurements

- Issues with Uplink Measurements
  - Need one receiver at each repeater site
  - To discriminate sites, will need one mobile TX for each site
  - Transmitter is mobile, receiver is stationary
  - Receiver does not know location of transmitter
  - Post-Processing of RX and TX files is necessary
  - If conducting downlink survey simultaneously, mobile transmit may desense receiver(s)
  - To compare apples to apples, need to scale uplink measurements for gain and noise figure of uplink path

Repeater Site Measurements

Why Repeater Site Measurements?

- Especially Important for Proving Equivalency
  - A 1 dB loss in transmitter power is easy to detect at the repeater site, hard to detect in drive test survey.
- Measurements Required:
  - Output power of each transmitter at combiner output
  - Return loss of all antennas (if changes are made)
  - Insertion loss of all coaxial cable (if changes are made)
  - Insertion loss of all components after the combiner (surge arrrestor, duplexer, external cavity filter, etc.
- Do These Measurements Before and After Rebanding

Case Study
Newport News, VA

Newport News

- **System Description**
  - Three site, 800 MHz mobile data system
  - Multiple repeaters at each site
- **Rebanding Impact**
  - Two of three sites were affected by rebanding
  - One frequency affected at each site
- **Objectives**
  - Conduct pre and post rebanding surveys
  - Compare pre and post results
  - Verify equivalent coverage

Test Setup

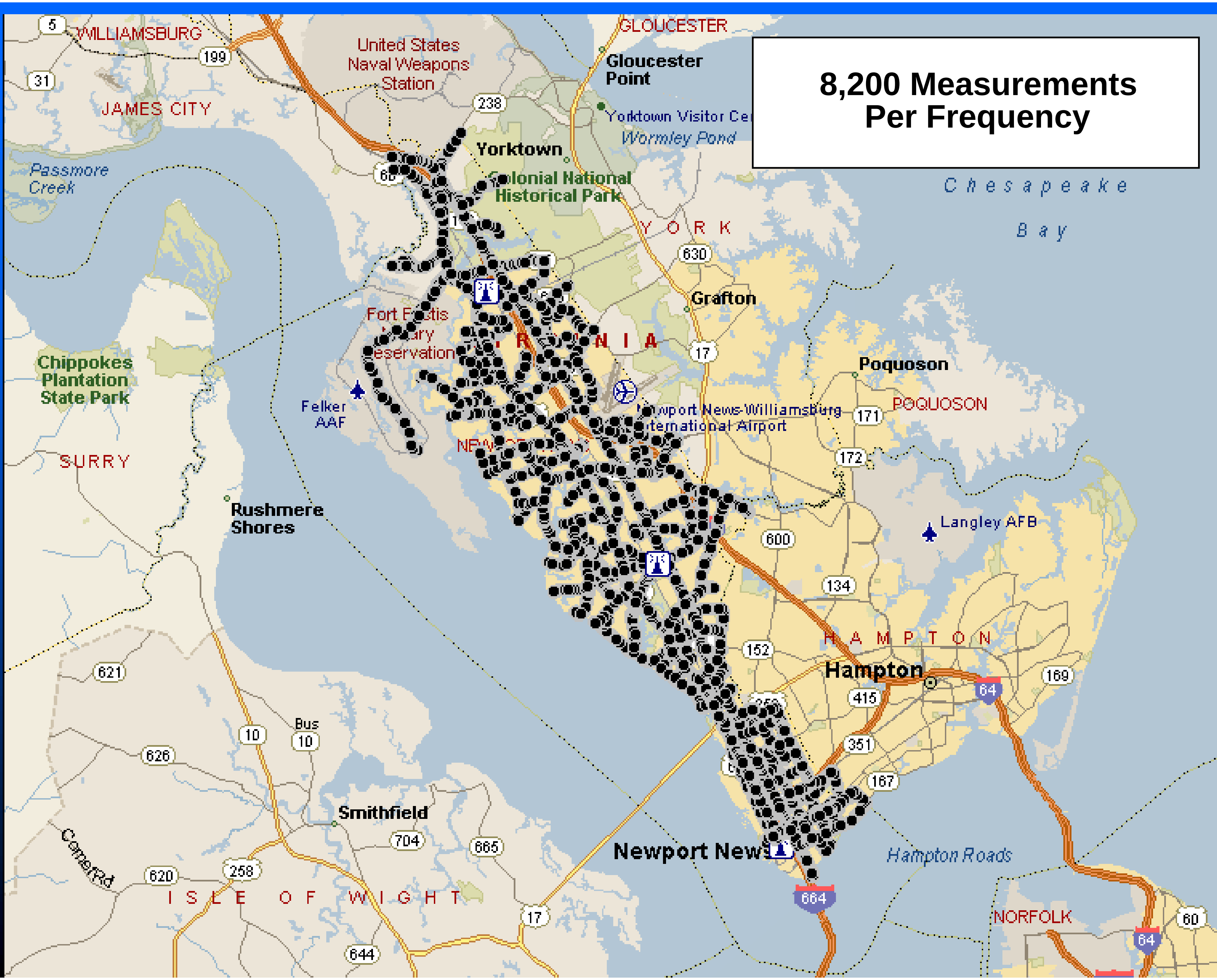
- **Measurements:**
  - 90% confidence level
  - +/- 1 dB confidence interval
  - Required subsamples = 50 (over 40 wavelengths)
- **Service Area Reliability:**
  - 90% confidence level
  - +/- 2% confidence interval
  - Required grid points = 1702
- **Drive Route**
  - Newport News is roughly 50 square miles
  - 1702 grid points = 905 feet = 275 meter square tiles

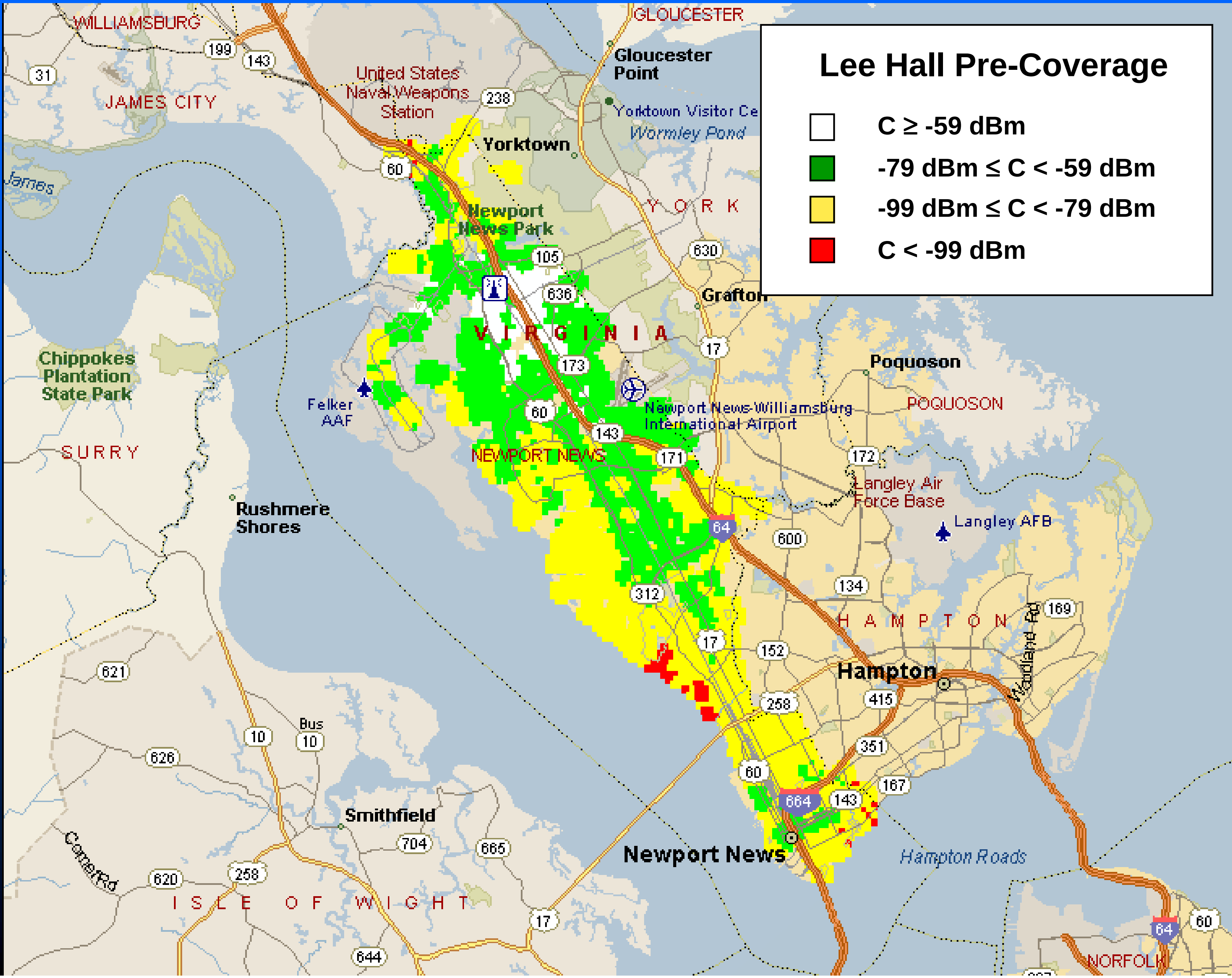
Test Setup (cont'd)

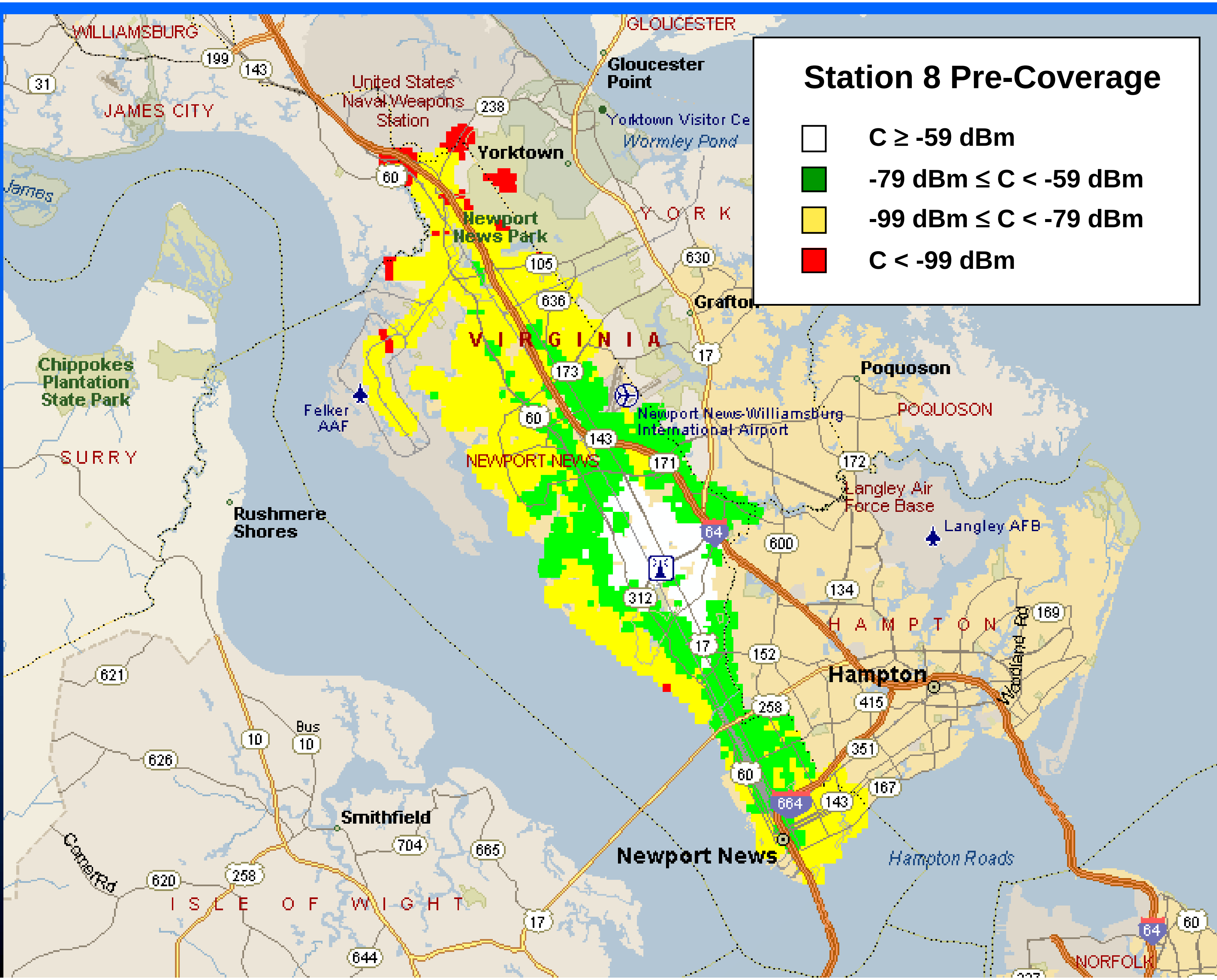
- **Actual Measurements:**
  - Three Sites Measured
  - Four frequencies measured:
    - » Lee Hall #1 (affected by rebanding)
    - » Station 8 # 1 (affected by rebanding)
    - » Station 8 #2 (not affected by rebanding)
    - » City Hall (not affected by rebanding)
  - 8,200 measurements collected (each 40 λ, 50 subsamples)

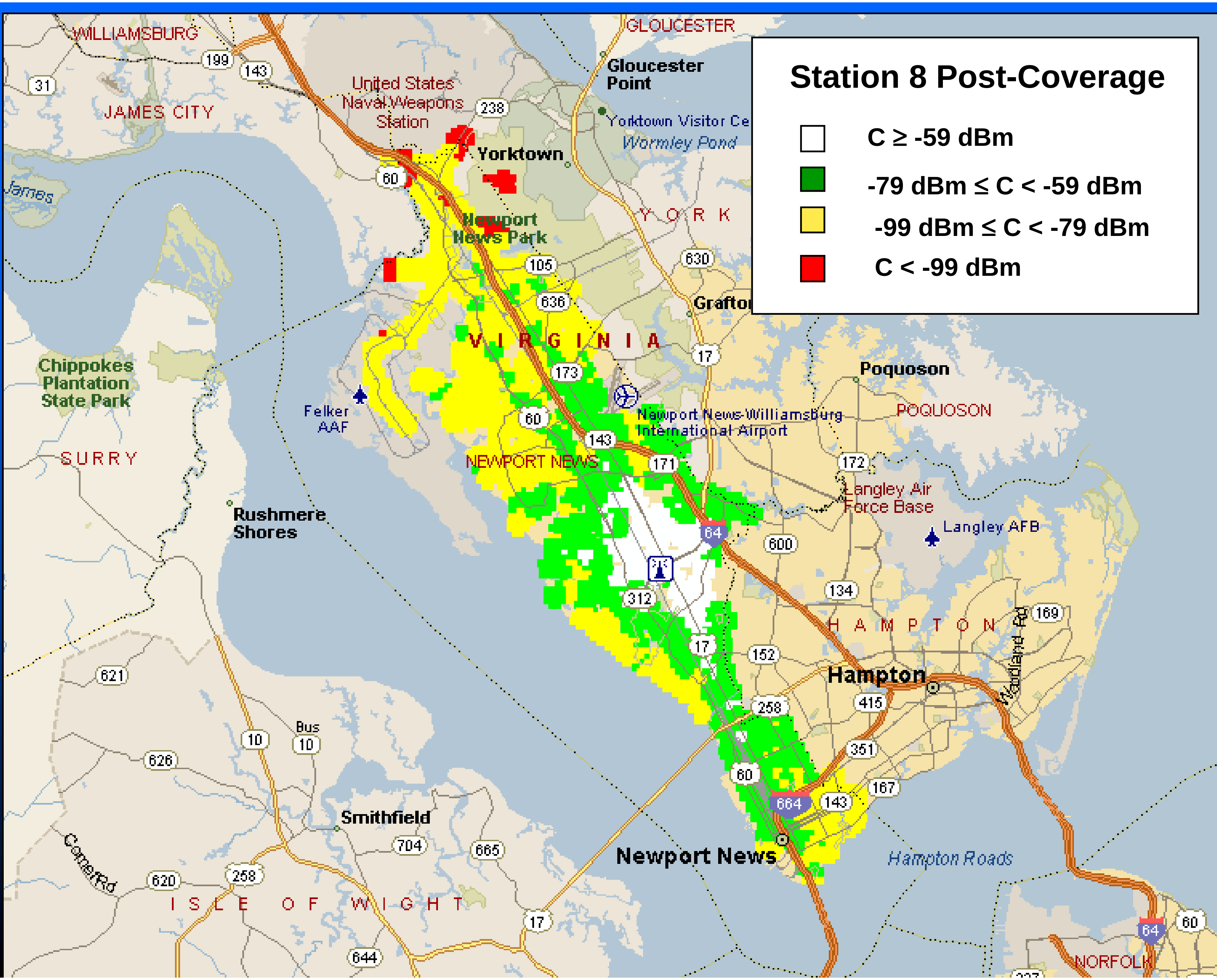
- **Analysis**
  - 200 meter square tiles
  - 400 meter search radius
  - Inverse distance squared interpolation
  - Results in 3,571 uniformly spaced points

8,200 Measurements Per Frequency




Lee Hall Pre-Coverage
C ≥ -59 dBm
-79 dBm ≤ C < -59 dBm
-99 dBm ≤ C < -79 dBm
C < -99 dBm
WILLIAMSBURG
JAMES CITY
GLOUCESTER
Gloucester Point
United States Naval Weapons Station
Yorktown
Wormley Pond
Newport News Park
YORK
Grafton
VIRGINIA
Poquoson
POQUOSON
Newport News-Williamsburg International Airport
Felker AAF
NEWPORT NEWS
Chippokes Plantation State Park
SURRY
Rushmere Shores
Langley Air Force Base
Langley AFB
HAMPTON
Hampton
Smithfield
Newport News
Hampton Roads
ISLE OF WIGHT
NORFOLK


Station 8 Pre-Coverage
C ≥ -59 dBm
-79 dBm ≤ C < -59 dBm
-99 dBm ≤ C < -79 dBm
C < -99 dBm
WILLIAMSBURG
GLOUCESTER
Gloucester Point
JAMES CITY
United States Naval Weapons Station
Yorktown
Yorktown Visitor Ce
Wormley Pond
Newport News Park
YORK
Grafton
VIRGINIA
Poquoson
POQUOSON
Chippokes Plantation State Park
Felker AAF
Newport News-Williamsburg International Airport
NEWPORT NEWS
Langley Air Force Base
Langley AFB
SURRY
Rushmere Shores
HAMPTON
Hampton
Woodland Rd
Smithfield
Newport News
Hampton Roads
ISLE OF WIGHT
NORFOLK



Station 8 Post-Coverage
C ≥ -59 dBm
-79 dBm ≤ C < -59 dBm
-99 dBm ≤ C < -79 dBm
C < -99 dBm
WILLIAMSBURG
GLOUCESTER
Gloucester Point
JAMES CITY
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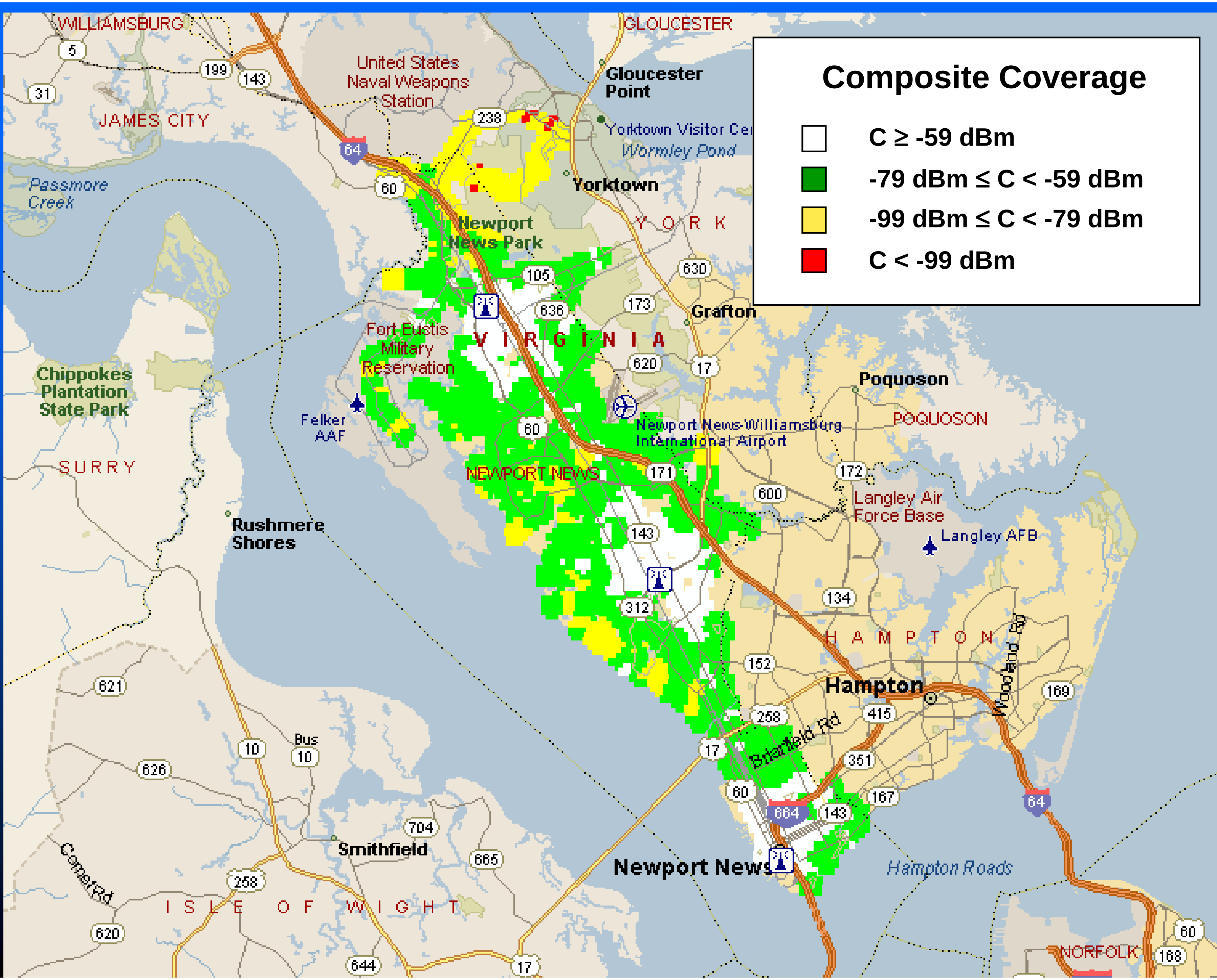
Rushmere Shores
HAMPTON
Woodland Rd
Hampton
Smithfield
Newport News
Hampton Roads
ISLE OF WIGHT
NORFOLK
Bus


Composite Coverage
C ≥ -59 dBm
-79 dBm ≤ C < -59 dBm
-99 dBm ≤ C < -79 dBm
C < -99 dBm
WILLIAMSBURG
GLOUCESTER
United States Naval Weapons Station
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Rushmere Shores
HAMPTON
Hampton
Woodland Rd
Briarfield Rd
Smithfield
Newport News
Hampton Roads
Cornerf Rd
ISLE OF WIGHT
NORFOLK

Service Area Reliability (SAR)

Site	-99 dBm		-79 dBm	
	Before	After	Before	After
Lee Hall	98.8%	99.9%	49.7%	57.9%
Station 8	97.3%	97.7%	47.2%	52.0%
Station 8 (Reference)	97.2%	97.6%	47.1%	51.7%

Difference Statistics
(Compared at Identical Grid Points)

Site	Mean	Median	Std. Dev.
Lee Hall	2.4 dB	2.5 dB	3.8 dB
Station 8	1.3 dB	1.2 dB	2.7 dB
Station 8 (Reference)	1.3 dB	1.2 dB	2.5 dB
City Hall	1.6 dB	1.5 dB	3.2 dB

Lessons Learned

- **Attention to Detail is Important**
  - Pre-rebanding survey done on weekend
  - Post-rebanding survey done on weekdays
  - Might account for 1.5 dB Difference
- **Include a Reference Signal**
  - Helps Troubleshoot Problems
- **Is the Nextel Frequency Really Turned Off?**

Conclusions

- Drive Test Surveys are Powerful Tools
- Usually More Accurate than Computer Model
- Automation Makes Them Cost-Effective
- Not for the Faint-Hearted
  - Attention to detail is important
  - Interpretation of results requires specialized knowledge

References

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[3] M. M. Peritsky, "Statistical Estimation of Mean Signal Strength in a Rayleigh Fading Environment," *IEEE Transactions on Communications*, November, 1973, pp. 1207-1213.

[4] G. C. Hess, Land Mobile Radio System Engineering, Artech House, 1993.

[5] R. J. Larsen, M. L. Marx, An Introduction to Mathematical Statistics and its Applications, Prentice-Hall, 1986, pp. 281.

[6] EIA-TSB-88-B, "Wireless Communications Systems – Performance in Noise and Interference-Limited Situations, etc." May 1, 2005.

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Questions?