3.0 The ModCod is Right

A Tribute to Bob Barker

With your host: Jim Stenberg

From: Over the Air RF Consulting

and

Your announcer: Dan Glavin

From: American Tower Corp

Over The Air RF Consulting LLC

AMERICAN TOWER®

WHAT THE HECK ARE WE DOING?

- The price is right began in 1956 and was revived in 1972 when Bob Barker became the host.
- Bob was the host for 39 years!
- The Show was inducted into the NAB Hall of Fame in 2022

12/12/1923 – 8/26/2023

- Use show format to learn how 3.0 modulation and coding variables affect station coverage and capacity
- Contestants guess population counts for each configuration
- Win fabulous prizes

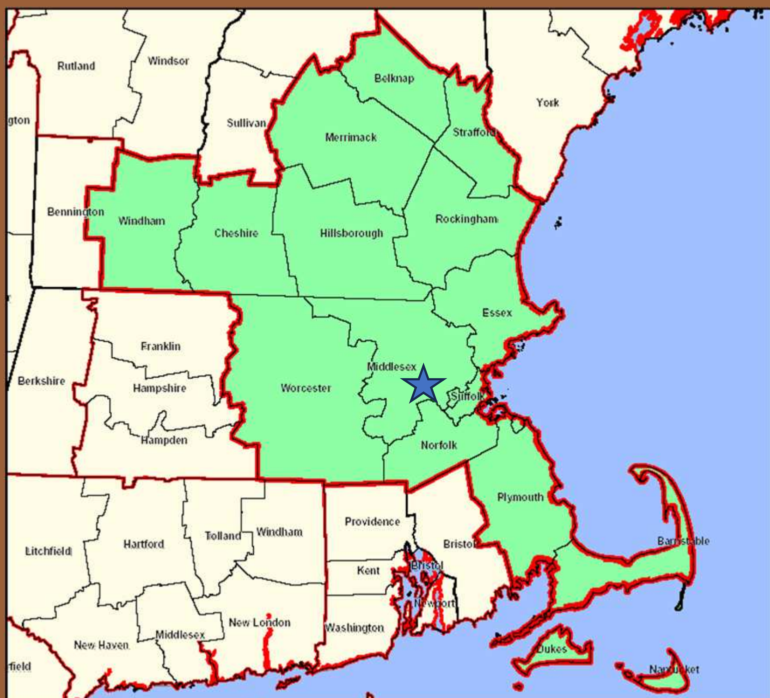
Introduction and Some Disclaimers

- There are millions of combinations of ATSC 3.0 physical layer variables.
- Each has importance to a particular aspect of performance and may/may not be right for your intended use.
- The art of designing a configuration is optimizing these variables for your particular situation.
- It is NOT difficult to change parameters. You should experiment.

- Coverage, SNR and Capacity are highly dependent on the calculation and measurement assumptions.
- My numbers will be slightly different than you and/or your consultants and/or your measurements. There are many valid ways to quantify ATSC 3.0 performance.
- My calculations use an outdoor antenna with gain at 10m height for comparison purposes. Receivers using lower gain antennas require more signal level particularly indoors.

OUR REFERENCE STATION: WUNI DT 27 UNIVISION

Some information:



BOSTON TV DMA = #9

- 3.0 host for wgbh, wbz, wcvb, wbts, wfxt, wwje, and wuni
- RF Channel = 27
- ERP = 400kw
- AMSL = 1434 ft
- Haat = 1168 ft
- Cardioid azimuth pattern facing Northeast

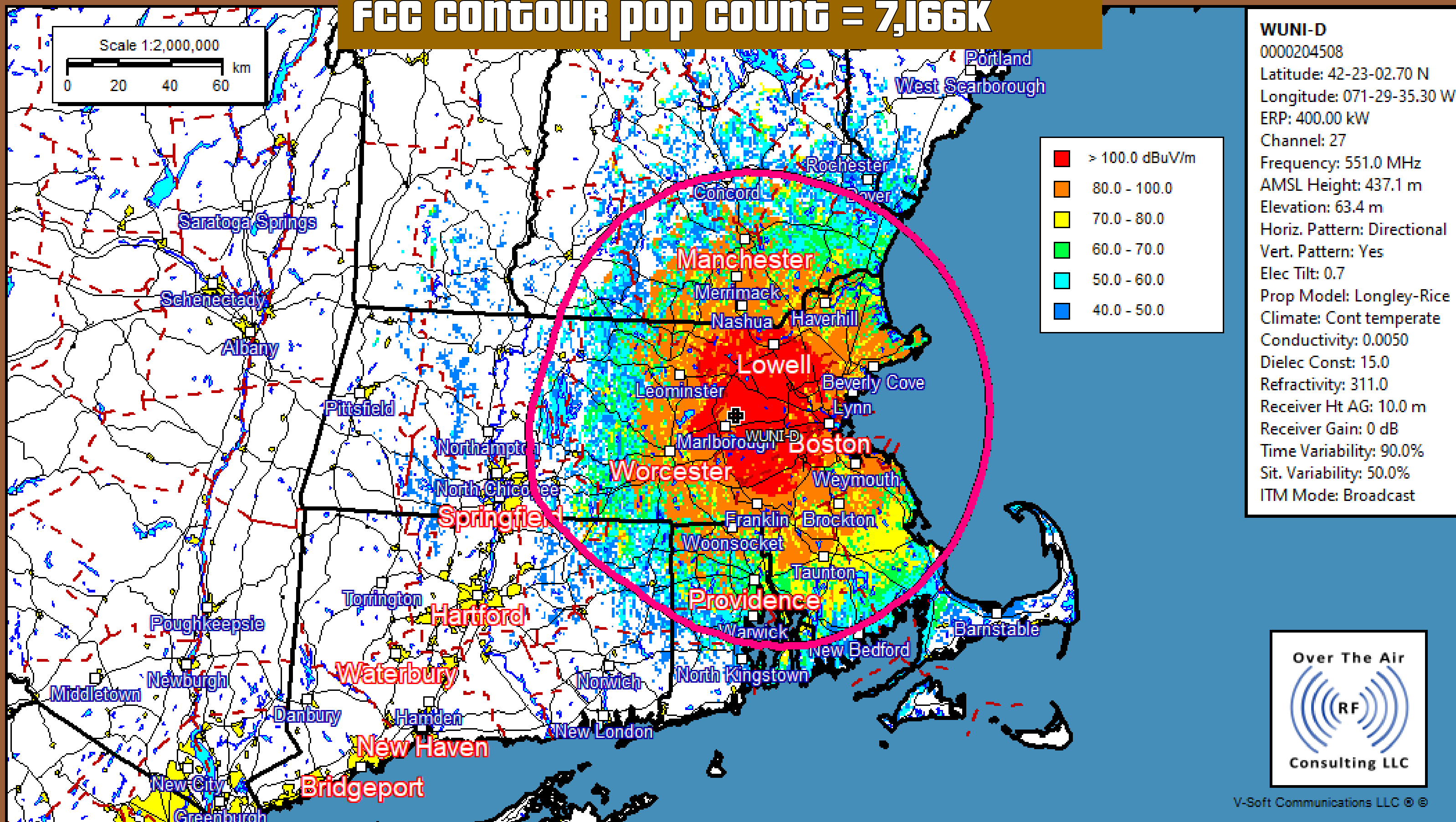
UNIVISION BOSTON

Reference Station: WUNI Signal Strength

ATSC 1.0

- Designed to deliver
  - 19.2 Mb
  - @ 15.2 dB SNR
  - @ 41 dBu minimum signal strength
  - to fixed antennas @ 10m

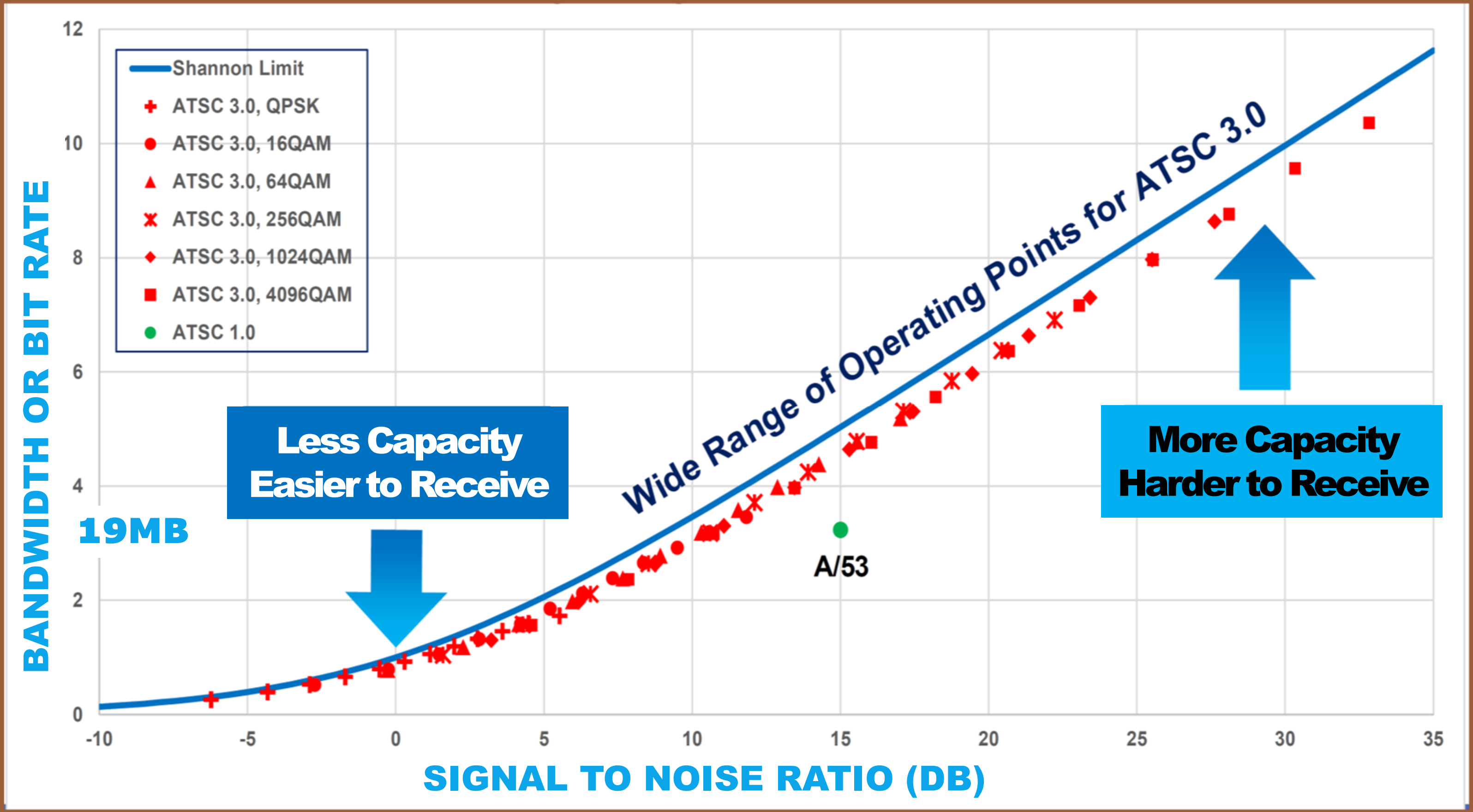
FCC Contour Pop Count = 7,166K



Longley-Rice Predicted 41 dBu Pop Count = 7,943K

SIGNAL TO NOISE RATIO VERSUS BANDWIDTH

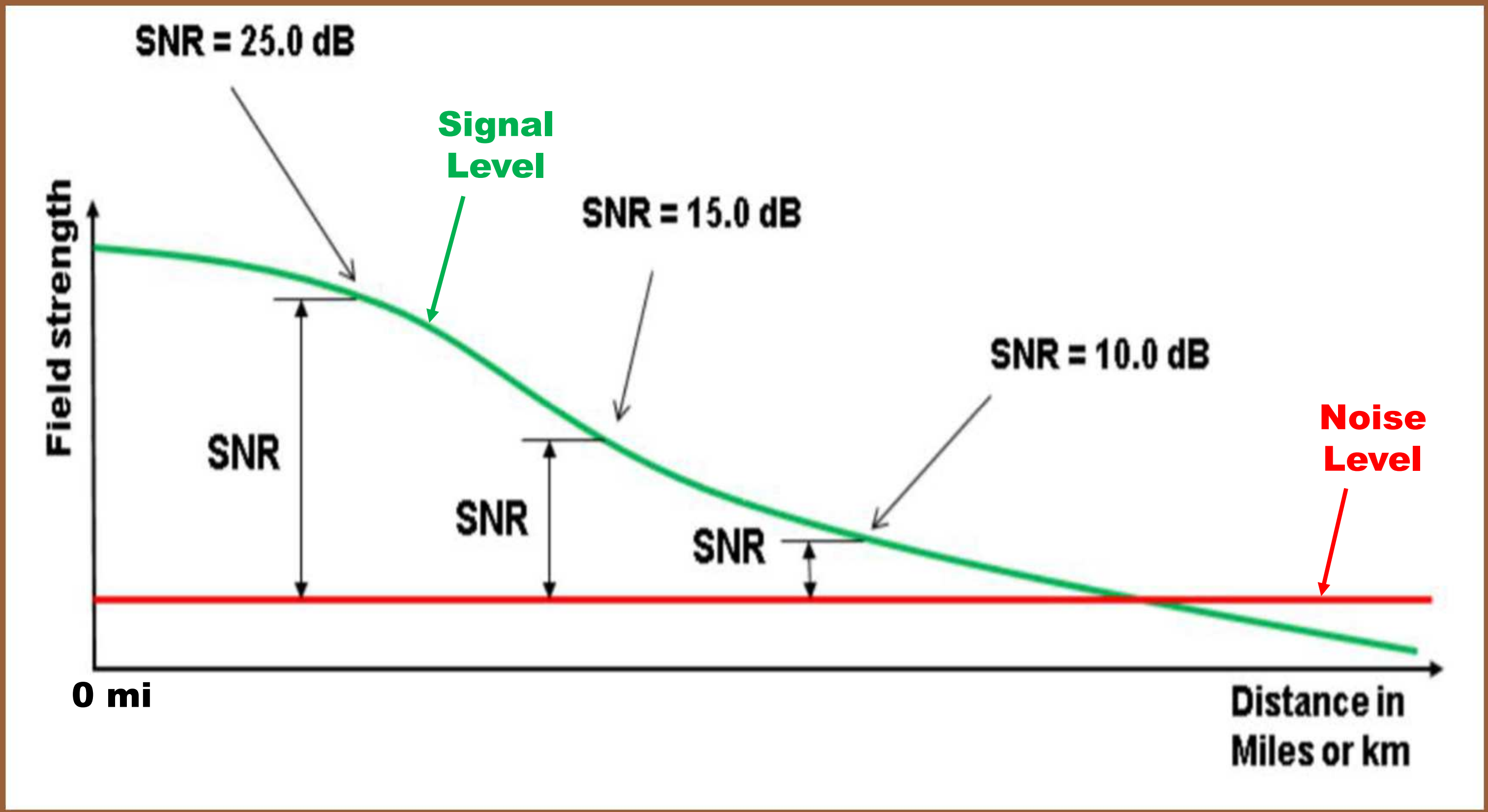
- Higher order modulation yields more capacity
- Higher capacity takes more signal strength



THE SHANNON LIMIT DESCRIBES THE, CAN'T GET SOMETHING FOR NOTHING TRADEOFF

Signal to Noise Ratio Versus Coverage

- Signal levels decrease by distance squared from the transmitter
- For digital signals, reception occurs only above a given S/N ratio (SNR)



This graph is the fundamental relationship to keep in mind

most important variables: modulation rate

- Number of possible symbol choices each time period is varied
  - QPSK (4 symbols) = most robust, lowest capacity, -6 to 11 dB SNR, 1.5 to 10 MB
  - 16QAM = very robust, limited capacity, -2 to 17 dB snr, 3 to 21 mB
  - 64QAM = fairly robust, moderate capacity, 1 to 22 dB snr, 5 to 31 mB
  - 256QAM = good robustness, good capacity, 3 to 27 dB snr, 6 to 41 MB
  - 1024QAM = poor robustness, high capacity, 5 to 32 dB SNR, 8 to 52 MB
  - 4096 QUAM = very high signal needed, HUGE capacity, 7 to 37 dB snr, 9 to 62 MB
- Most direct effect on capacity
- Nu = non uniform constellations optimize performance
- 1024 and 4096 not currently recommended for OTA use

most important variables: code Rate and Lengths

- Determines the amount of redundant data and methods for ensuring delivery
- Rate defined as payload bits/total bits transmitted
  - 2/15 means 2 units of payload out of total = 13% payload, very robust
  - 13/15 means 13 units of payload out of total = 87% payload, not robust
- More coding (lower fraction) increases receivability in noise and channel variation = lower snr
- More coding reduces amount of capacity = lower mb
- Other Coding selections effect mobile reception, access time, and other performance
  - Code length, long for better snr performance but increased overhead, short for less power consumption, lower latency, mobile performance
  - Interleaving reduces errors, through time diversity

Most Important Variables: FFT Length

- Determines the maximum number of OFDM carriers
  - 8k FFT = △ Fc = 843Hz = 6913 carriers
  - 16k FFT = △ Fc = 422Hz = 13,825 carriers
  - 32k FFT = △ Fc = 211Hz = 27,649 carriers
- Size influences capacity, delay, and mobility tolerance
  - Smaller FFT better mobile performance, lower efficiency
  - Larger FFT has better efficiency and delay tolerance, better fixed reception

Most Important Variables: Pilot Patterns

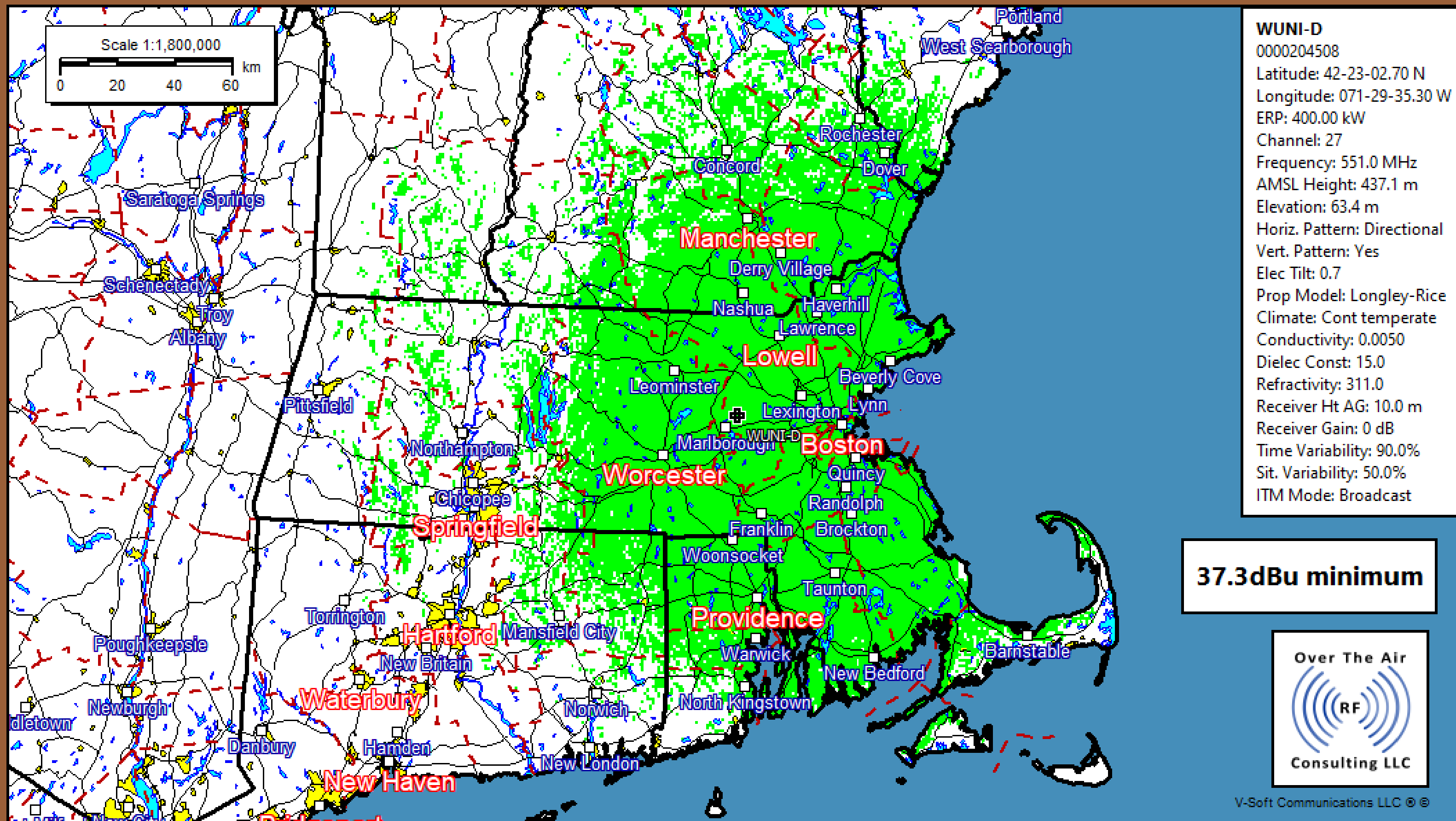
- Pilots estimate OTA channel performance
  - More pilots increase performance but decrease capacity
  - Less pilots decrease performance but increase capacity
  - Pilot spacing defines mobile speed tolerance
- Numbers relate to how many data cells are skipped in two directions
  - D_x = pilot separation
    - Values = 2, 3, 4,6,8,12,16,32
    - Higher # = less of them and therefore lower overhead
  - D_y = # of symbols in sequence
    - Values = 2 or 4
    - Selection has a big effect on capacity
- SP3_2 = 16.7% overhead, sp32_4 = 0.8% overhead

most important variables: GUARD INTERVAL

- Used to prevent intersymbol interference from reflections
- Significant benefit of OFDM modulation
- Longer intervals prevent interference over long echo distances
- Waves travel at 5.4 u_s/mile
- Interval measured in samples from 192 to 4864, some examples
  - 192 = shortest = 28 u_s = approx. 5 miles, least pilots, least overhead 0.6 - 2.3%
  - 512 = short = 74 u_s = approx. 14 miles, less pilots, low overhead 1.5 – 5.9%
  - 768 = short = 111 u_s = approx. 21 miles, moderate pilots, moderate overhead 2.3 – 8.6%
  - 2048 = long = 296 u_s = approx. 55 miles, many pilots, higher overhead 5.9 – 20.0%

3.0 Replication of 1.0 Bit Rate @WUNI

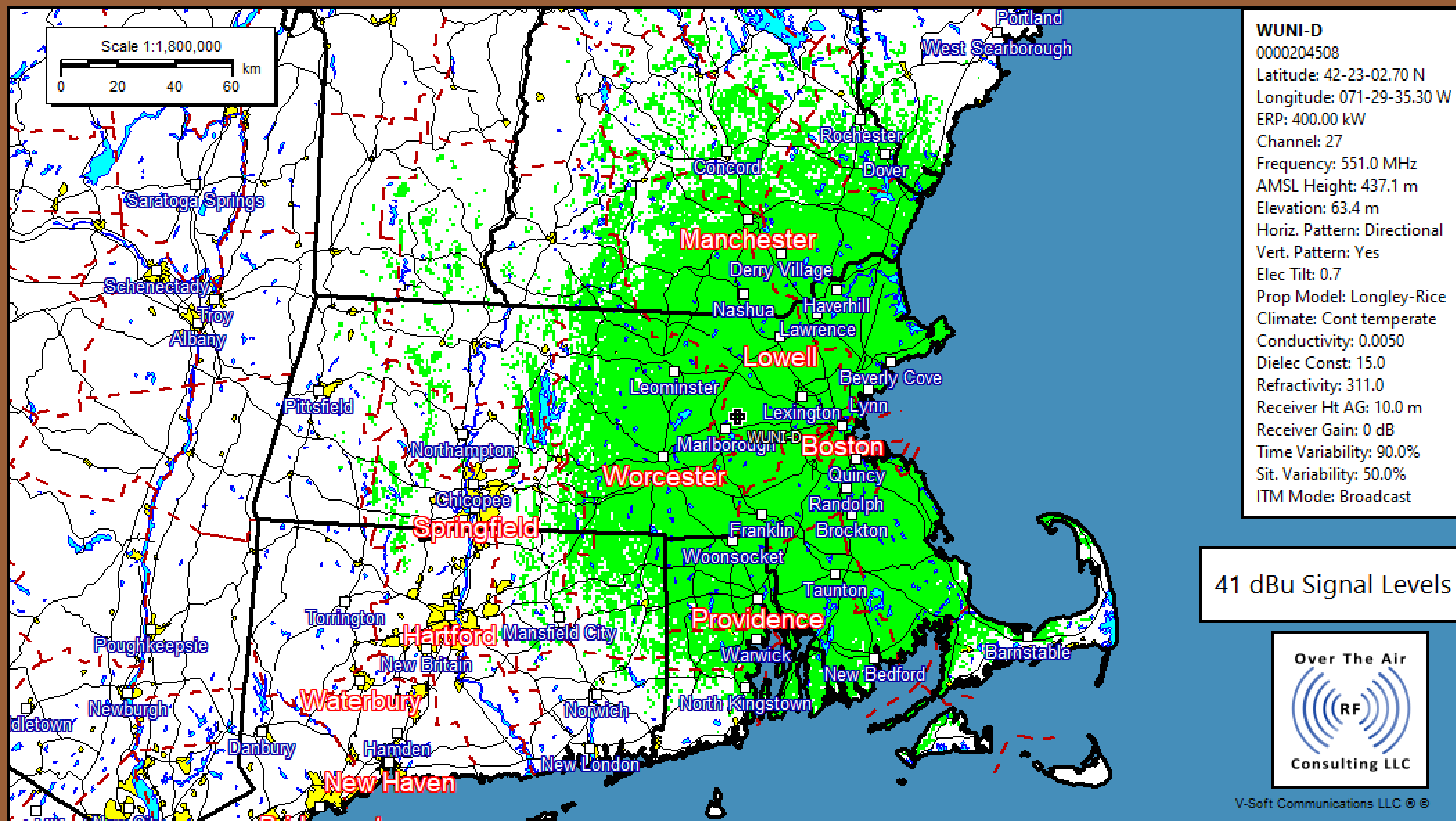
- Data Rate = 19 Mb
- SNR = 11.5 dB awgn
- Mod = 64QAM
- Code = 9/15 long
- FFT = 32k
- SP = 8_2
- G/I = 1536, 222us



Longley-Rice predicted 37.3dB pop count = 8,114K

3.0 Replication of 1.0 SNR @WUNI

- Data Rate = 25 Mb
- SNR = 15.5 dB awgn
- Mod = 256QAM
- Code = 9/15 long
- FFT = 16k
- SP = 12_4
- G/I = 1024, 148us



Longley-Rice Predicted 41 dBu Pop Count = 7,943K

Many Configurations for Similar Bit Rates

- For 19 MB (ATSC 1.0 Bit Rate) these are possible:
  - SNR = 11.5dB, Mod = 256QAM, Code = 9/15 long, FFT = 32k, SP = 8_2, G/I = 1536, 222us   A good fixed service replacement ready for SFN's
  - SNR = 11.8dB, Mod = 64QAM, Code = 9/15 short, FFT = 16k, SP = 12_2, G/I = 512, 74us   Better mobile performance
  - SNR = 12.1dB, Mod = 256QAM, Code = 7/15 long, FFT = 32k, SP = 16_2, G/I = 768, 111us   Another replacement, good error correction

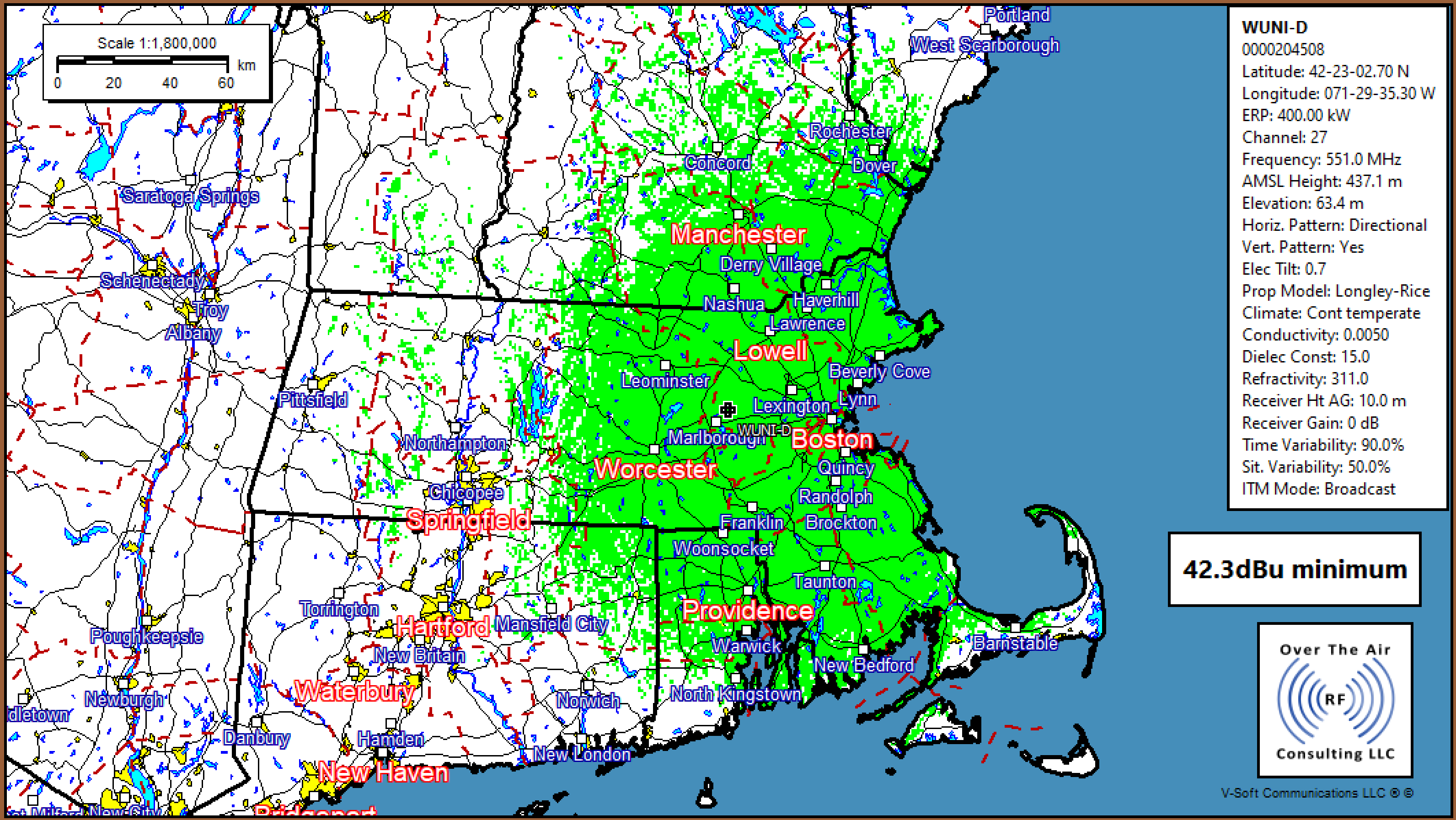
- We used to spend $$$$$ to increase ERP a few tenths of a dB and now we have a way to optimize and increase coverage quickly.
- ATSC 1.0 to 3.0 conversion at same bit rate is like doubling TX power
- 1.0 dB difference = 23% power difference
- 0.6 dB difference = 15% power difference
- 0.3 dB difference = 7% power difference

Let's start the game

- 4 contestants "come on down"
- Change variables and have contestants guess what new pop count value is
- Numbers are in 1000's i.e. 8114 = 8.114 million
- Contestant closest without going over advances to next round
- Second round explores variables deeper
- We will have at least two sets of rounds

ACTUAL WUNI CONFIGURATION FOR 6 HD + 1 SD

- Data Rate = 28.6 Mb
- SNR = 17.1 dB awgn
- Mod = 256QAM
- Code = 10/15 long
- FFT = 32k
- SP = 24_2
- G/I = 1024, 148us



LONGLEY-RICE PREDICTED 42.3 DBU POP COUNT = 7,888K

CODING CHANGES SNR AND BIT RATE

What is the new bit rate after changing the code rate for this mobile focused configuration?

Mod = 64QAM, Code = 9/15 short, FFT = 8k, SP = 4_2, G/I = 768, 111us

SNR = 11.8 dB, Bit Rate = 16.18 Mb

Mod = 64QAM, Code = 8/15 short, FFT = 8k, SP = 4_2, G/I = 768, 111us

SNR = 10.6 dB, Bit Rate = 14.3 Mb

Mod = 64QAM, Code = 7/15 short, FFT = 8k, SP = 4_2, G/I = 768, 111us

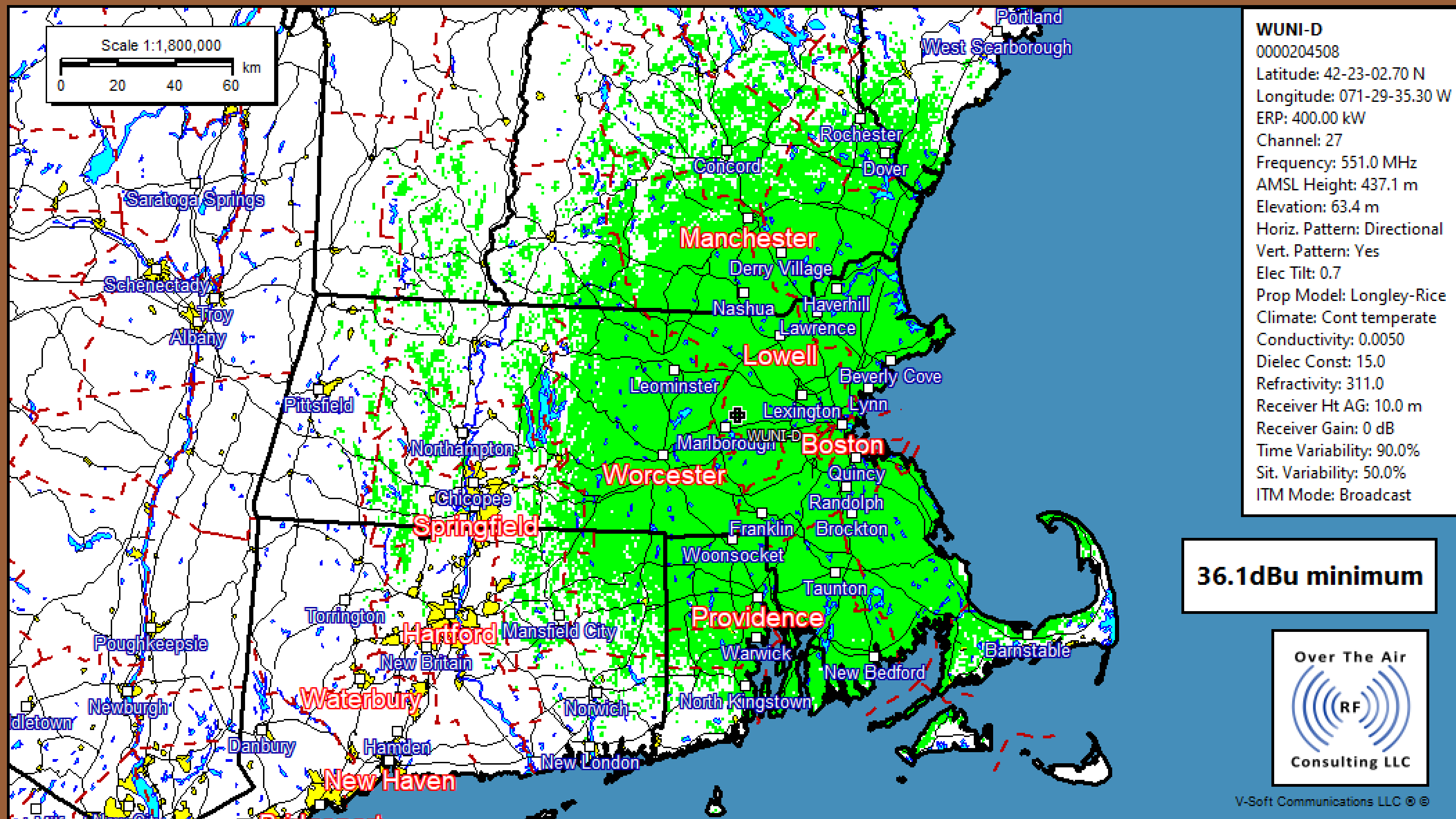
SNR = 9.3 dB, Bit Rate = 12.5 Mb

Mod = 64QAM, Code = 5/15 short, FFT = 8k, SP = 4_2, G/I = 768, 111us

SNR = 6.3 dB, Bit Rate = 8.9 Mb

3 HD + 2 SD CONFIGURATION

- Data Rate = 16.9 Mb
- SNR = 10.3 dB awgn
- Mod = 64QAM
- Code = 8/15 long
- FFT = 16k
- SP = 12_2
- G/I = 512, 74us



Longley-Rice predicted 36.1 dBu pop count = 8,167K

GUARD INTERVAL AND PILOTS CHANGE BIT RATE

What is the new bit rate after changing the guard interval and pilot configuration?

Mod = 256QAM, Code = 9/15 long, FFT = 32k, SP = 16_2, G/I = 768, 111us

SNR = 15.6 dB, **Bit Rate = 25.9 Mb**

Mod = 256QAM, Code = 9/15 long, FFT = 32k, SP = 12_2, G/I = 2048, 296us

SNR = 15.6 dB, **Bit Rate = 24.7 Mb**

Mod = 256QAM, Code = 9/15 long, FFT = 32k, SP = 6_2, G/I = 2048, 296us

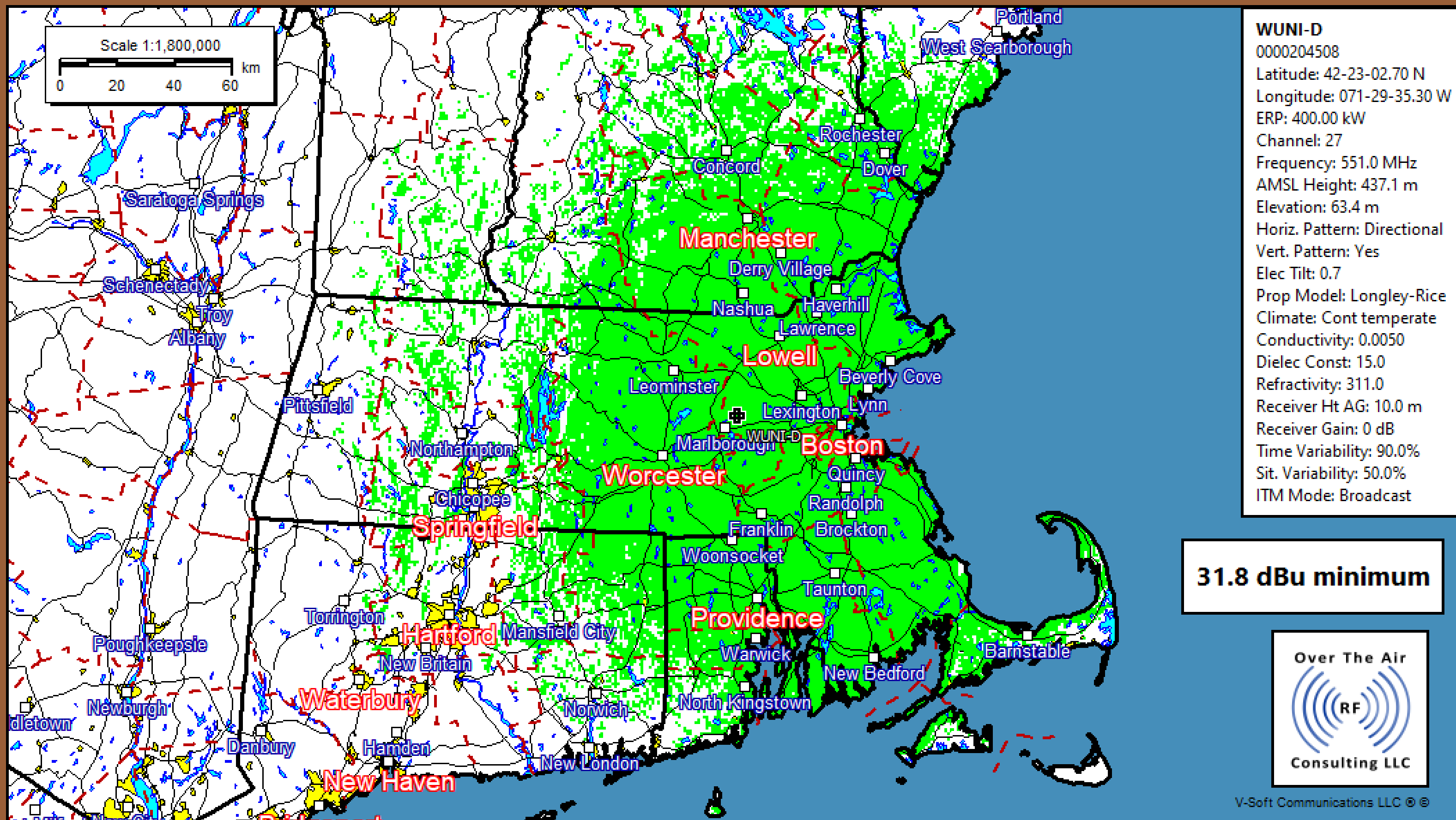
SNR = 15.6 dB, **Bit Rate = 23.7 Mb**

Mod = 256QAM, Code = 9/15 long, FFT = 32k, SP = 32_2, G/I = 192, 28us

SNR = 15.6 dB, **Bit Rate = 26.8 Mb**

2 HD + 1 SD CONFIGURATION

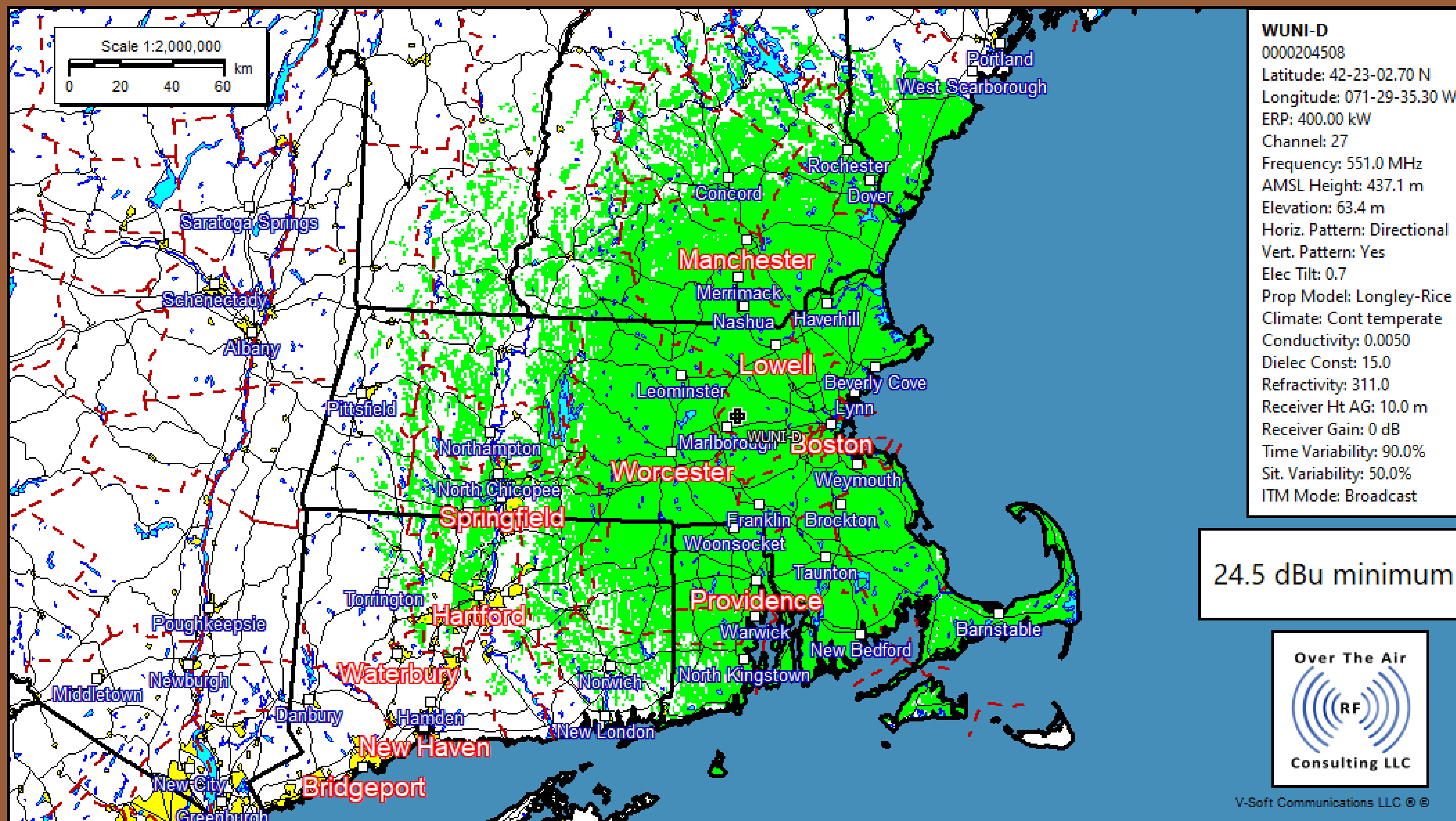
- Data Rate = 10.7 Mb
- SNR = 6.0 dB awgn
- Mod = 64QAM
- Code = 5/15 long
- FFT = 16k
- SP = 16_2
- G/I = 384, 56us



Longley-Rice Predicted 31.8 dBu Pop Count = 8,414K

Datacasting

- Data Rate = 3.1 Mb
- SNR = -1.3 dB awgn
- Mod = QPSK
- Code = 5/15 short
- FFT = 8k
- SP = 6_2
- G/I = 512, 74us



Longley-Rice predicted 24.5 dBu pop count = 9,152K

We need GASSeRs

GASSeRs = Generally Accepted Signal Strength Requirements

- Proposed as industry guidelines for determining real world coverage to different devices and locations
- They assume certain real world environmental losses, receive antenna gains, and noise conditions
- More testing with real receivers is needed to agree on them
- We did not establish these for 1.0
- They will be more important for 3.0 and predicting receivability

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THANK YOU FOR WATCHING AND PLAYING ALONG

SPECIAL THANKS TO UNIVISION FOR SHARING THEIR STATION INFORMATION AND TO DAN FOR ANNOUNCING