Ultra-Dense Networks

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We Need More Spectrum…?

Absolutely.

The challenge is to manage spectrum to the appropriate scales. Forecasted demand is the obvious scale, but the scale of geography (area) is critical as well.

The scales of geography and demand are contradictory in spectrum management:

- Higher carrier frequency = higher total capacity (via higher bandwidth) = smaller covered area.
- Smaller covered area = fewer covered users = less total capacity needed.

What do these scales look like in the real world?

Localization Study.

Identify all Census Block Groups (CBGs) within the urbanized area of sample cities.

- There are over 217k CBGs in the US.

Convert population to subscribers (market share).

Convert subs to usage (average usage per sub).

Convert usage to “RequiredMHz” at an average capacity spectral efficiency.

- The future state is the same as the current; no service improvement.

Forecast future usage and the corresponding RequiredMHz.

RequiredMHz is practical: adding spectrum, increasing Capacity Spectral Efficiency, and densification are all linear impacts.

Study does not include or consider usage from (1) other wireless providers or (2) wi-fi.

A Local Example.

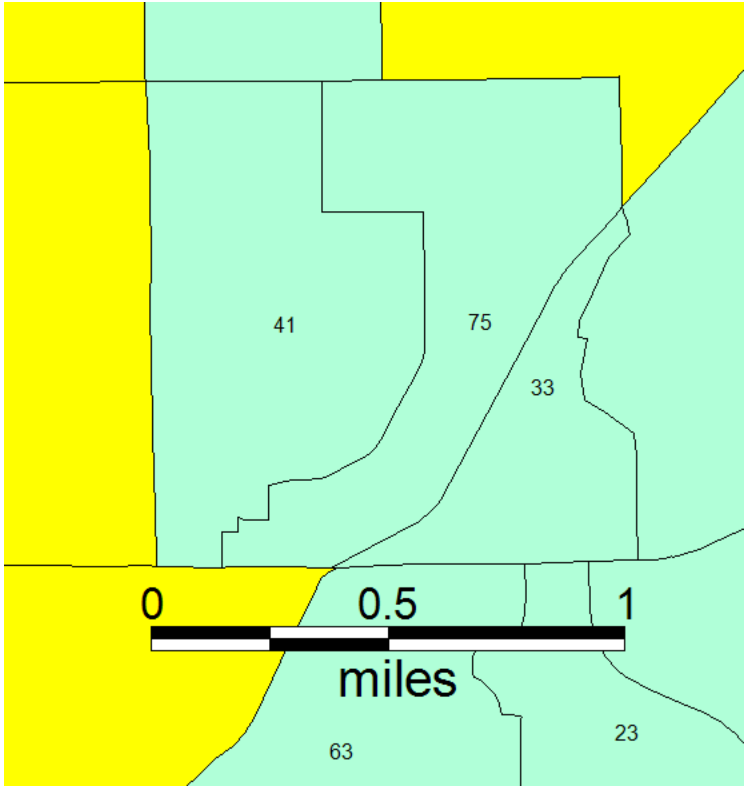
It would be simple to *cover* this square mile with a macro.

But you need 149 MHz of spectrum to deliver sufficient *capacity*.

- Just for Verizon
- Just to keep up with today's service levels

If you were able to place the site in the center, then a 3-sector site would need 50 MHz per sector *(terminology note)*.

- Notice that would mean a service radius of ~0.5 mile (800 meters).
- Next year, when these numbers have all increased, you will need either more spectrum or more access points.



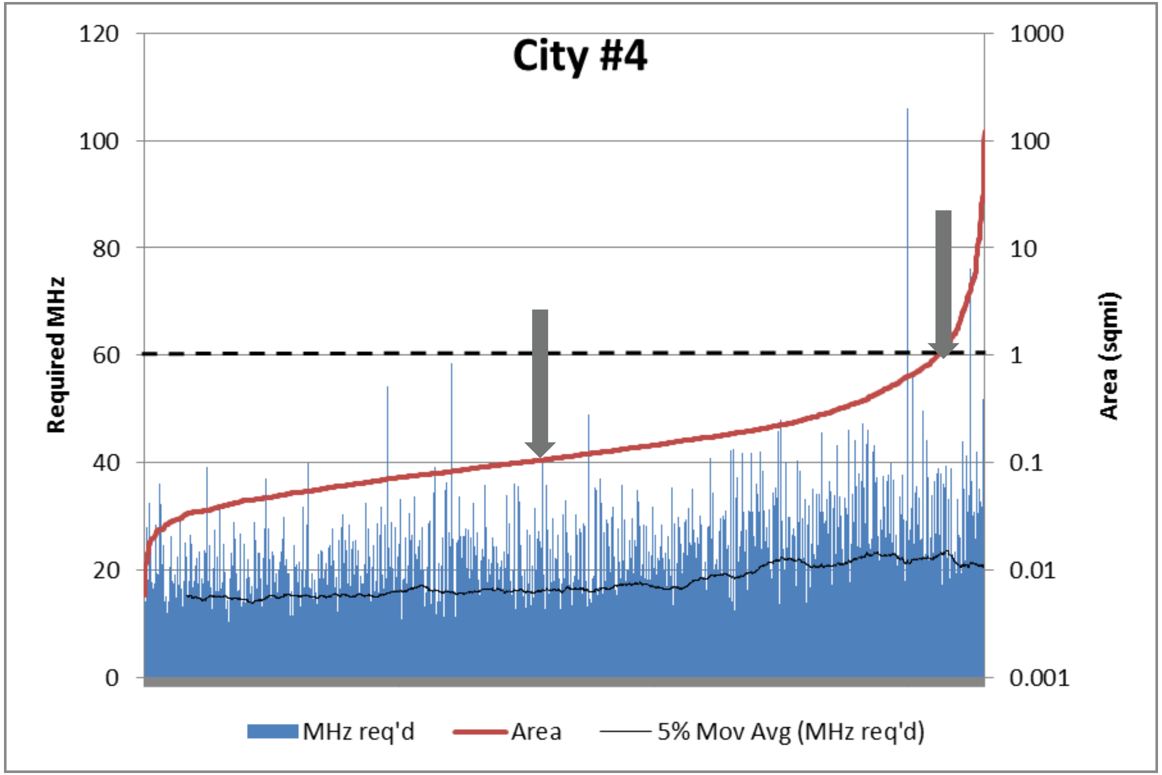
A Larger Example:

Almost half of the CBGs are "small" ***(terminology note).***

Little headroom per CBG, with many small CBGs over 30 MHz.

- These CBGs would be hard to merge with adjacent CBGs while staying under the licensed spectrum limit for this particular city (the dotted line).

Just as notable are the "nulls", where not much spectrum is needed.



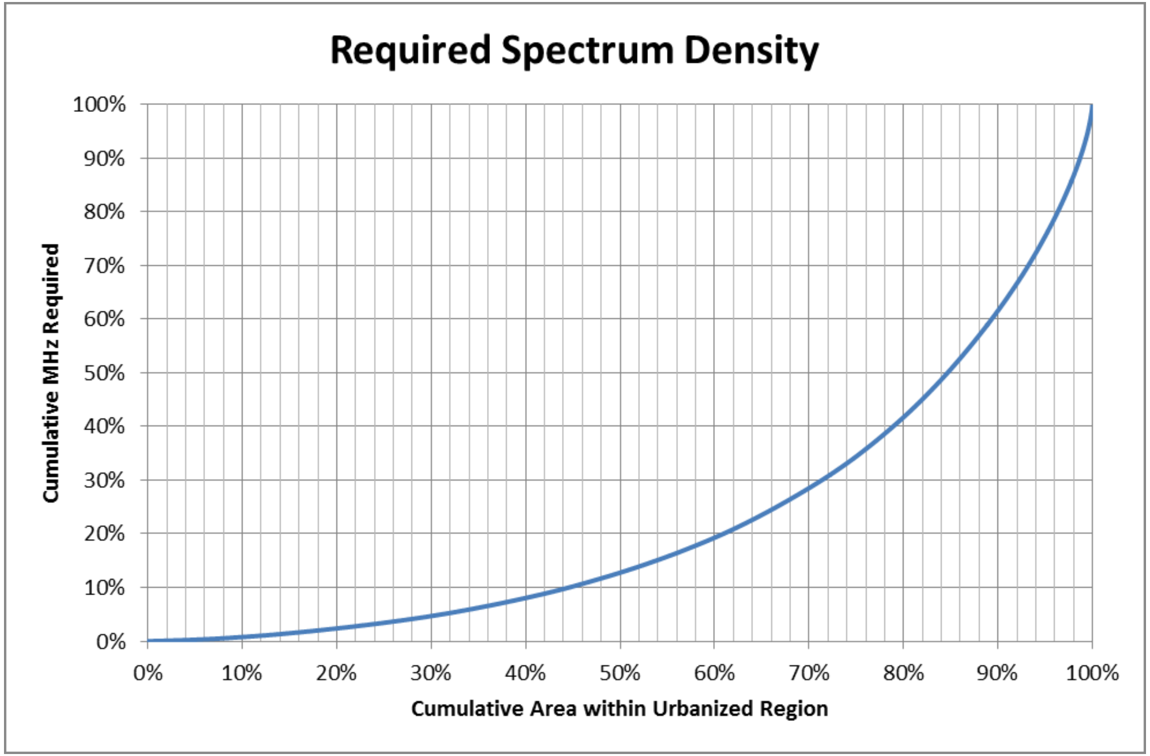
Gini

The chart shows the cumulative statistics of the CBGs from a random urban area.

This curve can be used to derive the *Gini Coefficient*, a relative measure of dispersion usually used in economics.

If the line were straight from (0,0) to (1,1), spectrum needs are uniform and purchasing more spectrum is the most economic choice.

For this city, the Gini Coefficient is 0.55, which is considered highly unequal. More spectrum would only help a small proportion of the total area of this city.

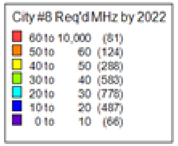


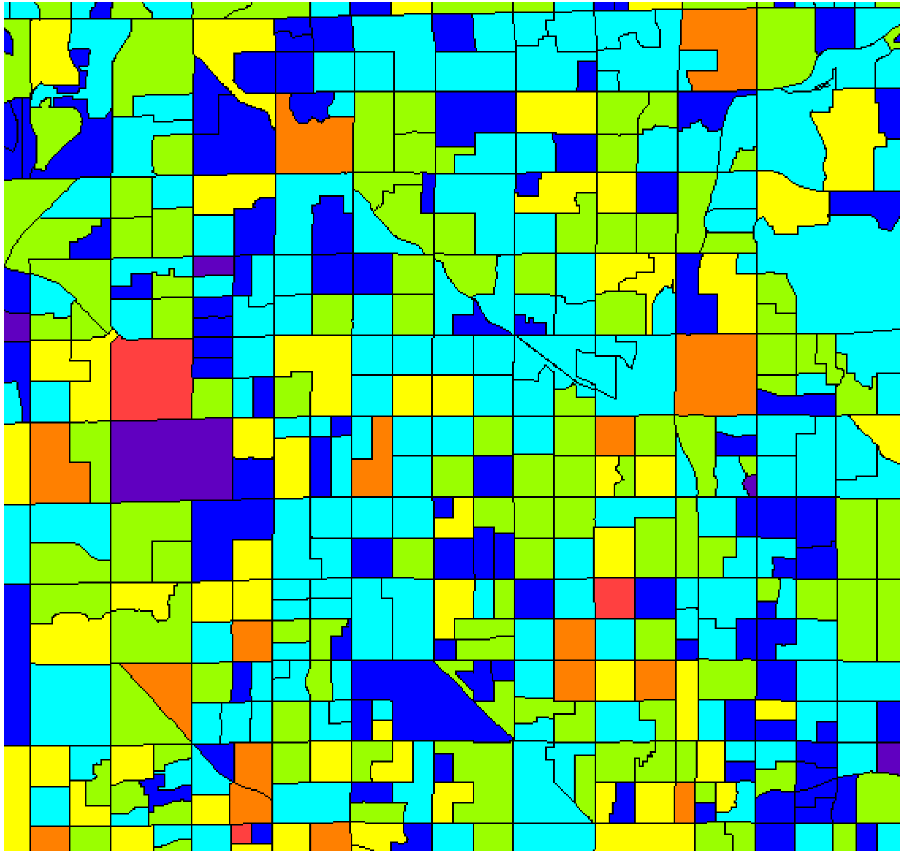
Spatial Dispersion.

Not only is the needed spectral density highly variable numerically, it is highly variable spatially.

Note how the “hot” colors don’t group together often.

It’s not very efficient to spread new spectrum across large geographies like peanut butter.





Solutions.

1. More Spectrum per site.
2. Higher Capacity Spectral Efficiency.
3. Denser Network (less area per site).

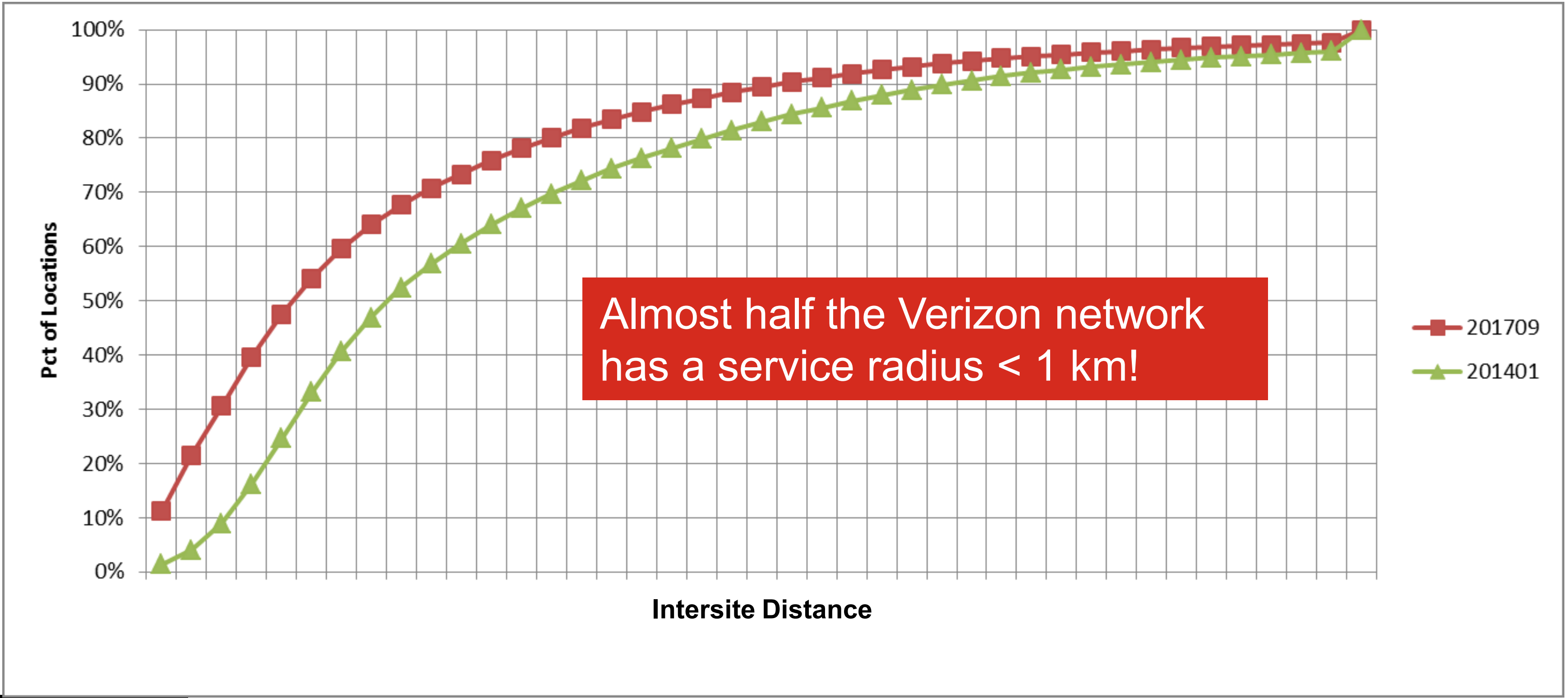
Essentially we are trying to manipulate the *Areal Spectral Efficiency* (bps/Hz/km²).

Increasing Areal Spectral Efficiency

How does one increase network capacity?

- Increase bps/Hz (base spectral efficiency).
  - 64->128->256QAM
  - 2x2->4x4->FD-MIMO
    - Not legacy hardware friendly.
    - Not Municipal Planning Desk friendly (more/larger antennas).
    - Only users in good radio conditions can take advantage (the rich get richer).
- Increase MHz (add spectrum).
  - Expensive. Average market value of spectrum today per macro cell site is ~$2M, by far the largest cost component.
  - Not legacy hardware or Municipal Planning Desk friendly either.
  - Very Chunky.
- Decrease area (densification)
  - Technology agnostic.
  - Reducing cost-per-bit means reducing cost-to-build…not a trivial matter.

Site Density.



Propagation Modeling–What We Do Today.

Detailed propagation modeling is generally accomplished using a statistical model:

Perform CW measurement campaign in areas of interest

- To some extent the areas of interest are subdivided based on observation and experience (e.g., “dense urban” vs. “urban”, “high foliage” vs “average foliage”, etc.

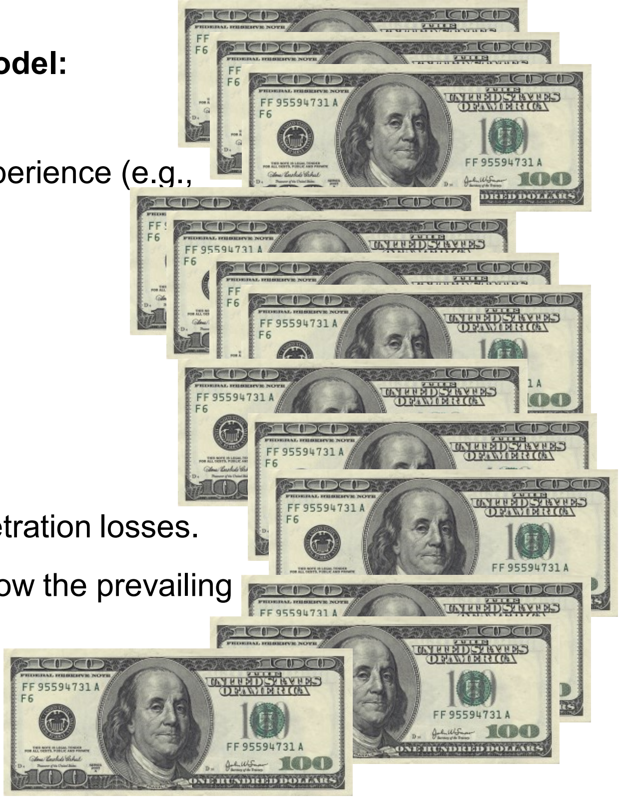
Process these measurements against high-resolution environmental data.

- At UHF, typically in the range of 15m to 5m resolution.
  - GIS resolution has steadily evolved from 30” (nearly 1km; early 1990s)
  - But every halving of resolution quadruples the size of the dataset
- mmWave requires at least 2m resolution

Determine a “best fit” against the environment, considering diffraction paths and penetration losses.

The problem evolves into some form of ray-tracing as base station centerlines go below the prevailing environmental clutter height (S-L-O-W).

Problem: This is an *a priori* situation.



Getting to Tomorrow.

There are no fewer than 7 “mid-band” (>2.5 GHz) allocations being discussed today.

How will the high-level planning of coverage and interference of those bands happen?

Not by calibrating the country!

A simpler way is needed by all stakeholders.

Too much choice (settings/considerations) can be paralyzing. Everything doesn’t need to be a science experiment.

Many real-life cases do not require detailed analyses up-front. Take any greenfield example—all the pain of site selection, plus the *a priori* requirement for calibrated models.

A simple means of assessing both coverage and interference potential. Old-timers (like me) used to moan at the mention of “Carey contours”, but they were a reasonable way of roughing-in a coverage/interference situation.

My Wish List.

Pathloss = f(freq_GHz, distance_m, HAAT(azimuth),…)

Where

- Freq_GHz ranges between 2 and 40 GHz
- Distance_m ranges from 10 to 2000
- These are the useful ranges for modern modeling!

Ideas, possibly Crazy.

Can the concept of HAAT simply be scaled down, particularly with the higher resolution GIS data available? Maybe HAAC (height above average clutter)? We used to sample terrain every 30”, now we can be sub-meter if needed.

Maybe “soft” clutter classes (e.g., trees) have a weighted contribution f(GHz) vs “hard” clutter classes (e.g., buildings)?

- For both diffraction and for penetration.

Maybe HAAC is locally-averaged (e.g., LOESS)? Over what interval?

Maybe some blending of the clutter data (e.g., this radial is x% this and y% that etc.)

Thank you.