Hilbert Curve Rendering Regional Area Network

Presentation to

2025 July _____

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- Contrary to the implication of its name, telephony started with fairly short service ranges by contemporary standards. It was only through interconnecting, with continuously improved technology, to ever farther distance communities that the worldwide PSTN was established. This growth naturally preserved the GeoLocation properties that are crucial for a trustworthy worldwide communication backbone. The current Internet lacks these characteristics, perhaps due to its explosive deployment over the well-established PSTN,
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- This document describes a technique that utilizes Hilbert Curve to allocate EzIP addresses starting from the network prefixes toward specific subscriber identifications by mimicking the progressively focused population density distribution statistics. This top-down approach establishes a numbering plan enabling ad hoc local deployments, while retaining the global perspective. So that, a RAN (Regional Area Network) can be started anywhere desired with the assurance that its numbering plan will be compatible with other RANs as they begin to interconnect.
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- The Hilbert Curve renders a set of linear (1D) data points into a squarish (2D) graph, packing the nearby data points close to one another.
  - Reference: https://en.wikipedia.org/wiki/Hilbert_curve
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- A. Applying this technique to IP address allocation, all neighboring subscribers receive IP addresses with the same network prefixes, thus preserves the GeoLocation properties that support efficient hierarchical routing.
  - Example - IPv4: https://thebayesianobserver.wordpress.com/2011/10/23/121/
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- B. By reserving spares at desired levels, future growth within a community as well as developments in the between areas will have low impact to already assigned IP addresses, preserving the full static address benefits for subscribers.
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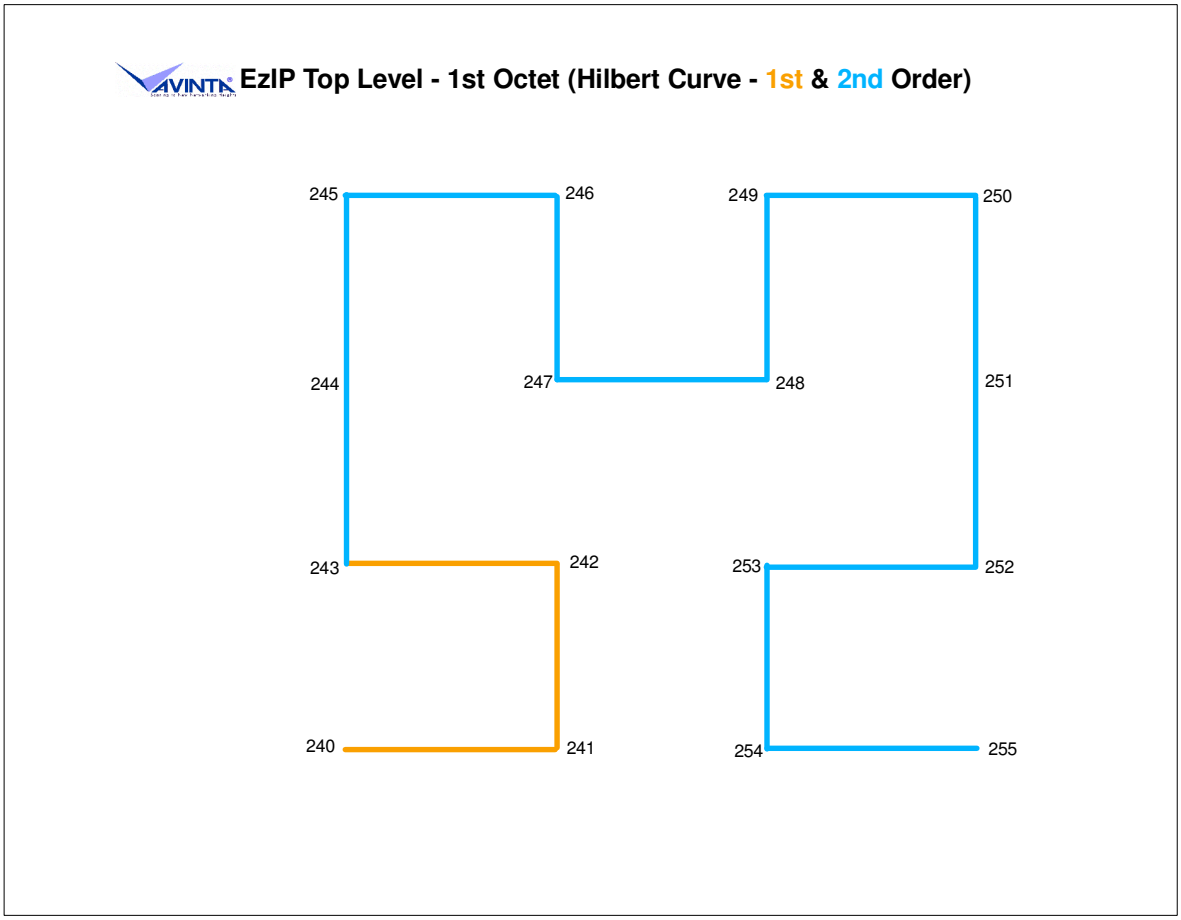
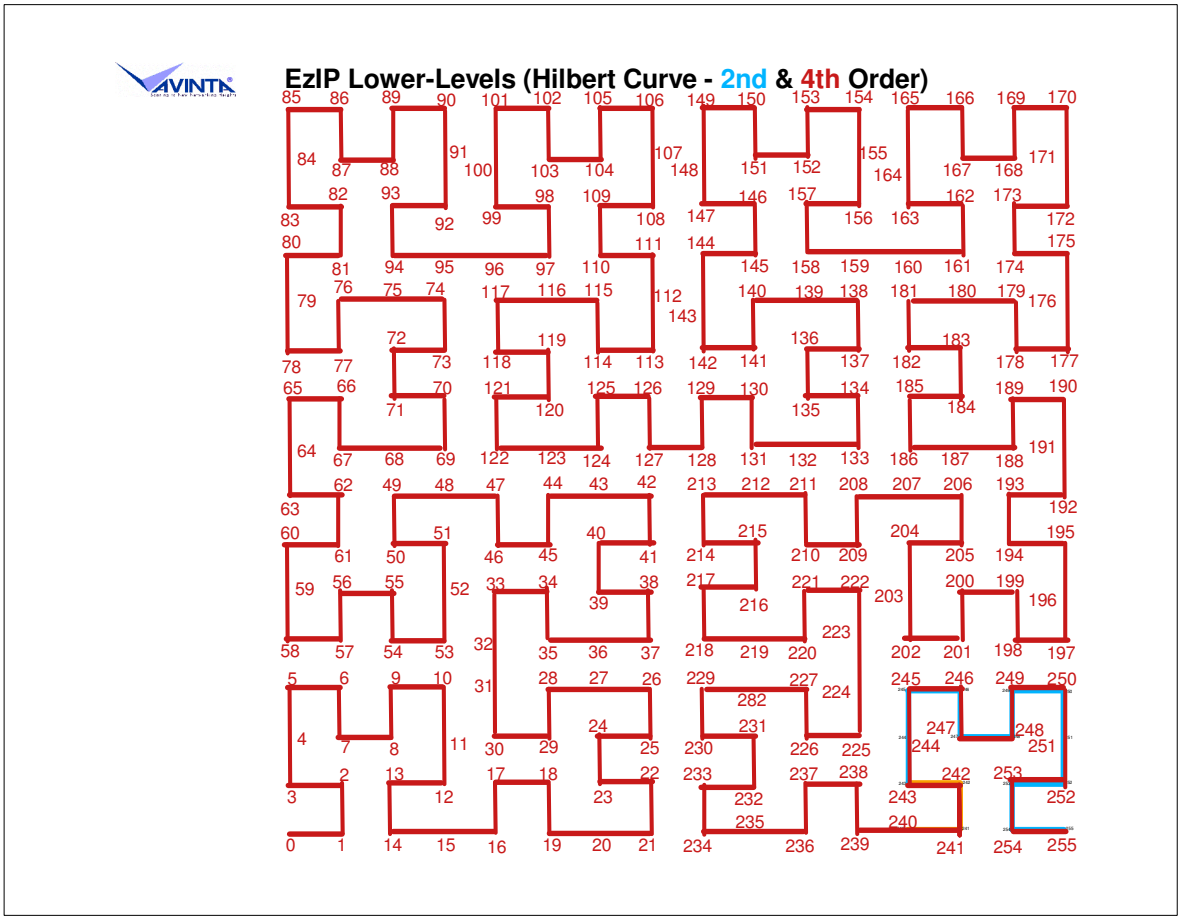
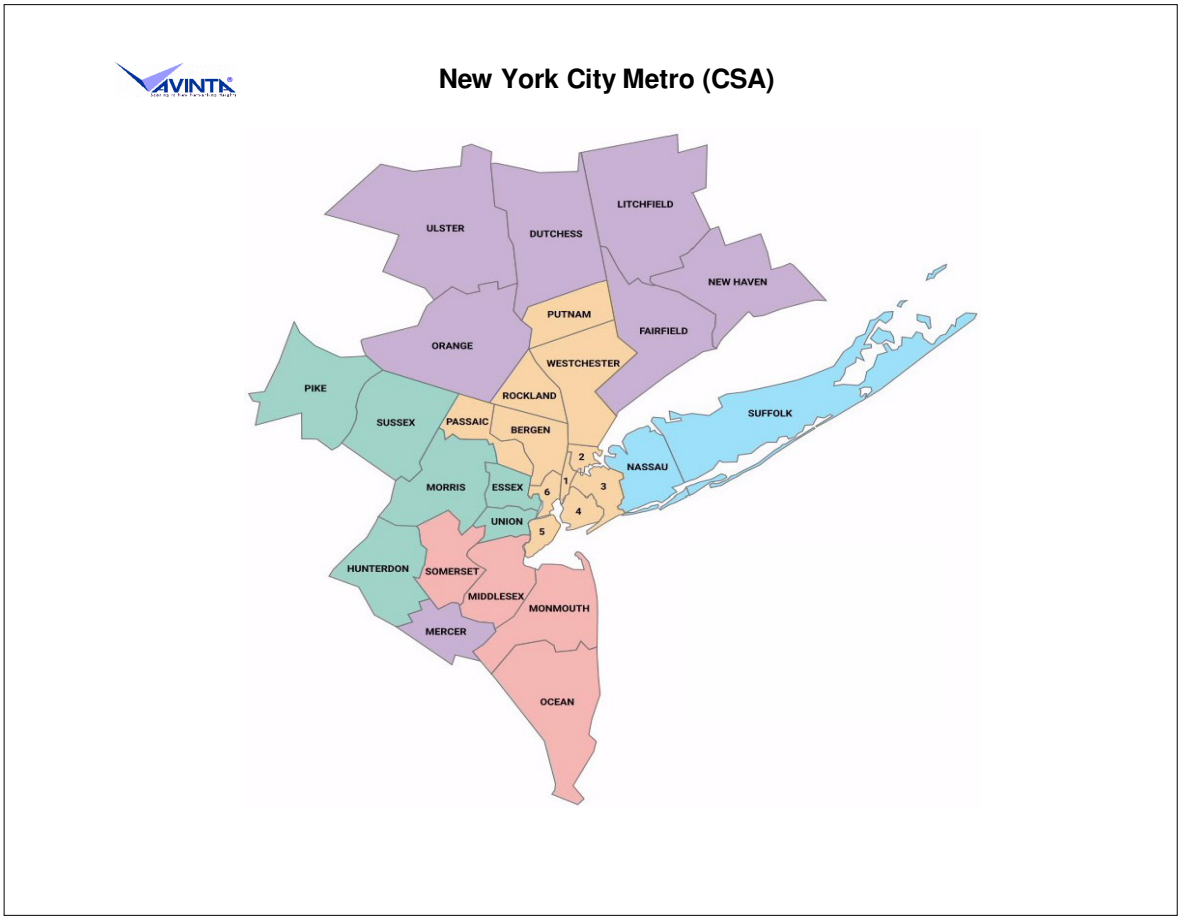
- Nomenclature:
- IPv4: xxx.xxx.xxx.xxx -- Where xxx = 0-255
- EzIP: NPA.DST.NHD.NBR -- Where
  - NPA (Numbering Plan Area) for a Country or a State: 240-255
  - DST (DiSTrict) for a County or a City: 0-255
  - NHD (NeighborHooD) For a section of a City: 0-255
  - NBR (NumBeR): Individual subscriber identification: 0-255



- Let's have a brief look at how the Hilbert Curve characteristics may be applied to IPv4 address allocation.
- The Hilbert Curve starts from the 1st Order that consists of four data points, as shown in the graph (240 - 243) with three orange colored connecting lines.
- The 2nd Order Hilbert Curve (orange plus blue lines) has 16 data points that match with those of the 1st Octet of EzIP address prefix or NPA (240 - 255). Since a 240/4 netblock contains a total of 256M IPv4 addresses, ***each of these NPAs represents 16M addresses***.
- In the basic Hilbert Curve presentation, each data point occupies a same sized square area.
- This uniformly squarish layout may be modified, by stretching or compressing the interconnecting lines, to conform with the geographic shape of a RAN being considered, as well as reflecting density of the population distribution.
- For each data point, we can apply another Hilbert Curve for representing the distribution of the next IP address Octet matching with the population distribution at a more local level.
- For future growth, consider reserving up to 5% (one out of 16) of these data points at this NPA level, during the initial allocation phase.



- Let's start with the Hilbert 2nd Order Curve (blue & orange). Then, place the 4th Order Curve (red) over it.
- This 4th order Hilbert Curve, having 256 (0-255) data points, matches with each of the three lower-levels (octets) DST, NHD & NBR in the EzIP address format:
  - A. Each data point in the DST (2nd octet) represents 64K IPv4 addresses with a total of 16M addresses. (Up to 10% is suggested to be reserved as spars at the beginning of the allocation for developing regions.)
  - B. Each data point in the NHD (3rd octet) represents 256 IPv4 addresses with a total of 64K addresses. (Up to 25% is suggested to be reserved as spars at the beginning of the allocation for underdeveloped regions.)
  - C. Each data point in the NBR (4th octet) represents 1 IPv4 address with a total of 256 addresses. (Up to 50% is suggested to be reserved as spares in general at the beginning of the allocation.)
- Note: As an example for some perspectives, a high-rise apartment building could have hundreds of residents or more who would require allocating more than several (say N) NHD data points. So that it may have N x 256 addresses for assigning to subscribers in that same building, which may appear as only a small dot in the map of a large city.

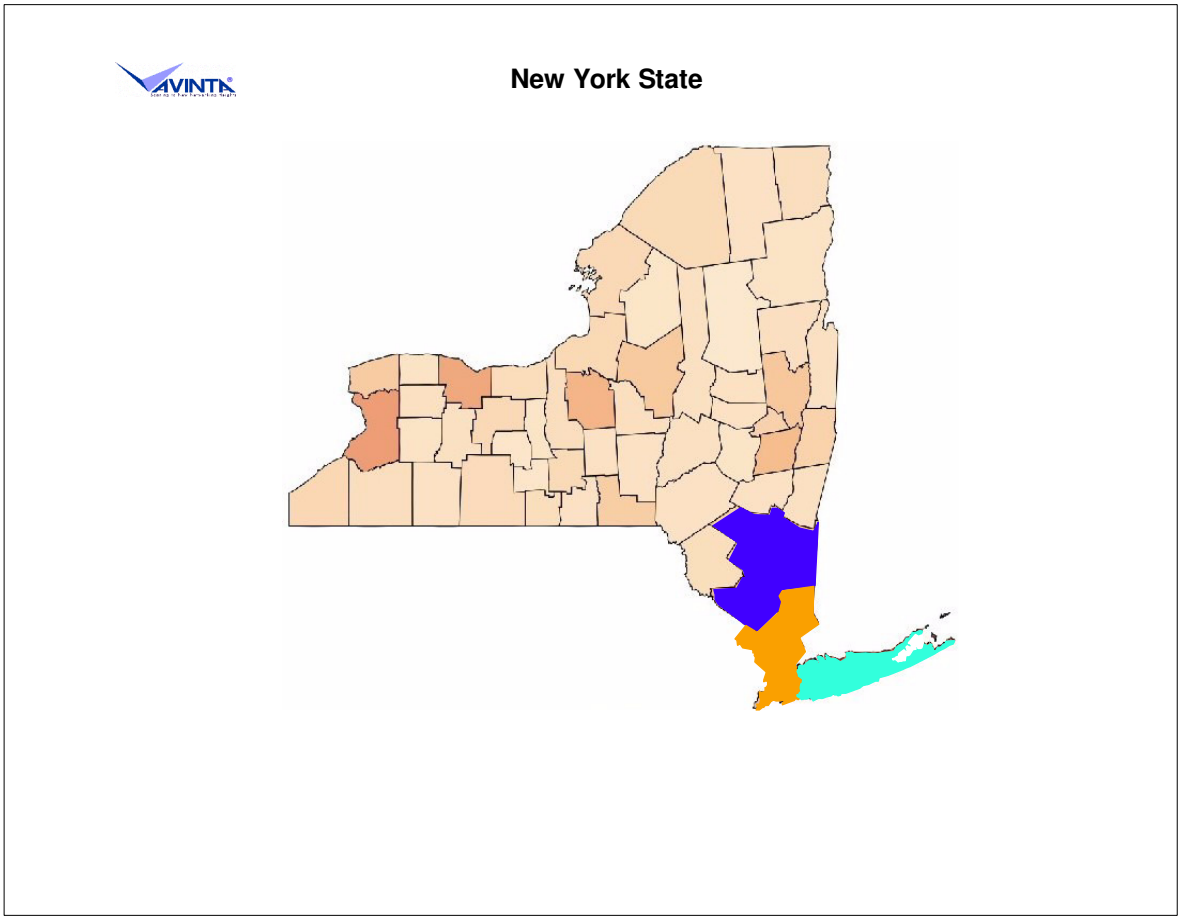


- To see how the Hilbert Curves may assist us to allocate the EzIP addresses, we will look at NYC Metro which ranks as the world's thirteenth largest metropolitan area. A metropolitan usually consists of geographically adjacent areas with various demographical divisions. For example, the NYC Metro consists of a small part of NYS in area, but the majority, yet not all of NYS populations. On the other hand, NYC Metro includes areas from several neighboring States:

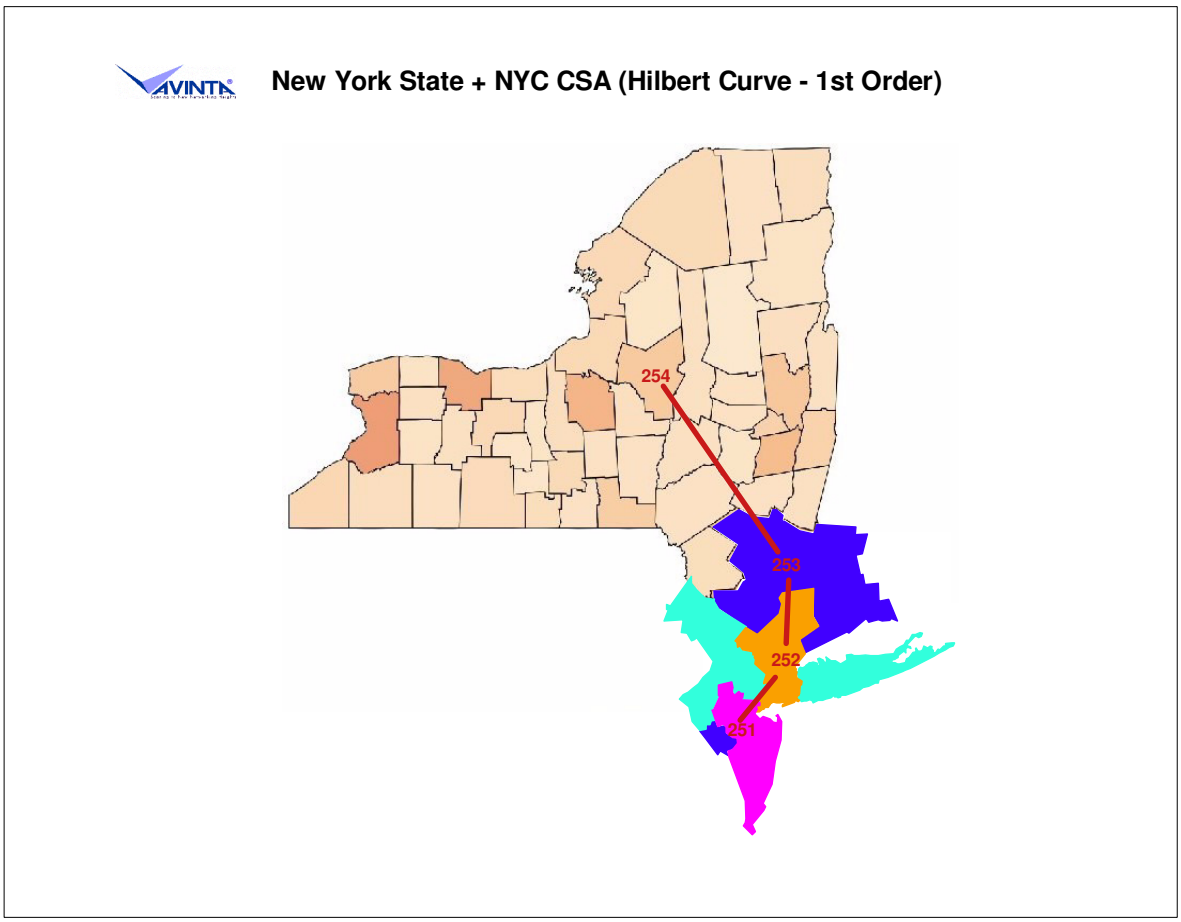
- MYC Metro Population:

- I. NYC (Five Boroughs): 8.18M
- II. NYS within NYC Metro: 5.21M
- III. New Jersey: 6.93M
- IV. Core Based Statistic Areas (Connecticut, New Jersey, Pennsylvania): 2.41M:

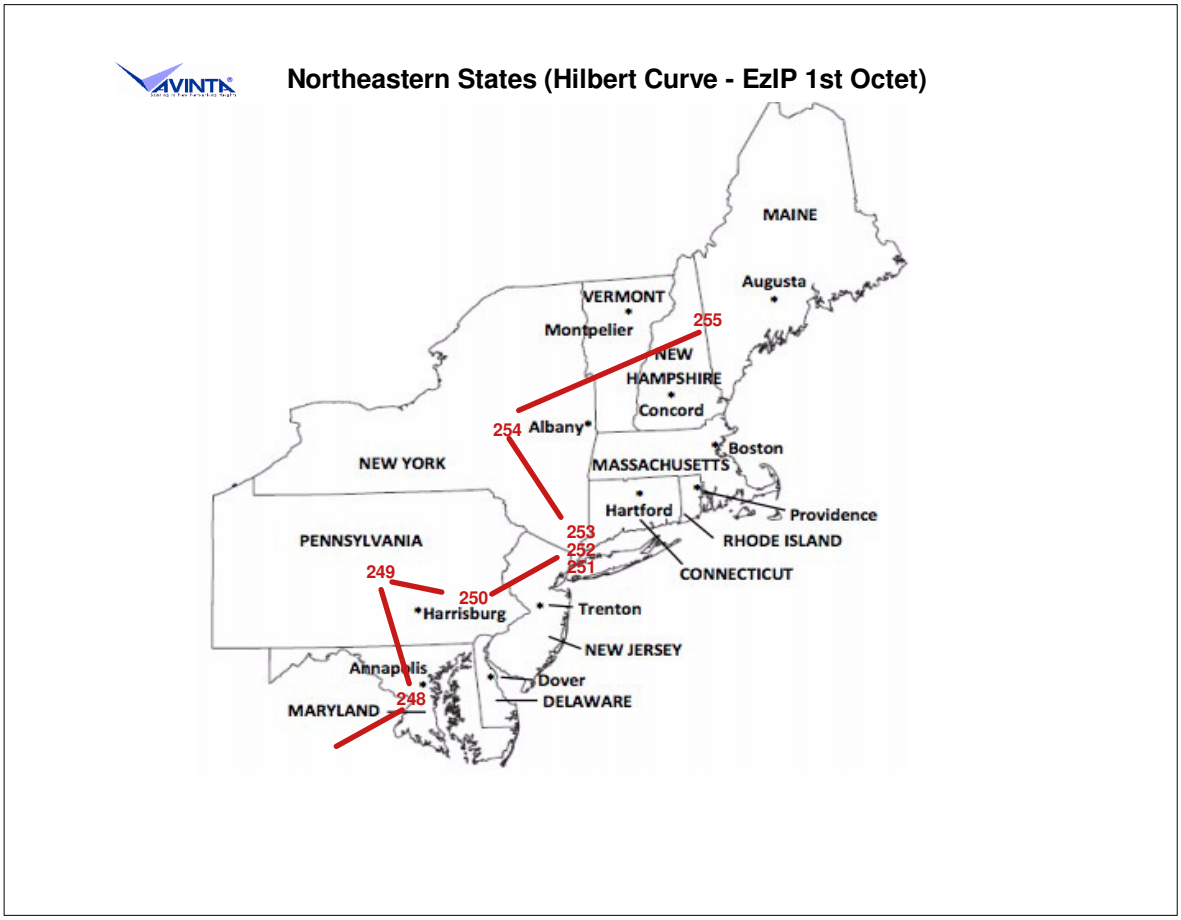
  - ***NYC Metro CSA (Combined Statistical Area) total population:*** 22,73M, Or, ***about 22.7M***



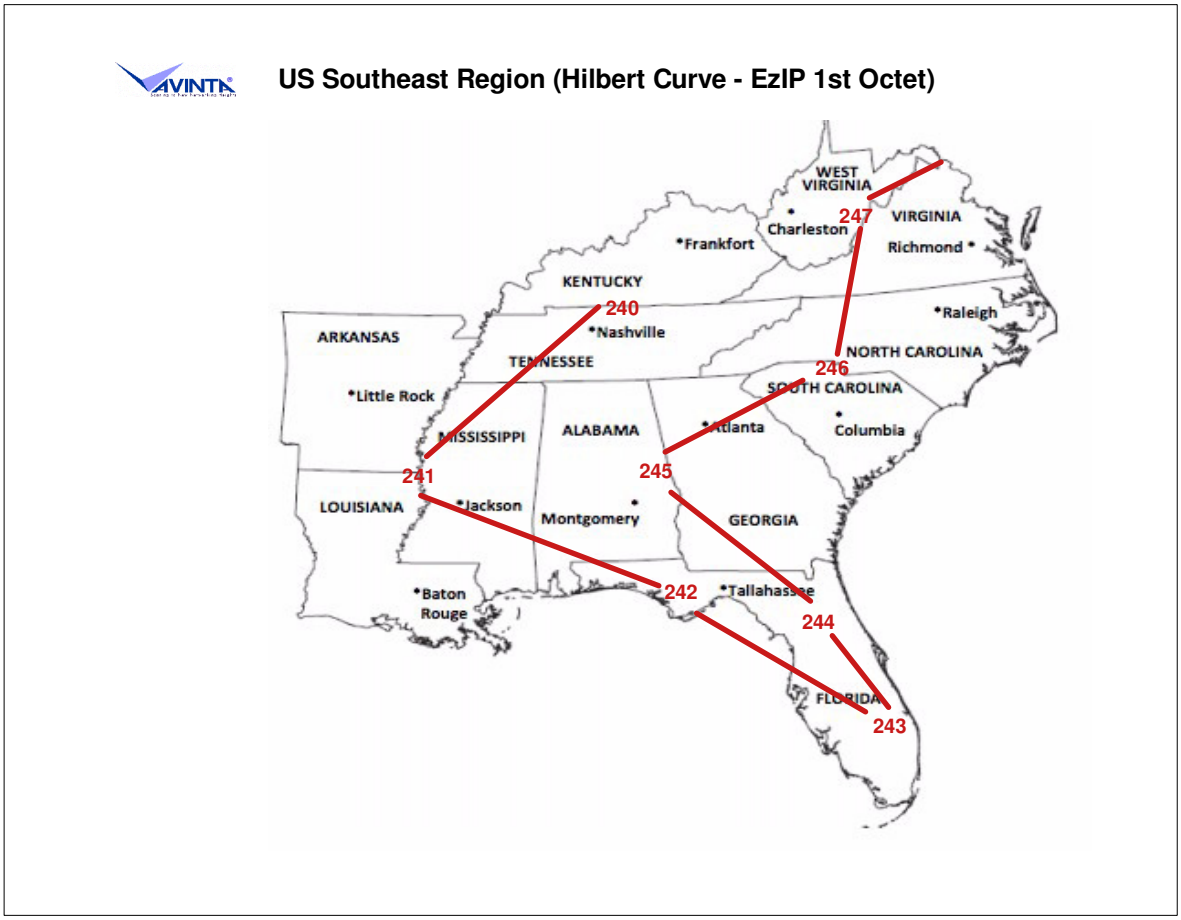
- The entire New Your State (NYS) population is 19,469,232.
- However, a substantial part of it falls within NYC Metro:
  - (NYC five boroughs (8,180,272) + NYS w/i NYC Metro (5,212,951) = 13,393,221.
- So, the majority of ***NYS population*** resides inside of NYC Metro. Or, ***the minority (6,076,009 Or, 6.1M) resides outside of NYC Metro.***



- We now start from,
- ***I. NYS w/o NYC Metro population: 6.1M***
- then add,
- ***II. NYC CSA population: 22.7M***
- ***Combined: 28.8M***
- Applying communications' 80/20 Rule, the estimated number of ***institutions is 7.2M***.
- ***Total estimated subscribers: 36.0M***
- Since each 2nd Order Hilbert Curve data point represents 16M, 4 will be used here totaling 64M which is 1.78 times of the estimated current need. Or there will be ***78% spare*** for the future growth.
- The 4 groups are then each assigned with one NPA:
- Allocate
  - ***A. 1 data point (16M addresses) to I.: NPA - 254***
  - ***B. 3 data points (48M addresses) to II.: NPA - 251, 252,253***



- Next, let's expand the area further to the adjacent States - the Northeast Region of US:
- **I.**
- Maine: 1,405,012 -- New Hampshire: 1,409,032 -- Vermont: 648,493 -- Massachusetts: 7,136,171 -- Rode Island: 1,112,308
- **Subtotal: 11,711,016**
- **II.**
- New York: 19,867,248 -- Connecticut: 3,675,069
- **Subtotal: 24,651,625**
- **III.**
- New Jersey: 9,500,851 -- Pennsylvania: 13,078,751
- **Subtotal: 23,539,317**
- **IV.**
- Delaware: 1,051,917 -- Maryland: 6,263,220 -- Washington, D.C.: 702,250
- **Subtotal: 6,965,470**
- ***Total population: 66,867,428***
- Applying communications' 80/20 Rule, the estimated number of institutions is **16,716,857**.
- ***Total subscribers:*** 83,584,285 or ***83.6M***
- Rounding up to next good Hilbert Curve number, 128M, which is 1.53 times, or **53% spare.** This is a little less spare than the case with NYC Metro alone.
- ***For 128M*** addresses which is **half of a 240/4 netblock**, or **8 x** 1st Octet data points (**16M each**), we can allocate:
- ***A. 4 data points for II. (The area of NYS + NYC Metro from preceding step.) NPA: 251 -254***
- ***B. 1 data point for I. NPA: 255***
- ***C. 2 data points to III. NPA: 249, 250***
- ***D. 1 data point to IV. NPA: 248***



- For the Southeast Region of US
- **I.**
- Virginia: 8,811,195 -- West Virginia: 1,769,979
- **Subtotal: 10,581,174**
- **II.**
- North Carolina: 11,046,024 -- South Carolina: 5,478,831
- **Subtotal: 16,524,855**
- **III.**
- Georgia: 11,180,878 -- Alabama: 5,157,699
- **Subtotal: 16,338,577**
- **IV.**
- Florida: 23,372,215
- **Subtotal: 23,372,215**
- **V.**
- Arkansas: 3,088,354 -- Louisiana: 4,597,740 -- Mississippi: 2,943,045
- **Subtotal: 10,629,139**
- **VI.**
- Kentucky: 4,588,372 -- Tennessee: 7,227,750
- **Subtotal: 11,816,122**
- ***Total: 89,262,082***
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- Applying communications' 80/20 Rule, the estimated institutions is **22,315,520**.
- ***Total subscribers:*** 111,577,602 or ***111.6M***
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- Rounding up to the next good Hilbert Curve number, 128M which is 1.15 times or **15% spare**. This is even tighter as spares than that for the NE Region.
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- **Using 128M** which is **half of the 240/4 netblock**, or **8 x** 1st octet data points, each with **16M** IPv4 addresses, we can allocate
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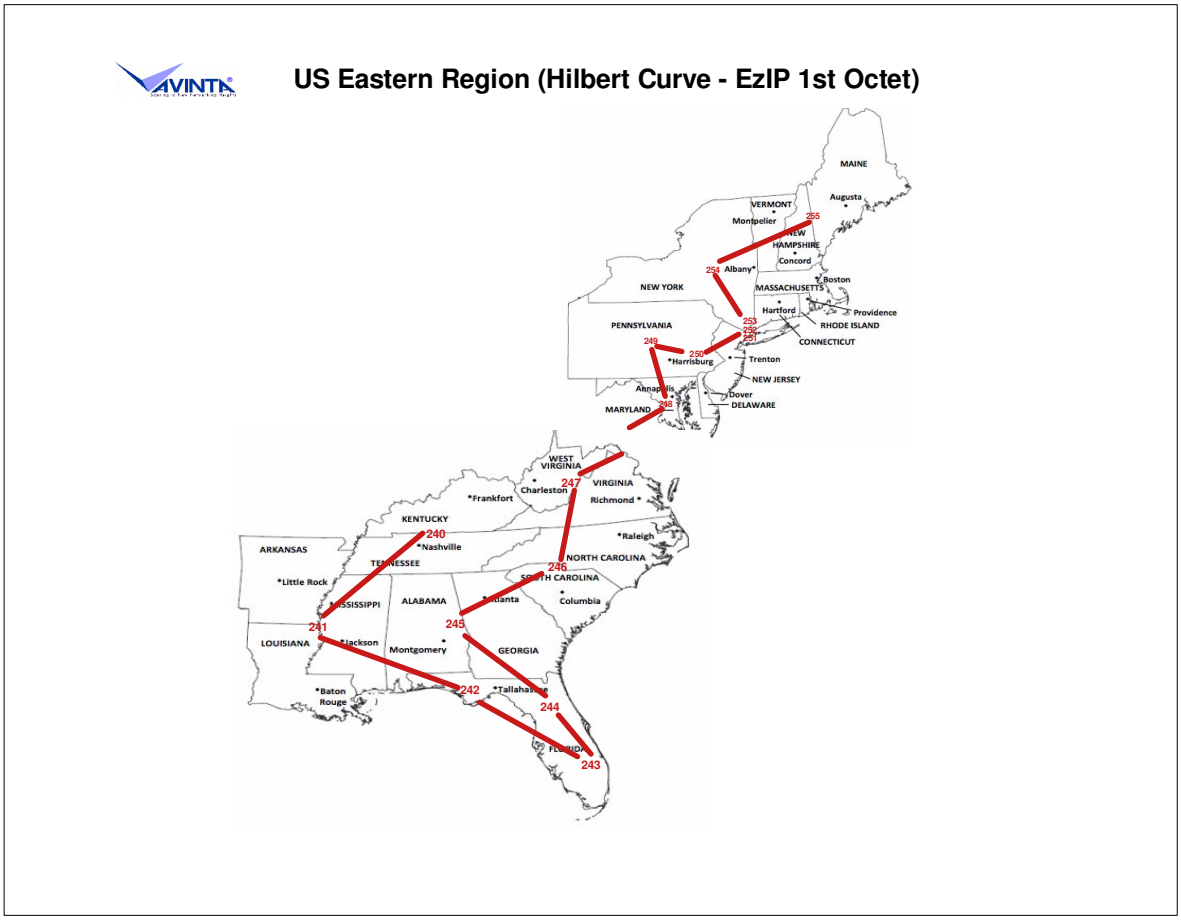
- ***1 data point to I. NPA: 247***
- ***1 data points to II. NPA: 246***
- ***1 data points to III. NPA:245***
- ***3 data points to IV. NPA: 242 - 244***
- ***1 data point to V. NPA: 241***
- ***1 data Point to VI. NPA: 240***



- Combining NE & SE Regions, the number of estimated subscribers are:
  - NE Region: 83.6M
  - SE Region: 111.6M
- ***Total estimated subscribers: 195.2M***
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- If we adjust the boundary between the two regions to share one 240/4 netblock, the 256M addresses is 1.31 times of the above total, **or 31% spare.**
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- Since the 31% spare may be still too tight, it would be advisable to start with allocating one full RAN (256M addresses) for each region, so that they may have **206% and 129% of spares**, respectively. With this doubled allocation, each data point shown in this graph would have two NPAs assigned to, easing the concern for future growth.
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- Following this line of reasoning, the rest of US may be divided into NW, SW, Middle North and Middle South Regions, for a total of 6 RANs. Each will be served by one separate RAN utilizing one full 240/4 netblock, with a total capacity of 1,536M static addresses,
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- The total US population is about 345M, Including approximately 88.5M institutions, the total number of estimated US subscribers is 433.5M at the initial planning phase. The reusable ***EzIP addresses are 3.54 times of the estimated US subscribers.***
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- Since most countries need only one RAN, the number of worldwide RANs will be finite for distinguishing one from another. For example, a small IPv4 address netblock can encapsulate the existing IDDD (International Direct Distance Dialing) country codes (249 by count, full 1 - 999 by format) verbatim, mirroring the PSTN prefix. There should remain enough space for including a suffix portion that identifies the multiple RANs (fewer than 10) within those larger countries.
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- Each RAN can begin L3 switching based services within itself independent of others, utilizing Gateway technology to interact with the rest of the Internet. In the long run, networking devices may develop RFC791 based address extension schemes (US Patent No. 11,159,425) to perform end-to-end communication via L3 switching as well. This will establish a worldwide deterministic backbone for a secure network that is robust against cyber intrusion.