



Point-to-Multipoint Coexistence with C-band FSS

March 27th, 2018

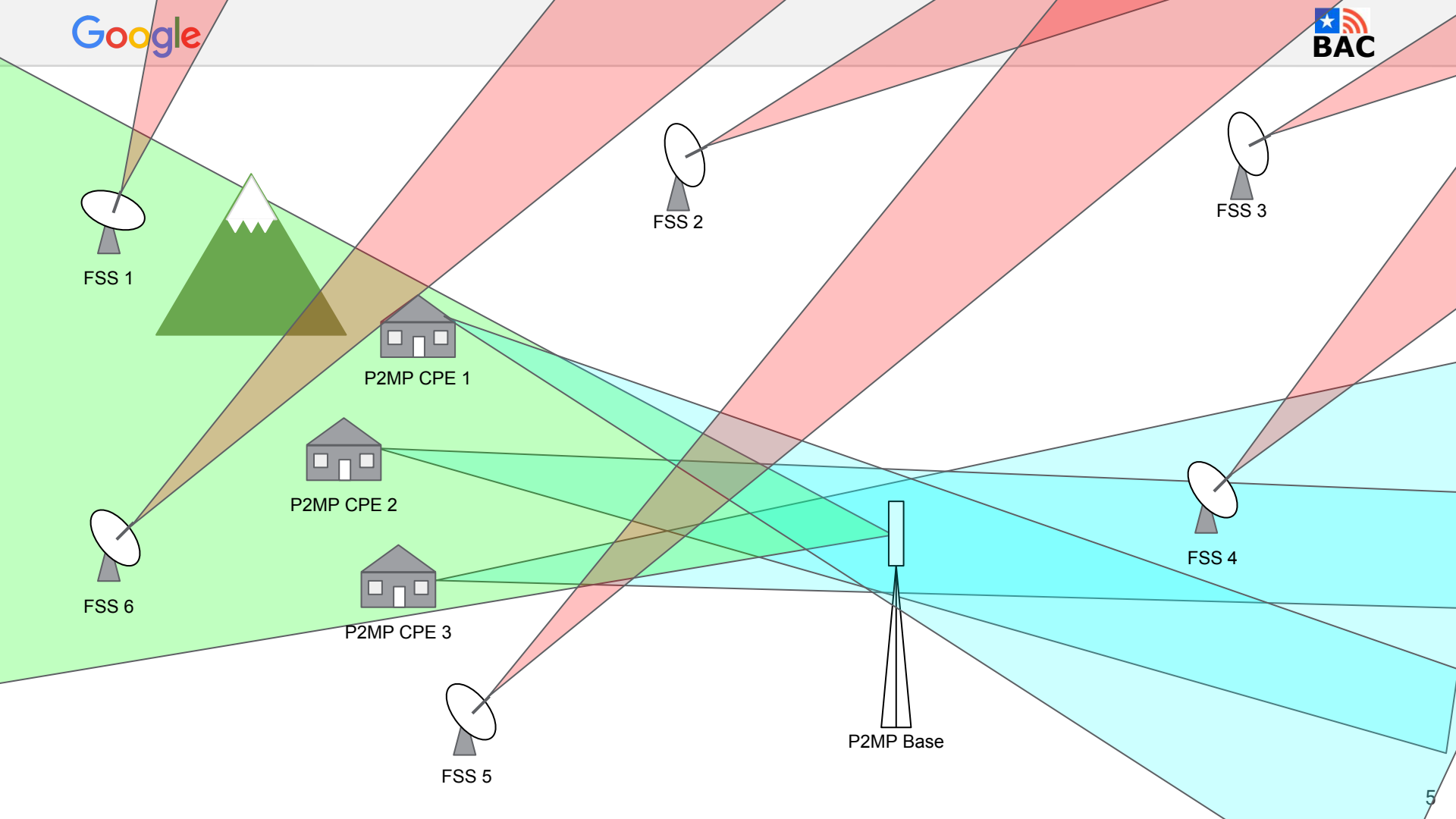
Conclusions

- 3700-4200 MHz point-to-multipoint (P2MP) systems could immediately provide gigabit-class broadband service to tens of millions of Americans, without causing disruption to FSS
 - In many areas of the country, P2MP systems can operate in C-band (3700-4200 MHz) without causing interference to co-channel fixed-satellite service (FSS) systems
 - Co-channel sharing is possible by considering geographic and directional isolation between P2MP and FSS; that is, operating in areas with a relatively low number of earth stations, and using directional antennas that don't point toward earth stations in the area.
- If actual FSS frequency use were known, frequency separation could allow 25 Mbps - 1 Gbps P2MP broadband service to as many as 120 million Americans

Contents

- Considerations for coexistence between P2MP and FSS
- Areas in which P2MP and FSS may be able to co-exist
- Real-world example: Co-channel & non-co-channel

Coexistence Considerations



Calculation of Co-channel Interference from P2MP into FSS

Assume n P2MP transmitters operating within C-band, with conducted power spectral densities of PSD_i (in dBm/MHz). The aggregate interference power spectral density $IPSD_j$ (dBm/MHz) received by FSS station j is:

$$IPSD_j = \sum_{i=1}^n (PSD_i + GT_{ij} - PL_{ij} + GR_{ij}),$$

where:

GT_{ij} = Gain of P2MP antenna i in the direction of FSS earth station j

PL_{ij} = Propagation loss from P2MP station i to FSS earth station j

GR_{ij} = Gain of FSS earth station j 's antenna in the direction of P2MP station i

Propagation Loss

- For analysis, PL is modeled by the NTIA Irregular Terrain Model (ITM) implementation of Longley-Rice
 - Same model adopted by WInnForum for protection of FSS due to Part 96 CBRS
- Very conservative model for interference prediction
 - Does not specifically take clutter (trees and buildings) into account
 - Extensive propagation testing in 3.6 GHz band shows clutter creates very high additional losses over ITM
 - Measured losses in urban and suburban environment are some 40-60 dB greater than ITM, due to buildings and foliage
 - Measured losses in rural environments have shown an additional ~ 17 dB/km of loss over ITM predictions, due to foliage
- Used WInnForum-compliant implementation of ITM for propagation analysis

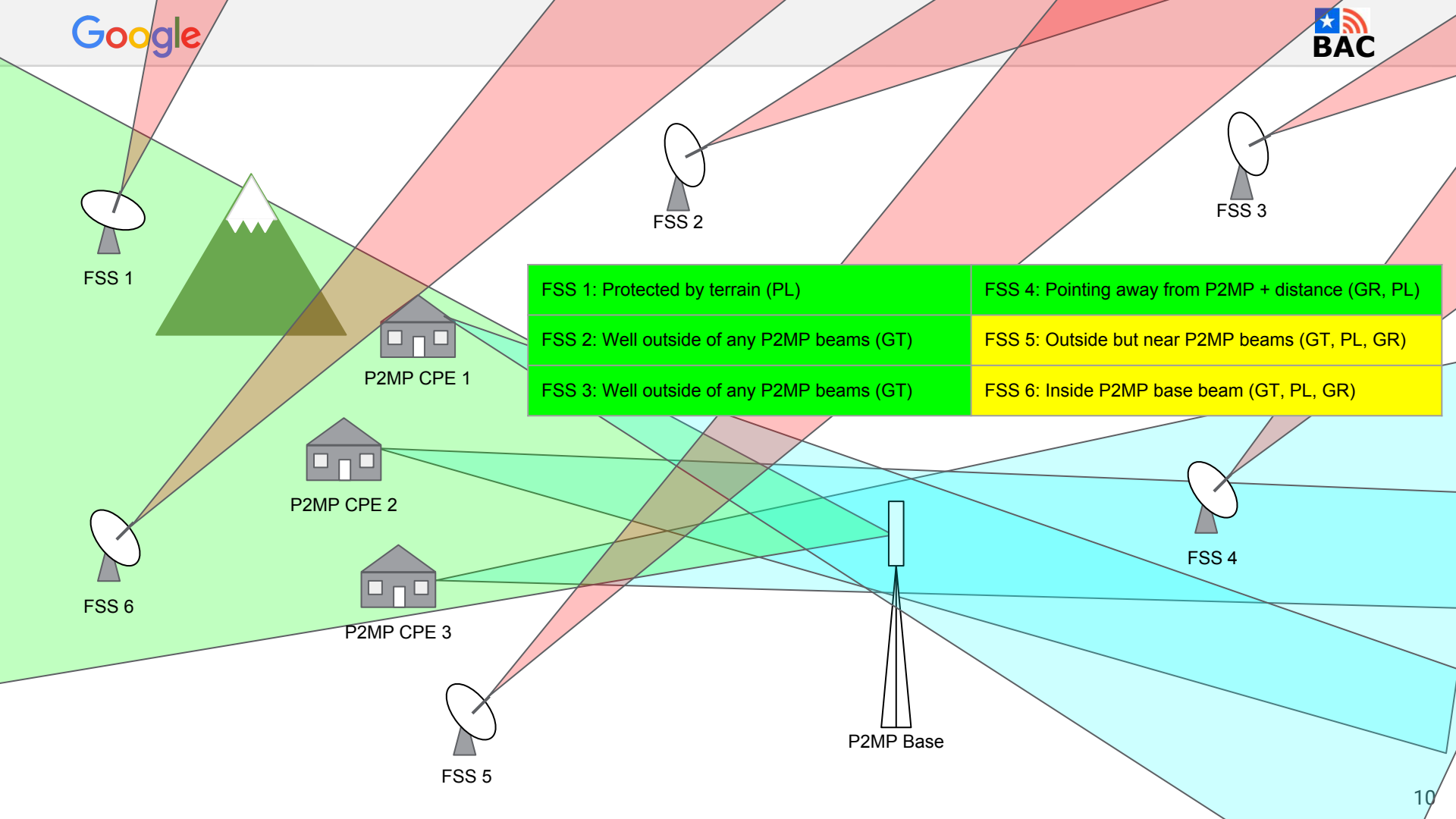
P2MP/FSS Coexistence

- Coexistence is achieved when the aggregate interference from planned P2MP deployments does not exceed the interference limit of any FSS earth station in the area
 - The “area” can be defined by a distance beyond which interference into FSS reaches an inconsequential level
 - This analysis considered FSS earth stations out to a distance of approximately 100 km
- We use a co-channel FSS interference limit (expressed in power spectral density) of -129 dBm/MHz, which is the same limit used to protect co- and adjacent-band FSS in the CBRS band (e.g., 47 CFR 96.17(a)(2))
- Coexistence criterion:

$$\max_j(IPSD_j) \leq -129 \text{ dBm/MHz}$$

Factors that Strongly Influence Coexistence (GT_{ij} , PL_{ij} , GR_{ij})

- Terrain blockage between P2MP and FSS creates high propagation loss, reducing interference power received by FSS (affects PL_{ij})
- Low height of P2MP antennas (affects PL_{ij})
 - Most customer premise equipment is located at relatively low heights above ground level, increasing propagation loss and reducing their interference impact on FSS
- The use of directional P2MP antennas (affects GT_{ij})
 - P2MP antenna discrimination reduces interference to FSS earth stations outside the P2MP beam.
- FSS beam discrimination (affects GR_{ij})
 - FSS antennas are generally pointed upward, with low gain towards the horizon, where P2MP systems are located
- Low height of some FSS antennas (affects PL_{ij})
 - While some FSS antennas are on rooftops, many are mounted on the ground, since they only need to see the sky. When mounted low to the ground, propagation losses to terrestrial systems are higher, reducing interference
- Frequency separation will provide additional isolation (discussed later)



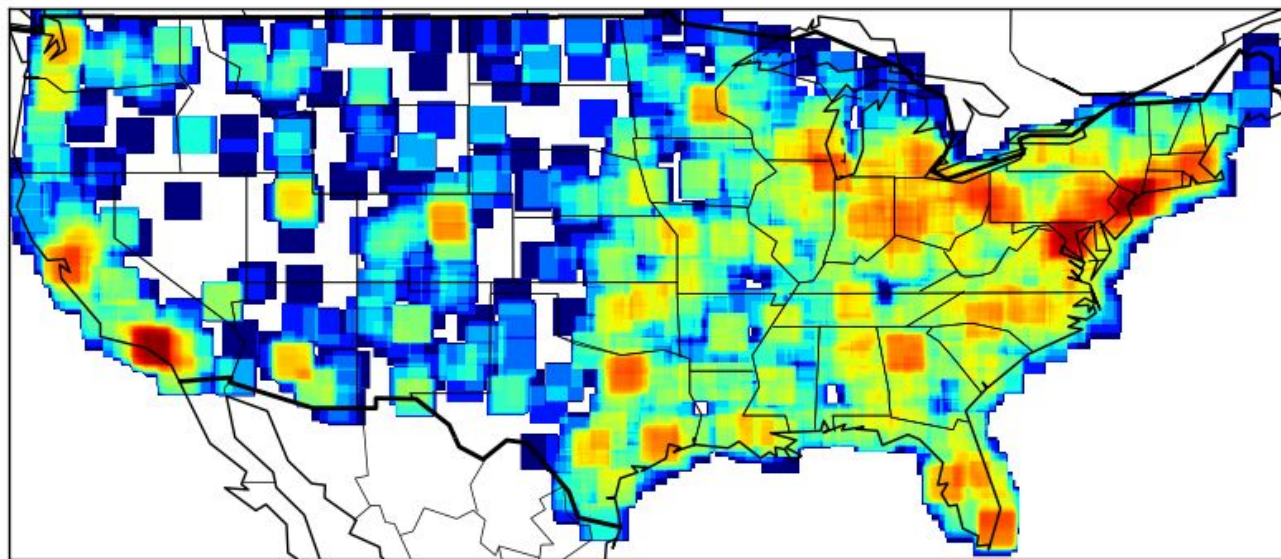
P2MP Data that Enter into Coexistence Calculation

- Required minimum information for each P2MP node (base and CPE)
 - Location (lat/lon)
 - Conducted power spectral density, including any cable losses between transmitter and antenna
 - Antenna pointing azimuth and elevation
 - Antenna beam pattern (i.e., gain as a function of azimuth and elevation)
 - Height of ground above mean sea level
 - Determined by lat/lon combined with a terrain database
 - Antenna height above ground level
 - Frequency and bandwidth of P2MP signal (for non-co-channel analysis)
 - Out-of-band emission levels (for non-co-channel analysis)
- Additional considerations
 - Clutter impacting propagation

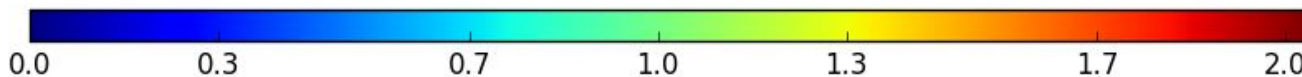
FSS Data that Enter into Coexistence Calculation

- Required minimum information for each FSS earth station
 - Location (lat/lon)
 - Antenna pointing azimuth(s) and elevation(s)
 - Can be determined by orbital slot (or range of orbital slots) received by the earth station, combined with the earth station's lat/lon
 - Antenna beam pattern (i.e., gain as a function of off-axis angle)
 - Height of ground above mean sea level
 - Determined by lat/lon in combination with terrain database
 - Antenna feed point height above ground level (reference point for interference calculation)
 - Actual operating frequencies of the FSS receiver (for non-co-channel analysis)
- Additional considerations
 - Clutter impacting propagation

Where could Co-channel FSS and P2MP Co-exist?

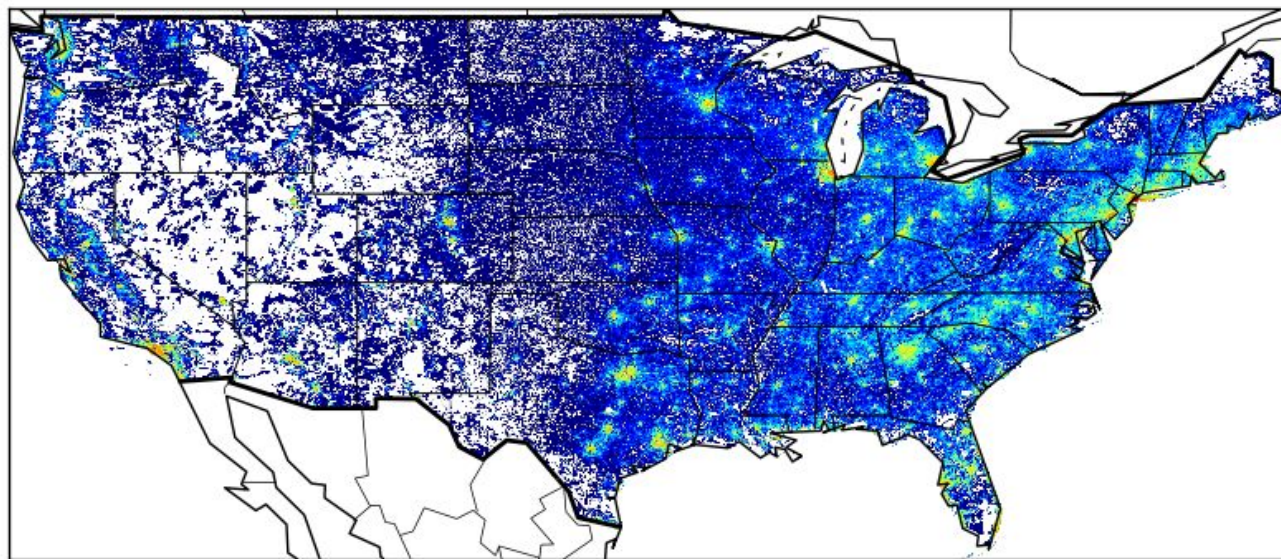


Number of Confirmed Registered C-band FSS Earth Stations within 100x100 km Box



Log10(Number of FSS Earth Stations) (1, 2, 5, 10, 20, 50, 100)

For each point in a 30 arc sec grid, this map displays the number of confirmed registered FSS earth stations within a 100x100 km box centered on the grid point. Source: FCC IBFS plus confirmation based on a 2014 Google Earth study.

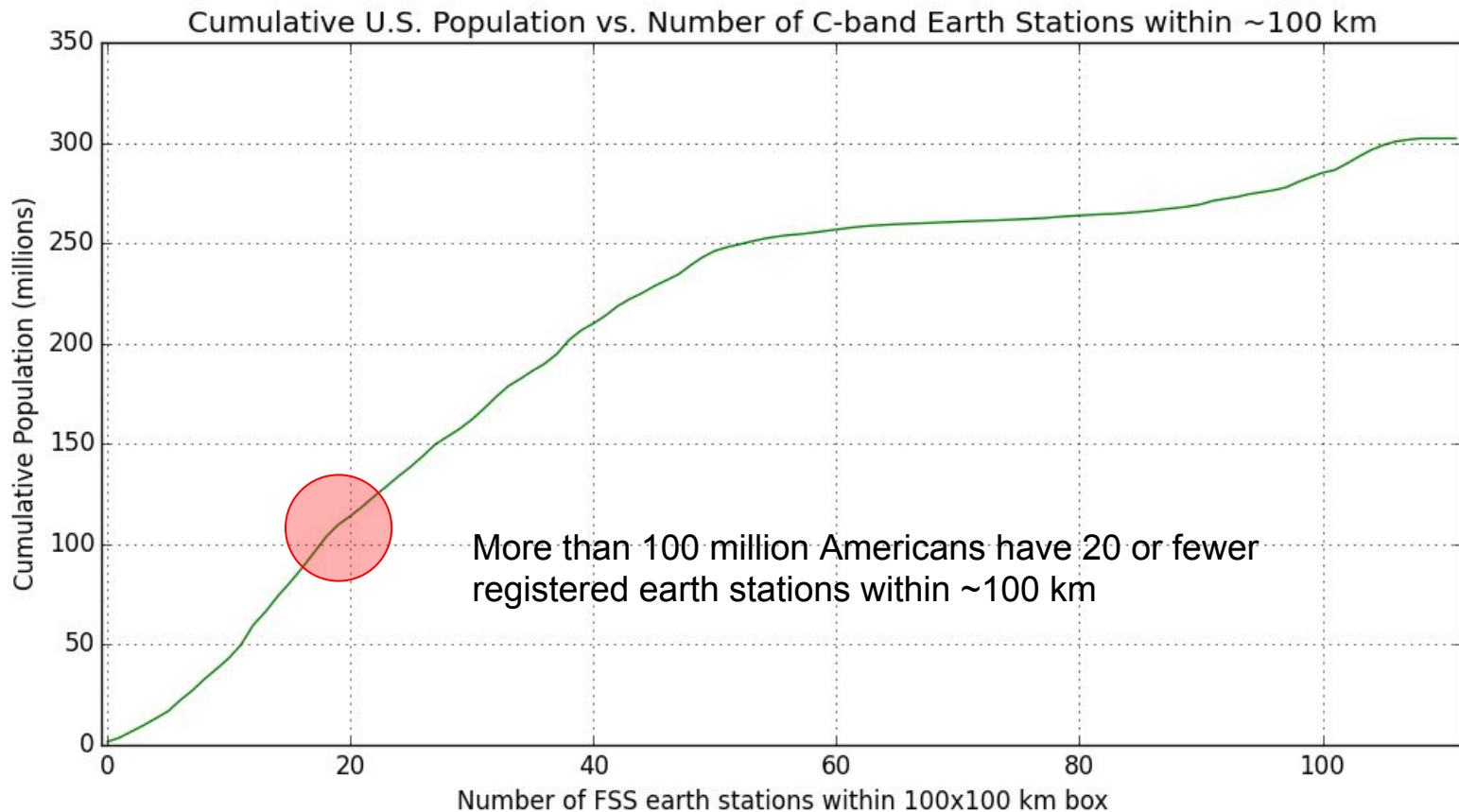


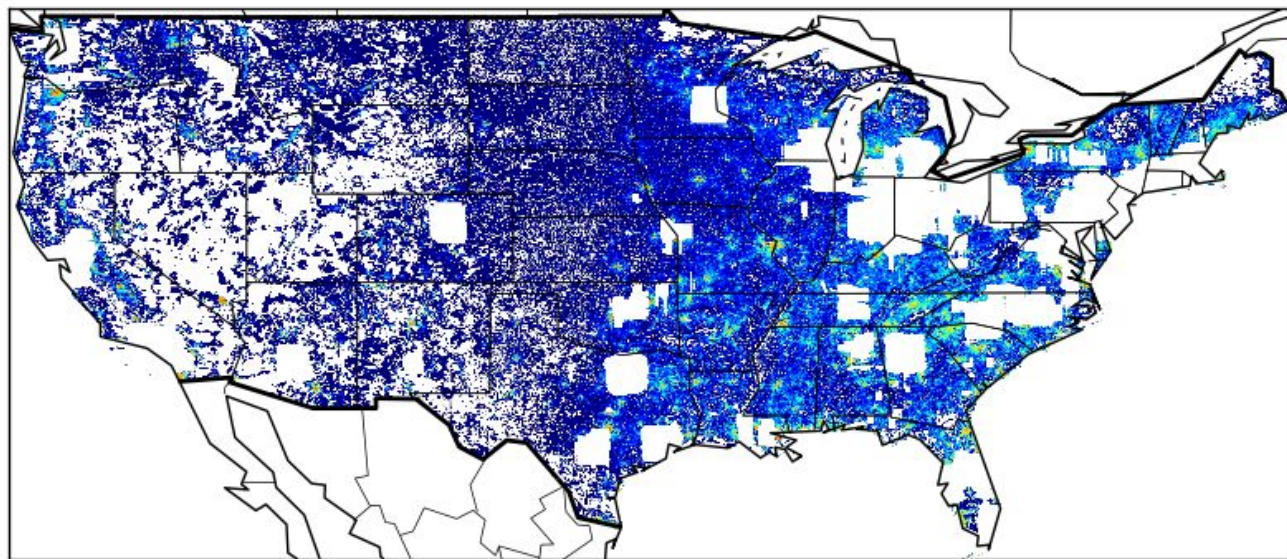
U.S. Population (2010 census)



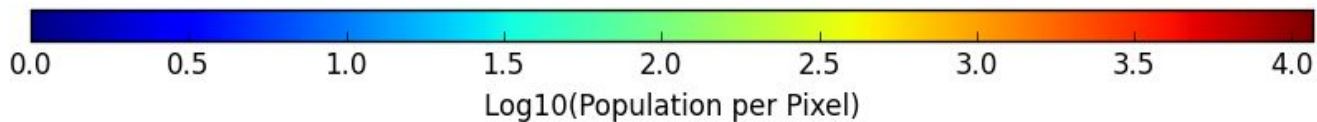
Log10(Population per Pixel) (1~32,000 per pixel)

Each pixel is 30x30 arc seconds = $\sim 0.75 \text{ km}^2$ depending on latitude. White = 0 population in the pixel. Population density >0 and ≤ 1 per pixel clipped at 1 for display. Data derived from U.S. Census Bureau statistics.

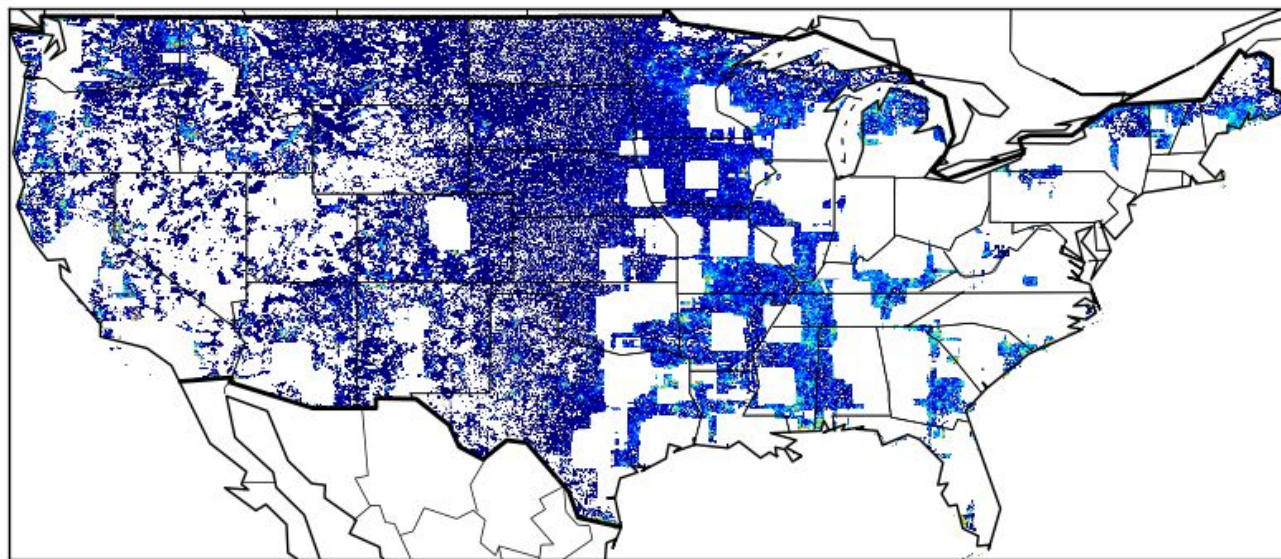




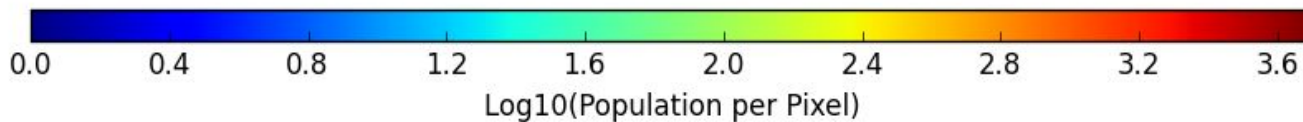
Population with 20 or fewer FSS within 100 km



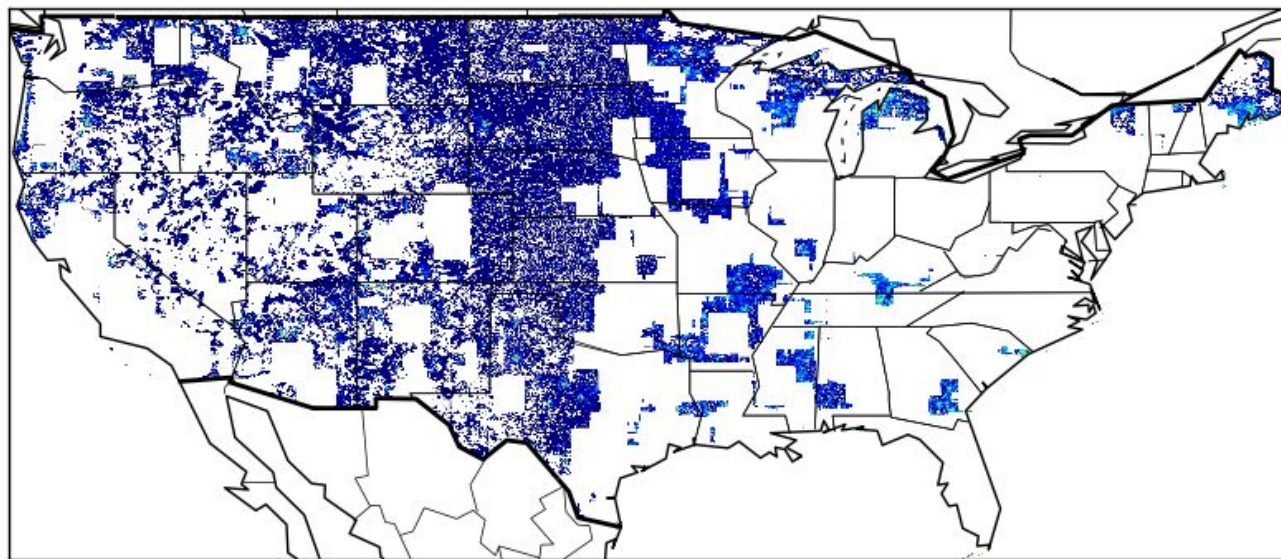
114 million Americans



Population with 10 or fewer FSS within 100 km



43 million Americans

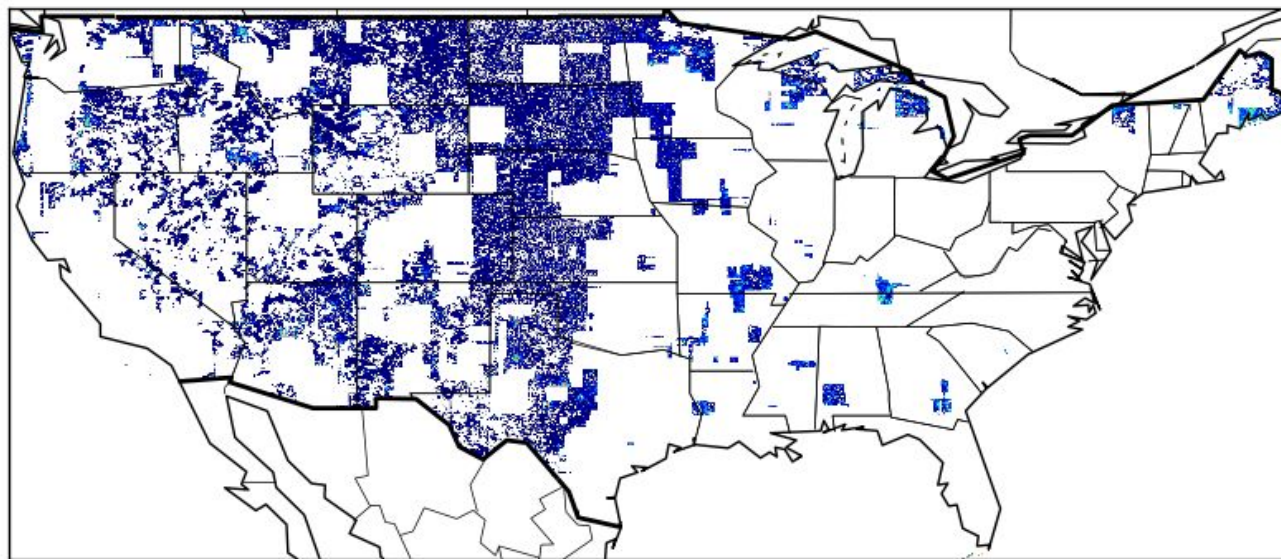


Population with 5 or fewer FSS within 100 km

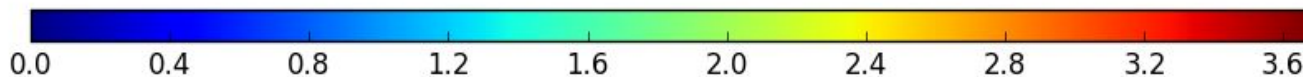


$\text{Log}_{10}(\text{Population per Pixel})$

17 million Americans



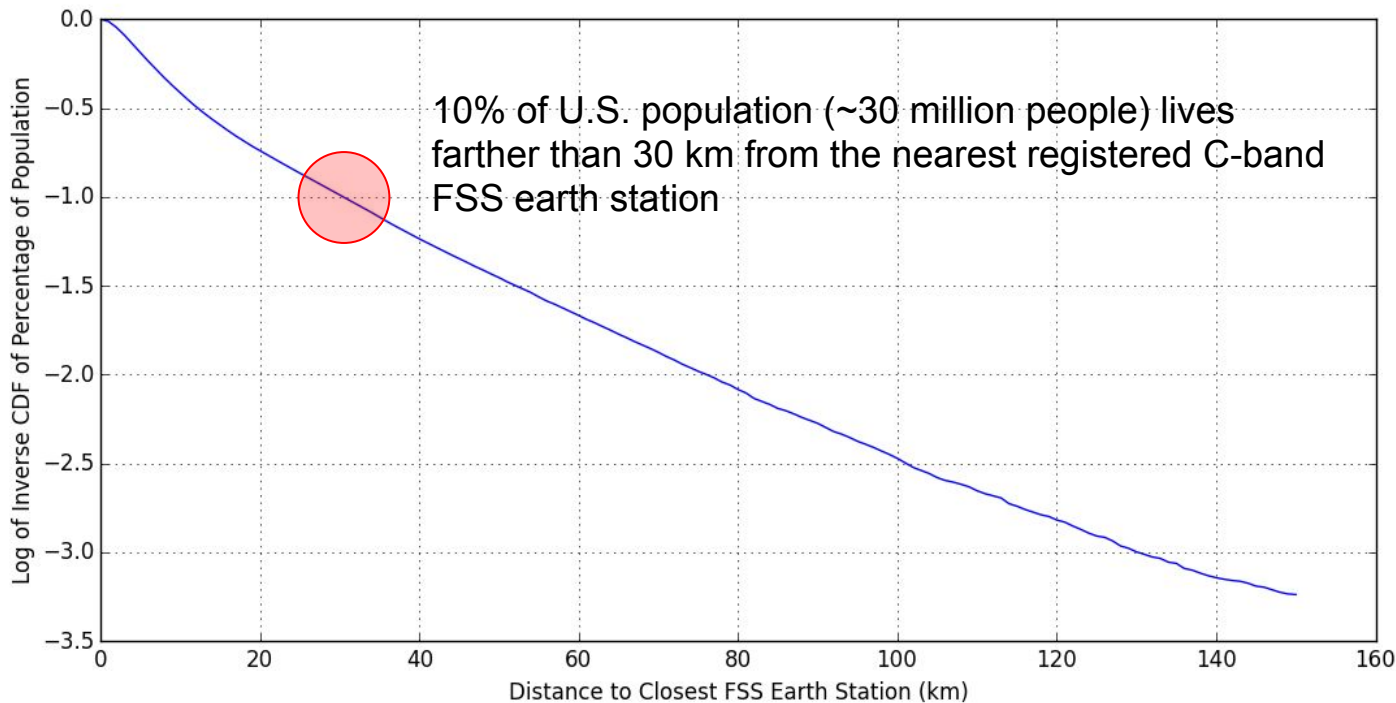
Population with 3 or fewer FSS within 100 km



$\text{Log}_{10}(\text{Population per Pixel})$

10 million Americans

Distance to Closest FSS C-Band Earth Station



Actual Co-channel Coexistence Example

Real-world Deployment

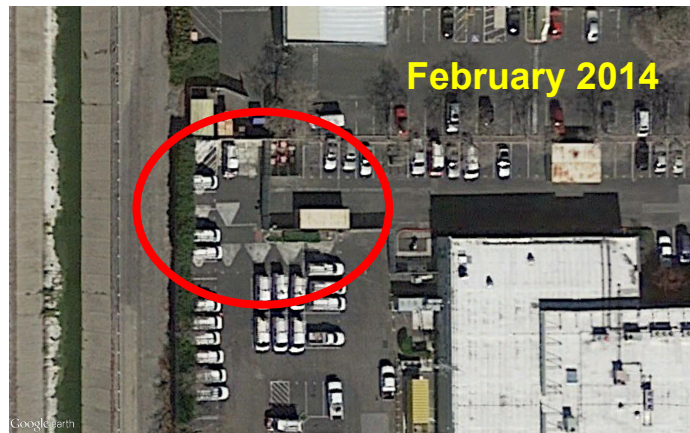
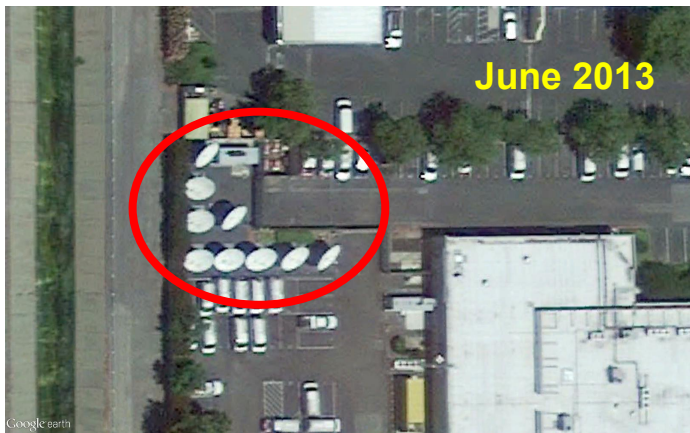
- Based on overlay/replacement of current 5 GHz (unlicensed) deployment now providing point-to-multipoint broadband service in California just outside of the Bay area
- The current deployment, without modification, was analyzed to determine if it could be replaced with, or complemented by, a system utilizing C-band (co-channel with FSS) to provide improved broadband service
- This example is not “cherry-picked”
 - Existing system deployed prior to, and without regard for, and considerations related to C-band FSS

Analysis Procedures

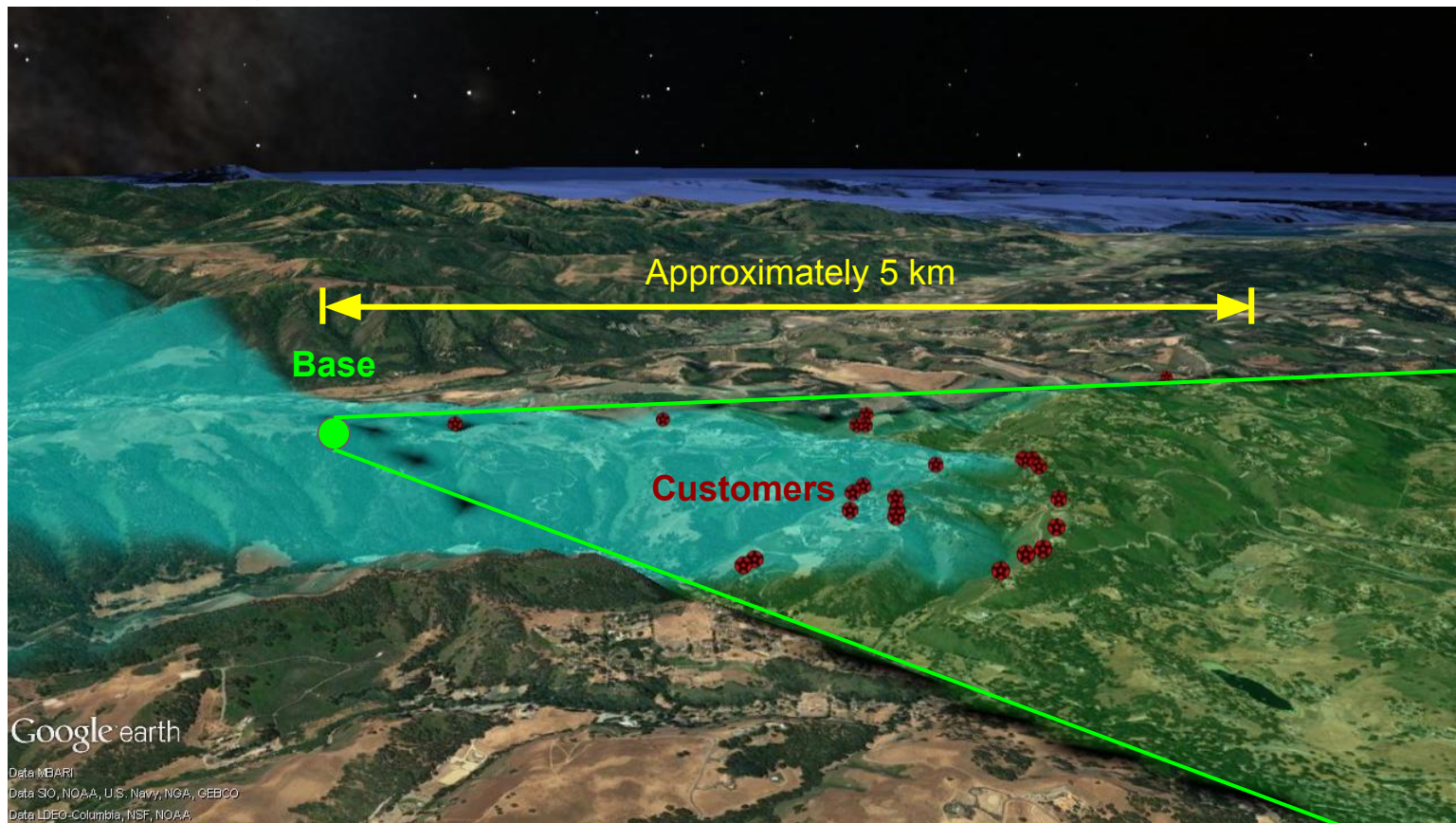
1. Pull IBFS list of registered 3700-4200 MHz FSS earth stations within 150 km of P2MP area of operation
2. Validate the existence and operation of the registered sites
 - a. Perform historical Google Earth imagery search for FSS antennas. Determine if antennas currently exist, or were removed in the past, or never existed, at or within ~1 km of registered coordinates
 - b. Drive by sites for further information gathering. Confirm no dishes are in place, or, if so, determine if dishes are actually in use. In some cases, talk to the dish owner or the owners of the building on which the dish is mounted to determine status.
 - c. If antenna(s) exist, correct antenna coordinates based on (a) and (b)
3. Gather all required operational data for P2MP and FSS (i.e., slides 11 & 12)
4. Compute best- and worst-case aggregate interference at each FSS earth station as a function of pointing, across its registered GSO arc range, in 1 deg increments
5. Based on actual P2MP and FSS operations, determine if coexistence criterion is met
 - a. If not, determine if simple solutions or mitigating factors can achieve the coexistence criterion

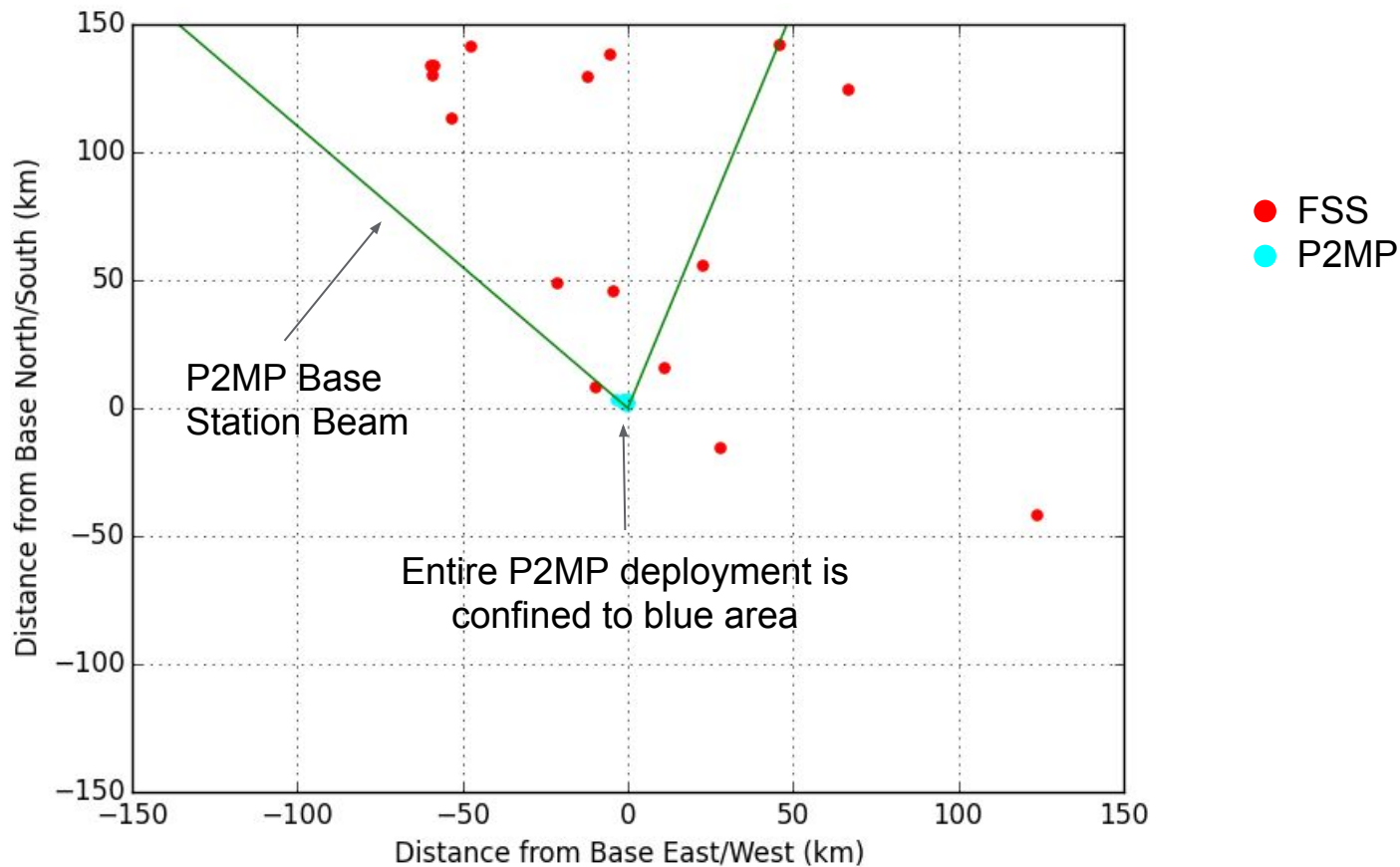
FSS Earth Station Registration Validation

- 37 registered FSS earth station sites were found in IBFS
 - All are full-band registrations (3700-4200 MHz)
- Of the 37 sites, Google Earth analysis and in-person visits determined that 21 of the registrations (57%) are not valid
 - 12 could not be found in any historical imagery back to the 1990s
 - 11 of the 12 belong to one licensee
 - 8 were previously removed (see one example below)
 - 1 exists but is no longer in operation (confirmed by in-person visit)



P2MP Deployment

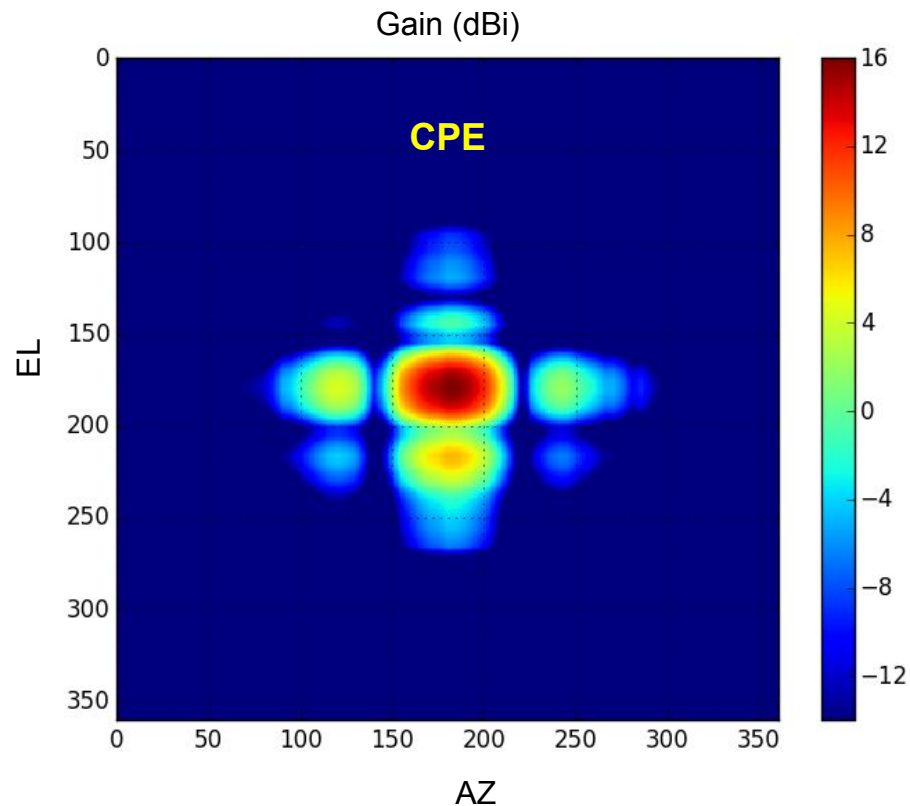
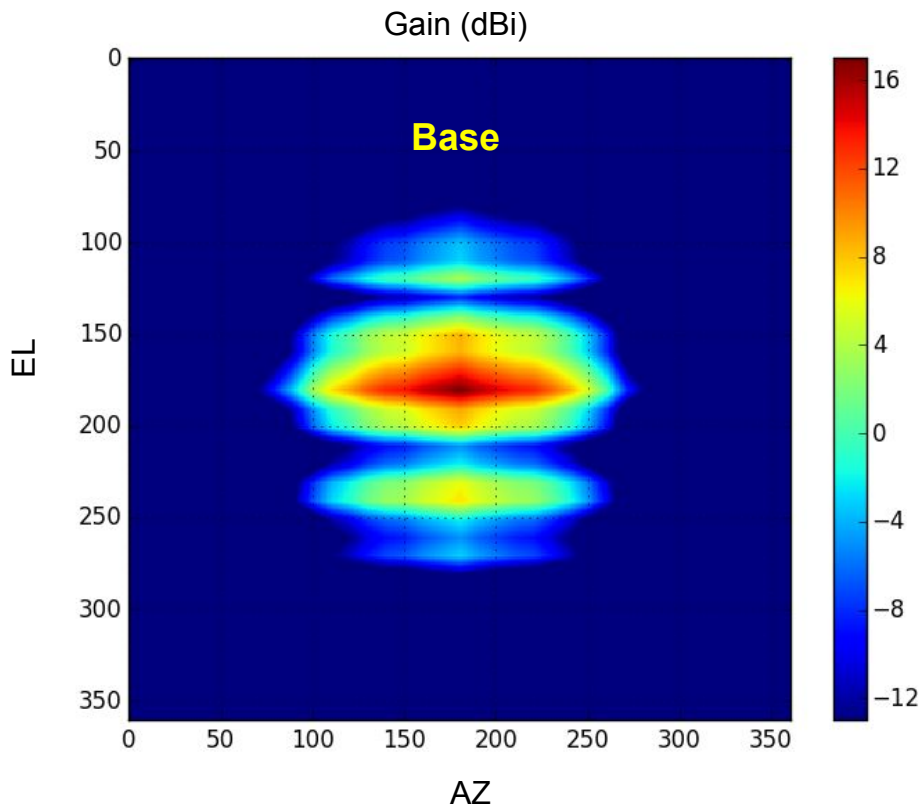




P2MP Characteristics

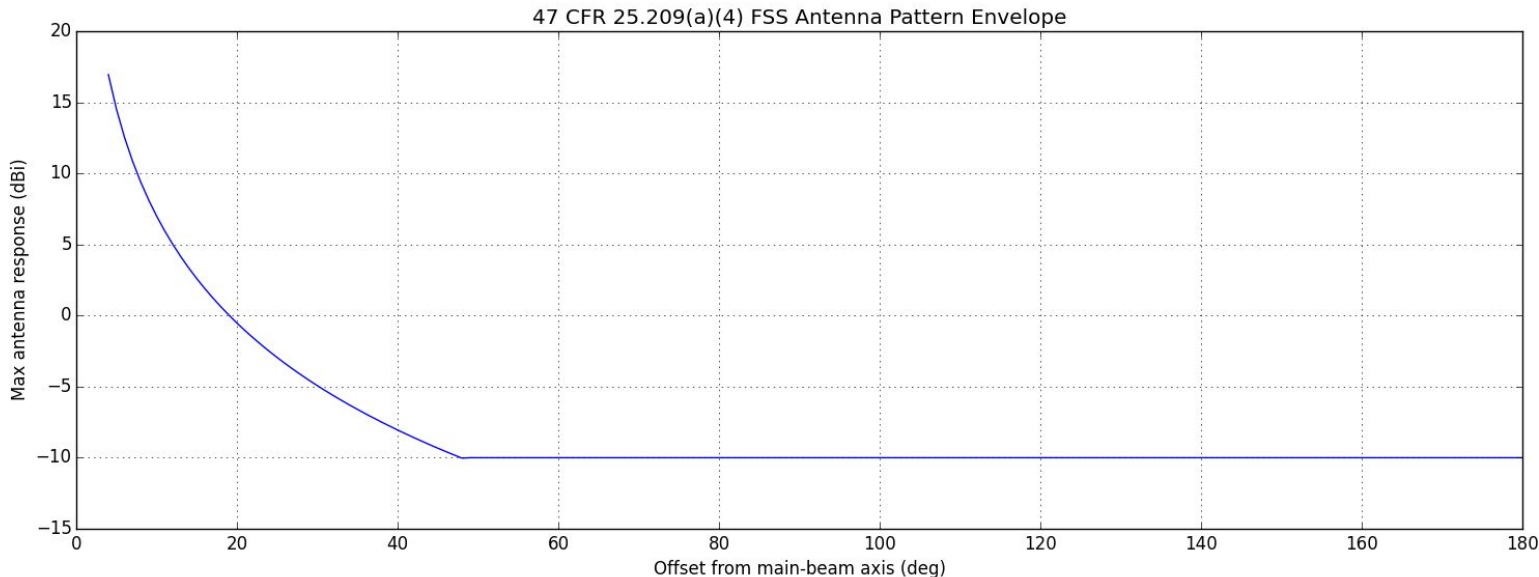
- Base height: 9.1 m AGL
- CPE height: 4.6 m AGL
- Bandwidth: 10 MHz
- Conducted Power (base and CPE): 30 dBm
- Antenna Gain (base): 17 dBi
- Antenna Gain (CPE): 16 dBi
- Base horizontal beamwidth: 60 deg
- CPE horizontal beamwidth: 40 deg

P2MP Antenna Patterns

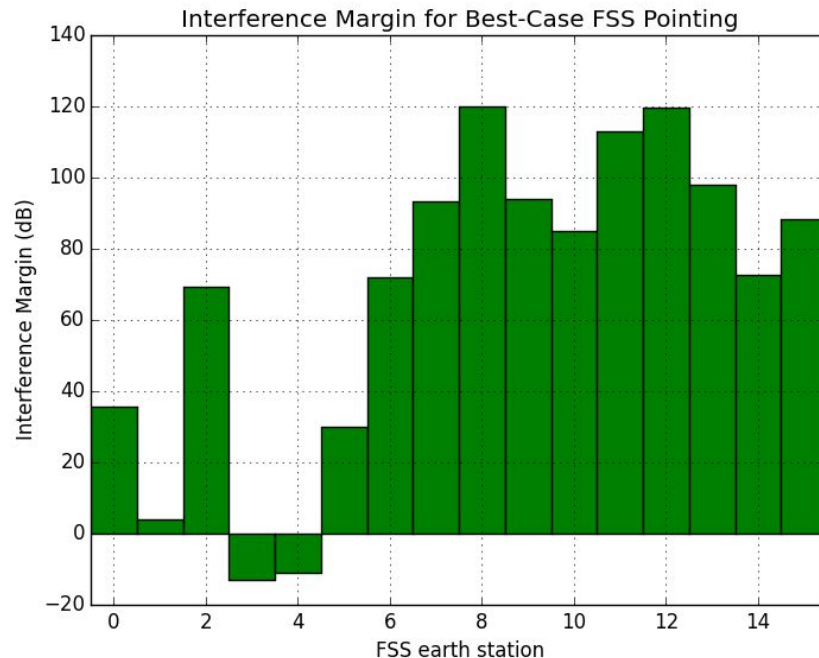
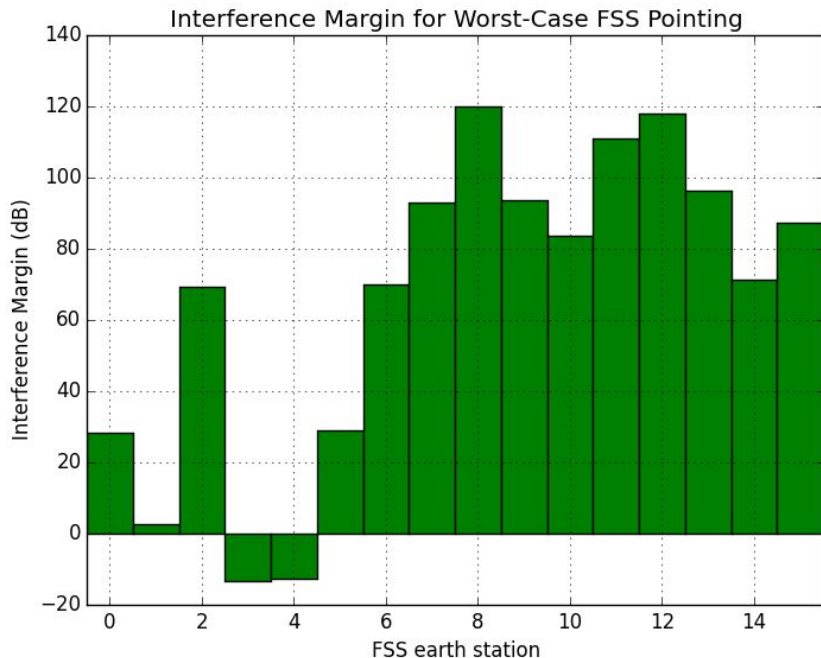


FSS Characteristics

- Lat/lon as confirmed by imagery
- Feed point height as registered and confirmed by imagery
- Antenna gain pattern envelope: 47 CFR 25.209(a)(4)

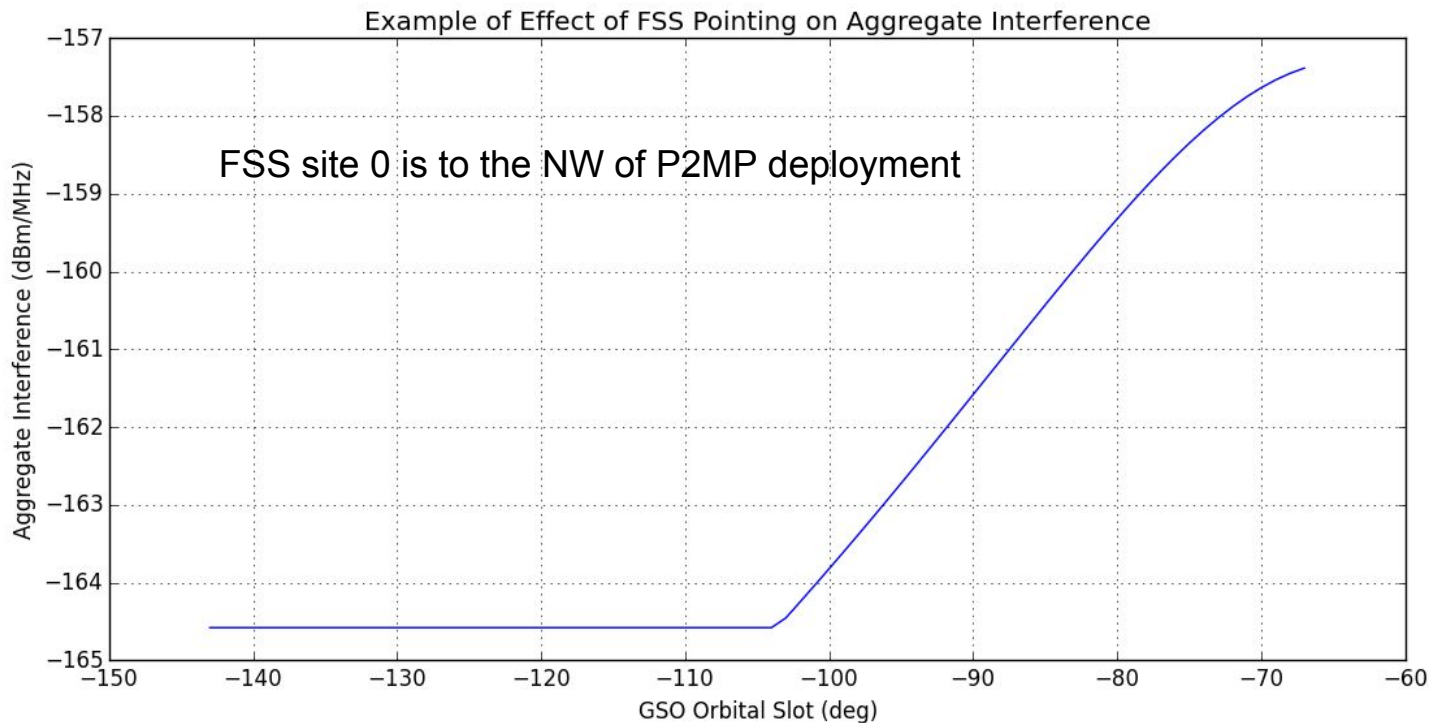


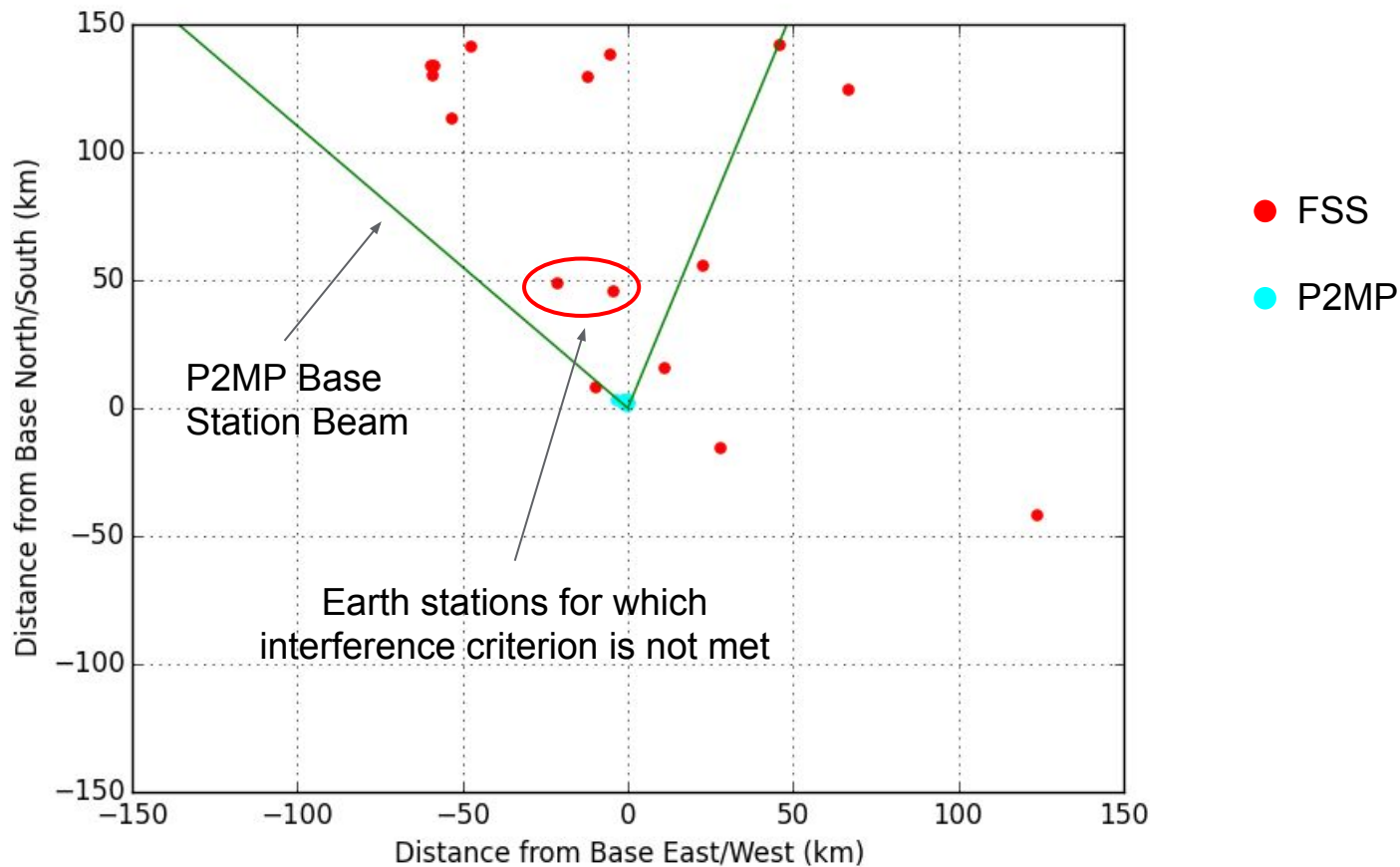
Results: Co-Channel Interference Margin



In most cases, the FSS interference criterion is met by tens to well over 100 dB. In two cases, the interference objective is not met under the default assumptions.

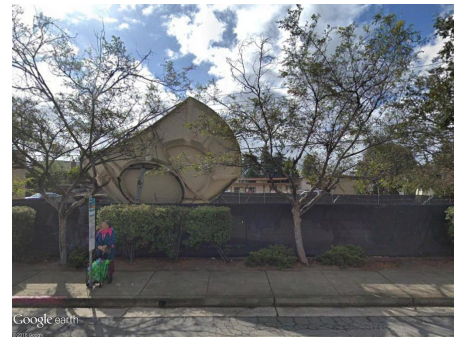
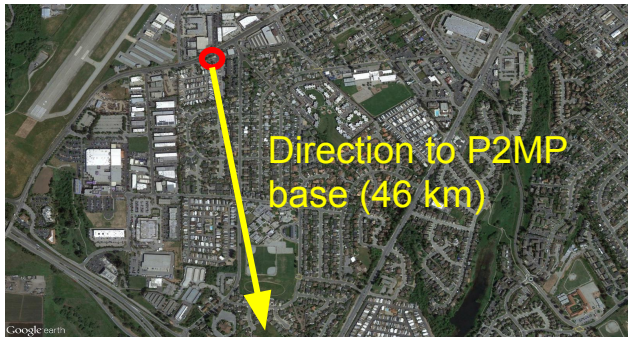
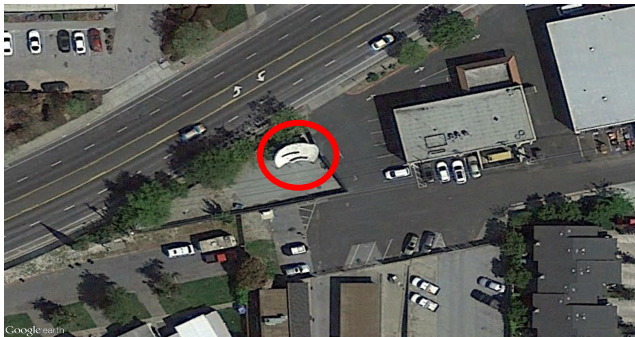
Aggregate Interference vs FSS Pointing





First FSS site over interference criterion

- Over margin by 13.4 dB
- Have met with operator to discuss nature of their operations
 - Most of their needs are now met by fiber
 - Use of FSS is limited to “a small portion of the upper part of the band”
- Potentially significant clutter loss in real-world propagation
 - Elevation to base antenna: 0.6 deg
 - Surrounding clutter exceeds path elevation
 - Needed clutter loss (~ 14 dB) is very small compared to observed clutter losses in measurements



Second FSS site over interference criterion

- Over margin by 12.7 dB
- 0.5 deg elevation to base; clutter likely a strong factor
- Site operated by licensee that uses only 23 MHz of spectrum at one carrier frequency, despite being registered for 500 MHz of spectrum



Side view showing elevation to P2MP base



Impact of Frequency Separation

- Although propagation and clutter losses likely clears all 500 MHz of spectrum for co-channel P2MP use in this specific scenario, the two earth stations that require additional study both limit their frequency use (one uses 23 MHz of spectrum, the other uses a “limited range of frequencies near the top of the band.”)
- If frequency separation is taken into account, interference objective is different since fundamental P2MP emissions would be placed outside of the frequency range being received by the earth station
- Relevant interference criteria become:
 - Blocking interference: keeping the overall signal strength low enough so as not to cause overload of the earth station’s front end. The blocking criterion for C-band FSS established in Part 96 is -60 dBm
 - Out-of-band emissions: OOB from P2MP appearing in-band for FSS. The objective is the same as for the co-channel case (-129 dBm/MHz), but the OOB level for P2MP is much lower (by tens of dB) than the in-band power spectral density

Blocking Criterion

- Blocking criterion: Total aggregate power of P2MP signals as received by FSS is less than -60 dBm
- Assuming n P2MP transmitters each with transmit power P_i (dBm), the aggregate interference power I_j (dBm) is given by:

$$I_j = \sum_{i=1}^n (P_i + GT_{ij} - PL_{ij} + GR_{ij}),$$

where (as before):

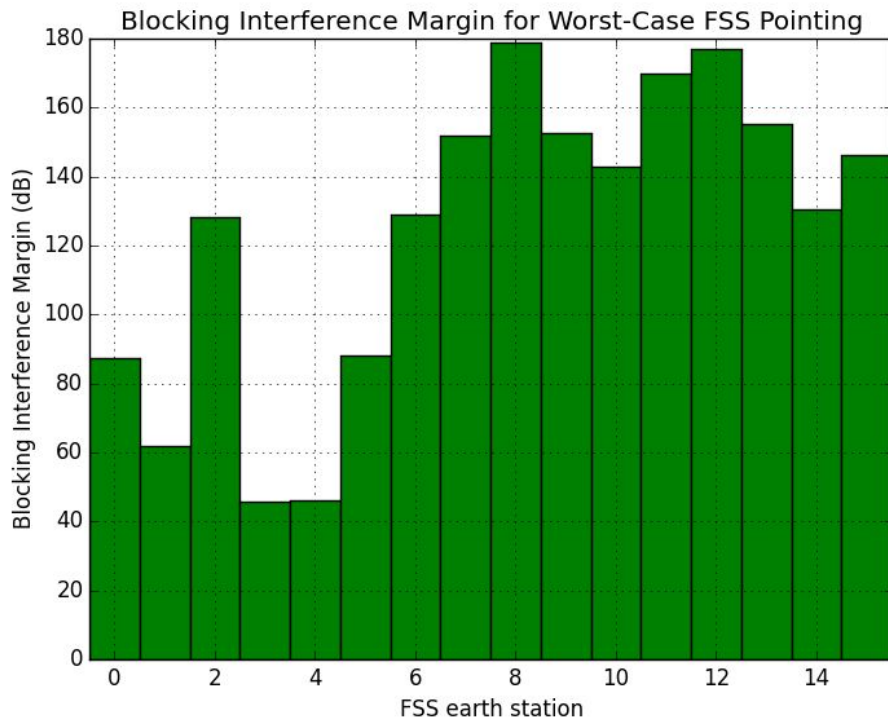
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PL_{ij} = Propagation loss from P2MP station i to FSS earth station j

GR_{ij} = Gain of FSS earth station j 's antenna in the direction of P2MP station i

- Relevant factor is total power, not power spectral density

Results: Blocking Margin



- Blocking criterion is met by a minimum of 45 dB, up to nearly 180 dB
- Operating non-co-channel in this scenario is absolutely not a factor based on blocking criterion

Out-of-Band Emissions Criterion

- OOBE criterion: Total aggregate OOBE power spectral density from P2MP signals as received by FSS is less than -129 dBm/MHz
- Assuming n P2MP transmitters each with OOBE of $OOBE_i$ (dBm/MHz), the aggregate interference power spectral density $IPSD_j$ (dBm/MHz) is:

$$IPSD_j = \sum_{i=1}^n (OOBE_i + GT_{ij} - PL_{ij} + GR_{ij}),$$

where (as before):

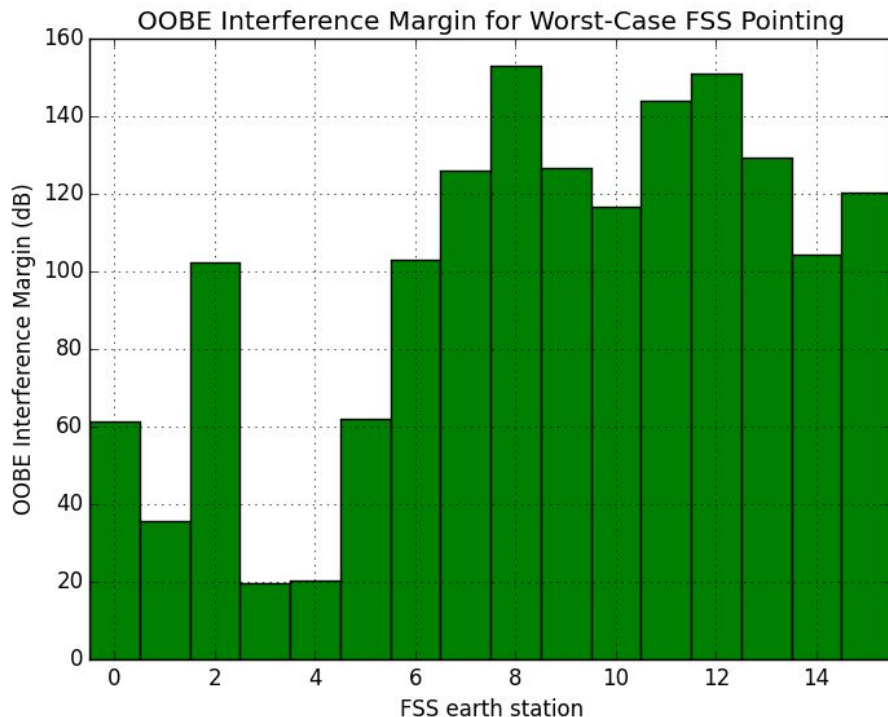
GT_{ij} = Gain of P2MP antenna i in the direction of FSS earth station j

PL_{ij} = Propagation loss from P2MP station i to FSS earth station j

GR_{ij} = Gain of FSS earth station j 's antenna in the direction of P2MP station i

For this analysis, a worst-case OOBE level of -13 dBm/MHz is assumed

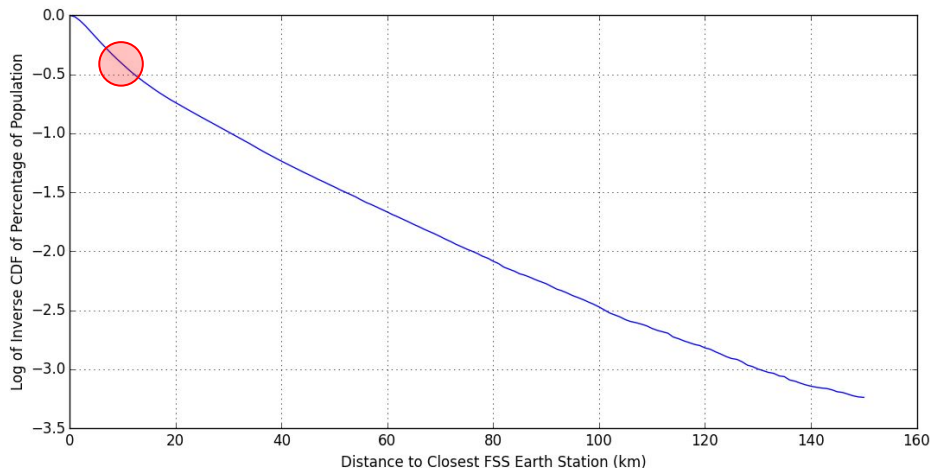
OOBE Margin Results



- Assumed OOBE = -13 dBm/MHz
- OOBE criterion is met by a minimum of ~20 dB, up to nearly 150 dB
- Operating non-co-channel in this scenario is absolutely not a factor based on OOBE criterion

Non Co-Channel Summary

- All interference margins are met by at least tens of dB when operating non-co-channel with FSS earth stations in the given scenario
- Result is consistent with very small non-co-channel exclusion zones as computed in ITU-R Recommendation S.2199: “a few to several km” to protect against blocking, “a few km” to protect against OOB



Assuming “a few to several km” means 10 km, as much as 40% of the U.S. population (~120 million Americans) could potentially be served by non-co-channel P2MP broadband.

Without accurate information on actual FSS frequency use, the true number cannot be determined.

Conclusions

- 3700-4200 MHz point-to-multipoint (P2MP) systems could immediately provide gigabit-class broadband service to tens of millions of Americans, without causing disruption to FSS
 - In many areas of the country, P2MP systems can operate in C-band (3700-4200 MHz) without causing interference to co-channel fixed-satellite service (FSS) systems
 - Co-channel sharing is possible by considering geographic and directional isolation between P2MP and FSS; that is, operating in areas with a relatively low number of earth stations, and using directional antennas that don't point toward earth stations in the area.
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