Evaluating the FCC's IBFS Database

A Quantitative and Qualitative Analysis of

Satellite Dish Downlink Locations Registered in the IBFS

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ABSTRACT

Abstract - In 2017 and early 2018, the United States' Federal Communications Commission outlined its consideration of the 3,700 - 4,200 MHz "C-band" spectrum as a potential source of spectrum for new 5G networks. This band is currently used nearly exclusively for satellite downlinks, so any reuse of the band must be coordinated with the operators of those downlink sites. Before 2018, the FCC's database of optional registrations of C-band downlink sites only contained around 3,600 unique currently authorized sites. Extrapolating from an old study of that data set, 5G proponents claimed that C-band was underutilized and should be repurposed for 5G use. In early 2018, the FCC opened up a filing window for all existing C-band downlinks, resulting in nearly 10,000 new sites within six months. Since then, no public study has been performed to evaluate the accuracy of the database. This research project quantifies and qualifies the downlink site location errors in the FCC's database and identifies areas of improvement to the registration process. Methods and processes employed for the research involve: statistical sampling of several subsets of the database; retrieving a local copy of the FCC's database for an offline in-depth analysis; mapping of downlink site locations; calculation of distance errors and qualification of common errors in submissions.

Index Terms – geospatial analysis, satellite antennas, satellite ground stations, downlink, satellite broadcasting, C-band, 5G mobile communication, spectrum, FCC, satellite imagery, Global Positioning System

EXECUTIVE SUMMARY

The United States' Federal Communications Commission is exploring the utilization of the frequencies currently used by C-band satellite downlinks and uplinks. This study analyzes the FCC's database, quantifying and qualifying the accuracy and error types of the locations recorded to provide a basis for either validating or disproving claims of widespread inaccuracies and disuse, thereby enabling the FCC to make the best policy choice possible in light of the actual usage of C-band frequencies in the United States. The results of the study will suggest areas of improvement to the new location registration process.

Using a downloaded local copy of the entire database of nearly 13,500 locations for offline querying and analysis, custom subsets of roughly 3,000 to 7,000 locations each are generated for a segmented and comparative analysis. Each subset of data is randomly sampled to produce a statistically valid representation of the entire subset, and then each of the roughly 350 samples in each group is reviewed visually using current and historical satellite and aerial imagery to quantify and qualify the errors in location accuracy for satellite downlink dish antennas. The results are tabulated and analyzed.

The results show that the older legacy location subset has a high rate (30%) of missing antennas, disproportionately influenced by a single registrant responsible for 17% of all locations in the subset wherein 82% of the registrant's sites are missing; the remaining 70% of locations were located within 88 m of the actual antenna. Only 16% of

this set accurately located their antenna. By comparison, another new registrant registered 95% of their 3,100 locations within 44 m of their dishes but only 1% of their dishes were accurately located. The remaining subset of new sites accurately located their dishes 53% of the time and another 39% were within 100 m of the dish. While 3% of all new sites did not contain a visible dish, none of the newer dishes were missing after being found in historical imagery (compared with 21% of the legacy sites). Overall, the newer data are relatively accurate, but the older data needs to be validated and scrubbed of invalid locations to be meaningful. Moving forward, the FCC should integrate embedded mapping features and address verification into its registration and renewal process to ensure that the data it gathers for each site is accurate.

CHAPTER I. INTRODUCTION

A. Introduction and Importance

In the race to deploy broadband access to the Internet quickly and widely, the global wireless industry is planning how to grow beyond its current fourth-generation cellular infrastructure into the next-generation 5G service. 5G service will require wide swaths of Radio Frequency bandwidth, and the common challenge facing every nation wanting to deploy 5G is to find and allocate lots of high-performance radio spectrum for it.

A large portion of the RF spectrum that is highly desired by the wireless industry is currently already globally allocated to C-band satellite downlink use. Claiming that C-band is “severely underutilized” and that current records are rife with errors and abandoned sites, 5G proponents are petitioning the regulatory agency in the United States to take away and reallocate some or all of the 500 MHz C-band frequency range and give it to the 5G industry to develop and deploy the next-generation 5G wireless platform. Doing so would necessarily come at the expense of the satellite industry and many other industries like broadcasting that depend heavily on C-band’s availability and reliability for satellite communications.

As the Federal Communications Commission is an independent governmental entity tasked with managing all radio communications in the United States ("About the FCC"), the FCC utilizes over 40 discrete databases and offers public access to search

them using pre-built search tools ("Search FCC Databases"). The International Bureau Filing System database in particular is used to track the locations of and current authorizations for satellite downlinks. To ensure that the public's interest is best served by the proper allocation of C-band spectrum, the FCC, incumbent satellite industries, and the nascent 5G wireless industries must be able to rely upon accurate records of the current utilization of C-band. This study will investigate the IBFS database's accuracy to that end, representing both a qualitative and quantitative analysis of the accuracy of the IBFS. In the quantitative portion of the study, we analyze the error (distance) between the registered location coordinates and the actual geographic location of the dish. The qualitative aspect of this study assesses the relative quality and error type of inaccurate site locations.

B. Background Information

Like many other developed countries around the world, the United States desires to foster innovation and achieve international technical superiority through its development and use of the latest technology. High-speed and ubiquitous wireless Internet access is seen by many high-ranking U.S. governmental leaders as the most promising means whereby businesses and the public are -- and will be -- enabled to innovate, communicate, entertain, and conduct business. ("NPRM"; Obama 3; Pai 1; Trump 1-2; Wheeler, Tom 1-3)

Starting with Presidential directives in 2010 (Obama) and further prompted by federal agency reports (Locke and Strickling) and Congressional acts (Thune 751), the FCC issued a Notice of Inquiry ("NOI") regarding the issue in late 2017. Directed by Congress to identify and report on the availability of 500 MHz of C-band spectrum, the FCC subsequently released its Notice of Proposed Rulemaking ("NPRM") in July 2018 incorporating responses to the antecedent NOI. The NPRM proposed reallocating or sharing some or all of the 3,700 – 4,200 MHz C-band downlink spectrum currently used to downlink satellite communications signals, and also sought to gather information regarding the current usage of C-band downlink frequencies.

The challenge facing the FCC and the 5G industry is that while the use cases and types of services currently provided using C-band are well-known, the true scope of C-band downlink usage has never been well-documented ("NPRM" 8) since registration of downlinks is not mandatory. To gain better perspective on the depth and breadth of the current C-band spectrum usage in the United States with the goal of deciding whether reallocation of C-band spectrum to 5G would be in the public's best interest, the FCC instituted a freeze on April 19, 2018 of all new downlink site registrations and opened a filing window whereby any site which was operational before the freeze date could register their existence and be afforded future protection against interference from any new uses or users of C-band spectrum ("Freeze Announcement").

Further complicating the issue, the FCC's database of satellite and C-band usage contains many erroneous legacy records and allows mistakes in new registrations to be

submitted. The FCC personnel responsible for licensing and registration must manually verify all new submissions and modifications (Blais), a process that results in a simple registration taking many months to be approved (Christopherson).

C. Problem Definition

The key problem facing both the FCC, the 5G industry, the satellite industry, and the myriad other industries dependent on satellite-delivered services is that the omissions and inaccuracies in the FCC's IBFS database of known satellite downlink locations preclude making a well-informed decision as to the best use of the spectrum to serve the American public. No current public study has been done to assess the validity and accuracy of the data contained in the IBFS database now that the filing window has been completed with over 10,000 new sites registered, yet an accurate assessment of the data contained within it is essential to future policy decisions affecting over 100 million Americans.

D. Project Objectives

The objectives of this study are:

- Identify methods and processes to verify the downlink site location information already present in the FCC's database
- Quantify the distance error magnitudes and rates for locations in the database
- Qualify the types of location accuracy errors present in the database
- Identify and recommend improvements to the registration process in order to validate and verify downlink site location information prior to the registration being submitted

CHAPTER II. PRIOR STUDIES AND LITERATURE REVIEW

To assess the accuracy of the data entered in the database, we first look at the accuracy of the underlying system and the means of entering it into a database. The Global Positioning System is a United States government-owned and -operated satellite-based utility that is widely used for precise terrestrial location measurement and timing ("GPS.gov: Surveying & Mapping"). Latitude and Longitude coordinates read from GPS receivers or from online mapping tools such as Google Maps must be registered in the database maintained as a part of the International Bureau Filing System, hereafter referred to as the IBFS.

Bigham, Strang, and Oum conducted a study into the accuracy of latitude and longitude coordinates recorded from GPS units for vehicle accident locations in California. (Bigham et al.) Through an analysis of geocoordinates recorded over a three-year period from 2009-2011, they found that there were systematic user-level failures to properly locate and report locations into the state's accident database. Noting that accuracy improved during the studied period in part due to additional training, they still found an overall 54.5% discrepancy rate with only 43% of the sites correctly located. They also describe a methodology of description and categorization of errors involved in the data collection and entry into the database; that methodology of accuracy and/or error qualification was adopted in part to the study of the IBFS database and system at hand today.

Similarly, a study by Sarasua et al. also noted that allowing untrained users to enter data is a major source of introducing accuracy errors into geo-coordinate databases maintained by the state of South Carolina (Sarasua et al.). In both Bigham's and Sarasua's studies, recommendations were made as to how to improve the accuracy of the data entered by a known universe of users; specifically, law enforcement officers who can receive specific GPS-related training. This improvement, while measurable and possible in Sarasua's closed-universe population, may not be directly realizable in this study as the coordinates submitters are members of the general public; however, lessons learned from the results of Sarasua's and this study do lead to recommendations for this case.

Further research by Green and Agent found in 2004 that the major source of errors in a Kentucky accident location database of GPS coordinates resulted from issues related to the operator and not the GPS units used to capture the coordinates (Green and Agent). Green found that the equipment generally operated accurately to get the correct location as long as proper procedures were followed, yet only 55% of the sampled coordinates were correct when compared with recorded street identifiers. Green concluded that proper operator training, minimizing data entry and transcription errors, and a good method of data entry into the form report were key to achieve a higher level of accuracy in the database. As we again see a strong correlation between user input and the accuracy of the database at hand, we will incorporate the lessons learned into recommendations for this case.

In 2014, Google performed a comprehensive analysis of the entire IBFS database to ascertain the accuracy of the database (Clegg). Their brute-force analysis of Google Earth imagery for 4,724 previously-registered sites showed 29% of the sites did not have an obvious satellite dish within 1 km of the registered location (Purdy et al.). In the analysis section of this study, the high rate of missing dishes will be explored and compared to the results of studying the same database with additional changes from the last four years, including over 10,000 new registrations filed during the freeze window between April, 2018 and November, 2018. Google has not undertaken and has no current plans to pursue a similar study with the much larger current database now containing nearly 13,500 total registrations in the database, nor has Google decided to invest the work required to build and train an artificial intelligence (AI) system to do this type of visual research (Clegg).

A separate Google study presented to the FCC in March, 2018 -- a month before the filing freeze and subsequent addition of many new site registrations -- shows a single-case analysis wherein they found 57% of the 37 sites nearest to a single terrestrial transmitter location were not in service (Calabrese). Citing the findings of its own two studies, Google has petitioned the FCC to require all registered location owners and users to update their GPS information and usage of the C-band frequencies in the IBFS database. As the analysis section of this report will show, removal of inactive or non-existing sites from the IBFS database would definitely provide a more accurate

representation of the actual C-band satellite usage in the United States and would certainly be in the public's best interest.

Another potential source of prior work and research is found in the public comments that companies and individuals may submit to the FCC on matters of public interest. In response to the NPRM and NOI, over 750 public comments and notices were filed with commenter's opinions, experimental data, concerns, background information and explanations, and recommendations to the FCC. Aligning with the research objective of this study, a fair portion of the comments question the validity and accuracy of the information in the IBFS. Many of those comments are based on Google's studies from 2014 and early 2018 before the filing freeze and resultant large number of new site registrations. The results of this study should provide sufficient current and wide-ranging data to better make policy decisions that will affect the entire nation's broadband future.

Another aspect of Green and Agent's work utilized a means of translating known address information into latitude-longitude coordinates, a process known as geocoding. Much public research has been done on the subject geocoding; for example, Texas A&M University has an entire department and web-based service ("TAMU GeoServices") developed from their Department of Geology's geocoding research, and many commercial entities offer the same service (both online real-time use and offline bulk data processing) for a fee. There are many online geocoding services available for free ("Available Geocoding Software"); some are limited or may not offer bulk conversion services, while others offer unlimited or bulk lookups for an optional upgrade fee.

As the accuracy of the data is the focus of this study, another key area of prior research and work is location verification. Having accurate location information is very important to various industries: the insurance sector, for example, depends on accurate location to fully assess its protected clients' exposure and therefore the insurance companies' liability in the event of a catastrophic loss (O'Donnell). Experian, one of the consumer credit reporting agencies in the United States, has an entire business division devoted to data verification that includes address verification. Their verification tools can be integrated into real-time data entry methods or offline bulk data sanitization. Using a small dataset of addresses submitted during a portion of the filing window after the freeze was implemented, we will examine whether geocoding addresses is useful or even possible with data from the IBFS and make recommendations for future improvements thereof.

CHAPTER III. METHODOLOGY

A. Project Population: Accessing the Data

The FCC stores all location-related information for each satellite downlink site in the IBFS. The IBFS contains the operational parameters of each site: registrant, locational coordinates, street address, satellite dish antenna(s) and specifications thereof, etc. As each location may have multiple satellite dish antennas, each antenna that is registered becomes a unique “site” record in the IBFS; however, if more than one frequency or range of frequencies is registered per antenna, each such frequency registration becomes a unique “site” such that multiple “sites” may exist for a single dish.

For the sake of this study, we discard all such duplicate “site” registrations leaving only a single location record for each satellite dish. Furthermore, if a single geographic location or street address had multiple dishes registered separately, each dish was treated as a separate site as its latitude and longitude coordinates were different. Only currently authorized pre-freeze sites and all post-freeze sites were included in the population of this study.

In order to obtain a list of de-duplicated sites, it was necessary to run a custom query on the IBFS data set. The public search tools on the IBFS website allow simple single-field searches (e.g. Company Name, File Number, etc.) ("MyIBFS") or advanced complex multi-field searches (e.g. list all current satellite earth stations utilizing C-band downlink frequencies) ("Advanced IBFS Search"). The search tools do not, however,

offer the ability to download the results in batch form in a form usable for post-processing, nor do they allow for custom queries with duplicate removal, so they were not helpful for this study.

The International Bureau also has a poorly-referenced web link that provides a direct download of the full set of tables and records exported nightly from the FCC's Sybase SQL database server. Once the post-freeze filing window closed, a complete nightly snapshot was retrieved from the FCC's FTP server and converted using custom scripts to a MySQL database. This database contained all the downlink site geographical (latitude/longitude) coordinates and registered site addresses that were the key data required to make the quantitative and qualitative assessments of C-band satellite usage. After exporting the results of customized queries to obtain the list of all unique currently authorized sites, the results were loaded into Microsoft Excel for further tabulation.

After all de-duplication, there were a total of 13,484 total unique latitude-longitude coordinate pairs in the entire population.

B. Data Collection: Stratification of the Data

In order to make a better analysis of the entire data set of 13,484 unique latitude/longitude coordinates, the data set was stratified into several sets of grouped data according to commonality. First, to establish a baseline comparison of the current data against Google's 2014 study, all 3,606 currently authorized sites that had been registered before the freeze on April 19, 2018 were grouped into a "Pre-Freeze" group.

A further set of 3,161 unique sites registered by a single organization after the freeze sites was segmented out as a single "Post-Freeze - LDS" group. This large set represented a set of filings performed by Intelsat (the largest satellite owner and operator and FCC licensee in the United States) on behalf of The Church of Jesus Christ of Latter-day Saints (hereafter referred to as "LDS").

The next "Post-Freeze - Other" data set represented the remaining 6,717 new sites registered by any organization or individual other than the LDS.

As a statistical comparison control set, the final data set analyzed was the summation of all three data subsets from the entire IBFS database; all 13,484 sites were left as the control group.

C. Data Collection: Statistical Sampling from the Total Population

For each of the four data sets, a proper sample size was established next. Using the population size for each data set, a set of possible sample sizes were calculated according to the following formula for a finite universe data set of known size:

$$Sample\ Size = \frac{\frac{z^2 * p(1-p)}{e^2}}{1 + \frac{z^2 * p(1-p)}{e^2 N}}$$

Where:

N = Population Size e = Margin of Error (in decimal form)

z = Z-Score p = Standard Deviation (Assumed) = 0.5

Formula from: ("Sample Size Calculator: Understanding Sample Sizes")

Using this formula, the following possible sample sets were calculated:

Table 1: Sample Size Calculation

	Data Set Population	Calculated Sample Set Size			
Pre-Freeze	**3,606**	348	1,442	561	1,929
Post-freeze - LDS	**3,161**	343	1,365	549	1,794
Post-freeze - other	**6,717**	364	1,769	604	2,564
Post-freeze - all (not analyzed separately)	***9,878***	*370*	*1,932*	*622*	*2,921*
Total Set in entire IBFS database	**13,484**	374	2,039	633	3,172
	Margin of Error (Confidence Interval)	5%	2%	5%	2%
	Confidence Level	95%	95%	99%	99%
	Z-Score (from confidence Level)	1.96	1.96	2.58	2.58
	Assumed Standard Deviation	50%	50%	50%	50%

Selecting a typical confidence level of 95% and a 5% acceptable margin of error, the chosen sample set size for each group ranged from 343 to 374 locations to be analyzed for accuracy (highlighted in orange in the chart above).

To gather a randomly sampled set, the Sampling algorithm in the Data Analysis add-in for Excel was used with the required number of random samples specified. The coordinates resulting from each sample set were then tabulated onto a spreadsheet. Some duplicate random samples within each group were replaced with additional random samples until at least the minimum quantity required to meet the required confidences was satisfied.

D. Limitations of the Study

Due to limited resources, this study made use of a smaller statistical sample set to compare against Google's 2014 comprehensive study of a much smaller database at that time. The number of samples required to produce typical and acceptable confidence levels and intervals were manageable for this study.

In cases where the intended site location had multiple satellite dishes and the registered dish location did not land on top of or within the diameter of the nearest dish antenna, the distance was measured to the nearest satellite dish. While the IBFS does contain the brand and size data for each registered dish antenna at each site, it was not practical to ascertain which dish on a site with multiple dishes was the one that was registered due to the limitations on aerial or satellite imagery quality without an in-person site visit.

The widely varying quality of the imagery was indeed one of the two largest externally-limiting factors on the validity of this study: the other, the age of the imagery. The imagery in some cases (e.g. Google Street View) was nearly good enough to read the manufacturer's label on the satellite dishes near a road, while in other cases imagery resolution was barely adequate to discern general geographic features in remote areas such as parts of Alaska.

Another limitation on accuracy beyond the control or scope of this study is the method of gathering the latitude and longitude coordinates for the site registration.

Whereas some registrants might have had access to a professional site survey from a civil engineering company with an extremely precise benchmark location reference for their satellite dish, others may have only had access to a GPS reading from a single cell phone or from a geocoded street address. Still others may have simply looked on Google Maps and clicked on their dish to read the coordinates.

Finally, the ability for any member of the general public to register a site for themselves or on behalf of another obviously allows a wide variety of skill and GPS familiarity levels to be represented in terms of the understanding of the coordinate reference system, data entry, and other tasks required of all registrants. Without any practical means of qualifying or quantifying the technical and clerical skill level of the registrants, the universe of data in the database should be expected to naturally have some variation in it. This study will enumerate that variation but will not attempt to explain or differentiate the reasons behind the variation.

CHAPTER IV. ANALYSIS

A. Process Steps

1. Global Population Reference Markers

Once the four sample sets were defined and created, the analysis and site verification phase of the project commenced. To serve as a reference for the analysis of the sample sets in the next step, all three complete data subsets were initially imported into Google Earth Pro and displayed as color-coded sets of markers.

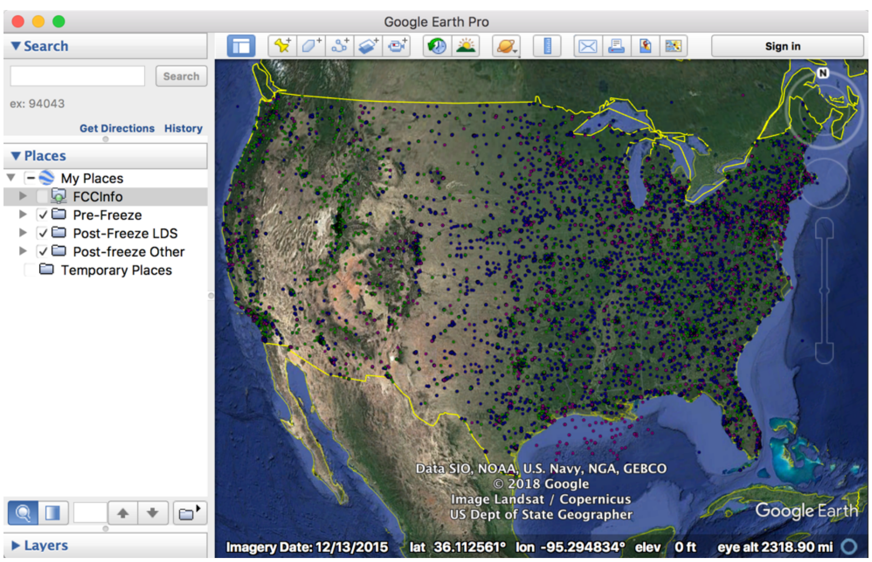

Figure 1: Google Earth map of all currently authorized or pending sites

Clicking each marker brought up the relevant site information such as registrant's name, address, latitude/longitude coordinate pair, FCC registration number and file number, along with a direct link to the license on the FCC's website (used to randomly spot-check the validity and accuracy of the exported information).

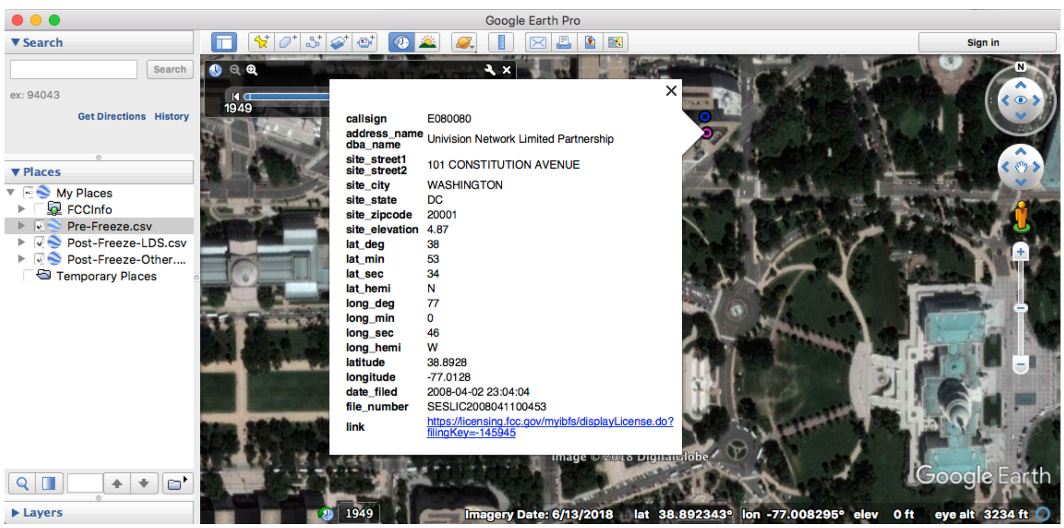

Figure 2: Downlink Site Information

2. Sample Set Reference Markers

Once the three complete data [sub]sets were loaded for reference, each of the four sampled sets of data (reduced to only the latitude/longitude pair) was imported one at a time to Google Earth Pro. As seen in Figure 3, clicking on each link snapped the view to that site and allowed for visual examination to locate the dish, if present.

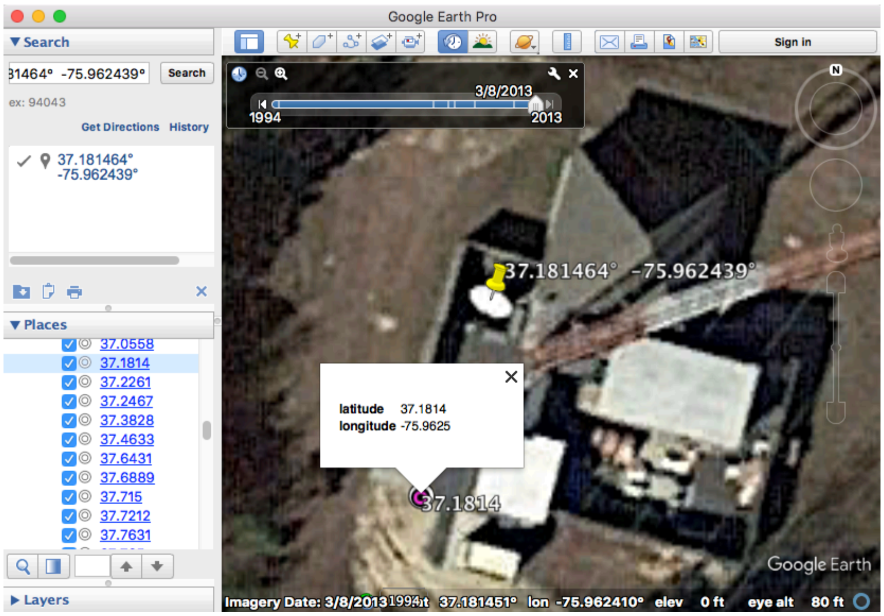

Figure 3: Site Location Identification

3. Locating the Dish

If a dish was visually located at or near the site, the coordinates were recorded and entered into the spreadsheet. If no dish was visible, historical imagery was reviewed to determine whether a dish was previously visible. Failing that, the address filed with the registration was searched to determine if the corresponding latitude/longitude coordinates were correctly entered and/or had a dish visible.

In cases where neither the geocoded address nor coordinates displayed a dish, a general Internet-based search for the registrant was performed to determine if a different address or location was similar in some fashion to the registered address or coordinates.

In some cases (particularly those on file prior to the freeze, and most frequently from one particular registrant with hundreds of sites registered in the mid-2000's), no proper address was filed with the coordinates, so a geographical proximity search for related businesses that would typically have utilized satellite dishes historically was performed.

4. Quantification of the Distance Error

Once a dish was located (either in most-current or historical imagery), the coordinates were entered into the database with six decimal places of precision (yielding a potential maximum accuracy of around 10 cm, obviously very dependent upon the precision of the geocoded imagery and placement of the marker) and the distance to the registered site location was calculated.

Because the earth is a spheroid (flattened at the poles and bulging at the equator) instead of a perfect sphere, we use the following formula (Kummer) to calculate the radius of the earth at the sample point:

$$\mathrm{r_{samp}} = el + \sqrt{\frac{\left(\mathrm{r_{eq}^2} * \cos(\mathrm{lat})\right)^2 + \left(\mathrm{r_{pol}^2} * \sin(\mathrm{lat})\right)^2}{(\mathrm{r_{eq}} * \cos(\mathrm{lat}))^2 + (\mathrm{r_{pol}} * \sin(\mathrm{lat}))^2}}$$

Where:

el = Elevation above sea level, in meters

lat = Latitude at registered sample point, in radians

$\mathrm{r_{eq}}$ = Earth radius at equator = 6,378,137 m

r_{pol} = Earth radius at poles = 6,356,752 m

r_{samp} = Earth radius at sampled site

Once the Earth radius is known at the sample point, the distance between it and the actual discovered location of the satellite dish was calculated with the following Excel formula ("Excel distance formula") :

$$\text{Distance} = \text{acos}\big(\cos\big(\text{radians}(90 - \text{lat}_1)\big) * \cos\big(\text{radians}(90 - \text{lat}_2)\big) + \sin\big(\text{radians}(90 - \text{lat}_1)\big) * \sin\big(\text{radians}(90 - \text{lat}_2)\big) * \cos\big(\text{radians}(\text{lon}_1 - \text{lon}_2)\big)\big) * \ r_{samp}$$

Where:

lat_1 = Latitude at registered site, in decimal degrees

lat_2 = Latitude at actual site, in decimal degrees

lon_1 = Longitude at registered site, in decimal degrees

lon_2 = Longitude at actual site, in decimal degrees

In cases where the actual coordinates of the dish were found to be within a distance equal to or less than the diameter of the dish antenna (as observed visually or confirmed by reviewing the registered dish antenna information), the distance was set to zero. No coordinates or distance was recorded in cases where the dish could not be conclusively located.

5. Qualification of the Registered Site Location Accuracy

Finally, the last stage of analysis was to classify the primary type of error that most likely led to the inaccuracy in cases where the registered coordinates did not align precisely with the dish antenna itself. The following classifications were used to qualify the accuracy of the registered location with respect to the actual location of the dish.

Table 2: Accuracy Qualification

Classification	Description or example
Satellite Dish Antenna	**Coordinates were on top of or within dish diameter's distance of dish**
Main Building on property	Coordinates entered are on the main building of the property containing the dish
Somewhere else on property	Coordinates are somewhere on property (other than the building) containing the dish
Dish found; Incorrect digit(s) in D-M-S field(s)	123˚ 45' 6.78" actual 123˚ 15' 6.78" registered
Dish found; Transposed digits in D-M-S field(s)	123˚ 45' 6.78" actual 132˚ 45' 6.78" registered
Dish found; Missing digit(s) in D-M-S field(s)	123˚ 45' 6.78" actual 123˚ 5' 6.78" registered
Dish found; Transposed D-M-S fields	23˚ 45' 6.78" N, 12˚ 34' 56.78" W actual 23˚ 34' 56.78" N, 12˚ 45' 6.78" W registered
Dish found; D-M-S field(s) used from another site	23˚ 45' 6.78" N, 12˚ 34' 56.78" W actual 23˚ 45' 6.78" N, 12˚ 27' 32.10" W registered
Dish found; D-M-S coordinates misunderstood	39° 37' 35.558" N, 99° 49' 19.956" W actual 37° 35' 54.0" N, 49° 19' 60.0" W registered
Dish found: Wrong N-S or E-W hemisphere	23˚ 45' 6.78" N, 12˚ 34' 56.78" W actual 23˚ 45' 6.78" S, 12˚ 34' 56.78" E registered
Dish found; Property abandoned	Dish located in current imagery but property containing it was abandoned/razed
Dish Found; Lat-Lon switched	23˚ 45' 6.78" N, 12˚ 34' 56.78" W actual 12˚ 34' 56.78" N, 23˚ 45' 6.78" W registered
Dish found on property other than registered site	Dish located anywhere from property immediately adjacent to actual site to anywhere else; basically a catch-all for any other unknown errors
Dish gone; Dish found in historical imagery	Dish not visible in most current imagery, but was visible in historical imagery
Dish not found; Inadequate imagery quality	Imagery was not detailed enough to detect dishes or other discernable feature; usually very remote sites or over water (Gulf of Mexico)
Dish not found; Clear imagery of property	Site was obvious, Imagery was clear, but no historical or current imagery showed any dish
Dish not found; Intended site not identifiable	Intended location not discernable in imagery or based on registered address

Once all the distance quantifications and accuracy qualifications were completed, the results were tallied using Pivot Tables, charts, and graphs for further insight, analysis and recommendations.

6. Geocoding

As a completely separate qualification and quantification experiment, a geocoding evaluation was performed on 1,000 sequential registrations started at random from the post-freeze data set to investigate the usability of addresses submitted during the freeze's filing window. The registered addresses were submitted without manual correction to six different geocoding services, including Google, Texas A&M's Geocoding service, the United States Census Bureau, and others. The resulting latitude/longitude coordinates were then compared to the registered site location coordinates using the same distance calculation process as described above, and then the average and median distance results from the six geocoding services were calculated for each of the 1,000 address/coordinate pairs.

The averaged and median results of the 1,000 sites were then evaluated as a set. While the median distance between the geocoded location results and the registered locations was only 100 m, the average distance was over 110,000 m and the standard deviation of the results was over 800,000 m. The extreme variability of this comparison shows either that: a) the geocoding sites that were evaluated are not consistent and/or

reliable enough to use for automated purposes of site verification; and/or b) that the address data or format submitted was unusable by the geocoding services.

Wide variances were noted between the services even in cases where the addresses were properly formed. However, many of the addresses submitted were missing one or more fields such as their street number, the street name, city, etc. Conversely, others put some or all of the entire address into multiple fields, producing too much information to be properly parsed automatically.

Consequently, the option of using current geocoding services to automatically validate the submitted coordinates was not pursued further because the registration process allows incomplete, malformed, or duplicate information to be submitted.

B. Results

As expected based on the results of the 2014 Google study, the pre-freeze data do indeed show that the sites registered before the freeze are in large part very inaccurate and a large percentage of dishes were missing. The sites that have been registered since the freeze have a much higher accuracy rate, however, bringing up the overall average. Looking at each sample set in turn reveals very definitive characteristics for each set.

1. Pre-Freeze Sites: All

Of the pre-freeze sample set, 21.0% of the sites showed no dish in the most current imagery, though a dish was confirmed in historical imagery. Another 9.2% of the registered sites did not show a dish in any imagery, yielding a total of 30.2% of all pre-freeze sites not showing a dish in the most current imagery available. This data closely aligns with the 29% statistic cited by Google in their 2014 study of the entire IBFS, reinforcing the validity of Google's study data and the sampling method of this study.

Table 3: Pre-Freeze Statistics

Pre-Freeze: All Combined				
Accuracy of Location Registered	Count	Percent of Total	Distance Avg. (m)	Distance StdDev (m)
Main Building on property	30	8.6%	24.6	20.5
Dish found on property other than registered site	45	12.9%	338.7	1,043.6
Dish not found; Intended site not identifiable	13	3.7%		
Dish gone; Dish found in historical imagery	73	21.0%	145.9	329.8
Somewhere else on property	109	31.3%	66.1	165.1
Satellite Dish Antenna	55	15.8%	0.0	0.0
Dish not found; Clear imagery of property	11	3.2%		
Dish found; Transposed digits in D-M-S field(s)	1	0.3%	28,194.1	
Dish found; Incorrect digit(s) in D-M-S field(s)	3	0.9%	2,075.2	2,118.0
Dish not found; Inadequate imagery quality	8	2.3%		
Grand Total	**348**	**100.0%**	**216.4**	**1,665.0**

2. Pre-Freeze Sites: Associated Press only

A more in-depth analysis of the currently authorized pre-freeze sites in the IBFS reveals that the Associated Press is the entity with the largest number of sites registered before the freeze, standing at 615 unique coordinates (17.1%) out of the total 3,606 sites

that are still currently authorized. Of the 348 pre-freeze sites, a total of 62 Associated Press sites were included, yielding a ratio of 17.8% of the pre-freeze sites sampled (closely to the overall ratio of Associated Press sites in the entire pre-freeze population).

For the Associated press sites, the results are striking: out of 62 sites, 51 sites (82.3%) showed that the dish had been there previously yet was removed in the most recent imagery; those 51 sites represent part of a total of 88.7% of sites where a dish was not visible in current imagery. Only 11.3% of the dishes were found at all in the most current imagery.

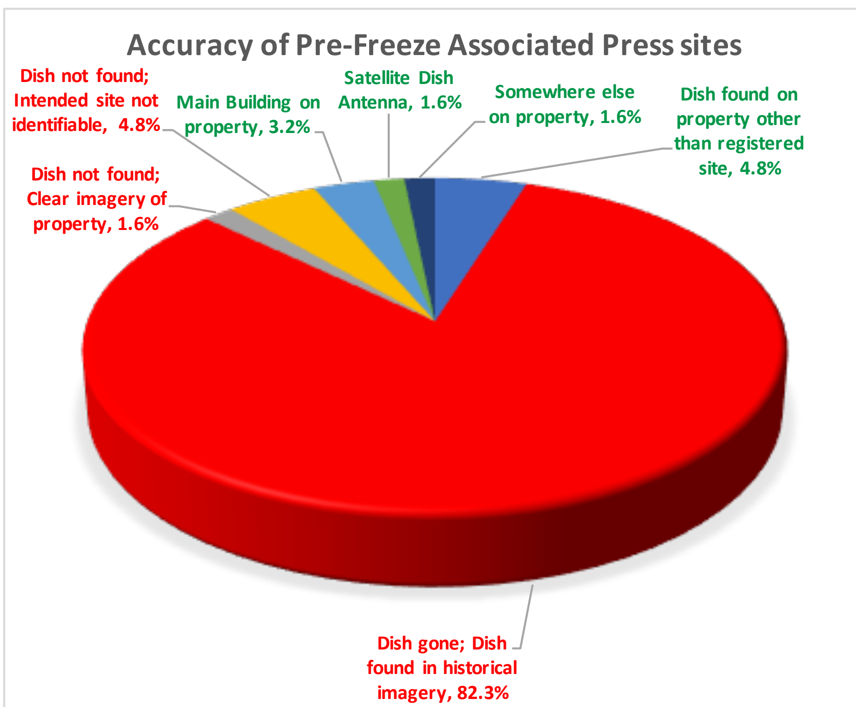

Figure 4: Associated Press Accuracy

By extrapolation to the entire pre-freeze population, we could conclude that roughly 545 of the 615 Associated Press sites still authorized in the IBFS are likely not present or visible in imagery.

The statistics for the Associated Press deserve more attention given the fact that the Associated Press has reportedly moved all of its distribution of content off of C-band years ago, and off satellite altogether a couple years ago in favor of using the Internet instead (Conrad). If this is indeed the case, then nearly all of the 615 remaining Associated Press sites should be purged from the IBFS if the local organizations are not otherwise using the dishes. Given the results of this study, it is extremely likely that most press organizations that formerly used C-band satellite downlink dishes to retrieve Associated Press content are not using their dishes even if they are still installed.

3. Post-Freeze Sites: LDS

With 3,161 unique latitude-longitude coordinates registered during the six-month filing freeze, the Latter-Day Saints church became the registrant with the largest quantity of sites registered by a single entity into the IBFS. Of the LDS sites sampled, only 1.2% were registered using the actual dish coordinates, while 95.0% of the sites were registered using the main building's coordinates, at a median distance of 44.4 m away from the dish.

Since all the LDS sites were registered by a single entity (Intelsat, the satellite operator that provides the LDS' satellite service) (VanBeber), it was expected to see a high degree of consistency amongst their filings. As the data show, the tight correlation

between the average and median distances to the dish suggests a commonality of design layout of the site (which was noted in the imagery during the study). The few errors actually observed in this sample set are easily attributed to clerical errors during data entry.

Table 4: Post-Freeze - LDS Statistics

Post-Freeze: Church of Jesus Christ of Latter-day Saints				
Accuracy of Location Registered	**Count**	**Percent of Total**	**Distance Avg. (m)**	**Distance StdDev (m)**
Dish found on property other than registered site	2	0.6%	114.2	19.8
Dish found; D-M-S field(s) used from another site	1	0.3%	36,291.3	
Dish found; Incorrect digit(s) in D-M-S field(s)	4	1.2%	2,077.9	2,399.9
Dish found: Wrong N-S or E-W hemisphere	1	0.3%	3,176,705.5	
Main Building on property	326	95.0%	47.0	23.1
Satellite Dish Antenna	4	1.2%	0.0	0.0
Somewhere else on property	5	1.5%	54.1	34.7
Grand Total	**343**	**100.0%**	**9,437.7**	**171,527.9**

4. Post-Freeze: Other

The other 6,717 sites that were registered during the filing freeze were all lumped together into a single data set regardless of how many sites each registrant entered.

Overall, the data show that these Other members were much more accurate than the LDS set, and far more accurate than the pre-freeze set. 52.9% of the sites were registered with coordinates at the dish itself. Including that statistic, a total of 92.0% registered a location within a median distance of 98.8 m of the actual dish. Only 2.9% of the Other set registered sites for which no location could be conclusively identified. In at

least one case, the registration data contained a note to inform the FCC that their dish had been installed in 2017 but the most recent Google imagery for the site was from 2016; this situation could well be the cause for the missing dishes.

Table 5: Post-Freeze - Other Statistics

Post-Freeze Other (de-duplicated)				
Accuracy of Location Registered	**Count**	**Percent of Total**	**Distance Avg. (m)**	**Distance StdDev (m)**
Satellite Dish Antenna	198	52.9%	0.0	0.0
Somewhere else on property	77	20.6%	38.1	81.1
Main Building on property	38	10.2%	21.1	15.9
Dish not found; Intended site not identifiable	6	1.6%		
Dish found on property other than registered site	31	8.3%	1,482.7	5,963.9
Dish found; Incorrect digit(s) in D-M-S field(s)	11	2.9%	239,140.9	295,770.1
Dish found; Property abandoned	1	0.3%	8.0	
Dish not found; Clear imagery of property	5	1.3%		
Dish found; D-M-S field(s) used from another site	1	0.3%	189,899.0	
Dish found; D-M-S coordinates misunderstood	1	0.3%	4,334,129.6	
Dish found; Missing digit(s) in D-M-S field(s)	3	0.8%	749.0	650.4
Dish found; Transposed D-M-S fields	1	0.3%	28,935.9	
Dish found: Wrong N-S or E-W hemisphere	1	0.3%	11,397,734.1	
Grand Total	**374**	**100.0%**	**51,331.1**	**642,161.5**

5. Entire IBFS Database

The final set of data points sampled were taken from the 13,484 unique coordinates from the entire IBFS database. In order to obtain a truly random sample that was representative of the entire data set, the random samples from each of the three sets were ignored and a new random set was taken from the entire population.

As may be expected, the stark contrasts of the prior stratifications were smoothed out in the entire data set. Of the samples for the entire IBFS, 29.4% were registered with

actual dish coordinates, while another 29.6% registered the main building on their property at a median distance of 31.4 m from the dish. Another 20.6% registered a location somewhere else on their property at a median 25.8 m from dish.

In summary for the entire database: 85.4% of the sites are within 57.3 m of the actual dish; 9.5% have no dish visible in any imagery; and 3.7% have been removed from service in the most current imagery.

Table 6: Entire IBFS Statistics

Entire IBFS Database				
Accuracy of Location Registered	**Count**	**Percent of Total**	**Distance Avg. (m)**	**Distance StdDev (m)**
Dish not found; Intended site not identifiable	22	5.8%		
Satellite Dish Antenna	111	29.4%	0.0	0.0
Main Building on property	112	29.6%	36.8	23.1
Dish found on property other than registered site	22	5.8%	861.3	3,565.6
Somewhere else on property	78	20.6%	100.1	236.4
Dish gone; Dish found in historical imagery	14	3.7%	65.5	68.9
Dish found; D-M-S field(s) used from another site	1	0.3%	1,243,750.8	
Dish found; Incorrect digit(s) in D-M-S field(s)	2	0.5%	213,174.4	294,952.6
Dish not found; Clear imagery of property	6	1.6%		
Dish found; Transposed D-M-S fields	1	0.3%	12,450.1	
Dish found: Wrong N-S or E-W hemisphere	1	0.3%	9,399,761.5	
Dish not found; Inadequate imagery quality	8	2.1%		
Grand Total	**378**	**100.0%**	**32,881.2**	**515,962.8**

C. Sample Set Results Comparison and Analysis

A side by side comparison of the four sample sets' accuracy is useful to compare the accuracy and error type distribution. The accuracy of the post-freeze filings is greatly superior to the pre-freeze filings primarily due to three primary factors: first, the negative weight that the non-operational and non-existent Associated Press sites have on the pre-freeze and overall statistics. Second, the ubiquity of free or low-cost yet highly accurate geolocation resources that allow more recent registrants to easily and accurately determine their coordinates. Third, accuracy ensures they will have protection from possible frequency interference in light of the FCC's current intentions regarding 5G.

Table 7: Accuracy of All Sample Sets

Accuracy Tabulation of All Sample Sets				
Quality	**Pre-Freeze: All Combined**	**Post-Freeze: Latter-day Saints**	**Post-Freeze: Other**	**Entire IBFS**
Satellite Dish Antenna	15.8%	1.2%	52.9%	29.4%
Main Building on property	8.6%	95.0%	10.2%	29.6%
Somewhere else on property	31.3%	1.5%	20.6%	20.6%
Dish found on property other than registered site	12.9%	0.6%	8.3%	5.8%
Dish found; Incorrect digit(s) in D-M-S field(s)	0.9%	1.2%	2.9%	0.5%
Dish found; Transposed digits in D-M-S field(s)	0.3%			
Dish found; Missing digit(s) in D-M-S field(s)			0.8%	
Dish found; Transposed D-M-S fields			0.3%	0.3%
Dish found; D-M-S field(s) used from another site		0.3%	0.3%	0.3%
Dish found; D-M-S coordinates misunderstood			0.3%	
Dish found: Wrong N-S or E-W hemisphere		0.3%	0.3%	0.3%
Dish found; Property abandoned			0.3%	
Dish gone; Dish found in historical imagery	21.0%			3.7%
Dish not found; Inadequate imagery quality	2.3%			2.1%
Dish not found; Clear imagery of property	3.2%		1.3%	1.6%
Dish not found; Intended site not identifiable	3.7%		1.6%	5.8%
Grand Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**

Comparing the highlights of the pre-freeze and post-freeze (other) groups, we see that **the number of accurate site registrations for satellite dishes rose from about 16% to nearly 53%**; the rate of **registrations located on other properties dropped from nearly 13% to just over 8%**, and the **rate of dishes gone from current imagery dropped from 21% to zero**. The distance error between the registered locations and the actual dish locations likewise improved from the pre-freeze set, as the next two tables show. The first shows average distance, and the second gives the median distance.

Table 8: Average Distance Comparison

Average Distance (m)				
Quality	**Pre-Freeze: All Combined**	**Post-Freeze: Latter-day Saints**	**Post-Freeze: Other**	**Entire IBFS**
Satellite Dish Antenna	-	-	-	-
Main Building on property	24.6	47.0	21.1	36.8
Somewhere else on property	66.1	54.1	38.1	100.1
Dish found on property other than registered site	338.7	114.2	1,482.7	861.3
Dish found; Incorrect digit(s) in D-M-S field(s)	2,075.2	2,077.9	239,140.9	213,174.4
Dish found; Transposed digits in D-M-S field(s)	28,194.1			
Dish found; Missing digit(s) in D-M-S field(s)			749.0	
Dish found; Transposed D-M-S fields			28,935.9	12,450.1
Dish found; D-M-S field(s) used from another site		36,291.3	189,899.0	1,243,750.8
Dish found; D-M-S coordinates misunderstood			4,334,129.6	
Dish found: Wrong N-S or E-W hemisphere		3,176,705.5	11,397,734.1	9,399,761.5
Dish found; Property abandoned			8.0	
Dish gone; Dish found in historical imagery	145.9			65.5
Dish not found; Inadequate imagery quality				
Dish not found; Clear imagery of property				
Dish not found; Intended site not identifiable				
Average of Averages	**4,406.4**	**459,327.1**	**1,472,012.6**	**1,207,800.1**

Table 9: Median Distance Comparison

Median Distance (m)				
Quality	**Pre-Freeze: All Combined**	**Post-Freeze: Latter-day Saints**	**Post-Freeze: Other**	**Entire IBFS**
Satellite Dish Antenna	-	-	-	-
Main Building on property	16.3	44.4	16.5	31.4
Somewhere else on property	26.5	63.0	19.1	25.8
Dish found on property other than registered site	87.4	114.2	98.8	57.3
Dish found; Incorrect digit(s) in D-M-S field(s)	1,844.6	1,180.5	59,251.6	213,174.4
Dish found; Transposed digits in D-M-S field(s)	28,194.1			
Dish found; Missing digit(s) in D-M-S field(s)			1,008.2	
Dish found; Transposed D-M-S fields			28,935.9	12,450.1
Dish found; D-M-S field(s) used from another site		36,291.3	189,899.0	1,243,750.8
Dish found; D-M-S coordinates misunderstood			4,334,129.6	
Dish found: Wrong N-S or E-W hemisphere		3,176,705.5	11,397,734.1	9,399,761.5
Dish found; Property abandoned			8.0	
Dish gone; Dish found in historical imagery	61.2			35.4
Dish not found; Inadequate imagery quality				
Dish not found; Clear imagery of property				
Dish not found; Intended site not identifiable				-
Average of Medians	**4,318.6**	**459,199.8**	**1,455,554.6**	**1,086,928.7**

The astute reader might notice a few anomalies in the above tables. There were several instances where one of the subsets had some instances of one particular type of error that did not appear in the sample set taken from the entire IBFS database. While it is expected that an occurrence sampled in a subset should show up in the parent (all-inclusive) superset, in these cases the very small percentage of errors is lower than the expected margin of error for the sample size taken from each set. As such, it is entirely reasonable to see a low-frequency error in a subset that is not present in the sampled superset, and the converse is also true (a particular error mode might be present in the superset but not appear in any of the subsets).

A larger sample size would obviously lessen the chance of this anomaly (by reducing the margin of error), but at the cost of much more labor to manually inspect that many more sites. Another way to reduce the likelihood of this anomaly appearing in the sample set would be to repeat the random sampling process again multiple times and then average the results much like a Monte Carlo simulation process would do. Given that the process of visually inspecting, researching, and recording the data for each site may take anywhere from 15 seconds (where the dish is precisely and accurately located) to 15-30 minutes (where the registered location is obviously wrong (like in the middle of a forest) and the address is missing, leading the researcher to a general Internet search to attempt to figure out where the registrant's relevant place of business may be located), however, running multiple samples for each subset and superset is beyond the scope of this project.

D. Sample Set Results Graphs

The following graph shows the distribution of the four data sets' accuracy, generally ranging from most frequent occurrence on the left to least frequent error modes on the right. The most obvious outliers are: the 53% of accurate locations in the post-freeze - other group; the 95% statistic from the LDS' use of the main building as their site location instead of the dish itself; and the 21% of dishes that are now gone yet still active in the [Associated Press-influenced] pre-freeze group.

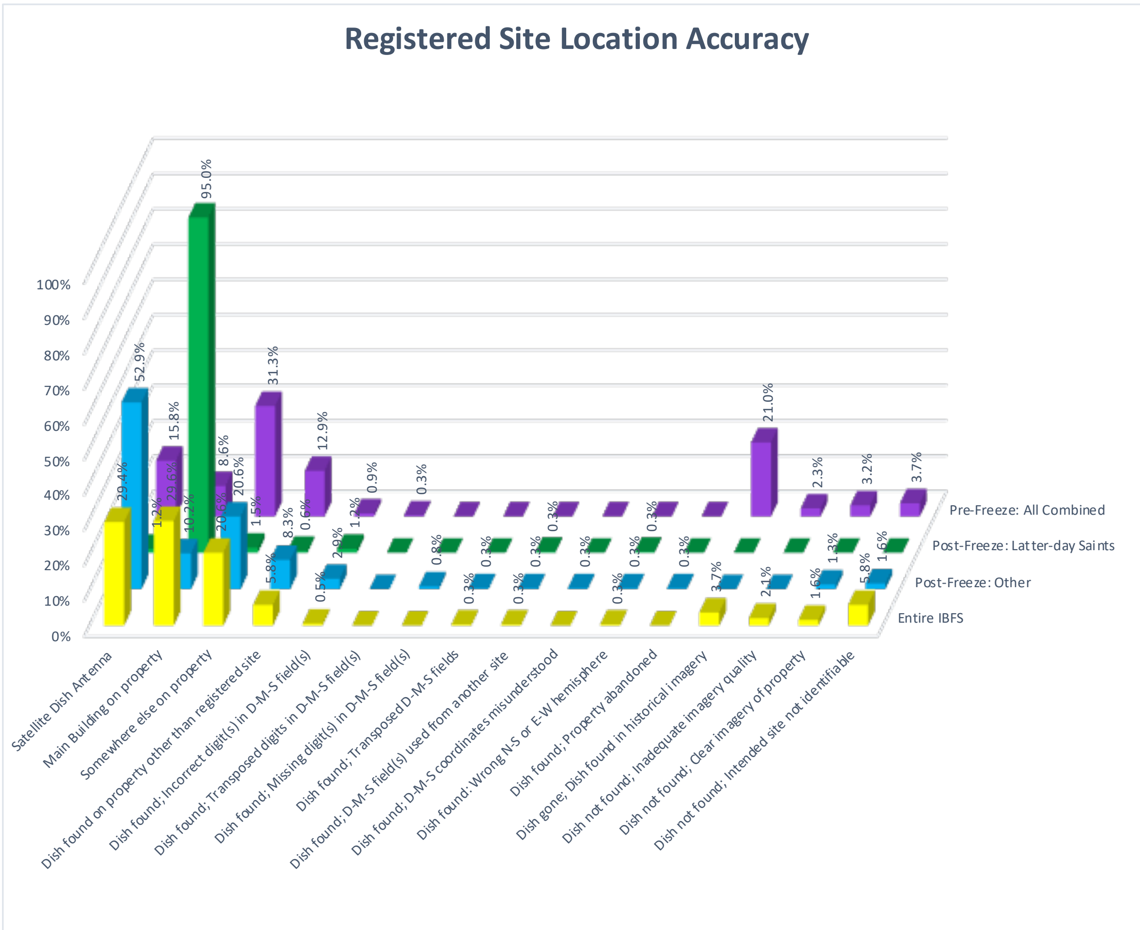

Figure 5: Registered Site Location Accuracy

Finally, a comparison of the median distance between the registered location and the actual location shows a wide range of values. The largest outliers are caused by entering incorrect values in the Hemisphere (North vs. South, and East vs. West) or Degrees, Minutes, or Seconds field(s) of the registration forms. Single-digit transcription errors or checkbox button mis-selection on the FCC registration web form can easily result in millions of meters of difference.

To show the entire set of data, a logarithmic vertical scale is used on this graph, with the disclaimer that the unlabeled columns on the floor of the graph are actually either zero or a null set (instead of the value of 1.0 shown as the minimum value of the log scale vertical axis).

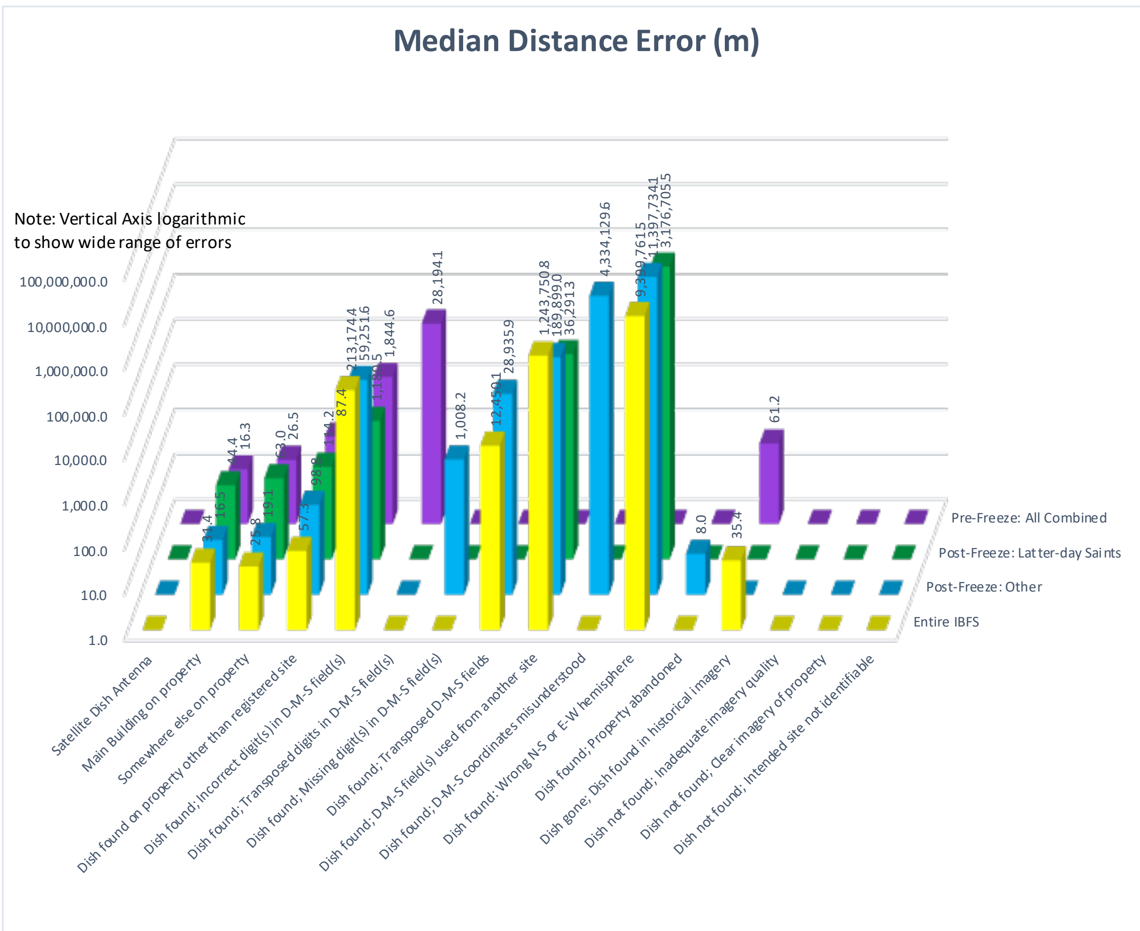

Figure 6: Median Distance Error

CHAPTER V. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

To verify the accuracy level of currently authorized C-band downlink locations in the FCC database, a local copy of the FCC database is downloaded and parsed into three major subsets: sites registered before the FCC-mandated freeze of new applications on April 19, 2018; sites registered after the freeze by one entity with over 3,000 locations; and the rest of the sites registered during the post-freeze filing window by all other parties. The entire set of all currently authorized or pending new registrations was also separately analyzed.

The data show that the pre-freeze sites do indeed have a high rate (30.2%) of active registrations where no dish is found. 21.0% of all pre-freeze registrations are sites where a dish was confirmed in historical imagery but is gone in current imagery. 68.4% of the pre-freeze sites have a dish visible within a median distance of 88 meters from the registered location. 15.8% of all locations registered in this group were accurately placed on the satellite dish.

The LDS church with over 3,000 sites was much more precise, and had no sites missing a dish. 98.3% of all locations registered to this group were within 115 meters of the dish, yet only 1.2% of this set had the dish accurately located.

The set of all other post-freeze applicants were also much more accurate than the pre-freeze locations, though slightly different from the preceding group. This set had

92% of all locations registered within 99 meters of the actual dish, with 52.9% of all locations accurately placed on the satellite dish itself.

The superset of all registrations yielded a much more averaged set of data, as expected. 29.4% of the superset accurately registered the dish itself; including that group, a total of 85.4% registered a location within 58 meters of the actual dish. 13.2% of all sites are missing completely, including 3.7% of all sites where the dish formerly existed but is no longer present in current imagery.

In summary, the database contains a wide range of accuracy when comparing older data to the newer data, and the broad range of intra-set error types and the associated effects on accuracy confirm prior studies showing that user input error adversely affects the overall reliability of such data sets. (In contrast, the LDS group shows the consistency benefit of having a single agent register a large number of sites.)

The high rate of errors and missing sites in the pre-freeze data affirms the conclusion that the older data should be thoroughly vetted and cleaned up, and by doing so the overall accuracy of the database will dramatically improve thereby giving the FCC a more well-informed basis to make a recommendation to Congress on how much C-band spectrum is actually in use and what spectrum to allocate for 5G.

Finally, while geocoding the submitted site address could potentially be used to perform a cross-check with the registered coordinates for new sites, the address data existing in the database currently is inadequate to be used reliably.

B. Recommendations

Given the results of this study, it is clear that much cleanup work needs to be done before the current IBFS database should be relied upon for any policy decisions by the FCC. The FCC should make the following changes in order to render the data useful, reliable, and publicly regarded as trustworthy:

- As has been proposed by the FCC ("NPRM"), all registrants who registered before the freeze should affirm or deny the current usage of their registered dish(es) and/or location(s) and affirm or update the actual location(s) to accurately locate the dish(es).
- The FCC should integrate a reliable, easy-to-use location-verification tool (possibly one such as they already use internally) to validate and verify the registration's location accuracy into their new submission and previously-registered affirmation process. Specifically, the registration form should include and use an embedded, searchable Google Map and require the user to locate and click on their specific dish in the best, most current actual imagery so that the actual correct coordinates are automatically passed from the map to the registration form, thereby eliminating all transcription errors. On any multi-site bulk submission that contains multiple sets of coordinates, the submitter should be presented with a sequence of embedded current images from Google Maps; one for each site with a dropped pin, requiring the

submitter to affirm that the map and dropped pin accurately reflect the correct location for each site in turn.

- The FCC should not allow any submission to be entered without an accurate street address. The FCC should utilize a real-time address verification service such as the one that Experian offers (Wheeler, Rachel) to ensure that all addresses entered can be properly recognized and geocoded. In cases where sites are not geocode-able (e.g. remote mountaintop transmitter sites without postal addresses) the application would automatically be sidelined for manual review of the imagery.
- The submission process should take the real-time geocoded results of the verified site address and compare its distance against the submitted coordinates, again presenting the submitter with a map of the geocoded site address and requiring the submitter to affirm the dropped pin on the image accurately reflects the correct postal address before the registration is allowed to be submitted.
- The FCC should implement automated tools to make their completed submission review process more efficient and rapid to reduce the months-long processing time.

If the FCC makes these changes, new registrations will be more accurate and easier to create and submit; internal application reviews (prior to granting approval for a new site license) will be faster since less time will be spent searching; and the resulting database will be more trustworthy and usable by the FCC as well as ultimately the

legislative branch of the government that relies upon the FCC to manage the RF spectrum resources for the good of the American public.

C. Future Studies and Research

Along with a variety of industries that rely on (or want to) rely on the frequency allocations and licenses tracked in the IBFS, the FCC is very well aware of the issues with its database. As noted in the first recommendation above, the FCC has already declared its intention to require currently authorized licensees to reaffirm their site information. Once that process completes, repeating this study with the invalid data removed or replaced with corrected information would further bolster confidence in the database.

Further in-depth analysis of the other registrants with large numbers of site registrations may also reveal trends like that exposed for the Associated Press. Beyond the two largest entities (the LDS church and the Associated Press) that collectively represent around 3,775 sites, there are six other large entities with over 100 sites (three of which have over 200) that are currently pending or authorized.

Another means of evaluating this data on a more regular basis would be to work with the daily snapshots and simply keep track of the changes submitted each day to the IBFS. Even after the upcoming required affirmation by all pre-freeze licensees, it would also be good to keep track of the old sites that "age out" of the database as their ten- or fifteen-year licenses expire without getting renewed.

If the FCC implements these common-sense changes to their registration system, as time progresses the data will naturally improve as the bad data are eliminated through attrition. The public stands to gain much when the government's public policy decisions and industry moves are based on accurate data.

GLOSSARY

4G	Fourth-Generation cellular communications technology and protocols
5G	Fifth-Generation cellular communications technology and protocols
Commission	Federal Communications Commission
C-band	Frequencies between 3,700 – 4,200 MHz (commonly used for downlinks) and 5,925 – 6,425 MHz (commonly used for uplinks)
Downlink	RF signal sent from an orbiting satellite to the earth; the process of receiving the RF signal and processing it
Earth Station	Site location of a satellite downlink antenna and receiving apparatus
FCC	Federal Communications Commission
IBFS	International Bureau Filing System; the FCC's database and web-based portal allowing entry, modification, and viewing of database records for C-band frequency and other satellite usage allocations, registrations, and licenses
NOI	Notice of Inquiry; a document the FCC uses to initiate gathering information from interested parties on a topic
NPRM	Notice of Proposed Rulemaking; a document the FCC uses to propose new rules and open up a period of public comments regarding the proposal
RF	Radio Frequency (signals; communication method utilizing radio signals)
Uplink	RF signal sent from the earth to an orbiting satellite

BIBLIOGRAPHY

"About the FCC." FCC https://www.fcc.gov/about/overview. Accessed November 2, 2018.

"Advanced IBFS Search." FCC http://licensing.fcc.gov/cgi-bin/ws.exe/prod/ib/forms/reports/swr030b.hts?set=#earthReport. Accessed November 2, 2018.

"Available Geocoding Software." https://geoservices.tamu.edu/Services/Geocode/OtherGeocoders/. Accessed October 21, 2018.

"Excel formula to calculate distance between 2 latitude, longitude (lat/lon) points (GPS positions) " http://bluemm.blogspot.com/2007/01/excel-formula-to-calculate-distance.html. Accessed November 21, 2018.

"GPS.gov: Surveying & Mapping." National Coordination Office for Space-Based Positioning, Navigation, and Timing https://www.gps.gov/applications/survey/. Accessed November 26, 2018.

"MyIBFS Login and Search Page." FCC http://licensing.fcc.gov/myibfs/. Accessed November 2, 2018.

"NOTICE OF INQUIRY: Expanding Flexible Use in Mid-Band Spectrum Between 3.7 and 24 GHz." edited by Federal Communications Commission, FCC. https://www.fcc.gov/document/fcc-opens-inquiry-new-opportunities-mid-band-spectrum-0https://www.fcc.gov/document/fcc-opens-inquiry-new-opportunities-mid-band-spectrum-0, November 1, 2018.

"ORDER AND NOTICE OF PROPOSED RULEMAKING: Expanding Flexible Use of the 3.7 to 4.2 GHz Band." edited by Federal Communications Commission, FCC. https://www.fcc.gov/ecfs/filing/07131575002139https://www.fcc.gov/ecfs/filing/07131575002139, November 1, 2018.

"Sample Size Calculator: Understanding Sample Sizes." Survey Monkey https://www.surveymonkey.com/mp/sample-size-calculator/. Accessed November 21, 2018.

"Search FCC Databases." FCC https://www.fcc.gov/licensing-databases/search-fcc-databases. Accessed November 2, 2018.

"TAMU GeoServices." Texas A&M University http://geoservices.tamu.edu/. Accessed October 21, 2018.

"TEMPORARY FREEZE ON APPLICATIONS FOR NEW OR MODIFIED FIXED SATELLITE SERVICE EARTH STATIONS AND FIXED MICROWAVE STATIONS IN THE 3.7-4.2 GHz BAND." edited by International Bureau, Federal Communications Commission. https://www.fcc.gov/document/bureaus-announce-freeze-and-limited-filing-window-37-42-ghz-bandhttps://www.fcc.gov/document/bureaus-announce-freeze-and-limited-filing-window-37-42-ghz-band, November 23, 2018.

Bigham, John et al. "Evaluation of the Accuracy of Global Positioning System Coordinates for Collision Locations in California." UC Berkeley, July 25, 2014. general editor, UC Berkeley, https://escholarship.org/uc/item/2kh3z760https://escholarship.org/uc/item/2kh3z760, November 3, 2018.

Blais, Paul. "Interview with Paul Blais." Interview by Sherrod Munday, October 9, 2018 Telephone.

Calabrese, Michael. "Point-to-Multipoint Coexistence with C-band FSS." https://www.newamerica.org/documents/2119/FCC_Tutorial_Technical_Preso_on_C-Band_Sharing_BACGoogle_FINAL_03.27.18.pptxhttps://www.newamerica.org/documents/2119/FCC_Tutorial_Technical_Preso_on_C-Band_Sharing_BACGoogle_FINAL_03.27.18.pptx, November 20, 2018.

Christopherson, Bruce. "Email from Bruce Christopherson." Email, October 17, 2018.

Clegg, Andrew. "Interview with Andrew Clegg." Interview by Sherrod Munday, Telephone.

Conrad, Dan. "Interview with Dan Conrad." Interview by Sherrod Munday, November 19, 2018 Telephone.

Green, Eric R. and Kenneth R. Agent. "Evaluation of the Accuracy of GPS as a Method of Locating Traffic Collisions." University of Kentucky. general editor, Kentucky

Transportation Center, https://uknowledge.uky.edu/cgi/viewcontent.cgi?article=1216&context=ktc_researchreportshttps://uknowledge.uky.edu/cgi/viewcontent.cgi?article=1216&context=ktc_researchreports, November 21, 2018.

Kummer, Jürgen. "Earth Radius by Latitude Calculator." https://rechneronline.de/earth-radius/.

Locke, Gary and Lawrence E. Strickling. "Plan and Timetable to Make Available 500 Megahertz of Spectrum for Wireless Broadband." edited by U.S. Department of Commerce, p. 34. https://www.ntia.doc.gov/files/ntia/publications/tenyearplan_11152010.pdfhttps://www.ntia.doc.gov/files/ntia/publications/tenyearplan_11152010.pdf, November 1, 2018.

O'Donnell, Anthony. "Location, Location, Location." *Insurance & Technology*, vol. 32, no. 1, pp. 34-37, https://search-proquest-com.proxy.lib.utc.edu/georef/docview/229282968/abstract/73213B883BD243D7PQ/1?accountid=14767.

Obama, Barack. "Presidential Memorandum: Unleashing the Wireless Broadband Revolution." edited by White House, Office of the Press Secretary, p. 1. https://obamawhitehouse.archives.gov/the-press-office/presidential-memorandum-unleashing-wireless-broadband-revolutionhttps://obamawhitehouse.archives.gov/the-press-office/presidential-memorandum-unleashing-wireless-broadband-revolution, October 31, 2018.

Pai, Ajit. "Remarks Of FCC Chairman Ajit Pai White House 5G Summit, Washington, DC." edited by Federal Communications Commission, FCC, p. 1. https://docs.fcc.gov/public/attachments/DOC-354323A1.pdfhttps://docs.fcc.gov/public/attachments/DOC-354323A1.pdf, October 31, 2018.

Purdy, Michael R. et al. "Comments of Google LLC and Alphabet Access." FCC. https://ecfsapi.fcc.gov/file/1002676317625/2017.10.02%20Google%20and%20Access%20Comments.pdfhttps://ecfsapi.fcc.gov/file/1002676317625/2017.10.02%20Google%20and%20Access%20Comments.pdf, November 20, 2018.

Sarasua, Wayne A. et al. "Use of Global Positioning System to Identify Crash Locations in South Carolina " *Journal of the Transportation Research Board*, vol. 2064, pp. 43-50, https://doi.org/10.3141/2064-07.

Thune, Sen. John. "Consolidated Appropriations Act, 2018." 115 edition, March 23, 2018, 605.3 3 GIGAHERTZ SPECTRUM. *U.S. House of Representatives*, https://www.congress.gov/bill/115th-congress/house-bill/1625/text#toc-HF828A4740CA1499E9701826F541A1DD8https://www.congress.gov/bill/115th-congress/house-bill/1625/text#toc-HF828A4740CA1499E9701826F541A1DD8, November 1, 2018.

Trump, Donald J. "Presidential Memorandum on Developing a Sustainable Spectrum Strategy for America's Future." GPO, pp. 1-2. https://www.gpo.gov/fdsys/pkg/FR-2018-10-30/pdf/2018-23839.pdfhttps://www.gpo.gov/fdsys/pkg/FR-2018-10-30/pdf/2018-23839.pdf, October 31, 2018.

VanBeber, Dianne. "Interview with Diane VanBeber." Interview by Sherrod Munday, October 10, 2018 Telephone.

Wheeler, Rachel. "Government venture encounters data quality problems." Experian Information Solutions https://www.edq.com/blog/government-venture-encounters-data-quality-problems/. Accessed October 30, 2018.

Wheeler, Tom. "Remarks of Chairman Tom Wheeler, As Prepared for Delivery, 19th Annual Satellite Leadership Dinner, Washington, D.C." edited by Federal Communications Commission, FCC, pp. 1-3. https://docs.fcc.gov/public/attachments/DOC-338135A1.pdfhttps://docs.fcc.gov/public/attachments/DOC-338135A1.pdf, October 31, 2018.

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