

An Analysis and Comparison of FCC Auction 107 (C-Band) with Auctions 1000 (600 MHz Band), 101 (28 GHz Band), 102 (24 GHz Band), 103 (Upper 37, 39, and 47 GHz Bands), 105 (CBRS Band).

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1. Executive Summary [In Progress]

From 2015 to 2021, the FCC held eleven auctions, an unprecedented amount [1]. Analysis and comparison of these auctions provide a unique opportunity to quantify bidding trends and auction results based on metrics like frequency, geographic factors, and population data.

This paper primarily assesses Auction 107 (C-Band) data and compares the findings with those of Auctions 1000 (600 MHz Band), 101 (28 GHz Band), 102 (24 GHz Band), and 103 (Upper 37, 39, and 47 GHz Bands), and 105 (CBRS Band).

This analysis specifically finds:

- An unexpectedly high auction premium for obtaining C-band licenses that are available for early use. During Auction 107 (C-Band), bidders were willing to pay approximately 31.6% more for the A Block in the 46 PEAs where it would be available within 12 months, versus the B or C Blocks that would not be available for two additional years. This finding is supported by a 9,109% increase in minimum opening bid prices for the first fifty PEAs between Auction 107 (C-Band) and Auctions 101 (28 GHz Band), 102 (24 GHz Band), and 103 (Upper 37, 39, and 47 GHz Bands).
- Most minimum opening bids for Auction 107 (C-Band) fall roughly in line with similar increases from Auctions 101 (28 GHz Band), 102 (24 GHz Band), and 103 (Upper 37, 39, 47 GHz Bands), which the FCC set using a price index based on historical auction data. However, four outliers that had prices that deviated substantially from expected results due to the bidding behavior of a single bidder were identified.
- Auction 1000 (600 MHz Band) had generally higher minimum opening bids in comparison with Auction 107.
- Auction 101 (28 GHz Band), 102 (24 GHz Band), and 103 (Upper 37, 39, and 47 GHz Bands) had [\[insert exact amount\]](#) lower minimum opening bid values set by the FCC in comparison with Auction 107 (C-Band).
- Higher frequencies, such as millimeter-wave, have a smaller coverage area than lower frequency bands. Intuitively, one would expect the relative value of higher frequency bands to decline more in rural areas than lower frequency spectrum. Our analysis finds [\[In Progress\]](#)
- The analysis that compared Auction 107 to 1000, 101, 102 and 103 individually, produced trends in the valuation of spectrum over time. Our analysis finds [\[In Progress\]](#)

2. Auction 107 (C-Band): Band Plan, Geographic Areas, and Transition Plan

Auction 107, commonly referred to as the C-band Auction, set an FCC record for total proceeds, and aimed to repurpose spectrum used by incumbent fixed-satellite service (FSS) networks for terrestrial 5G use in exchange for reimbursement of relocation costs [2]. Satellite operators relied heavily on C-band in the 1980s and 1990s, but satellite applications slowly moved to the higher Ku- and Ka-bands. As a result, the value for C-band orbital slot authorizations had fallen considerably. However, demand for C-band for terrestrial wireless use increased as improvements in air interface, antenna technology, and computational power made the band viable for mobile applications.

In this auction, 5684 flexible use licenses, each renewable and valid for fifteen years, were auctioned across 280 MHz between 3.7 to 3.98 GHz, a part of the C-band (3.4 - 4.2 GHz). As shown in Figure 1, the FCC divides the lower 280 MHz of the C-band into three Blocks: A, B, and C, which the FCC further divided into 20 MHz slices, each available for auction. Figure 1 shows the division of the 3.7 to 4.0 GHz spectrum into the 20 MHz slices and the FCC's naming convention used in the auction. Both the A and B Blocks are 100 MHz wide. Only the lower 80 MHz of the C Block are available for auction since the uppermost 20 MHz are reserved as a guardband to protect remaining satellite operations in the 4.0 to 4.2 GHz range.

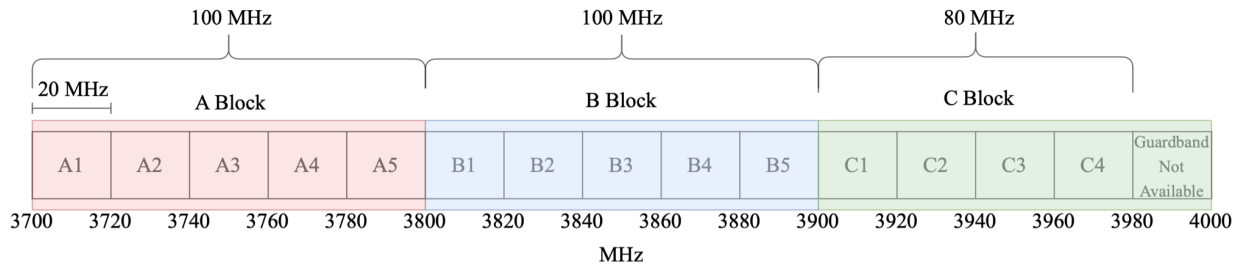


Figure 1: Band Plan for the Lower 280 MHz of the C-band for Auction 107 (C-Band)

Across the United States, the U.S. Department of Commerce (DoC) defines 176 Economic Areas (EAs), which the FCC further divided into 416 Partial Economic Areas (PEAs) in 2014 [3]. The FCC awarded C-Band licenses in geographic units called Partial Economic Areas (PEAs). In each PEA, there are fourteen potential licenses available for bidding, as defined by the 20 MHz slices of the A, B, and C, as shown in Figure 1. As shown in Appendix 1, PEAs are numbered in order of decreasing population, with PEA1 being New York, NY, followed by PEA2 being Los Angeles, CA, and PEA3 being Chicago, IL [4]. All PEAs in the continental United States, therefore excluding Honolulu, Anchorage, Kodiak, Fairbanks, Juneau, Puerto Rico, Guam-Northern Mariana Islands, U.S. Virgin Islands, American Samoa and the Gulf of Mexico were available for auction in Auction 107 (C-Band) [2].

2.1 Auction 107 (C-Band): Transition Plan

In 2018, several incumbent FSS operators, namely Intelsat, SES Satellites, Eutelsat, and Telesat formed the C-band Alliance. Initially, the C-band Alliance proposed to vacate the lower 300 MHz for 5G use in exchange for the reimbursement of relocation costs paid by the winning bidders [2]. Ultimately, additional accelerated relocation payments, also paid for by the winning bidders, were offered to eligible FSS operators who chose to follow an accelerated timeline for clearing the lower 280 MHz of the C-band. All eligible incumbents decided to follow the accelerated relation timeline as shown in Figure 2, and vacate by December 5th, 2023.

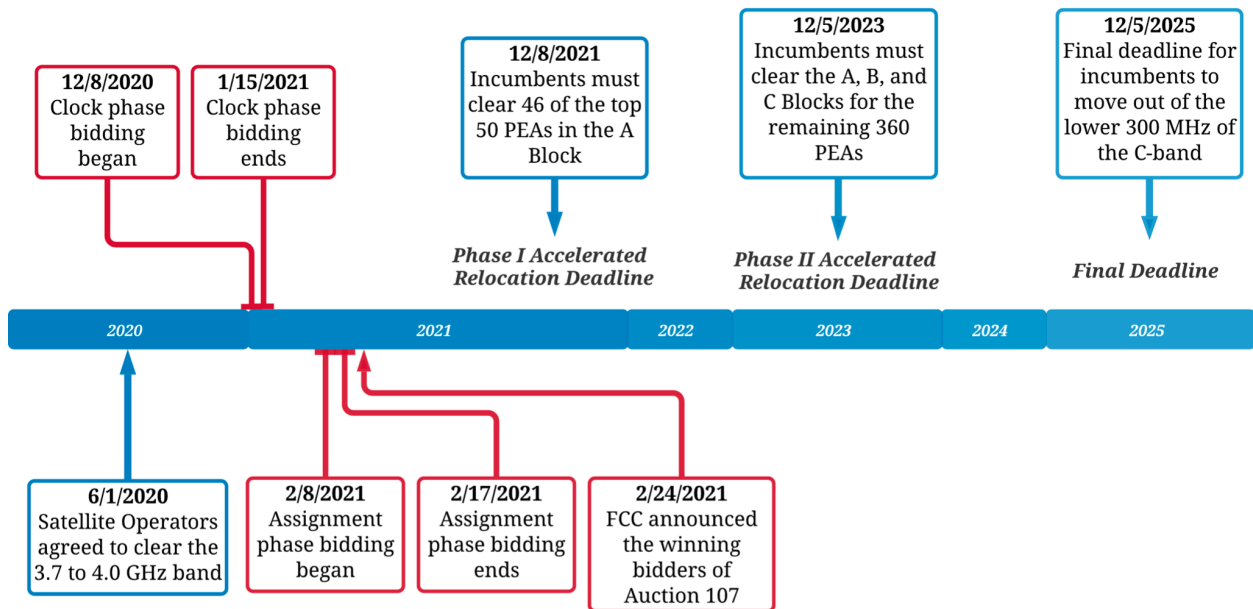


Figure 2: Auction 107 (C-band) Multi-Year Transition Timeline and Major Events for FSS Operators

By December 8, 2021, the end of *Phase I* of the accelerated relocation timeline, incumbents must free the A Block (3.7 - 3.8 GHz) in 46 out of the first fifty PEAs, shown in Figure 3. Incumbents must vacate the A, B, and C Blocks in the remaining 360 PEAs by December 5, 2023, the end of *Phase II* accelerated relocation timeline.

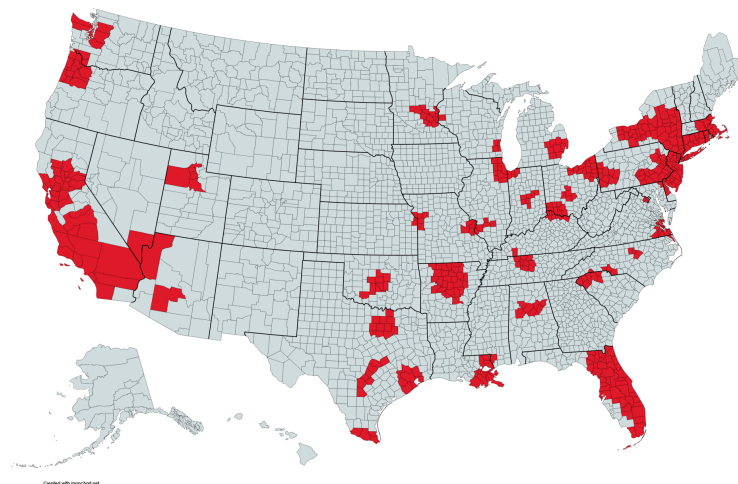


Figure 3: FSS Operators Must Vacate 46 out of Fifty PEAs (shown in red) in Block A (3.7 GHz - 3.8 GHz) by the End of 2021 Under Accelerated Relocation Timeline.

2.2 Auction 107 (C-Band): Auction Mechanics

In addition to the accelerated relocation timeline shown in blue, Figure 2 shows the schedule for the two Auction 107 (C-Band) phases, the clock and assignment phases, in red.

The clock phase has two phases. In Phase I, PEAs are auctioned in two separate groups, A and BC, whereas the FCC sold all Phase II PEAs in a single group, ABC. For example, a bidder may place a bid in Phase I on PEA1, group A, for five licenses, 20 MHz each. In Phase II, this bidder may bid on PEA51, but can not specify a particular block, thereby bidding on group ABC.

In the assignment phase, depending on the number of licenses individual bidders won in the clock phase, bidders can optionally bid more in the assignment phase for specific 20 MHz frequency slots. The FCC designated these 20 MHz slots in the same way as in Figure 1. However, bidders are guaranteed the number of licenses they won in the clock phase regardless of any bids placed in the assignment phase. To ensure efficient use of spectrum, the FCC awards the bidders contiguous spectrum.

Bidding credits, which incentivize participation in the auction, are available for small businesses or rural service providers. Qualified *small businesses* receive a discount between 15% to 25% on their winning bids up to a \$25 million cap, and qualified *rural service providers* receive a 15% discount on their winning bids up to a \$10 million cap. To qualify as a rural service provider, the bidder must primarily service PEAs with less than 100 people per square mile [5]. Figure 4 shows these rural, small markets in green and the large markets in red.

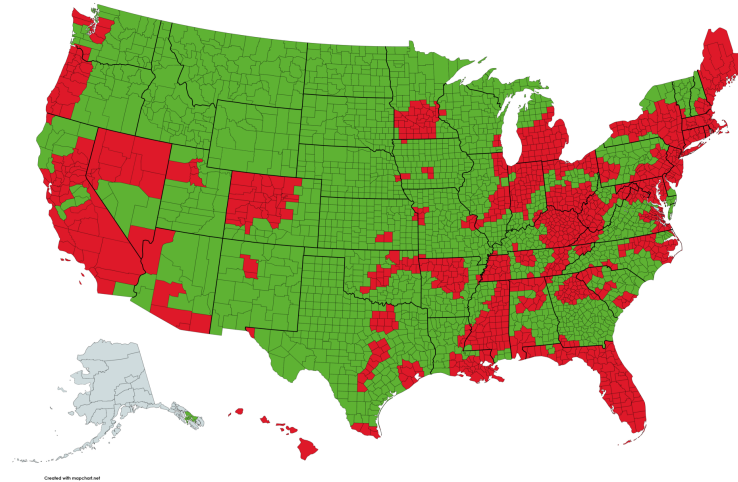


Figure 4: All PEAs - Small Markets Shown in Green, Large Markets in Red

3. Auction 107 (C-Band): Highest Grossing Bidders

The C-band auction consisted of \$81.2 billion in bids, with Cellco Partnership, AT&T, and T-Mobile making over 96% of the total amount spent. The top five highest-grossing bidders and bidders who won the largest amount of licenses are listed in Table 1.

Table 1: Top 5 Highest Grossing Auction 107 (C-Band) Bidders and Number of Licenses Won

Bidder	Total Gross Winning Bids	Number of Licenses Won
Cellco Partnership	\$45,454,843,197	3,511
AT&T Spectrum Frontiers LLC	\$23,406,860,839	1,621
T-Mobile License LLC	\$9,336,125,147	142
United States Cellular Corporation	\$1,282,641,542	254
NewLevel II, L.P.	\$1,277,395,688	10
Canopy Spectrum	\$172,021,760	84

NewLevel II, L.P. had the 5th highest total gross winning bids, and Canopy Spectrum had the 5th highest number of licenses won. Cellco Partnership, AT&T, T-Mobile, and U.S. Cellular ranked first through fourth, respectively, in both total gross winning bids and the number of licenses won.

4. Auction 107 (C-band): Investigation Into Group A vs. Group BC Pricing

The accelerated relocation timeline requires that 46 of the first fifty PEAs be cleared by December 8, 2021. For these 46 PEAs, the clock round partitions the spectrum into two groups (A and BC). FSS operators must clear group A by December 8, 2021 and group BC by December 5, 2023. To investigate differences in selling price (i.e. highest bidding price) between group A and group BC, Figure 5 shows the percent difference of selling prices between these two groups for these 46 PEAs, where positive values signify group A prices as greater than group BC prices.

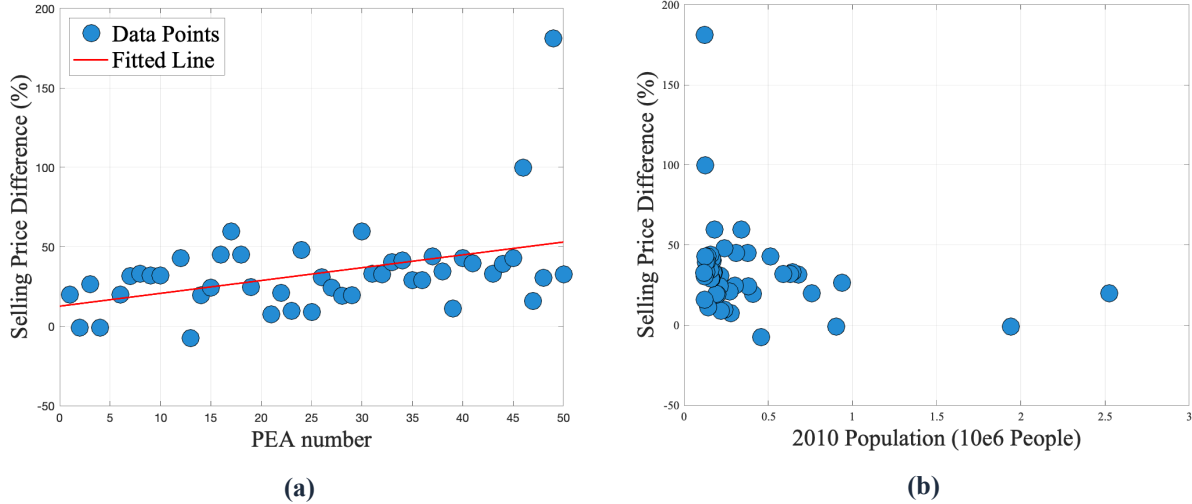


Figure 5(a,b): Price Difference Between the group A Selling Price and group BC Selling Price (%) As A Function of (a) PEA Number and (b) Population

The mean selling price between group A and group BC was 31.6% across the 46 PEAs. Between each PEA in ascending order, the percent difference between licenses in group A and BC increased on average by 0.8% per PEA count, as shown by the fitted line in Figure 5(a). The highest percent difference was 181.31%, with group A having a higher price than group BC in for PEA49 (Albany, NY). The lowest percent difference was -7.63%, with group BC having a higher closing price than group A in PEA11 (Atlanta, GA). The most common difference, or the mode of this data, was 28.61%. Figure 5(b) shows that as the population in each PEA increases, the price difference between licenses in group A and group BC decreases. PEA49 (Albany, NY) held the highest percent difference at 181.31% and has 1,222,542 people. PEA46 (Little Rock, AR) had the second-highest percent difference at 99.86%, with 1,275,690 people. In conclusion, bidders were willing to pay about 30% more for early access to Phase I spectrum that would be available two years in advance.

5. Comparison of Auction 107 with Auctions 1000 (600 MHz Band), 101 (28 GHz Band), 102 (24 GHz Band), 103 (Upper 37, 39, and 49 GHz Bands), and 105 (3.5 GHz Band)

Auction 107 was compared with Auctions 1000 (600 MHz Band), 101 (28 GHz Band), 102 (24 GHz Band), 103 (Upper 37, 39, and 49 GHz Bands), and 105 (3.5 GHz Band). Comparison of the opening and closing bids with relevant means, medians, interquartile ranges (IQR), outliers, and trend analysis. These statistics were split into two groups for each auction: one—the first fifty and two—the remaining PEAs for all the auctions due to a large difference between the minimum opening bids between these groups. Table 2 and Table 3 summarize bid price statistics for the first fifty PEAs and remaining PEAs, respectively. These statistics may differ from statistics shown in the comparison sections below due to these statistics encompassing all PEAs instead of only overlapping PEAs.

[Insert timeline of all of the auctions here]

Table 2. Summary of Normalized (\$/MHz) Bid Price Statistics For First Fifty PEAs

	Auction 107 (C-band)	Auction 1000 (600 MHz Band)	Auction 101 (28 GHz Band)	Auction 102 (24 GHz Band)	Auction 103 (Upper 37, 39, and 49 GHz Bands)	Auction 105 (3.5 GHz Band)

					39, and 49 GHz Bands)	Band) [In Progress]
Median	1,378,000	9,000,000	258,000	439,000	439,000	
Mean	2,399,875	18,529,592	455,326	789,102	789,102	
IQR	1,856,750	18,500,000	564,250	596,000	596,000	
1st Quartile	967,250	5,500,000	101,500	317,000	317,000	
3rd Quartile	2,824,000	24,000,000	665,750	913,000	913,000	
# of Outliers	3	2	1	3	3	

Table 3. Summary of Normalized (\$/MHz) Bid Price Statistics For PEAs Past the First Fifty

	Auction 107 (C-band)	Auction 1000 (600 MHz Band)	Auction 101 (28 GHz Band)	Auction 102 (24 GHz Band)	Auction 103 (Upper 37, 39, and 49 GHz Bands)	Auction 105 (3.5 GHz Band) [In Progress]
Median	15,000	412,500	14,810	4,900	4,900	
Mean	26,076	722,090	25,715	8,692	8,744	
IQR	18,900	825,000	20,975	6,425	6,375	
1st Quartile	7,100	125,000	6,535	2,200	2,300	
3rd Quartile	26,000	950,000	27,510	8,625	8,675	
# of Outliers	50	25	24	51	51	

5.1 Auction 1000 (600 MHz Band): Background

To increase the availability of spectrum, Congress passed the Middle Class Tax Relief and Job Creation Act of 2012, which, among other things, commissioned the FCC to repurpose spectrum that was initially licensed to television broadcasters [6]. In 2016, the FCC responded with Auction 1000 (600 MHz Band), the first-ever incentive auction in the 600 MHz band [7]. Auction 1000 involved three components: one—Auction 1001 (reverse auction), two—repacking of the spectrum to free a portion of the Ultra-High Frequency (UHF) band, and three—Auction 1002 (forward auction). In Auction 1001 (reverse auction), television broadcasters voluntarily handed over their licenses while in Auction 1002 (forward auction), flexible-use licenses in the 600 MHz band were made available for mobile broadband services. Ultimately, the FCC integrated these two auctions, by setting prices interdependent on what incumbents were willing to hand over licenses for in Auction 1001 (reverse auction) and what bidders were willing to bid for in Auction 1002 (forward auction). In total, Auction 1000 repurposed 84 MHz of spectrum, with 70 MHz of this 84 MHz licensed through this auction in 5 MHz paired blocks (10 MHz total) [8].

5.2 Auction 107 (C-Band) and Auction 1000 (600 MHz Band): Minimum Opening Bid Comparison

Figure 6 compares the minimum opening bids (MOBs) set by the FCC for Auction 107 (C-band) and Auction 1000 (600 MHz Band). The MOBs have been normalized to dollars per MHz, as the MOBs for Auction 107 (C-Band) are for a 20 MHz block while the MOBs for Auction 1000 (600 MHz Band) are for 5 MHz paired blocks. The

populations that the MOBs were based on are the same for both auctions. In addition, any PEAs that the FCC did not offer in both Auction 1000 (600 MHz Band) and Auction 107 (C-Band) are not included in these graphs. The y-axes of these two graphs are in a logarithmic scale and cover different magnitudes.

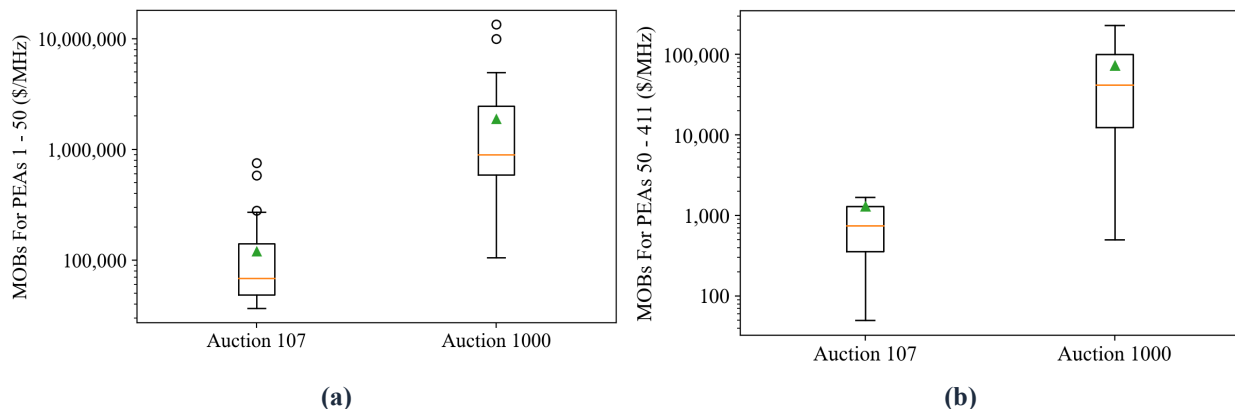


Figure 6(a,b): Box plots of the MOBs in \$/MHz for Auction 1000 (600 MHz Band) and Auction 107 (C-Band) for (a) PEA1 - PEA50 and (b) PEA51 - PEA411

Figure 6(a) shows the MOBs for the first fifty PEAs. The middle 50% of the opening bids for Auction 1000 (600 MHz Band) were higher than the middle 50% opening bids for Auction 107 (C-Band) with the third quartile of Auction 107 (C-Band) MOBs ending at \$141,200/MHz and the first quartile of Auction 1000 (600 MHz Band) MOBs starting at \$587,500/MHz. Additionally, there was a greater spread in the MOBs in Auction 1000 (600 MHz Band) with an interquartile range (IQR) of \$1,887,500/MHz over Auction 107 (C-Band) IQR of \$92,837/MHz. The mean MOB (green triangle) was \$119,993/MHz in Auction 107 (C-Band) and \$1,886,354/MHz in Auction 1000 (600 MHz Band). The median MOB (orange horizontal line) was \$68,900/MHz in Auction 107 (C-Band) and \$900,000/MHz in Auction 1000 (600 MHz Band). A skewed-right distribution is defined as data points clustering towards the left, or at lower values. Since the median MOBs were significantly lower than the mean MOBs, the MOB distributions for these two auctions are skewed to the right. In summary, MOBs for Auction 1000 (600 MHz Band) were, on average, 15.7 times greater than the MOBs for Auction 107 (C-Band) and both distributions are skewed to the right. [\[Add sentence explaining why this occurred\]](#)

Outliers are defined as existing a distance 1.5 times the IQR outside of the upper and lower quartiles. The MOBs for PEA1 (New York, NY) and PEA2 (Los Angeles, CA) were outliers in the set of MOBs for the first fifty PEAs for both Auction 107 (C-Band) and Auction 1000 (600 MHz Band). PEA1 (New York, NY) had a MOB of \$15.14M in Auction 107 (C-Band) and \$135M in Auction 1000 (600 MHz Band). PEA2 (Los Angeles, CA) had a MOB of \$11.65M in Auction 107 (C-Band) and \$100M in Auction 1000 (600 MHz Band). PEA3 (Chicago, IL) was an additional outlier in Auction 107 (C-Band) with a MOB of \$49.5M, but was not an outlier in Auction 1000 (600 MHz).

Figure 6(b) shows the MOBs for the remaining 360 PEAs (PEA51- PEA411); 49 outliers in Auction 107 and 22 outliers in Auction 1000 were omitted from the graph for clarity. The MOBs for the remaining PEAs follow a similar trend as the first fifty where the data is skewed to the right and the spread of Auction 1000 (600 MHz Band) MOBs are on average 15.2 times greater than Auction 107 (C-Band). For the remaining 360 PEAs, the mean MOB (green triangle) was \$1,303/MHz for Auction 107 (C-Band) and \$72,774/MHz for Auction 1000 (600 MHz Band). The mean MOBs were 9,109% higher in Auction 107 (C-Band) and 2,492% higher in Auction 1000 (600 MHz Band) for the first fifty PEAs. The median MOB (orange horizontal line) was \$750/MHz for Auction 107 (C-Band) and \$42,000/MHz for Auction 1000 (600 MHz Band). The median MOBs were 9,087% higher in Auction 107 (C-Band) and 2,042% higher in Auction 1000 (600 MHz Band) for the first fifty PEAs. The IQR of MOBs was

\$945/MHz for Auction 107 (C-Band) and \$87,500/MHz for Auction 1000 (600 MHz Band). The median and mean were significantly higher for the first fifty PEAs than the remaining 360 PEAs. In addition, there was a greater increase between the first fifty and last 360 PEAs in Auction 107 (C-Band) than in Auction 101 (28 GHz Band). [Add sentence explaining why this occurred] The remaining 360 PEAs also had a skewed-right distribution as the medians were lower than the means same as the first fifty.

There are several differences between Auction 1000 (600 MHz Band) and Auction 107 (C-Band), which may contribute to the higher MOB in Auction 1000 (600 MHz Band). [Add sentence explaining what these differences were] In conclusion, the FCC had lower bid expectations for Auction 107 relative to Auction 1000.

5.3 Auction 107 (C-Band) and Auction 1000 (600 MHz Band): Closing Bid Comparison [In Progress]

5.4 Auction 101 (28 GHz Band): Background

The FCC initially auctioned Local Multipoint Distribution Service (LMDS) spectrum for considerable amounts in the 1990s. Investors believed they could use LMDS spectrum for wireless cable, but those efforts failed. LMDS spectrum largely lay fallow until, nearly twenty years later, the potential demand for 5G and the FCC’s Spectrum Frontiers proceeding liberalized use for mobile applications. Despite the use of FSS operations in portions of the LMDS bands [insert portions here], the FCC put forth concrete proposals reiterating LMDS (mobile operations) on a primary basis in the LMDS Report and Order [9].

In 1997, the FCC created a band plan that opened 1,300 MHz of LMDS spectrum in the U.S and divided the U.S. into 493 basic trading areas (BTAs). In each BTA, the FCC divided the available spectrum into two blocks: A Block (1,150 MHz wide) and B Block (150 MHz wide). Figure 7 shows the division of the LMDS spectrum into sub-bands.

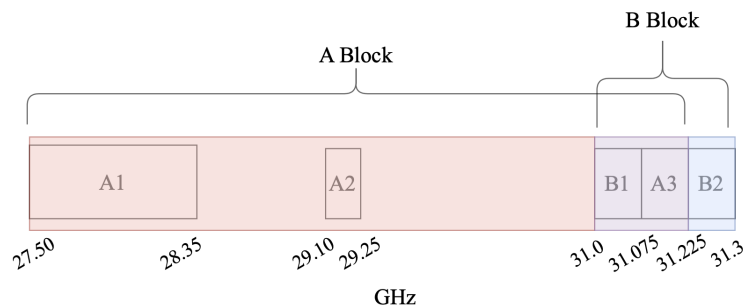


Figure 7: Division of the LMDS Spectrum Made Available in 1997

The A Block contains the A1 (27.50 - 28.35 GHz), A2 (29.10 - 29.25 GHz) and A3 (31.075 - 31.225 GHz) sub-bands. Additionally, the B Block contains the B1 (31.000 - 31.075 GHz) and B2 (31.225 - 31.300 GHz) sub-bands. Note that the end of the A Block (A3) overlaps with the beginning of the B Block (B1). In each BTA, the FCC made two LMDS licenses available, the A Block and B Block, creating 986 designated license areas [9].

In Auction 101 (28 GHz Band) which began November 14, 2018 and ended January 24, 2019, the FCC offered 3,072 Upper Microwave Flexible Use Service (UMFUS) licenses in the A1 (27.5 - 28.35 GHz) sub-band, or the 28 GHz band, a part of the collective UMFUS bands (28 GHz and 24 GHz bands). The FCC split the 28 GHz band into two 425 MHz blocks for licensing: Block 1 (27.5-27.925 GHz) and Block 2 (27.925-28.35 GHz) [10]. The FCC sold these licenses on a county basis defined by the 1990 boundaries to align with incumbent 28 GHz licenses [11]. Auction 101 (28 GHz Band) had \$702,572,410 in gross bids and 2,965 of 3,072 available licenses were sold [12].

5.5 Auction 107 (C-Band) and Auction 101 (28 GHz Band): Minimum Opening Bid Comparison

Figure 8 compares the MOB of Auction 107 (C-Band) and Auction 101 (28 GHz Band) in dollars per MHz. Since the FCC sold licenses in Auction 101 (28 GHz Band) on a county basis, several steps were taken to allow comparison between them and the PEA-based licenses in Auction 107 (C-Band). First, the licenses in Auction 101 (28 GHz Band) were grouped by their respective PEA, and the MOB and populations summed to gain an estimate of the related population and MOB relative to a PEA rather than counties. Since the MOB for licenses in Block 1 and Block 2 were the same, only licenses in Block 1 were used to avoid double counting. In addition, since not all counties in each PEA were included in Auction 101 (28 GHz Band), the population was used to estimate the fraction of the PEA the counties covered. This fraction was then used to adjust the Auction 101 (28 GHz Band) MOB to make them comparable to the licenses from Auction 107 (C-Band). Only overlapping PEAs between the two auctions were included in this analysis. Lastly, since the MOB were related to a 425 MHz block size in Auction 101 (28 GHz Band) and a 20 MHz block size in Auction 107 (C-Band), the MOB were normalized to dollars per MHz. Note that the y-scales are logarithmic and cover different ranges of values.

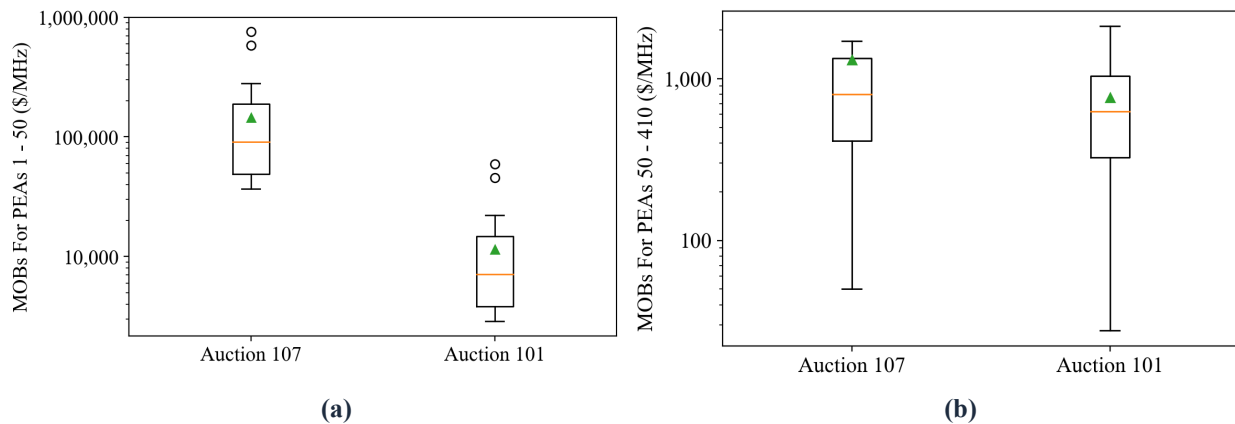


Figure 8(a,b): Box plots of the MOB in \$/MHz for Auction 101 (28 GHz Band) and Auction 107 (C-Band) for (a) PEA1 - PEA50 and (b) PEA51 - PEA 410

Figure 8(a) shows the distribution of MOB for the first fifty PEAs. The mean MOB (green triangle) for the first fifty PEAs was \$145,377/MHz for Auction 107 (C-Band) and \$11,402.50/MHz for Auction 101 (28 GHz Band). The median MOB (orange horizontal line) was \$90,700/MHz for Auction 107 (C-Band) and \$7,112.10/MHz for Auction 101 (28 GHz Band). Both means were higher than the medians, indicating a skewed-right distribution. On average, the MOB in Auction 107 (C-Band) were 1,175% greater than MOB in Auction 101 (28 GHz Band). The IQR for the first fifty PEAs was \$140,100/MHz for Auction 107 (C-Band), and \$10,987.62/MHz for Auction 101 (28 GHz Band). The MOB distribution indicates that while, due to the logarithmic scale, the middle 50% of the Auction 107 (C-Band) opening bids look similar in size to the middle 50% of the Auction 101 (28 GHz Band) opening bids, there is a 1,175% increase in IQR with Auction 107's IQR being greater. Both the center and the spread of Auction 107 (C-Band) are significantly greater than the center and spread of Auction 101 (28 GHz Band). The two common outliers between the two auctions shown in Figure 8(a) are PEA1 (New York, NY) and PEA2 (Los Angeles, CA).

Figure 8(b) shows the distribution of opening bids for the remaining PEAs from PEA51 to PEA410. The centers and spreads for the MOB of these PEAs were more similar than the centers and spreads of the MOB for the first fifty PEAs. The mean MOB (green triangle) were \$1,308/MHz in Auction 107 (C-Band) and \$760/MHz in Auction 101 (28 GHz Band). The median MOB (orange horizontal line) were \$800/MHz for Auction 107 (C-Band) and \$628.68/MHz for Auction 101 (28 GHz Band). The mean and median MOB for Auction 101 (28 GHz Band) were closer together with a distance of \$132.32/MHz as opposed to a distance of \$508/MHz for Auction 107 (C-Band). The first quartiles began on \$413.75/MHz \$325.34/MHz while the third quartiles ended on \$1,337.5/MHz and

\$1,041.38/MHz for Auction 107 (C-Band) and Auction 101 (28 GHz Band), respectively. In conclusion, the MOBs for Auction 107 (C-Band) were generally higher for the first fifty PEAs than Auction 101 (28 GHz Band). However, this difference is smaller and the MOBs are comparable for PEA51 through PEA410 over both auctions.

In summary, the FCC set MOBs for Auction 107 were higher in comparison to Auction 101. Potentially, this increase can be attributed to either an increased value of 5G spectrum from 2018 to 2021 or adjustments made by the FCC based on the results from previous auction results. [\[Add more to this paragraph dependent on new research\]](#)

5.6 Auction 107 (C-Band) and Auction 101 (28 GHz Band): Closing Bid Comparison [In Progress]

5.7 Auction 102 (24 GHz Band): Background

The FCC auctioned the A1 sub-block or 28 GHz band in the LMDS spectrum was auctioned during Auction 101 (28 GHz Band) for mobile applications. Auction 102 (24 GHz Band) was proposed at the same time as Auction 101 (28 GHz Band) and was scheduled to occur after it. In Auction 102 (24 GHz Band), the FCC auctioned 2,912 UMFUS licenses in the 24 GHz band (24.25-25.25 GHz). Auction 102 (24 GHz Band) began March 14, 2019 and ended May 28, 2019 following Auction 101 (28 GHz Band) and occurred for the same reason: to increase spectrum availability for 5G, Internet of Things (IoT), and other spectrum-based services into millimeter wave frequencies [10].

Licenses were auctioned based on PEAs in seven 100 MHz blocks: Block 1 (24.25-24.35 GHz), Block 2 (24.35-24.45 GHz), Block 3 (24.75-24.85 GHz), Block 4 (24.85-24.95 GHz), Block 5 (24.95-25.05 GHz), Block 6 (25.05-25.15 GHz), and Block 7 (25.15-25.25 GHz) [10]. Auction 102 (24 GHz) had \$2,024,268,941 in gross bids and 2,904 of 2,909 available licenses were sold. Together, Auction 101 and 102 sold 5,869 licenses with \$2.7 billion dollars in gross bids [12].

5.8 Auction 107 (C-Band) and Auction 102 (24 GHz Band): Minimum Opening Bid Comparison

Figure 9 compares the MOBs of Auction 107 (C-band) and Auction 102 (24 GHz Band). These MOBs have been normalized to dollars per MHz as the MOBs are related to a 100 MHz block size in Auction 102 (24 GHz Band) and a 20 MHz block size in Auction 107 (C-Band). The populations used at each PEA were the same across both auctions and only PEAs that the FCC offered in both auctions are included in the data analysis and plots below. Note that the y-axes of these two graphs are in a logarithmic scale and span different ranges.

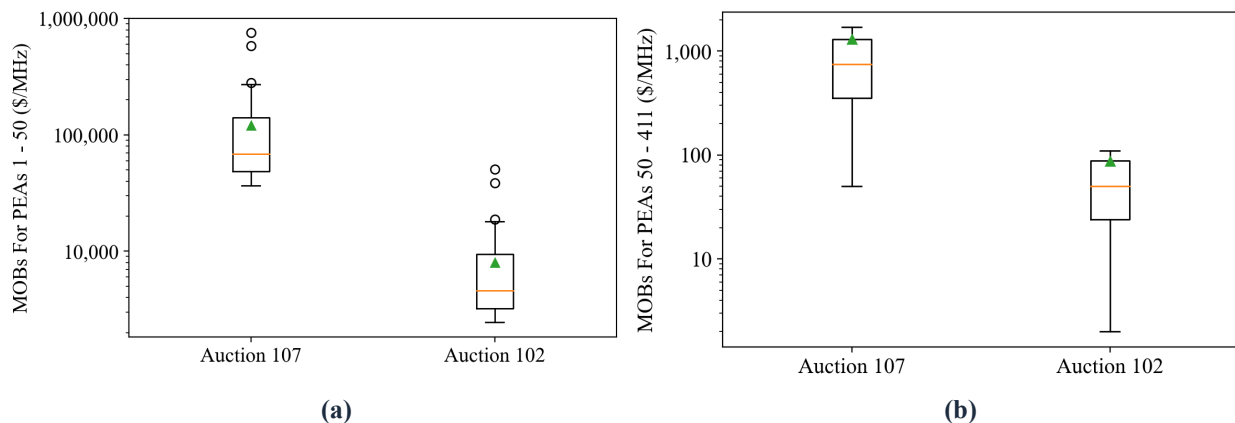


Figure 9(a,b): Box plots of the MOBs in \$/MHz for Auction 102 (24 GHz Band) and Auction 107 (C-Band) for (a) PEA1 - PEA50 and (b) PEA51 - PEA 411

Figure 9(a) shows the MOBs for the first fifty PEAs. The lower whisker of Auction 107 (C-Band) begins at \$36,700/MHz where the upper whisker of Auction 102 (24 GHz Band) ends at \$18,060/MHz. Since there aren't any lower outliers, all MOBs in Auction 107 (C-Band) are above the vast majority of the MOBs in Auction 102 (24 GHz

Band). The mean MOB (green triangle) was \$119,993.75/MHz for Auction 107 (C-Band) and \$7,998.75/MHz for Auction 102 (24 GHz Band). The mean values are significantly higher than the median values in both auctions, meaning that both MOBs are skewed to the right. The three outliers (black circles) in Auction 107 (C-Band) and Auction 102 (24 GHz Band) were PEA1 (New York, NY), PEA2 (Los Angeles, CA), and PEA3 (Chicago, IL). The two auctions may misleadingly seem to have a similar distribution due to the logarithmic scale. However, the IQR of Auction 107 (C-Band) was \$92,837.50/MHz, while the IQR of Auction 102 (24 GHz Band) was \$6,192.50/MHz. The spread of Auction 107 (C-Band) was about fifteen times the spread of Auction 102 (24 GHz Band).

Figure 9(b) shows the MOBs for the remaining PEAs. Outliers are not included in this plot as there were 49 outliers in Auction 107 (C-Band) while there were fifty outliers in Auction 102 (24 GHz Band). The middle 50% of MOBs in Auction 107 (C-Band) were above the middle 50% of MOBs in Auction 102 (24 GHz Band). Similar to Figure 9(a), the distribution looks the same, but it is important to note that this is only due to the logarithmic scale. The IQR of Auction 107 (C-Band) was \$945/MHz, while the IQR of Auction 102 (24 GHz Band) is \$64/MHz. The means (green triangles) for these two auctions were significantly closer to the edge of the third quartile than the median. The mean opening bid values (green triangles) were \$1,303.81/MHz and \$86.89/MHz for Auction 107 (C-Band) and Auction 102 (24 GHz Band), respectively. The third quartile ended at \$1,300/MHz and \$88/MHz for Auction 107 (C-Band) and Auction 102 (24 GHz Band), respectively. The mean for Auction 107 (C-Band) was just shy of four dollars outside the third quartile. The median opening bid values (orange horizontal line) were \$750/MHz for Auction 107 (C-Band) and \$50.50/MHz for Auction 102 (24 GHz Band). [Add more conclusion and transition]

Figure 10 shows the difference in MOBs between Auction 107 (C-Band) and Auction 102 (24 GHz Band). These differences in opening bid price were calculated using the normalized dollars per MHz and are only for PEAs that are shared between the two auctions.

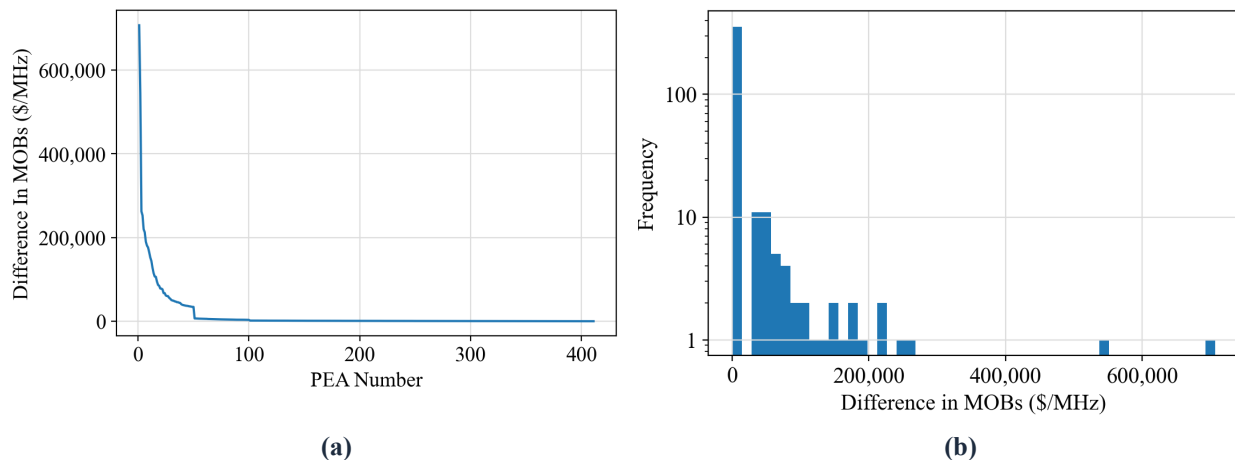


Figure 10(a,b): (a) Difference In MOBs (\$/MHz) between Auction 102 (24 GHz Band) and Auction 107 (C-Band) and (b) Distribution of This Difference

Figure 10(a) shows the differences in MOBs for each PEA in dollars per MHz. There is a sudden drop in the MOB difference at PEA51. This drop appears where the difference in opening bid price for PEA50 (Greenville, SC) is \$34,210/MHz and \$6,670/MHz for PEA51 (Louisville, KY). Past this drop, the difference in opening bid prices seems to be relatively low compared with the first fifty PEAs with an average decrease of \$11.32/MHz with each increase in PEA. Figure 10(b) shows the distribution of the differences in MOBs in dollars per MHz on a logarithmic y-scale. Most differences lie between \$4.70/MHz and \$14,178.66/MHz, or the lowest histogram bin. This range accounts mainly for PEAs past PEA50. This distribution is skewed right, meaning that the tail of the

distribution extends significantly to the right. The MOB in Auction 102 relative to 107 hold a higher value predominantly in the first fifty PEAs. This results supports our finding in Section 4 that the early release of spectrum significantly increased its value, which is supported by this finding.

5.9 Auction 101 (28 GHz Band) and Auction 102 (24 GHz Band): Minimum Opening Bid Comparison

Since both Auction 101 (28 GHz Band) and Auction 102 (24 GHz Band) were proposed in the same report and order and run one after the other, Figure 11 compares the opening bids for all PEAs between Auction 101 and 102. For clarity, outliers have been omitted in this graph.

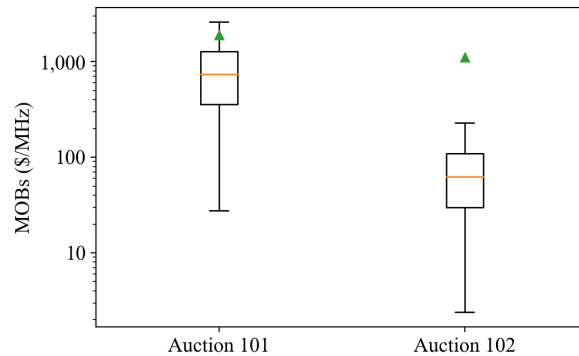


Figure 11(a,b): Box Plot of the MOB (\$/MHz) for Auction 101 (28 GHz Band) and Auction 102 (24 GHz Band)

The IQR was \$926.40/MHz for Auction 101 (28 GHz Band) and \$80/MHz for Auction 102 (24 GHz Band). The middle 50% began at \$355.55/MHz and ended at \$1,281.95/MHz for Auction 101 (28 GHz Band). The middle 50% started at \$30/MHz and ended at \$110/MHz for Auction 102 (24 GHz Band). The middle 50% of MOBs in Auction 101 (28 GHz Band) was significantly higher than the middle 50% of MOBs in Auction 102 (24 GHz Band). The mean MOB (green triangle) for Auction 101 (28 GHz Band) was \$1886.41/MHz and \$1104.84/MHz for Auction 102 (24 GHz Band). The means were closer in value than the medians. The median MOBs in Auction 101 (28 GHz Band) was \$737.68/MHz, while the median MOB in Auction 102 (24 GHz Band) was \$62.50/MHz. Surprisingly, the opening bids for these two auctions were not more similar considering they were proposed at the same time and occurred one after the other. However, the mean values are within \$800/MHz of each other.

Figure 12 shows the difference in MOBs between Auction 101 (28 GHz Band) and Auction 102 (24 GHz Band). These differences in opening bid price were calculated using the normalized dollars per MHz and are only for PEAs that are shared between the two auctions.

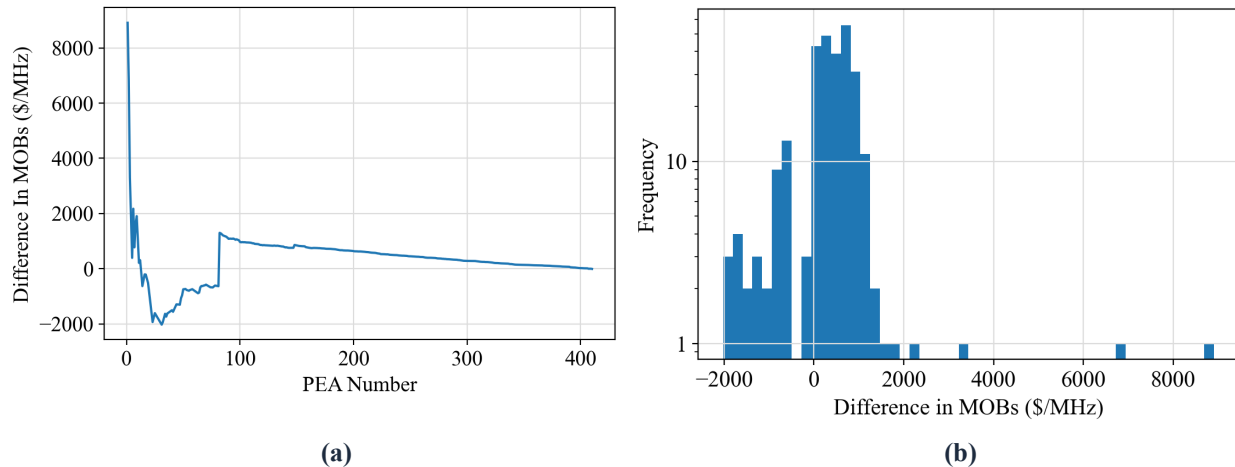


Figure 12(a,b): (a) Difference In Opening Bid Price (\$/MHz) for Auction 101 (28 GHz Band) and Auction 102 (24 GHz Band) and (b) Distribution of This Difference

Figure 12(a) shows the difference in MOBs where positive values indicate Auction 101 (28 GHz Band) being greater than Auction 102 (24 GHz Band) between Auction 101 (28 GHz Band) and Auction 102 (24 GHz Band) against the PEA number. Auction 101 (28 GHz Band) is greater for the majority of the PEAs. However, at PEAs between and including PEA13 (Orlando, FL) and PEA 81 (Saginaw, MI) Auction 102 (24 GHz Band) has higher MOB than Auction 101 (28 GHz Band) with the maximum difference occurring at PEA31 (Indianapolis, IN) with a difference of \$2027.62/MHz. Past PEA81, the differences in MOB follow a more linear pattern with the MOB for the two auctions coming closer in value by \$1/MHz with each increase in PEA.

Figure 12(b) shows the distribution of differences in MOB between Auction 101 (28 GHz Band) and Auction 102 (24 GHz Band). The vast majority of MOB between the two auctions lie within \$2000/MHz of each other. In summary, Auction 101 (28 GHz Band) generally had higher MOB than Auction 102 (24 GHz Band), but the inclusive range of PEAs 13 through 81 was where Auction 102 was greater by, at maximum, \$2,027.62/MHz.

5.10 Closing Bid Comparison of Auction 107 (C-Band) and Auction 102 (24 GHz Band) [\[In Progress\]](#)

5.11 Auction 103 (Upper 37, 39, and 47 GHz Bands): Background

The FCC used UMFUS rules to increase the availability of spectrum for mobile applications in Auction 101 (28 GHz Band) and Auction 102 (24 GHz band). The Spectrum Frontiers Fourth Report and Order, also mentioned opening up the Upper 37 GHz Band (37.6-38.6 GHz), 39 GHz Band (38.6-40.0 GHz), and the 47 GHz Band (47.2-48.2 GHz) for mobile applications as well. An auction in these bands would encompass 2,400 MHz of contiguous spectrum across the Upper 37 and 39 GHz Bands and an additional 1000 MHz of spectrum in the 47 GHz Band. Thus, an incentive auction, Auction 103 (Upper 37, 39, and 47 GHz Bands), was created where incumbent operators in the 39 GHz Band were given a choice to accept a modified license or receive an incentive payment in exchange for cancellation of their license. This auction began December 10, 2019 and ended on March 12, 2020 following Auction 102 (24 GHz Band) [13].

Auction 103 (Upper 37, 39, and 47 GHz Bands) offered the largest amount of spectrum in any auction [14]. There were 14,144 licenses available across the three bands with 4,160 licenses available in the Upper 37 GHz Band, 5,824 licenses available in the 38 GHz Band, and 4,160 licenses available in the 47 GHz band. In the Upper 37 GHz band, the FCC auctioned licenses in 100 MHz Blocks designated M1 through M10. In the 39 GHz band, the FCC auctioned licenses in 100 MHz Blocks designated N1 through N14. In the 47 GHz Band, the FCC auctioned licenses in 100 MHz Blocks designated P1 - P10. [15] This auction had \$7,558,703,201 in net bids with 14,142 of

14,144 licenses sold. The existing payments to incumbents of the 39 GHz Band totaled \$3,084,172,898, leaving net proceeds from the auction to \$4,474,530,303.

5.12 Auction 107 (C-Band) and Auction 103 (Upper 37, 39, and 47 GHz Bands): Minimum Opening Bid Comparison

Figure 13 shows the comparison between the opening bids of Auction 107 (C-Band) and Auction 103 (Upper 37, 39, and 47 GHz Bands) normalized to dollars per MHz as the block size for Auction 103 (Upper 37, 39, and 47 GHz Bands) was 100 MHz and the block size for Auction 107 (C-Band) was 20 MHz. Only PEAs that overlapped between Auction 107 (C-Band) and Auction 103 (Upper 37, 39, and 47 GHz Bands) are included. The y-scale is a logarithmic axis in both graphs.

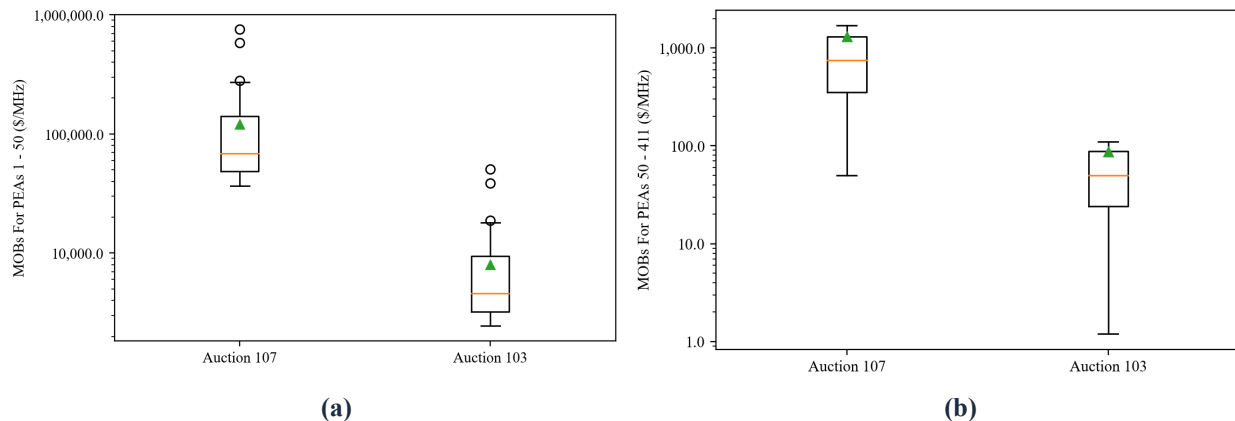


Figure 13(a,b): Box plots of the Opening Bid Price in \$/MHz for Auction 103 (24 GHz Band) and Auction 107 (C-Band) for (a) PEA1 - PEA50 and (b) PEA51 - PEA 411

Figure 13(a) shows the distribution of MOB for Auction 107 (C-Band) and Auction 103 (Upper 37, 39, and 47 GHz Bands) for the first fifty PEAs. The mean MOB were \$119,993.75/MHz for Auction 107 (C-Band) and \$7,998.75/MHz for Auction 103 (Upper 37, 39, and 47 GHz Bands). The median MOB were \$68,900/MHz for Auction 107 (C-Band) and \$4,590/MHz for Auction 103 (Upper 37, 39, and 47 GHz Bands). Both the median and mean were higher in Auction 107 (C-Band) compared to the median and mean in Auction 103 (Upper 37, 39, and 47 GHz Bands). Although the distribution may look visually similar due to the logarithmic scale, the IQR was \$92,837.50/MHz for Auction 107 (C-Band) and \$6,192.50/MHz for Auction 103 (Upper 37, 39, and 47 GHz Bands). The IQR difference means that the spread of Auction 107 (C-Band) MOB was just shy of fifteen times the spread of Auction 103 (Upper 37, 39, and 47 GHz Bands) MOB. The three outliers are again PEA1 (New York, NY), PEA2 (Los Angeles, CA), and PEA3 (Chicago, IL) for both auctions.

A similar trend where MOB were generally higher in Auction 107 (C-Band) is shown in Figure 13(b) for the remaining PEAs. For clarity, outliers are excluded from this graph. The mean MOB were \$1,303.81/MHz for Auction 107 (C-Band) and \$86.88/MHz for Auction 103 (Upper 37, 39, and 47 GHz Bands). The median opening bids were \$750/MHz for Auction 107 (C-Band) and \$50/MHz for Auction 103 (Upper 37, 39, and 47 GHz Bands). Both the mean and median opening bids were significantly greater for Auction 107 (C-Band). The IQR of Auction 107 (C-Band) was over fifteen times the IQR of Auction 103 (Upper 37, 39, and 47 GHz Bands). The IQRs were \$945/MHz for Auction 107 (C-Band) and \$64/MHz for Auction 103 (Upper 37, 39, and 47 GHz Bands). In summary, the MOB were generally higher for Auction 107 (C-Band) in comparison to Auction 103 (Upper 37, 39, and 47 GHz Bands).

5.13 Auction 107 (C-Band) and Auction 103 (Upper 37, 39, and 47 GHz Bands): Closing Bid Comparison [In Progress]

5.14 Auction 105 (3.5 GHz Band): Background [In Progress]

With the international community making the 3.5 GHz Band available for advanced mobile applications, namely 5G, the FCC proposed and adopted rules to share the 3.5 GHz Band (3550 - 3700 MHz), also known as the CBRS Band, as set in the 3.5 GHz Report and Order released in October of 2018. In 2015, the FCC adopted a three-tiered system in the 3.5 GHz Band (CBRS Band) in order to coordinate federal and non-federal access [16]. Tier 1 (Incumbent Access) includes authorized federal users, FSS earth stations in the 3600 MHz to 3650 MHz range, and grandfathered wireless broadband licenses between 3650 MHz to 3700 MHz for a limited time. Tier 2 (Priority Access) covers new county-based Priority Access Licenses (PALs) based on the 2017 county definitions. Tier 3 (General Authorized Access (GAA)) is licensed-by-rule meaning that radio stations are authorized to operate in the relevant sub-bands without individual licenses following, essentially, a general permit system [17] [18]. Tier 1 (Incumbent Access) offers protection from Tier 2 (PAL) and Tier 3 (GAA) users. Tier 2 (PAL) users must protect and accept interference from Tier 1 (Incumbent Access) users, but are protected from Tier 3 (GAA) users. Tier 3 (GAA) users are required to protect and accept interference from Tier 1 (Incumbent Access) and Tier 2 (PAL) users [18]. Figure 14 shows the band plan for the 3.5 GHz Band (CBRS Band) [18].

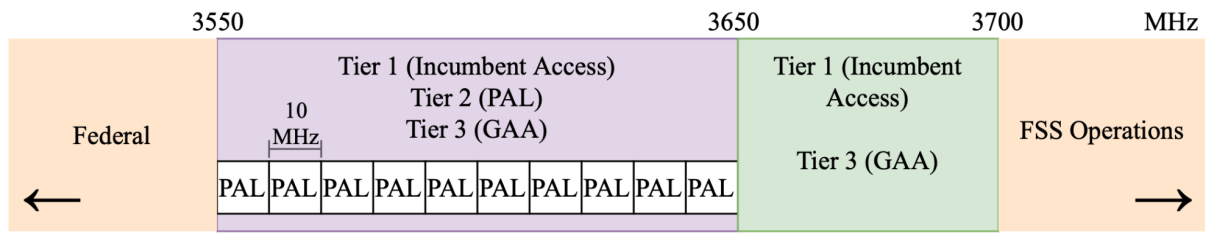


Figure 14: 3.5 GHz Band (CBRS Band) Band Plan

Auction 105 which began July 25, 2020 and ended August 25, 2020 auctioned 2017 county-based PAL licenses between 3.55 and 3.65 GHz. In each county, up to seven 10 MHz unpaired PALs were available, totalling 22,631 PALs. Bidders were only allowed to bid on a maximum of four generic blocks of spectrum per county. Similar to Auction 107 (C-Band), bidding credit caps of \$25 million and \$10 million were adopted for small businesses and rural service providers, respectively [20].

5.15 Auction 107 (C-Band) and Auction 105 (3.5 GHz Band): Minimum Opening Bid Comparison [In Progress]

[Figure 15](#) compares the MOBs for Auction 107 (C-Band) and Auction 105 (CBRS Band). In order to be able to compare the MOBs, the county-based MOBs were converted and summed to the equivalent PEAs. To account for counties that were not included in Auction 105 (CBRS Band), In order to account for The y axis is on a logarithmic scale for clarity.

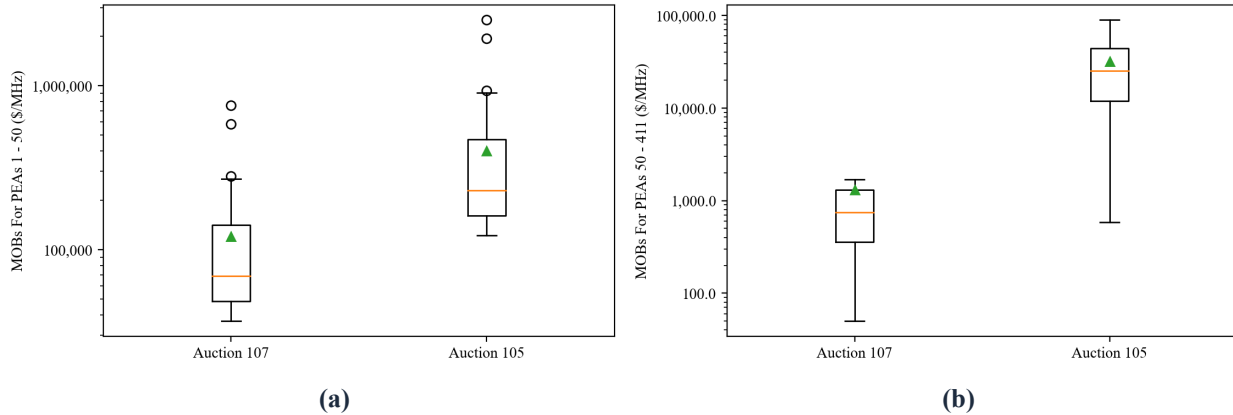


Figure 15(a,b): Box plots of the Opening Bid Price in \$/MHz for Auction 105 (CBRS Band) and Auction 107 (C-Band) for (a) PEA1 - PEA50 and (b) PEA51 - PEA 411

First 50 Numbers:

Auction 107 [{'mean': 119993.75, 'iqr': 92837.5, 'cilo': 47862.09592076244, 'cihi': 89937.90407923756, 'whishi': 270850.0, 'whislo': 36700.0, 'fliers': array([757100., 582300., 281000.]), 'q1': 48362.5, 'med': 68900.0, 'q3': 141200.0}]

Auction 105 [{'mean': 399991.1875, 'iqr': 309401.475, 'cilo': 159554.83773502495, 'cihi': 299781.762264975, 'whishi': 902793.7, 'whislo': 122254.2, 'fliers': array([2523706.1, 1941016.9, 936671.3]), 'q1': 161233.65, 'med': 229668.3, 'q3': 470635.125}]

Remaining PEAs Numbers:

Auction 107 [{'mean': 1303.8095238095239, 'iqr': 945.0, 'cilo': 671.4769151590364, 'cihi': 828.5230848409636, 'whishi': 1700.0, 'whislo': 50.0, 'q1': 355.0, 'med': 750.0, 'q3': 1300.0}]

Auction 105 [{'mean': 31781.027450980393, 'iqr': 32001.2, 'cilo': 22587.61752104482, 'cihi': 27905.78247895518, 'whishi': 89712.1, 'whislo': 587.4, 'q1': 11869.3, 'med': 25246.7, 'q3': 43870.5}]

5.16 Auction 107 (C-Band) and Auction 105 (3.5 GHz Band): Closing Bid Comparison [\[In Progress\]](#)

5.17 Auctions 107 (C-Band), 1000 (600 MHz Band), 101 (28 GHz Band), 102 (24 GHz Band), 103 (Upper 37, 39, and 49 GHz Bands), and 105 (3.5 GHz Band): Opening Bid Comparison [\[In Progress\]](#)

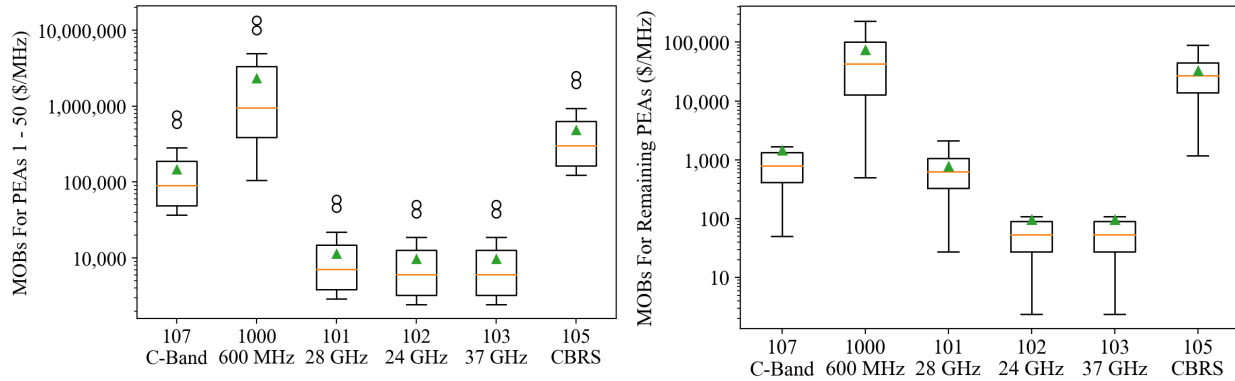


Figure 16(a,b): Box plots of the Opening Bid Price in \$/MHz Auctions 107 (C-Band), 1000 (600 MHz Band), 101 (28 GHz Band), 102 (24 GHz Band), 103 (Upper 37, 39, and 49 GHz Bands), and 105 (3.5 GHz Band) (a) PEA1 - PEA50 and (b) PEA51 - PEA 410

First 50 Numbers:

Auction 107 [{'mean': 145377.58620689655, 'iqr': 140100.0, 'cilo': 49855.0105005902, 'cihi': 131544.9894994098, 'whishi': 281000.0, 'whislo': 36700.0, 'fliers': array([757100., 582300.]), 'q1': 48650.0, 'med': 90700.0, 'q3': 188750.0}]

Auction 1000 [{'mean': 2297758.620689655, 'iqr': 2915000.0, 'cilo': 100156.0000658133, 'cihi': 1799843.9999341867, 'whishi': 4950000.0, 'whislo': 105000.0, 'fliers': array([13500000., 10000000.]), 'q1': 385000.0, 'med': 950000.0, 'q3': 3300000.0}]

Auction 101 [{'mean': 11402.50953346856, 'iqr': 10987.616470588235, 'cilo': 3908.753001133553, 'cihi': 10315.449351807623, 'whishi': 22039.324705882354, 'whislo': 2876.569411764706, 'fliers': array([59381.32, 45670.98588235]), 'q1': 3816.8070588235296, 'med': 7112.101176470588, 'q3': 14804.423529411764}]

Auction 102 [{'mean': 9691.034482758621, 'iqr': 9340.0, 'cilo': 3327.0007000393466, 'cihi': 8772.999299960653, 'whishi': 18730.0, 'whislo': 2450.0, 'fliers': array([50470., 38820.]), 'q1': 3240.0, 'med': 6050.0, 'q3': 12580.0}]

Auction 103 [{'mean': 9691.034482758621, 'iqr': 9340.0, 'cilo': 3327.0007000393466, 'cihi': 8772.999299960653, 'whishi': 18730.0, 'whislo': 2450.0, 'fliers': array([50470., 38820.]), 'q1': 3240.0, 'med': 6050.0, 'q3': 12580.0}]

Auction 105 [{'mean': 484606.6551724138, 'iqr': 466973.7, 'cilo': 166122.00254817598, 'cihi': 438406.597451824, 'whishi': 936671.3, 'whislo': 122254.2, 'fliers': array([2523706.1, 1941016.9]), 'q1': 162214.3, 'med': 302264.3, 'q3': 629188.0}]

Remaining PEAs Numbers:

Auction 107 [{'mean': 1451.336032388664, 'iqr': 932.5, 'cilo': 706.8463199884387, 'cihi': 893.1536800115613, 'whishi': 1700.0, 'whislo': 50.0, 'q1': 417.5, 'med': 800.0, 'q3': 1350.0}]

Auction 1000 [{'mean': 73576.92307692308, 'iqr': 87250.0, 'cilo': 33784.01224556705, 'cihi': 51215.98775443295, 'whishi': 230000.0, 'whislo': 500.0, 'q1': 12750.0, 'med': 42500.0, 'q3': 100000.0}]

Auction 101 [{'mean': 769.133403191236, 'iqr': 725.9564705882351, 'cilo': 561.884044473775, 'cihi': 706.9253672909308, 'whishi': 2110.8729411764707, 'whislo': 27.755294117647058, 'q1': 328.24470588235295, 'med': 634.4047058823529, 'q3': 1054.201176470588}]

Auction 102 [{'mean': 96.74858299595142, 'iqr': 62.0, 'cilo': 47.80640411719378, 'cihi': 60.19359588280622, 'whishi': 110.0, 'whislo': 2.4, 'q1': 27.5, 'med': 54.0, 'q3': 89.5}]

Auction 103 [{'mean': 96.74858299595142, 'iqr': 62.0, 'cilo': 47.80640411719378, 'cihi': 60.19359588280622, 'whishi': 110.0, 'whislo': 2.4, 'q1': 27.5, 'med': 54.0, 'q3': 89.5}]

Auction 105 [{'mean': 32688.169635627528, 'iqr': 30853.15, 'cilo': 23880.07189013544, 'cihi': 30044.32810986456, 'whishi': 89712.1, 'whislo': 1179.6, 'q1': 13950.4, 'med': 26962.2, 'q3': 44803.55}]

5.18 Auctions 107 (C-Band), 1000 (600 MHz Band), 101 (28 GHz Band), 102 (24 GHz Band), 103 (Upper 37, 39, and 49 GHz Bands), and 105 (3.5 GHz Band): Closing Bid Comparison [In Progress]

6. Auction 107 (C-Band): Top Twenty Most Expensive PEAs

Figure 17 below shows the price difference (where Auction 1000 is greater than Auction 107) in the opening bid price between Auction 1000 (600 MHz Band) and Auction 107 (C-Band) for the top twenty most expensive PEAs (tabulated in Appendix 2) in both dollars and percent. As explained earlier, the FCC auctioned 46 of the top fifty PEAs in two groups: A and BC. In Figure 17(a,b), this is reflected by PEAs lower than fifty being in either group A (blue circle) or BC (brown nabla) while the rest of the PEAs are sold in group ABC (orange triangle).

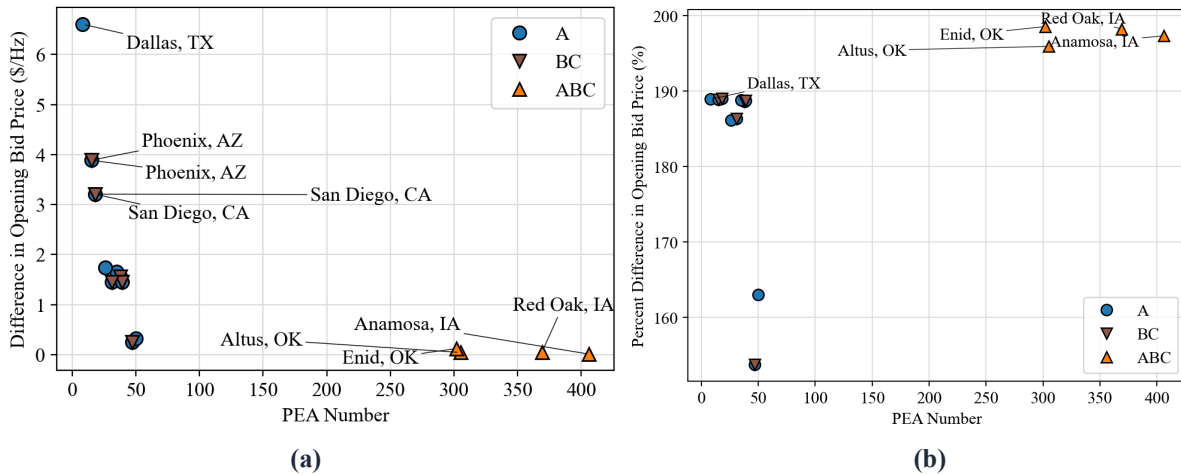


Figure 17(a,b): (a) Difference and (b) Percent difference in the opening bid price between Auction 107 (C-band) and Auction 1000 (600 MHz Band)

In Figure 17(a), it is shown that the majority of twenty most expensive PEAs are lower-numbered (with larger populations) and have a larger \$/Hz difference between the opening bid price of Auction 1000 (600 MHz Band) and Auction 107 (C-Band). PEA8 (Dallas, TX) had the largest difference in opening price between Auction 1000 (600 MHz Band) and Auction 107 (C-Band) with 6.61 \$/Hz. However, there are four larger numbered (with smaller populations) PEAs (orange triangles) that do not follow this observation: PEA302 (Enid, OK), PEA305 (Altus, OK), PEA369 (Red Oak, IA), and PEA406 (Anamosa, IA). PEA406 had the lowest difference in opening price with \$0.0089/Hz, followed by PEA305 with a difference of \$0.042/Hz. PEA369 had a difference in opening bid price of \$0.043/Hz, and PEA302 had a difference of \$0.12/Hz. The mean difference was \$1.71/Hz and the median was \$1.46/Hz.

Figure 17(b) shows the percent difference between the opening bid price of Auction 1000 (600 MHz Band) and Auction 107 (C-Band) for the twenty most expensive PEAs. The four PEAs designated by orange triangles are now

shown to have the largest percent increase in opening bid price. PEA302 (Enid, OK) had the largest percent difference of 198.57%. PEA369 (Red Oak, IA) had a percent difference of 198.23%, PEA305 (Altus, OK) had a percent difference of 195.95%, and PEA406 (Anamosa, IA) had a percent difference of 197.35%. All of these values are above the mean of 185.40% and median of 188.80%. Thus, the four larger numbered PEAs in the twenty most expensive PEAs experienced a significant drop in opening bid price between Auction 1000 (600 MHz Band) and Auction 107 (C-Band).

Figure 18 depicts the price increase by the end of the clock round for the top twenty most expensive PEAs in both dollars and percent.

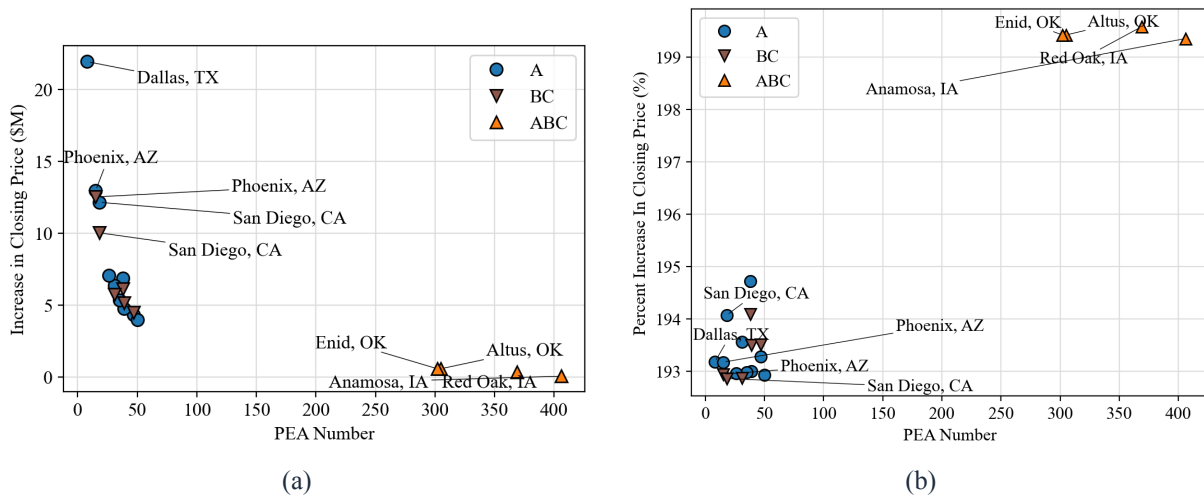


Figure 18(a,b): (a) Increase and (b) Percent difference of the closing clock round price from the opening bid price for the top twenty most expensive PEAs

Figure 18(a) shows the dollar increase by the end of the clock round. PEA8 (Dallas, TX) had the highest dollar increase of \$21.92 M. PEA15 (Phoenix, AZ) followed by a dollar increase of \$12.96M for group A and \$12.52M for the BC group. The mean dollar increase across all twenty PEAs was \$6.58M by the end of the clock round.

However, as shown in Figure 18(a) (and earlier in Figure 17(a)), there are four PEAs designated by orange triangles that do not follow the general trend. PEA406 had the lowest dollar increase of all with \$0.074 M. PEA302 and PEA305 increased by \$0.59M, and PEA369 increased by \$0.37 M.

Although these four PEAs had comparatively lower dollar increases, Figure 18(b) shows they had the highest percent increases compared to lower-numbered PEAs (with higher populations). PEA369 had the highest percent increase with 199.58%, PEA305 and PEA302 both increased by 199.42%, and PEA406 increased by 199.35%. The PEA with the lowest percent increase was PEA18 (San Diego, CA) with 192.86%. The average percent increase across these twenty PEAs was 194.57%.

As these four PEAs experienced the highest percent increase, further analysis of this difference relative to similar PEAs will answer whether this amount of increase could be considered normal. Figure 19 compares the increase in price by the end of the clock round for these last four PEAs with PEAs of a similar population (PEA300 - PEA410).

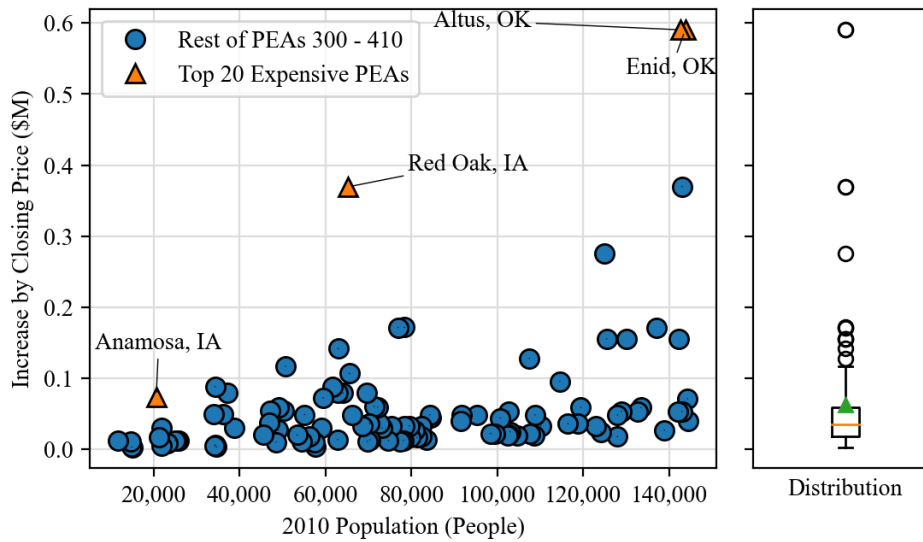


Figure 19: Increase in closing clock round price from the opening bid price for PEAs 300 - 410

The mean increase by closing price (green triangle) is \$0.063M. The median (orange horizontal line) was \$0.035 M. The middle 50% spanned an increase of \$0.018M to an increase of \$0.059 M. As mentioned earlier, PEA406 (Anamosa, IA) had an increase of \$0.074M which is above the middle 50%. PEA302 (Enid, OK), PEA305 (Altus, OK), and PEA369 (Red Oak, IA) were outliers to the entire group of PEAs 300 - 410. Although PEA406 (Anamosa, IA) wasn't an outlier with respect to this entire group, it was an outlier to groups with closer population counts. Further investigation into bidding trends is necessary to understand how these four PEAs increased in price relative to PEAs with similar populations.

Figure 20 below shows the bidding trends for the four outlier PEAs, along with the bidding trends for PEAs of similar numbers (and similar populations).

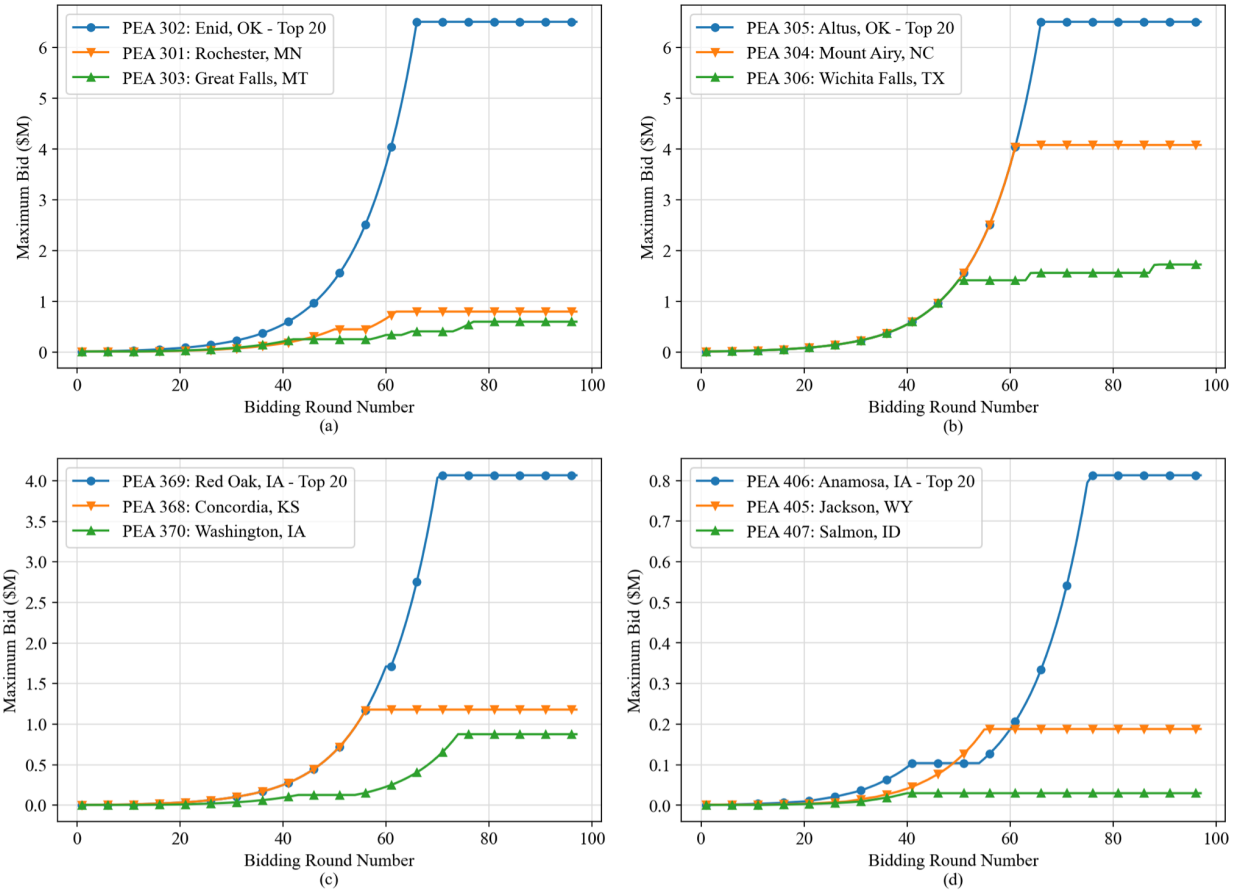


Figure 20(a-d): Maximum bid per round for (a) Enid, OK; (b) Altus, OK; (c) Red Oak, IA; (d) Anamosa, IA; and surrounding PEAs

Figure 20(a) shows that the bidding pattern for PEA302 (Enid, OK) diverged by Round 40 from the bids made for PEA301 (Rochester, MN) and PEA303 (Great Falls, MT). Successive bids for PEA301 and PEA303 increased in smaller increments in comparison to PEA302. In Figure 20(b) the bidding curves for PEA304 (Mount Airy, NC) and PEA306 (Wichita Falls, TX) followed a similar trend as PEA305 (Altus, OK). However, PEA304 leveled off at Round 61, while in PEA305 (Altus, OK) prices continued to increase until Round 65. This bidding pattern means that while bidders were no longer willing to bid higher for PEA304 and PEA306, they were for PEA305. A similar trend appears in Figure 20(c) and Figure 20(d).

Thus, these higher closing prices for the four outlier PEAs were not due to population. Further investigation shows that a cooperatively owned telecom (Pioneer Telephone Cooperative, Inc.) bid pushed the prices above \$2/MHz/pop in PEA305 (Altus, OK) and PEA302 (Enid, OK) [19]. As a result, U.S. Cellular dropped out of the bidding for PEA305 (Altus, OK) and PEA302 (Enid, OK) in Round 59, leaving Pioneer Telephone Cooperative, Cellco Partnership, and AT&T. These three entities continued increasing bids until Round 66 where the price leveled off at \$6.5M. In PEA406 (Anamosa, IA), bidding leveled off in Round 76 at \$0.81M. In Round 54, U.S. Cellular joined Cellco Partnership, AT&T, and LICT Wireless Broadband Company in bidding. All of these entities continued increasing bids until Round 76.

In PEA369 (Red Oak, IA), the most expensive PEA resulting from this auction, Cellco Partnership, U.S. Cellular, AT&T Spectrum, and Grand River Communications all continued bidding until Round 71 where the price leveled off at \$4.1M. Grand River Communications dropped out of the bidding in Round 69 at \$3M, two rounds before

Cellco, U.S. Cellular, and AT&T stopped increasing bidding prices. Table 4 below shows the bid prices leading up to Round 71 for these three entities.

Table 4: Bid Price for PEA369 (Red Oak, IA) in Rounds 69 - 71

	Round 69	Round 70	Round 71
Cellco Partnership	\$3.670M <i>8 Licenses</i>	\$3.697M <i>7 Licenses</i>	\$4.067M <i>7 Licenses</i>
AT&T Spectrum Frontiers LLC	\$3.670M <i>4 Licenses</i>	\$4.037M <i>4 Licenses</i>	\$4.067M <i>4 Licenses</i>
United States Cellular Corporation	\$3.670M <i>3 Licenses</i>	\$4.037M <i>3 Licenses</i>	\$4.067M <i>4 Licenses</i>

Cellco initially created excess demand for these licenses by bidding for eight licenses in Round 69, and then seven licenses in Round 70. Bid prices were the same in Round 69 regardless of license quantity. However, Cellco decreased its license count in Round 70.

7. Acknowledgments [In Progress]

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Appendix 1. First 50 PEA Location and Population

PEA Number	PEA Name	Population 2010
1	New York, NY	25,237,061
2	Los Angeles, CA	19,410,169
3	Chicago, IL	9,366,713
4	San Francisco, CA	9,027,937
5	Baltimore, MD-Washington, DC	7,842,134
6	Philadelphia, PA	7,587,252
7	Boston, MA	6,776,035
8	Dallas, TX	6,452,472
9	Miami, FL	6,291,880
10	Houston, TX	5,891,999
11	Atlanta, GA	5,435,312
12	Detroit, MI	5,137,479
13	Orlando, FL	4,562,642
14	Cleveland, OH	4,096,678
15	Phoenix, AZ	3,817,117
16	Seattle, WA	3,792,218
17	Minneapolis-St. Paul, MN	3,390,091
18	San Diego, CA	3,095,313
19	Portland, OR	3,022,643
20	Denver, CO	2,789,669
21	Tampa, FL	2,783,243
22	Sacramento, CA	2,722,415
23	Pittsburgh, PA	2,399,667
24	Saint Louis, MO	2,396,938
25	Cincinnati, OH	2,196,428
26	Las Vegas, NV	2,151,455

27	Salt Lake City, UT	2,142,152
28	San Antonio, TX	1,999,689
29	Jacksonville, FL	1,918,264
30	Kansas City, MO	1,810,075
31	Indianapolis, IN	1,769,011
32	Nashville, TN	1,748,445
33	Virginia Beach, VA	1,698,835
34	Fresno, CA	1,676,476
35	Austin, TX	1,628,809
36	New Orleans, LA	1,622,143
37	Columbus, OH	1,582,917
38	Milwaukee, WI	1,555,908
39	Oklahoma City, OK	1,446,527
40	Birmingham, AL	1,399,686
41	Syracuse, NY	1,371,959
42	Honolulu, HI	1,360,301
43	Charlotte, NC	1,327,006
44	Rochester, NY	1,316,146
45	Raleigh, NC	1,302,381
46	Little Rock, AR	1,275,690
47	Brownsville, TX	1,264,091
48	Harrisburg, PA	1,244,058
49	Albany, NY	1,222,542
50	Greenville, SC	1,220,968

Appendix 2. Top Twenty Most Expensive PEAs

PEA Number	Market Name	Category Sold In Auction 107	Price (MHz-Pop)
369	Red Oak, IA	ABC	\$2.834888
38	Milwaukee, WI	A	\$2.24513
305	Altus, OK	ABC	\$2.072642
302	Enid, OK	ABC	\$2.056968
38	Milwaukee, WI	BC	\$1.999349
18	San Diego, CA	A	\$1.993159
31	Indianapolis, IN	A	\$1.833482
39	Oklahoma City, OK	BC	\$1.817184
47	Brownsville, TX	BC	\$1.816246
406	Anamosa, IA	ABC	\$1.789878
47	Brownsville, TX	A	\$1.753276
8	Dallas, TX	A	\$1.728469
15	Phoenix, AZ	A	\$1.727573
39	Oklahoma City, OK	A	\$1.683349
35	Austin, TX	A	\$1.677905
26	Las Vegas, NV	A	\$1.675740
15	Phoenix, AZ	BC	\$1.670246
50	Greenville, SC	A	\$1.668673
31	Indianapolis, IN	BC	\$1.652837
18	San Diego, CA	BC	\$1.650721