

Up in the Air: GTE's Experience in the MTA Auction for Personal Communication Services Licenses

DAVID J. SALANT

*Law & Economics Consulting Group
2000 Powell, Suite 600
Emoryville, CA 94608
david_salant@lecg.com*

In late 1994, GTE, one of the largest telecommunications firms in the world, entered an auction for the rights to provide personal communications services (PCS) using the electromagnetic spectrum. The administering agency, the Federal Communications Commission, adopted a novel multiple-round format for the PCS auction. The format presented GTE with a complex bidding problem. This article describes how the GTE bidding team answered the following question: Given its budget and valuations and the information available about rival bidders, how should GTE bid to achieve the best attainable outcome?

1. Introduction

In a series of auctions starting in 1994, the Federal Communications Commission (FCC) sold the rights to provide personal communications services (PCS) using the electromagnetic spectrum. The rights are defined by both wavelength and geographic coverage. The largest of these auctions, for ninety-nine 30-MHz licenses in 51 major trading areas (MTAs) in the United States and its territories (two per MTA, except one each in New York, Los Angeles, and Washington, DC) began on December 5, 1994. Thirty bidders registered and qualified for the auc-

During the auction, I was a Principal Member, Technical Staff, at GTE Laboratories and was a member of GTE's bidding team. Their support, especially that of Ed Horner and Bill Pallone, is greatly appreciated. I would also like to thank Bob Rosenthal and Rob Porter for comments on an earlier draft. I also wish to acknowledge helpful input from Carol Bjelland, Terry O'Connor, Mike Weintraub, Ron Williams, and Israel Zibman.

tion and spent over \$7 billion acquiring licenses. This report describes how our team (for GTE) answered the following question: Given the information we had about GTE's valuations, budgets and objectives, the valuations, budgets and objectives of rival bidders, and the rules, how should we bid to achieve the best attainable outcome?

In developing our auction strategy we relied on (1) our knowledge of the other bidders and market opportunities, (2) our understanding of GTE's senior management's objectives, and (3) the ability to adapt game theory to model the behavior of bidders in the auction. Going into the auction, GTE's senior management gave our bidding team an outline of the company's objectives. Because we had limited information about our rivals, we needed to make some guesses about their interests, valuations, and budgets, as well as about the auction's duration and the price threshold.

The FCC used a novel simultaneous, multiple-round ascending-bid SMR format for this auction (see Cramton (1995) or McAfee and McMillan (1995) for a more detailed description). In summary, 30 firms simultaneously bid on 99 PCS licenses in a sequence of rounds. At the end of each round, the FCC posted all the bids from that round, and the bidders then had the chance to place new bids in the next round (subject to constraints imposed by the activity rules). The auction rules specified that the auction would close on all 99 properties at the same time.

This was one of the few times this auction format had ever been used. Although filings at the FCC by the leading auction experts preceded the FCC's adoption of the SMR format, no one had fully analyzed the equilibria. Most of our rivals had auction experts helping them determine their strategies.¹ The expert advice should have ensured that our rivals had well-formulated plans. However, we still needed to form guesses as to what strategies our rivals would use. Our ideas were speculative, as (1) there was, and is, no reliable theory on which to predict our rivals' bidding and (2) we had limited knowledge about their objectives and resources. Moreover, there was no reason to believe that each of the other bidding teams would adhere to a single well-formulated strategy throughout the auction.

In what follows I explain how our team devised its bidding strategy using game theory. I also explain why GTE's senior management

1. Among the experts working for various bidders were Jeremy Bulow and Barry Nalebuff for Bell Atlantic, Rob Gertner for WirelessCo, Ron Harstead for Southwestern Bell Corporation, R. Preston McAfee for Airtouch and PCS PrimeCo, Paul Milgrom and Bob Wilson for PacTel, John Riley for BellSouth, and Michael Rothkopf for USWest. GTE had Rob Porter and Bob Rosenthal advising.

concluded that our bidding team did well in the auction. Section 2 describes GTE and the bidding problem we faced going into the auction. Section 3 outlines how we formulated our bidding strategy. In Section 4, I describe a computerized auction simulation model we developed to assist us in formulating our bidding strategy. Section 5 describes some of the key decision points we faced and how we fared. Section 6 concludes with a discussion of the value and limitations of using game theory to formulate our bidding strategy.

2. How GTE Prepared for the Auction

This section provides relevant facts about GTE, its objectives, and the information we had about rival bidders going into the auction.

2.1 GTE and Its Objectives

To understand the problem facing our team going into the auction, it is necessary to first describe GTE, its auction competitors, and how PCS licenses would complement GTE's other lines of business. The spectrum licenses for sale would allow GTE to offer PCS. Going into the auction, the concept of PCS was unclear because every bidder had its own definition. Every definition of PCS, however, included wireless voice telephone service. PCS is thus best described, although somewhat imprecisely, as "advanced cellular services." Depending on the price charged, PCS can substitute for cellular service and/or regular plain old telephone service (commonly referred to as POTS). PCS can also be provided in conjunction with POTS.

A local exchange (telephone) carrier (LEC) might want to acquire PCS licenses within its telephone service areas for the defensive purpose of protecting its franchise area as well as to expand its service offerings. In addition, many parts of a LEC's facilities can be used to reduce the cost and speed deployment of PCS. LECs were allowed to acquire PCS licenses within their franchise areas. However, cellular carriers, being viewed as providers of virtually perfect PCS substitutes, were prohibited from bidding on PCS in areas where they had a significant cellular presence (meaning that the cellular carrier's franchise area covered more than 20 percent of the population in the MTA). However, cellular carriers could acquire MTAs in areas adjacent to their cellular holdings.

GTE is one of the largest telecommunications firms in the world, with a market value of over \$30 billion. In terms of telephone subscriber numbers, GTE was the largest LEC in North America, larger than any of the seven Regional Bell Operating Companies (RBOCs) at the time

of the auction. GTE had over 15 million access lines in the US. GTE is also one of the five largest cellular carriers in the US.

Another significant fact about GTE is that although it is basically as large or larger than any of the RBOCs, it does not enjoy their regional concentration. The RBOCs' telephone service areas are each concentrated in one part of the country.² In the MTAs where GTE provides POTS, the local RBOC usually has a significantly higher percentage of both the cellular and the local telephone businesses than does GTE. The major exceptions are the Tampa and Honolulu MTAs, where, because of its cellular holdings, GTE was not eligible to bid.

GTE's position in the Los Angeles MTA provides an example of the types of situations facing the company. GTE provides telephone service to over 20 percent of the people in this MTA, which includes Los Angeles, Santa Barbara, Orange County, and San Diego. However, PacTel, the local RBOC, serves over twice as many households in the Los Angeles MTA as does GTE. (GTE and PacTel do not compete directly for telephone service, as they serve geographically distinct markets.)

Because its cellular and telephone franchise areas do not overlap very much (approximately 20 percent of its cellular markets coincide with its LEC franchises and vice versa), GTE could bid on licenses to serve many markets where it had a significant number of telephone lines.³ The most notable case where GTE had a significant wireline presence and was eligible to bid for a PCS license was Seattle. GTE was eligible to bid in 34 MTAs. The markets in which GTE was eligible and also had a large number of telephone access lines also included Chicago, Detroit, Cincinnati, and St. Louis. In total, GTE had at least 1000 access lines in 10 of the MTAs in which it was eligible to bid and at least 50,000 access lines in 18 of those MTAs. In only a few MTAs, such as Tampa and Hawaii, was there a significant overlap of GTE's cellular and telephone coverage. GTE would have been eligible to bid in Dallas and Los Angeles had it not signed deals before and during

2. NYNEX serves New York and the New England states, Bell Atlantic the mid-Atlantic states, BellSouth the southeast, SBC, south central and southwestern US, Ameritech the upper Midwest, PacTel California and Nevada, and US West the northwest. GTE has some market presence in each of these regions, although it is minimal in the area served by NYNEX.

3. The auction rules did not permit a firm to bid on an MTA in which it also owned cellular franchises covering over 20 percent of the population.

the auction.⁴ GTE had a strong presence in Atlanta, where its headquarters for cellular operations are located.

Thus, there were a large number of MTAs in which GTE had some interest because of a desire to obtain wireless coverage for its wireline service areas. In addition, GTE's cellular serving area covered much of the southeast. However, there were a number of holes that an additional MTA, such as Atlanta, Jacksonville, or Washington, DC, could help fill in.

Prior to the auction, our team assessed the value of each license for which GTE was eligible to bid. These valuations, in part, reflected synergies between existing operations. The budget parameters determined by GTE's management were in part based on these valuations. The team felt that a few of the MTAs were unlikely to be very profitable regardless of the license cost. GTE did have some interest in acquiring licenses in virtually every major market as well as almost every MTA in which it had a significant fraction of the local telephone business. GTE's senior management had a particular interest in acquiring licenses in Seattle and Atlanta.⁵

2.2 Competitive Assessments

Prior to the auction, our team assessed the competition on a market-by-market basis. One aspect of the auction, which had a significant bearing on our bidding strategy, was the overall amount of competition and how the level of competition varied across markets. Probably the best measure of the overall level of competition is the aggregate population eligibility of all the bidders. In the PCS A- and B-block auction, there were 99 licenses whose aggregate population (pops) totaled approximately 450 million. The ability of bidders to make bids and win licenses (that is, their eligibility) as well as their bidding activity was measured in terms of pops. Initially, aggregate eligibility was approximately 1.9. This means that there were, on average, no more than two bidders per pop, or per license. Although an auction with 10 objects and 11 bidders each seeking one object could prove to be highly competitive, this did not seem to be the case in most of the markets. Only

4. GTE swapped its Portland cellular franchise for San Diego during the auction. San Diego is in the Los Angeles MTA. Because GTE entered into a resale agreement with SBC corporation in Dallas and Houston shortly prior to the auction, GTE was ineligible to bid on the Dallas MTA.

5. Since the close of the auction, GTE has sold off its Atlanta and Denver licenses. I am no longer with GTE. I can only guess that there has been some change in managerial direction corresponding to the turnover that has occurred in the ranks of senior management.

a few of the markets were strongly contested. The largest three bidders were WirelessCo (a consortium of Sprint and three of the largest cable operators: TCI, Cox, and Comcast), AT&T, and PCS PrimeCo (a consortium consisting of three Regional Bell Operating Companies: NYNEX, Bell Atlantic, and US West, plus Airtouch, the cellular carrier that was formerly part of PacTel). They were competing against each other for licenses only in Chicago, New Orleans, St. Louis, Milwaukee, Memphis, and Birmingham. Moreover, Memphis went to Powertel and Southwestern Bell, and one side of Birmingham went to Powertel. At the outset, the industry's expectation was that these three bidders had the largest budgets and the highest private-value components for their valuations. Some of the other local exchange carriers, viz., GTE, Ameritech, BellSouth, PacBell, and Southwestern Bell, could also be expected to have fairly high private-value components and significant amounts to spend. However, our team felt that the three bidders seeking national networks would include an additional component in their valuation that reflected the superadditivity from acquiring a national network.

Markets such as New York, Los Angeles, Charlotte, Dallas, Philadelphia, Boston, and Minneapolis had relatively little effective competition from the major bidders. The lack of competition in these markets was due to several factors:

1. At least one of the three largest bidders was not eligible to win a license in most markets, due to its existing cellular holdings.
2. The preauction agreements, especially that of the PCS PrimeCo coalition involving Airtouch, Bell Atlantic, NYNEX, and USWest, reduced the number of bidders and limited their eligibility. The PCS PrimeCo agreement essentially reduced four bidders to one, and also reduced the number of different markets in which those firms could bid. For instance, had it not entered the coalition, NYNEX could have competed for the Los Angeles and Washington DC licenses. Other significant agreements included the one between Sprint and its three cable-television partners (TCI, Comcast, and Cox) to form WirelessCo, and the resale agreement between GTE and SBC. Other confidential negotiations during the auction probably reduced competition even further, as evidenced by the WirelessCo agreement with the Pioneer's Preference winner in Washington during the auction.
3. Most of the LECs were reluctant to bid outside their existing local exchange franchise areas. For instance, BellSouth has extensive cellular holdings, but apparently was not interested in filling in gaps or extending the footprint of its wireless network with new MTA licenses.

4. Only a few firms had the resources to develop large markets. Buildout costs could easily be two or three times the cost of acquiring licenses. Additionally, the technical and marketing personnel needed to build and roll out services would likely be scarce in the next few years. A startup, with limited staff—even a Craig McCaw—could find it difficult and very expensive to get services to market.
5. MCI, potentially one of the largest bidders, decided not to participate in the auction. A possible explanation for its absence is that the auction rules did not permit it to bid for a national license.
6. The other options available certainly affected bidders' valuations. Such options included acquiring coverage via cellular deals; participating in the upcoming auction for the smaller basic trading areas; postauction agreements across different areas, such as the resale or roaming agreements that exist for cellular; and other related activities, such as investing in video and/or broadband networks, or investing outside the United States.

Beyond this overall assessment of competition intensity, we also made assessments regarding the amount of competition in each MTA. To do so, we informally divided the eligible bidders in each MTA into larger (those likely to have relatively high valuations) and smaller (those with relatively low valuations). Thus, we thought GTE would be able to outbid most small bidders in a market but we were very uncertain about GTE's ability to outbid any large bidder in any market.

In the remainder of this section I provide a brief overview of the stronger bidders—those we thought might have valuations higher than GTE's for licenses in which GTE had a significant interest. Other bidders, such as Poka Lambro, CCI Data, and Century Communications, are not discussed in detail, because we considered them to be smaller bidders.⁶

As noted above, AT&T, WirelessCo, and PCS PrimeCo were the three biggest bidders in the auction. We expected each would be willing to outbid almost anyone else almost anywhere. This was true wherever they were eligible to bid. AT&T is the largest long-distance carrier in

6. Among the "small" bidders, Western PCS surprised us by being willing to pay prices, in some western markets, that were close to what GTE was willing to pay. We were not greatly concerned about the other cable companies, such as Continental or Cox, where they were bidding on their own and not as part of the WirelessCo consortium. Although these cable operators were large firms, it was not clear that they would be willing to invest a large amount in PCS with the possible exception of one or two MTAs in which a cable operator served a significant fraction of the population, e.g., Continental in Minneapolis.

the US and one of the largest firms in the world. It also has some of the best technological capabilities. One strong rationale for AT&T, and also for Sprint (WirelessCo), entering the PCS market was to limit access payments to the LECs for originating and terminating long-distance calls. These fees comprise close to half of AT&T's long-distance revenues.

PCS PrimeCo was the largest consortium of local telephone companies and cellular carriers in the auction. Going into the auction, they had cellular franchises in approximately half the MTAs and telephone service in close to half the country. Sprint, the lead partner in the WirelessCo consortium, is the third largest long-distance carrier in the US. The other firms in WirelessCo—TCI, Comcast, and Cox—are three of the largest cable operators in the US. As a long-distance carrier, Sprint had a strong incentive to acquire PCS licenses to avoid access charges. Its cable television partners had substantial facilities that could aid deployment of service.

We also considered any RBOC to be a major bidder in any MTA in which it also provided local telephone service. For example, we viewed PacTel as a very strong bidder in its home MTAs, Los Angeles and San Francisco. We thought PacTel would be a much weaker bidder elsewhere, especially east of the Rockies. Similarly, we thought Ameritech would be a strong bidder in its home markets of Cleveland and Indianapolis.

In relatively few MTAs was the local RBOC eligible to bid. This is because in most MTAs the local RBOC owns one of the two cellular franchises. The most prominent exception was in California. Prior to the auction, PacTel had spun off its cellular division into a separate entity called Airtouch. In virtually every MTA in which the RBOC that provided local telephone service was eligible to bid, that RBOC won the license.⁷

Los Angeles was the only significant MTA in which GTE could compete with the local RBOC, namely PacTel. We thought it likely that PacTel would outbid us for the one available Los Angeles license.⁸ Both PacTel and GTE would have an interest in acquiring this license, for many of the same reasons. One was the protection that a PCS license could provide to its wireline business. Another was the synergies between the two networks. Some of the same facilities and distribution

7. Some examples include PacTel winning licenses in the Los Angeles and San Francisco MTAs, BellSouth in the Charlotte and Knoxville MTAs, Ameritech in the Cleveland and Indianapolis MTAs, and Southwestern Bell in the Memphis, Little Rock, and Tulsa MTAs.

8. The FCC had awarded the other license as a Pioneer's Preference.

channels could be used for both. If these synergies were roughly proportional to the population sizes of the telephone franchise areas, then PacTel would be willing to pay a lot more than GTE for the license, having more than twice as large a telephone market in the Los Angeles MTA. Therefore, despite its potential attractiveness, the Los Angeles MTA was not one of GTE's main objectives in the auction. Through a swap of its Portland cellular franchise for the San Diego franchise during the auction, GTE gave up its eligibility to win this license during the auction.

We had some concerns about a number of other bidders, especially Powertel, APT, and Alaacr. We thought American Personal Telecommunications (APT) could be aggressive and was certainly going to be opportunistic. APT was the PCS Auction name for TDS, a sizable telephone and cellular provider.⁹ We thought that Powertel, an electric utility, could be a strong bidder, especially in the South. Like many others, we were uncertain about how Craig McCaw's organization, Alaacr, would bid. Craig McCaw's personal wealth meant that Alaacr could be considered a serious competitor in any market.

In short, in each market we tried to assess how strong a competitor each bidder would be. Then we made market-by-market assessments of the competition. For example, in Chicago, AT&T, PCS PrimeCo, WirelessCo, GTE, and APT were all eligible to bid. Thus, we thought this would be a very costly license to acquire. In New York, on the other hand, PCS PrimeCo and AT&T were not eligible. We thought that New York would likely sell at a lower price per pop than would Chicago. (New York sold for \$17/pop, that is, the price of the license divided by the population of the MTA was \$17; Chicago sold for approximately \$31.50/pop for each of the two licenses). In Charlotte (the sixth-largest MTA), the only significant bidders seemed to be AT&T and BellSouth. And the license for it sold relatively cheaply (approximately \$7.00/pop).

We looked at the competition for each MTA for which we might want to win a license. In many markets GTE's main competition was AT&T and WirelessCo. In addition, APT and Alaacr were perceived as potentially significant competitors, especially in Seattle.

3. Devising a Bidding Strategy

We entered the auction after forming projections about potential net present values of the different licenses, other GTE corporate objectives, a budget constraint, and rival bidders' interests. However, we really

9. Robert Weber was advising TDS. We thought that Weber would be able to assist TDS to develop an aggressive, well-formulated, and opportunistic bidding strategy.

had no way of accurately assessing rival valuations and budgets. Since there is no theory about determining the optimal bid in such a situation, this was our most significant question.

GTE spent over six months prior to the auction preparing its valuations. These efforts provided a good basis for evaluating how high prices would be at any point in the auction, since these numbers provided an idea about how much other bidders might be willing to pay. Shortly before the auction started, our team made some assessment of competitors' valuations. We did this to determine where competition was likely to be light and prices correspondingly low. This preauction assessment of the likely competition for different licenses helped the team select its target markets in the early phases of the auction.

We could conjecture that our rivals would use similar approaches to assess valuation to what GTE did. Each firm's valuation consists of a common value component and a private value component. We surmised that the common value component of GTE's rivals' valuations would be approximately the same as GTE's, net the difference in forecast errors. We estimated the private values for the more significant bidders in each market, such as the IXC's, who might be seeking to avoid access charges, and other LECs.

Our next step was to examine each of the roughly thirty markets in which we could bid and assess the competition in each of the markets. As noted above, GTE's senior management gave our bidding team strict orders to win licenses in Atlanta and Seattle. We were also told how much we could spend. We were not worried that we would be unable to win one of the two Seattle licenses. The most significant other bidder in Seattle was WirelessCo. PacTel, Alaacr (Craig McCaw), and APT were also eligible to bid for the Seattle licenses. PCS PrimeCo and AT&T were not. We did not feel that any of the bidders other than WirelessCo would be willing to outbid us there. Our only concern was that PacTel or Alaacr might drive up the price beyond what we were authorized to spend. We also thought that APT would be opportunistic. WirelessCo and GTE won the two Seattle licenses. Our preauction assessment of the competition for the Seattle licenses proved to be accurate.

Our view of the situation in Atlanta was much less sanguine. AT&T and WirelessCo were both eligible. In addition, there was another potentially strong competitor, Powertel. Powertel, a well-funded electric utility, could have been willing and able to outbid us for an Atlanta license. Powertel did eventually outbid GTE in Jacksonville. It also outbid AT&T, PCS PrimeCo, and WirelessCo in Memphis, and AT&T and PCS PrimeCo in Birmingham. Thus, the situation we faced in Atlanta involved two licenses and four potentially strong competitors.

GTE's senior management would not be pleased if we failed to win one of the Atlanta licenses. Senior management also wanted to limit the amount GTE spent in the auction or on any one MTA.

We made similarly detailed analyses of each of the markets in which we might bid. We divided the 51 MTAs into three broad categories: (1) markets we thought would not be very competitive, such as Seattle and Minneapolis (where we did not think there would be more strong competitors than there were licenses); (2) other markets that would be competitive only if GTE were trying to acquire a license, such as New York, Cincinnati, and Detroit (in these markets there were an equal number of licenses and strong competitors not counting GTE); (3) The most competitive markets, such as Chicago, Milwaukee, and St. Louis (the Big Three were eligible, and we thought competition would be strong in those markets even without GTE).

Since the format of the auction was novel, there was little in the literature to provide guidance as to the outcome. The possible synergies and the budget constraints facing many of the bidders made it even more difficult to predict the outcome.¹⁰ An efficient auction format would be expected to result in an allocation where licenses in each market would be won by the firms having the highest valuations.¹¹ The expected price would be approximately the highest losing bidder's valuation. However, because of the possible synergies and the fact that bidders faced budget constraints, the SMR format would not necessarily result in such an outcome. The budget constraints seemed to be significant during the auction. Additionally, we could not ignore the fact that firms had private information and could possibly enter bids as a means of sending signals.

Going into the auction, one synergy that we felt might be important was the advantage a firm could gain by obtaining a national license. Three firms were seeking to acquire national footprints, AT&T, PCS PrimeCo, and WirelessCo. Given their preauction holdings of cellular licenses, it was logically possible that all three could assemble an almost complete national license; there were only a few MTAs in which at least one of the three would necessarily have a hole, most notably Chicago, St. Louis, and Milwaukee. Aside from the efforts of the Big Three

10. Pitchik and Schotter (1988) and Gale and Stegeman (1995) have studied auctions in which bidders can be budget-constrained. However, the format of those auctions bears little resemblance to the PCS auction.

11. As Cramton (1995a) pointed out, bidders could withhold demand to depress price. In such a case it would not be expected that each license would be won by the bidders having the highest valuations, and at a price determined by the highest valuation among the losing bidders.

to put together national licenses, most markets were large enough so that there were few synergies across PCS licenses about which the team needed to be concerned.¹²

On the other hand, synergies between PCS and other existing operations were significant. GTE, in part, adjusted its valuations to account for possible synergies with its existing LEC facilities and market presence. Given the activity of RBOCs in their own franchise areas, it seems likely that they too felt there were potential synergies between PCS and their traditional service offerings. In addition, the two long-distance carriers in the auction, AT&T and WirelessCo (Sprint), had potential synergies between their long-distance businesses and PCS.

Synergies across MTAs can create an exposure problem. A bidder might end up having to bid beyond its standalone value on two or more licenses in order to stand a chance at winning the combination; this exposes the bidder to the risk that it will end up only winning some, and not all, of the licenses in the combination.¹³ The combination of budget constraints and the activity rules can create a similar exposure problem. A firm might maintain activity on more licenses than it wants to win. Failing to do so might deprive it of the flexibility it might need late in the auction (should it wish, for instance, to switch to a larger market because the price in a smaller market had increased).

Two additional aspects of the auction made devising a bidding strategy difficult:

1. Even in an auction in which every bidder knows every other bidder's valuations and budgets, there is a coordination problem. Given the multiround format of the auction and the budget constraints, the outcome can be very path-dependent.
2. The fact that there is imperfect information meant that bidders might wish to influence rivals' beliefs by signaling. The auction format provided bidders with ample opportunity to send signals, but did not provide a means by which any signal could have an unambigu-

12. One prominent exception was GTE's valuation of Jacksonville. Late in the auction, when it appeared likely that GTE had won Atlanta, the valuation of the adjacent Jacksonville license was revised upward to reflect some synergies.

13. Bykowsky et al. (1995) and Bykowsky and Cull (1995) discussed the exposure and threshold problems. This was also discussed by Milgrom and Wilson and McAfee in their filings on behalf of PacTel and Airtouch, respectively. An example of the problem is as follows. Suppose a bidder has standalone valuations on two MTAs, say New York and Boston, of \$300 million and \$150 million, respectively. That bidder might value the pair at, say, \$600 million. If the bidder were to win one, say New York at \$400 million, and not Boston, it would end up paying more than the standalone valuation for New York.

ous interpretation. For instance, a large hike in a bid could indicate a strong interest in a license or an attempt to scare away rivals.

As I have mentioned above, GTE had a strong presence in well over half of the 34 MTAs in which it was eligible to bid. We felt that other bidders would have an extremely difficult time guessing where our interests might be strongest. We thought that Los Angeles and Seattle were the two MTAs others might think we were most interested in. Those were the two MTAs in which GTE had the largest number of access lines. Also, GTE has a strong cellular presence on the West Coast. However, GTE never entered a bid in the Los Angeles MTA.

Partly because we did not think we would intimidate any other major bidders, we thought that it would be unwise to signal our intentions. We were most concerned that other bidders might ascertain our true interests in Atlanta. They could possibly take advantage of this interest to maintain their own eligibility at no cost. However, we were also concerned that Sprint or Powertel might set aside more of what might be limited budgets for Atlanta if they knew our true interests. Thus, we thought that it would be wise to defer bidding in Atlanta until late in the auction. We hoped to wait until our competitors, mainly WirelessCo and Powertel, had committed a great deal of money to other markets, before entering bids for the Atlanta MTA.

The auction is a bit like a poker game in that bidders might be able to take advantage of information about rivals' hole cards, i.e., their objectives, valuations, and budget constraints. It is probably unwise to bid in a manner that reveals too much about one's intentions during the auction. A bidder who, for instance, knows one rival's valuation in one market can take advantage of that information by continuing to bid there, maintaining eligibility and raising the rival's costs. Thus, a bidder might wish to remain active on markets that are of secondary importance until late in the auction, and only near the end switch to bidding on primary targets. (This carries the risk that the close of the auction can be misjudged.) Additionally, where rivals' budget constraints are likely to impinge, there can be strategic advantages from doing so, in that a bidder can make rivals spend more on some markets, leaving them with less to spend in other markets. Timing is critical. A crucial issue is predicting what other firms will do. A coy bidder can end up using all of its eligibility on licenses that are not as valuable as others that might have been available. It becomes difficult to enter new markets in stage III, unless a bidder standing high bids in one round gets topped in subsequent rounds. On the other hand, switching too early could mean jeopardizing chances at winning primary targets, overpaying, or giving up prematurely on licenses that might have been

the best deals. Moreover, maintaining maximum flexibility requires that bidding on groups of properties be in a sequence dependent on market size and valuation. In particular, the auction rules meant that during stage III, backup options always had to result in smaller-sized blocks than the primary options. Our bidding team spent much time devising plans for managing eligibility in order to maintain maximum flexibility.

We followed the above principles in devising our bidding strategy. In the earlier stages of the auction, most of our bidding activity was in markets of secondary interest to GTE. Our preauction assessment and computer simulations of the auction (described below) were very useful guides in timing when GTE would stop bidding in some markets and start bidding in others. Given our strategy of deferring bidding on high-priority markets, especially Atlanta, until the later stages of the auction, it was crucial that we carefully manage the timing of when we would switch. If the auction closed before we started bidding in Atlanta and Seattle, we could end up winning lower-priority markets; we might not have the flexibility, unless we risked a substantial penalty from a bid withdrawal to win those markets. As noted above, we did not want to switch too early, fearing that we would reveal our interests and drive prices higher than they would otherwise go, and possibly beyond GTE's willingness to pay.

In devising our bidding strategy, we needed to make assessments about how high to bid and how long to bid on less attractive (to GTE) markets, before moving to more attractive markets. I cannot prove that, by not bidding in Atlanta and Seattle and concealing our preferred choices until late in the auction, we had any significant effect on the outcome. However, had we bid aggressively on those markets from the outset, others might have taken advantage of this interest to reduce our budget or maintain their own flexibility. Because of this possibility, we did extensive calculations and computer simulations that made use of information about valuations and budgets that could be assessed from auction bidding behavior. It seems that Craig McCaw (Alaacr) took advantage of PacTel's interest in San Francisco and Los Angeles by jacking up the prices in those markets and preserving his own options. We did not want this to happen to us.

We knew that our early-round bids would represent no commitment. For example, GTE's opening bid of \$50 million on New York represented 78 million pops in eligibility ($= 26 \text{ million} \times 3$, where being active on 1 pop in stage I gave the bidders 3 pops of eligibility). This bid put no money at risk, as it was inconceivable that a \$50 million bid for New York would stand. However, GTE's high bid in Chicago for \$270 million near the end of stage II represented much more of a com-

mitment. We still felt that \$270 million was not enough to win a Chicago license. But at that point, we could not be sure. (The winning bids in Chicago in fact exceeded \$370 million.)

We were also concerned with how to manage our eligibility. Eligibility management was one of the trickier aspects of the auction. Managing eligibility is especially difficult in stage III of the auction, since the set of properties that a bidder wishes to buy depends on the prices, and some options are mutually exclusive.

For instance, suppose a bidder is interested in obtaining licenses in as many markets from a list as possible, subject to an overall budget constraint and valuation limits on each of the markets. If revealing interests to rival bidders is not a concern, the optimal strategy is to first bid on all the markets on the list as long as the sum of the bids remains below the overall budget. However, once the prices rise above a level where it is possible to purchase all the licenses on the list within the overall budget, then there are tactical choices to be made. Among the options is to continue bidding on all the markets for a while, which means there is some, albeit small, chance of winning all the markets and being overcommitted. It is clearly reasonable to take the risk of being just a little bit overcommitted, but there is a question of how far to go; the answer depends largely on the degree of the firm's risk aversion and budget flexibility. Furthermore, as prices rise, eligibility reductions need to be managed to maintain the greatest flexibility. Some of the tactics that can accomplish this include bidding on highly contested markets, double bidding (that is, submitting bids on both licenses in a market at the same time), and bidding in a way that minimizes chances of having a high bid in any one round. However, senior management prefers that the bidding team appear, at least to outsiders such as financial analysts and shareholders, to have a well-thought-out strategy. This may limit the extent to which these tactics can be used.

4. Simulations

We ran computer simulations of the auction, in large part, to assess how long the auction would last and to help us decide the timing of tactical moves during the auction. Our simulation software followed the procedures specified by the FCC for the MTA auction. We ran simulations in which the number of bidders, licenses, valuations, and bidder strategies came as close as possible to what we thought would happen in the actual auction. We did this by developing programs that could simulate actual bidder behavior and calculate the outcome of a multiple-round auction based upon the simulated bidder programs

and the values we entered for each bidder's budget, initial eligibility, and valuations. The simulation programs specified the licenses and the amount bidders would bid for the properties during each round. In addition, we added small random jumps to the amounts bid.¹⁴

We imposed a number of restrictions on simulated bidders that did not exist in the actual auction. We did not allow bidders to bid simultaneously on both the A and B licenses in an MTA. Also, the simulations did not allow bidders to withdraw bids. Despite these restrictions, the simulation fairly accurately captured the bidding behavior in the real auction. Our simulations employed a number of different bidding strategies, that are described as follows:

- *as is*. The list is used in the order given by the bidder's specification.
- *percent return*. Consider licenses with the largest percent return first:

$$\text{percent return} = \frac{\text{valuation} - \text{bid price}}{\text{valuation}}$$

- *net return*. Consider license with the largest net return first:

$$\text{net return} = \text{valuation} - \text{bid price}.$$

- *property price*. Consider the cheapest properties first.
- *importance*. Consider the most important properties first. The importance of a license is specified before the auction. This rating can define classes of importance or individual rank orderings.
- *price per pop*. Consider the properties with the least price per pop first.
- *biggest pop*. Consider the properties with the most MHz-pops first.

Each rule refers to a sorting rule that the algorithm used to generate bids. The *property price*, *price per pop*, and *biggest pop* rules created bids for the highest-ranking properties until the bidder fulfilled the required activity to maintain its eligibility. The other algorithms generated bids until the bidders' budgets were exhausted. The budget parameters were inputs to the simulations.

In addition, we allowed simulated bidders to combine strategies. For example, we considered strategies that combined *importance* and *price per pop*; in this case, the licenses are first ranked by *importance* and then by *price per pop*. We also allowed the simulated bidders to use one

14. The random component was drawn from a uniform distribution over a user-defined interval.

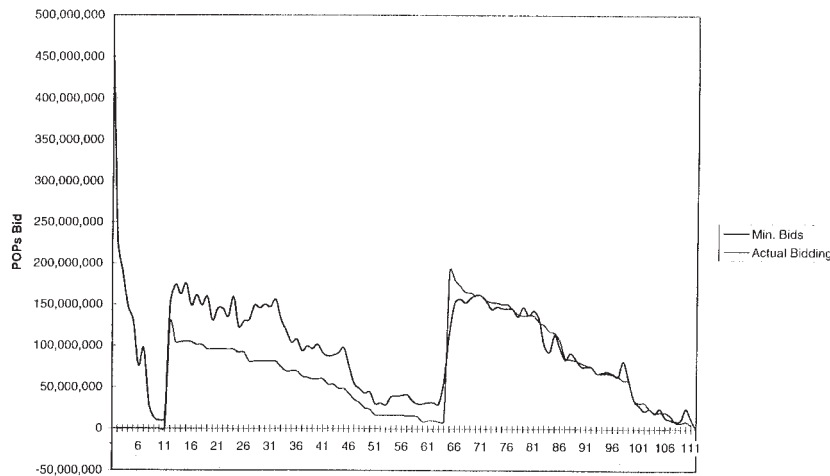


FIGURE 1. BIDDING ACTIVITY

set of strategies during one part of the auction and another set during another part of the auction. This allowed for the possibility that bidders might play a *snake-in-the-grass* strategy: wait until (they believed) the auction was about to end and then switch to a sincere bidding rule. The criterion the simulation program used for judging the proximity of the auction's close was based on the total license prices as a percentage of their expected valuations. Bidders using such two-phased strategies were parametrized by a cutover value, at which point the simulated bidder will begin to use its final bidding strategy.

Figure 1 plots the bids that were needed for all bidders to maintain their eligibilities versus actual bids. It demonstrates that bidding activity rarely differed much from what was required for bidders to maintain their eligibility. It also suggests that the *snake-in-the-grass* algorithms were a useful model of bidder behavior.

We adjusted our simulations throughout the first two stages of the auction to account for information revealed during the actual auction. License valuations, importance, and budgets of the various participants were adjusted as information presented itself. Likewise, new bidding strategies were considered as the auction progressed.

5. Revising the GTE Bidding Strategy during the Auction

In Section 3, I described GTE's basic bidding strategy: Bid to maintain eligibility, avoid sending signals, and defer bidding in Atlanta and Seattle until late in the auction. In this section, I describe the game-theoretic issues we considered prior to and during the auction, as well as the adjustments we needed to make during the auction.

5.1 Preauction Strategic Concerns

We viewed bidder valuations as consisting of private and common value components. Going into the auction, we felt that the long-distance carriers, AT&T and WirelessCo (Sprint), would have large private value components in their valuations. We also thought that the RBOCs would also have large private value components to their valuations in their home markets. Further, we felt that the private values would dwarf the forecast error of the common values. The results of the auction are consistent with this view.

The unimportance of the *winner's curse* was ironic. The winner's curse was a significant factor that led the FCC to adopt the SMR format, and it was one of the main topics discussed in the filings by leading game theorists who recommended various auction formats. A winner's curse occurs in common-value auctions for a single object when the most optimistic bidder wins but pays too much. However, the winner's curse is not nearly as relevant in an auction in which bidders have independent private values as in one in which there are common values.

The auction format did compel bidders to reveal significant information about their valuations. So, indirectly, the logic of the winner's curse was probably relevant. For instance, our observations about what other bidders were offering in other markets provided some reassurance about our own valuations. This would be the case if the factors that determine the value of one license, such as potential demand, equipment costs, and access charges paid to the LEC, were common across bidders and licenses. The lack of close competition in many markets meant that the winners need not worry a great deal about overpaying.¹⁵

15. For example, in a common-value auction with two identical licenses and three bidders who have unbiased estimates of the value of the license, the expected value of the lowest valuation is less than the true value of the license. More specifically, suppose each bidder's forecast error is uniformly distributed on an interval $[-a, +a]$. On average the forecast of the least optimistic bidder will be the true value less $a/2$.

There were a number of other concerns that the simultaneous ascending bid design helped alleviate. One potential problem was *exposure*. An exposure problem arises when a bidder enters bids on multiple markets that exceed the standalone values of those markets.¹⁶ The bidder might do this where, owing to synergies, the value of the package exceeds the sum of the parts. If the bidder then is outbid on some pieces, but not all, then that bidder will pay more than was intended for the markets won. We were concerned that GTE, or its rivals, could encounter this problem during the auction.

The auction format did allow bidders to first bid on the larger markets for which synergies existed, and then fill in the gaps. For example, a bidder seeking to win New York and Boston licenses could remain active in New York and bid later in Boston. Although there was also some risk that a high bid on the larger MTAs would be upset very late in the auction, the eligibility rules meant this risk was small. Our team based its bidding strategy on the assumption that the larger markets would effectively close before the smaller ones.

We were very concerned about how budget constraints could affect bidding. Most of the theoretical literature ignores budget constraints.¹⁷ In the MTA auction, budget constraints appeared to limit bids. Where there were a number of MTAs among which we were indifferent, and we were merely attempting to acquire those with the best ratio of value to price, the activity rules in stage III made it very difficult to manage eligibility and preserve our options. For example, if we were to stop bidding on Philadelphia and Boston and were to begin bidding on the smaller Washington and Atlanta MTAs, we would not have the eligibility to return to Philadelphia and Boston should prices make those markets more attractive. Thus, to preserve our options, we felt that it would be prudent to bid, at times, for more licenses than we really wanted to acquire and to have at stake more money than we were authorized to spend.

5.2 A Chronology of the MTA Auction as it Affected GTE

One of our main concerns was to determine how long it would be desirable to lie low by placing bids just to maintain eligibility, and when it would be in GTE's interests to be bidding on targeted markets. In the simulations we ran to help determine optimal timing, we assumed most bids would be made to maintain eligibility. The events of

16. See Bykowsky and Cull (1995).

17. Exceptions include Gale and Stegemen (1995) and Pitchik and Schotter (1988).

the first phase of the auction helped confirm these beliefs. In particular, there were essentially no bids made in stage I of the auction that could seriously be considered winning bids.

Almost all of the bids made in the first 11 rounds were close to the minimum bid levels set by the FCC. The few bids substantially above the minima, such as GTE's opening bid of \$50 million in New York and subsequent jumps in New York by Alaacr and WirelessCo, could not be considered anything other than bids designed to maintain eligibility for a few rounds or to push the pace at which prices rose in those markets. This is not surprising—there was little incentive to make more than the minimal bid, other than perhaps to send a signal or to move the auction along.¹⁸ Although there were a number of anomalous bids that could be interpreted as signals, there seemed to be little effective signaling, and there were few bids that exceeded the minimum by more than a few percent. This cautious bidding continued throughout the auction.

We conjectured that there would be an increase in bidding activity when the auction entered the second stage. At that point bidders would either have to increase their bidding activity or reduce their eligibility. At the beginning of stage II, prices were sufficiently low in enough markets that there was little incentive for bidders to reduce eligibility. This is what happened when the auction entered stage II in round 12.

We also thought that bidding activity would only gradually decrease as prices rose and bidders decided to reduce their eligibility. This is what actually happened in stages II and III. By the end of stage II, we felt that any bid could conceivably be a final one, and thus, bids would likely reveal information about each firm's true intentions. This was not the case in stage I or much of stage II, where bidders had no need to reveal much about what markets they wanted to acquire. So, for instance, throughout most of stage II we were still somewhat unsure about whether Alaacr or PacTel might want to acquire a Seattle license.

Once the auction entered stage III we felt more comfortable about our prospects in Seattle. We thought it was best to begin bidding in Atlanta once the auction entered stage III. At that time, two large questions remained: (1) would GTE be able to win an Atlanta license without violating the budget limitations imposed by senior management, and (2) what licenses, besides Seattle and Atlanta, would we be able to win?

18. With two exceptions, there seems to have been no effective signaling during the auction. And the exceptions did not seem to deter competition so much as to facilitate coordination. The cases where signaling seemed to be effective were (1) PCS PrimeCo and AT&T's apparent coordinated bidding and (2) the bid withdrawal by WirelessCo from Tampa and Houston, which apparently invited American Portable communications to bid there.

We had a wish list of about a dozen licenses, and a discretionary budget. We hoped to win as many of those as possible given our budget constraints.

It became difficult for us to manage eligibility in stage III. In stage III, the auction essentially reduces to a set of sequential auctions for each bidder, who has a list of mutually exclusive options. Such bidders have to bid first on the option with the largest population, and then work down to options with smaller aggregate populations. Our team spent a great deal of effort working out possible sequences of strategies we might want to pursue as prices rose.

For instance, suppose we wanted to win one license having between 5 and 6 million pops. The four MTAs that fall in this range are Minneapolis, Tampa, Houston, and Miami. In order to maximize our chances at winning one of these MTAs, and ignoring our valuations, we would want to first bid on Minneapolis (5.9 million pops), then on Tampa (5.4 million), then on Houston (5.2 million), and last on Miami (5.1 million). It could turn out that Minneapolis sells at a better price than do any of the other MTAs, and that Miami sells at a worse price. However, the activity rules might not allow us to withdraw from Minneapolis in order to bid on Miami. It could also turn out that the firm that won Miami would prefer Minneapolis and vice versa. This would be an example of an inefficient outcome. However, we might not want or have the budget and eligibility to switch to Miami and risk losing both Miami and Minneapolis.

This was the type of situation we faced in round 96, when we were topped in Denver, Phoenix, Salt Lake City, and Jacksonville. We wanted to enter new bids in Denver and Seattle without losing the option to reenter Phoenix and Jacksonville. However, if we stopped bidding on Phoenix and were later topped in Salt Lake City, we would be unable to resume bidding on Phoenix.

5.3 The End of the Auction

GTE had three objectives during the early rounds: (1) avoid bidding on the target markets, partly to keep rivals from guessing that GTE's target markets were Atlanta and Seattle; (2) maintain eligibility; and (3) push the price up in nontarget markets, partly to avoid escalating the price in target markets and partly to induce rivals to spend more money on those markets. These efforts might not have made a difference; I cannot demonstrate that GTE would not have won the Atlanta license if we had bid more naively. Our bidding strategy was designed to improve our prospects for success as defined by criteria established by GTE's senior management.

Going into the auction, we thought that Atlanta would be heavily

contested. GTE would be competing against AT&T, Powertel, and WirelessCo for the two licenses. WirelessCo spent over \$2 billion. However, it apparently was concerned about having to commit to spending an additional \$200 million in order to acquire an Atlanta license. One possible reason that WirelessCo ran out of money, or at least stopped bidding in Atlanta, was that they had already committed sizable sums in other markets by the time bidding intensified in Atlanta—although the unlikely possibility that WirelessCo was not that interested in Atlanta remains. The nature of the auction meant that a bidder who could effectively make the last bids would have a strategic advantage. The better values would only become apparent at the end of the auction, and it would be advantageous to be able to only bid on the better-priced markets and not commit to anything in the higher-priced markets. To preserve the flexibility needed to enter the late bids, a bidder had to maintain both eligibility and uncommitted pops (a bidder would have *uncommitted pops* if that bidder's eligibility at the end of a round exceeded its high bids; this could only occur when its bids were getting outbid). One of our team members, Ray Zibman, coined the phrase “losing is leading” to describe this phenomenon.

The difficulty a bidder faced in trying to use a “losing is leading” strategy is that it was hard to be certain which bids will be topped in subsequent rounds. Our efforts to preserve flexibility were inherently risky. Management and shareholders had definite limits on how much risk they felt would be consistent with GTE's policy. Due, in part, to limits on how far the team felt it could go in assuming the risk of winning licenses for nontargeted markets, GTE was limited in its ability to increase WirelessCo's costs in markets where GTE was the third major competitor, such as Detroit. However, APT also significantly raised WirelessCo's cost of acquiring a number of licenses, most notably Washington and San Francisco. The competition from both APT and GTE probably kept WirelessCo from winning a few more licenses, such as Atlanta and Chicago. GTE was interested in a limited number of other markets. We had no incentive to bid on the more attractive markets until late in the auction, when prices were closer to their final values. Our aim was to bid conservatively in markets of relatively little interest in order to maintain eligibility, and gradually shift to markets in which GTE had greater interest. We had relatively little interest in many of the East Coast markets that we bid on during the early rounds of the auction. We had stronger interests in the midwest markets, such as Cincinnati and St. Louis; we started bidding in those markets relatively early in the auction. As stated above, GTE's strongest interest was to acquire Atlanta and Seattle licenses. We waited until late in the auction to begin bidding for those licenses. The tricky part of the timing

was to not stay too long in secondary markets, nor to stop bidding in them too quickly.

6. A Final Assessment of How GTE Fared

In the auction, GTE paid \$400 million for Atlanta, Cincinnati, Denver, and Seattle. Given the constraints it faced, GTE did about as well as could have been hoped. Of the four markets GTE acquired, Seattle and Cincinnati fit in nicely with GTE's cellular and wireline networks. At the time, GTE's senior management felt Atlanta and Denver were very attractive and high-growth markets that fit in with a regional strategy. It is hard to imagine an alternative strategy for GTE that would have resulted in the company winning many more markets, or a more attractive combination of markets, given the limits on the amount of capital that senior management felt it prudent to invest in PCS.¹⁹

Overall, GTE managed the eligibility and timing fairly well. Our team won the two licenses we set out to win at prices well within our limits. This is not to say that GTE got every prime market it might have wanted. However, given all the circumstances, GTE got very good deals in each of the markets, especially Atlanta, for which GTE paid \$14 million less than AT&T did for the other Atlanta license.

At the end, there were probably no bids that GTE would have wished to make that had been prevented by eligibility constraints. The rules made it difficult, especially in stage III of the auction, for anyone to flip back and forth between various combinations of MTAs. GTE proceeded in a fairly logical sequence, which resulted in close to the best attainable set of MTAs at near-minimal prices. We heavily relied on *basic* game-theoretic principles in formulating our bidding strategy. However, we could not rely on standard textbook models, such as those of the winner's curse or of the signaling literature. I and GTE's bidding team differed from Cramton's (1995b) view about the usefulness of signals. We could not rule out the possibility that bid withdrawals, jump bids, and bidding both sides of a market were any more than cheap talk. For example, we could not rule out the possibility that a jump bid was any more than one bidder attempting to obtain a license cheaply by scaring off rivals.

We used a simple model of the PCS auction in which bidders faced budget constraints. The most rudimentary analysis suggested

19. Postauction transactions could be, and were, used to reduce GTE's stake in the PCS industry. However, there is significant uncertainty and large transactions costs associated with such transactions.

that bidders had strong incentives to only submit those bids needed to maintain their eligibility until prices reached a level which reduced demand. This simple observation helped us more accurately estimate how long the auction would run. A simple model of budget-constrained bidders suggested that the outcome of the auction could be very path-dependent, as bidders ran out of money. This simple observation was behind much of our bidding strategy.

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