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UNITED STATES DEPARTMENT OF COMMERCE
The Assistant Secretary for Communications and Information
Washington, D.C. 20230

February 28, 1994

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Honorable Reed Hundt
Chairman
Federal Communications Commission
1919 M Street, N.W.
Washington, D.C. 20554

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FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF SECRETARY

Re: Ex Parte Submission
Implementation of Section 309(j) of the Communications Act, Competitive Bidding
PP Docket No. 93-253

Dear Chairman Hundt:

I am writing to provide further views from the National Telecommunications and Information Administration (NTIA) on pending proposals to implement competitive bidding for spectrum licenses, including licenses to provide personal communications services (PCS). NTIA filed comments on this issue with the Commission on November 10, 1993 (November 10 comments). Because of the importance to the Administration of ensuring fair and efficient auctions for PCS licenses, NTIA has sponsored further research on PCS auctions by researchers at the California Institute of Technology (Caltech).

This letter summarizes the results of the experiments at Caltech and our response to the principal criticisms of NTIA's proposal. The experimental results and accompanying analysis are set forth in more detail in the accompanying paper prepared by NTIA staff (Attachment 1). Based on the Caltech research, NTIA's proposal stands out from the others proposed in this proceeding: we believe that the results from the experiments demonstrate that our proposed Electronic Iterative Combinatorial Auction (EICA) actually works in a live setting, and that it outperforms the alternatives as a fair and efficient way to assign PCS licenses.

Background: This proceeding represents a critical landmark, both in making PCS a reality for the American public and in testing the use of competitive bidding to assign portions of the electromagnetic spectrum. Several characteristics of PCS licenses make the task of designing a fair and efficient auction very difficult. First, NTIA believes that the PCS marketplace is likely to develop in such a way that there will be economies -- returns to scale -- in holding multiple PCS licenses. In its November 10 comments,

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NTIA referred to this characteristic as "value interdependency." This is due, in part, to the strong likelihood that PCS users will wish to roam across PCS license boundaries. As a consequence, the value of a group of geographically adjacent licenses, for instance, will likely be greater than the sum of their individual values.

Second, we believe that bidders are likely to have overlapping preferences for such groups of licenses -- that is, not all bidders will wish to acquire exactly the same sets of licenses. As a consequence, individual bidders will not be able to acquire their desired groups without precluding other bidders from acquiring some or all of the licenses they desire. Under such circumstances, it is critical that PCS licenses be assigned through a process that allows bidders to aggregate licenses easily when doing so creates value.

For these reasons, NTIA urged the Commission in its November 10 comments to use an Electronic Iterative Combinatorial Auction to assign PCS licenses. Under such an auction mechanism, bidders would be allowed to submit bids on combinations of PCS licenses and would have the opportunity to revise their bids (or submit an initial bid) in response to the actions of other bidders. Bidders would enter their bids on computer terminals and transmit them through an electronic bidding network. We suggested that the Commission use computer software entitled "Adaptive User Selective Mechanism" (AUSM) to record and compare the various bids and declare the winners for individual licenses or groups of licenses.

The Commission subsequently received over 130 reply comments in this proceeding. Some commenters in the reply round raised concerns about the feasibility of NTIA's proposal, its complexity, and its economic desirability.

Experimental Work and Conference: To address these concerns, NTIA sponsored a program of economic experiments at Caltech to test the performance of its proposed EICA (a "simultaneous-combinatorial" auction) and two alternatives, a "simultaneous-independent" auction in which bidders bid simultaneously on single licenses, and a sequential auction in which bidders bid on individual licenses in sequence.[1/] Two Caltech professors,

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1/ In the sequential auction experiments, bidders first bid on the entire group of licenses in an oral "Japanese" auction, followed by an oral

Dr. John Ledyard, Chairman of the Division of Humanities and Social Studies, and Dr. David Porter, Visiting Associate Professor of Economics, designed and supervised the NTIA-sponsored experiments. Dr. Charles Plott, Professor of Economics, conducted experiments separately sponsored by Pacific Bell and Nevada Bell.[2/] All of the experiments were conducted in an economics laboratory setting, using student volunteers and fictitious "licenses" to model a live bidding environment.

NTIA and the researchers at Caltech then arranged a two-day public conference at Caltech on January 27-28, 1994.[3/] Representatives from the Commission, academic institutions, the Congressional Budget Office, various parties, and NTIA attended.[4/] Professors Ledyard, Porter, and Plott presented the results of their experiments. The researchers also demonstrated the performance of NTIA's proposed simultaneous-combinatorial auction, with ten bidders using the AUSM software in real time to bid on 54 "licenses" from ten remote locations on campus.

Feasibility: The NTIA/Caltech conference established that electronic auctions, and particularly NTIA's proposal, are feasible. The Caltech researchers used the AUSM software to conduct an EICA for 54 licenses in an experimental setting. These experts have indicated that software capable of handling combinatorial bids could be developed quickly for the Commission's use in PCS auctions, especially in instances where relatively few licenses are being auctioned. For example, existing software could be modified to conduct a combinatorial auction for the eleven national narrowband PCS licenses. Similarly, we believe that such software could be altered to handle the auction of the 102 broadband Major Trading Area licenses (Channel Blocks A and B).

"Japanese" auction for each individual license.

2/ On behalf of Pacific Bell and Nevada Bell, Dr. Plott tested the performance of a simultaneous-independent auction and a variant of a sequential auction in which bidders first submitted a sealed bid for all the licenses up for auction, followed by a sequential "Japanese" auction for the individual licenses. We thank Dr. Plott and his sponsors for making these results available.

3/ NTIA mailed notice of this conference to all parties to this proceeding.

4/ A list of attendees is provided in Attachment 2.

We believe that software capable of handling combinatorial bids could be installed into an existing electronic bidding network. Representatives from the Pacific Stock Exchange and Cantor Fitzgerald, a securities brokerage firm, made presentations at the NTIA/Caltech conference explaining how they routinely use electronic networks to buy and sell securities, and how such networks could be adapted for use in PCS auctions. A representative of GTE Telephone Operations described alternative ways to use telecommunications networks to permit parties to bid on PCS licenses from remote locations.[5/] Each of these firms expressed a willingness to work with the Commission to provide a reliable, secure bidding network to conduct an EICA for PCS licenses.

Ease of Use: The NTIA/Caltech conference also established that NTIA's proposed auction process would be easy to understand and use. Some commenters in this proceeding have argued that NTIA's proposal would not provide sufficient "price transparency," meaning that bidders would be incapable of deducing from the information provided how much they needed to raise their bids in order to win a particular license. That simply is not the case. In the live demonstration on January 28, in which 10 bidders used AUSM to bid on 54 licenses, the bidders were able to determine rapidly from the information provided on their computer screens how to combine their bids with those of other parties to outbid the current "winning bid" and thereby achieve the optimal efficient allocation.[6/] We believe that prospective bidders in actual PCS auctions could be trained to

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5/ A copy of GTE's viewgraphs is provided in Attachment 3. See also Ex Parte Letter from Carol L. Bjelland, Director, Regulatory Matters, GTE Service Corp., to Acting Secretary William Caton, Federal Communications Commission (Feb. 22, 1994).

6/ The "stand-by queue" feature of AUSM allows parties seeking individual licenses to coordinate their bids in order to beat the currently prevailing bid for a combination of licenses. The stand-by queue displays the amount that other bidders are willing to pay for the licenses that are part of a combination bid. A bidder can determine from the sum of these amounts how much to raise his or her own bid in order to surpass the current winning bid.

use similar software just as effectively,[7] and we reiterate our recommendation in the November 10 comments that the Commission conduct such training.

Other commenters have expressed concerns about the "continuous" nature of NTIA's proposal, arguing that it would be difficult for bidders to participate continuously in tracking and updating their bids. The EICA would not have to run 24 hours a day, however, in order to retain its advantages. Rather, it would be preferable to operate the EICA for several hours per day -- in effect, a continuous auction during scheduled daily periods -- in order to give bidders ample time to consider and update their bidding strategies, and confer as necessary with their bidding partners.

Freedom from Bias: We also believe that NTIA's auction proposal is superior to the others proposed in terms of minimizing bias in the auction process, a key element of ensuring a fair auction. Because bidders would be free to bid on individual licenses or groups of licenses, the auction would not be biased towards one type of bidder over another. Some critics of NTIA's proposal have argued there would be a "free rider" problem for bidders seeking to combine their small combinatorial bids to supplant a large combinatorial bid.[8] This concern was not borne out by the experimental results, even in the 10-bidder/54-license environment. We found that bidders for small groups of licenses were able to coordinate their bids through the stand-by queue to outbid larger combination bids in those instances in which the sum of the valuations for the small bidders was greater than that of the large bidder.

In contrast, if the Commission chooses to define in advance the combinations on which a bidder may bid, it will automatically create an advantage for bidders that are interested in obtaining a permissible combination, and arbitrarily disadvantage those interested in combinations

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7/ We note that the student subjects had used the software in the 54-license environment for only one week prior to the demonstration. Presumably bidders for actual PCS licenses would be willing to invest an equivalent amount of time before bidding on licenses potentially worth millions of dollars.

8/ In this environment, critics argue, each small bidder prefers to let other bidders bear the lion's share of the burden of raising the small combination bids to overcome the large combination bidder.

that are not permitted. For example, Dr. Plott at Caltech found that when a sealed combination bid for all licenses is permitted prior to a sequential Japanese auction, the outcome of the auction is biased toward the bidder making the combination bid. In several instances, this bidder won the auction even though its valuation for the group of licenses was lower than the sum of the highest individual valuations.

A simultaneous-independent auction process would be biased against bidders that are interested in acquiring groups of licenses. In Dr. Plott's simultaneous-independent experimental trials, bidders seeking to win all of the licenses in the group frequently were unable do so, even when the combinatorial value for the group of licenses exceeded the sum of the values for the individual licenses. In several instances, the bidder that placed a high value on a combination of licenses did not attempt to assemble the package for fear of losing money by assembling only part of the package. In other cases in which the bidder with a high valuation for a combination did obtain all the licenses desired, it did so at a price higher than the sum of the highest valuations for the individual licenses. This indicates that some bidders were willing to bid above their valuations for individual licenses in an attempt to drive up the price paid by the bidder trying to obtain the entire group.

Economic Efficiency: The NTIA/Caltech conference also demonstrated that our proposed auction form is most likely to assign licenses to those that value them the highest, so that it is economically efficient. As noted above, we believe that there will be increasing returns to scale in acquiring a package of more than one PCS license, and bidders are likely to have overlapping preferences for such packages of licenses. It therefore is critical that PCS licenses be assigned through a process in which bidders are allowed to bid on a variety of groups of licenses.

This view was borne out by the Caltech experiments. NTIA's proposal consistently resulted in a more efficient allocation than any of the alternatives tested. In the experiments involving 10 bidders bidding on 54 licenses, 100% average efficiency was achieved when an EICA was conducted using the AUSM software, meaning that all the licenses were won by the subject that valued them the most. A 92% average efficiency rate was achieved using AUSM in environments with fewer bidders and fewer licenses (a 3-bidder/3-license environment and a 5-bidder/6-license environment), meaning that the valuations of the parties that won the licenses represented 92% of the valuation associated with the optimal allocation.

In contrast, the sequential Japanese auction produced less efficient results. When Dr. Porter tested the sequential auction in a 3-bidder/3-license environment, and a 5-bidder/6-license environment, that auction mechanism achieved an average efficiency of 84% and 57%, respectively, compared to a 92% average efficiency for NTIA's proposed auction mechanism. The less efficient allocation in a sequential auction can be explained by the fact that bidders are uncertain about the value of licenses to be auctioned later in the sequence, and consequently are unable to decide how to bid in the earlier rounds. Moreover, Dr. Plott found that when a sealed bid for all the licenses exists and is known to the bidders, those bidders who have won individual licenses early in the sequence have an incentive to bid above their valuations for the licenses auctioned later in the sequence to ensure that they defeat the sealed bid. Such a strategy harms bidders who win licenses auctioned in later rounds and can also lead to an inefficient assignment.

Similarly, the simultaneous-independent auction mechanism did not match the efficiency of NTIA's proposed auction form in any of the environments tested. For instance, in the 10-bidder/54-license environment, the simultaneous-independent auction achieved an average efficiency of 93%, compared to 100% for NTIA's EICA. In the 5-bidder/6-license environment, the simultaneous-independent auction achieved an average efficiency of 64%, compared to 92% for NTIA's EICA. This lower efficiency may be due, however, to the strict bid withdrawal rule used in those experiments.

Finally, we found that NTIA's EICA outperformed the other auction mechanisms in terms of revenue generation in virtually every instance. For instance, in the 10-bidder/54-license environment, average revenues were approximately 32% higher in the experimental trials using AUSM as opposed to the experiments involving a simultaneous-independent auction form.

<u>Conclusion</u>: We continue to believe that an EICA is a feasible, fair, and efficient way of meeting the Commission's objectives in awarding PCS licenses. The NTIA/Caltech presentation demonstrated its strengths relative to other proposed auction forms. For the reasons stated above, and in our

November 10 comments, we urge the Commission to adopt such a mechanism.

Sincerely,

Larry Irving

Attachments

cc: Secretary, Federal Communications Commission (two copies)
Commissioner Andrew C. Barrett
Commissioner James H. Quello

Attachment 1

PERSONAL COMMUNICATIONS SERVICES AUCTION: FURTHER ANALYSIS

Office of Policy Analysis and Development

Staff Paper

By

Mark Bykowsky & Robert Cull

with assistance from William F. Maher, Jr.

February 28, 1994

National Telecommunications and Information Administration

The views expressed herein are those of the authors, and do not necessarily reflect the views of the National Telecommunications and Information Administration nor the California Institute of Technology. The authors would like to thank Carol Mattey, Cynthia Nila, and Tim Sloan for their assistance in preparing this paper.

Table of Contents

I. Introduction 3

II. Feasibility of NTIA's EICA 5

III. Clarifications Regarding NTIA's Proposal 8

IV. PCS Assignment Mechanisms: Non-Combinatorial Versus Combinatorial Auctions 11
- A. Package-Induced Returns to Scale 12
  - 1. Theoretical Analysis 14
  - 2. Interpretation 18
- B. Heterogeneity in Bidder Preferences 20
  - 1. Theoretical Analysis 25
  - 2. Interpretation 31
- C. Merging Experimental Economics with Economic Theory 32

V. Overview of Experimental Results 33
- A. Sequential Auctions and Economic Efficiency 40
- B. Bias in PCS Auction Outcomes Due to Limitations on Packaging 43
  - 1. Sequential and Simultaneous-Independent Auctions 43
  - 2. Simultaneous-Combinatorial Auctions 47

Appendix A: Dr. Charles Plott's Experimental Designs
Appendix B: Dr. David Porter's Experimental Design (3x3)
Appendix C: Dr. David Porter's Experimental Design (5x6)
Appendix D: Dr. David Porter's Experimental Design (10x54)

List of Tables

TABLE 1: HYPOTHETICAL VALUATIONS - No Returns to Scale . . . 15
TABLE 2: HYPOTHETICAL VALUATIONS - Returns to Scale in (AB) 16
TABLE 3: HYPOTHETICAL VALUATIONS - Returns to Scale and Bidder Heterogeneity 26
TABLE 4: PERFORMANCE OF VARIOUS AUCTION MECHANISMS IN DIFFERENT ENVIRONMENTS 41
TABLE 5: FREQUENCY OF CORRECT PACKAGE ASSEMBLY 46
TABLE 6: EFFICIENCY COMPARISONS BETWEEN SEQUENTIAL JAPANESE AND SIMULTANEOUS-INDEPENDENT AUCTIONS 47
TABLE 7: EFFICIENCY AND REVENUE COMPARISONS BETWEEN AUSM AND SIMULTANEOUS-INDEPENDENT AUCTIONS 49

I. Introduction

The Federal Communications Commission (Commission) is required to begin assigning Personal Communications Services (PCS) licenses, through the use of an auction, by the 7th of May, 1994. While there exists consensus among the interested parties regarding the principles that should guide the Commission in selecting such an auction, there is general disagreement on the auction form that best satisfies these principles. Based upon our analysis of the reply comments in this proceeding and experimental work sponsored by NTIA, we believe that the design proposed in NTIA's initial comments -- an electronic iterative combinatorial auction (EICA) -- has the greatest likelihood of assigning PCS licenses in an economically efficient manner.

The EICA proposal received significant attention from commenters, many of whom expressed concerns regarding its feasibility, complexity, and economic desirability. To address these issues, NTIA sponsored research and a conference at the California Institute of Technology (Caltech) on January 27 and 28, 1994.

Presentations at the NTIA/Caltech conference discussed the feasibility and availability of: (1) software that permits combinatorial bidding as recommended by NTIA, (2) an electronic bidding network that permits such bidding, and (3) computing

capability that can process such bidding information. We believe that these presentations demonstrated the feasibility of the EICA.

The conference also included a presentation by Dr. John Ledyard of Caltech, who discussed the economic conditions under which a simple (i.e., non-combinatorial) auction would have difficulty assigning PCS licenses in an economically efficient manner. Drs. Charles Plott and David Porter of Caltech presented results involving economic experiments that shed important light on the performance characteristics of sequential, simultaneous-independent, and simultaneous-combinatorial auctions. The presentations by these experimentalists demonstrated the important problems associated with employing a sequential auction and the advantages of employing a simultaneous auction. Moreover, these presentations showed the importance of using a combinatorial auction in diverse experimental environments.

This paper describes our most recent analysis of the auction design issues involving PCS licenses. This analysis incorporates the results of the Caltech investigators' recently completed research and the information presented at the conference by GTE Service Corporation, the Pacific Stock Exchange, and the financial house, Cantor Fitzgerald. We believe that the market conditions that result in problems with the use of a non-combinatorial auction will exist in the PCS auction environment. Even if such conditions do not exist, a simultaneous-combinatorial auction appears to

perform better than other auction proposals under a variety of bidding environments.

II. Feasibility of NTIA's EICA

The NTIA/Caltech conference addressed concerns that the EICA proposal could not be implemented quickly enough for use in the PCS auction by the Commission. Experts from Caltech demonstrated its Adaptive User Selection Mechanism (AUSM) software for use in a multiple-unit combinatorial auction for 54 items. This software enabled bidders (Caltech students) at ten remote locations to submit bids electronically for any combination of the 54 items they desired.[1/] Each bidder had its own computer screen that displayed the current winning bids and the non-winning standing offers of all other bidders. One of the bidders was situated in an auditorium; its computer screen was projected onto a larger screen so that the audience could follow the progress of the auction.[2/] Based on the information contained on the computer screens, bidders were able to determine how to combine their bids with those of other parties to

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1/ Using this software in the PCS auction, bidders would choose the "packages" of licenses on which they bid. The Commission would not have to so choose. As will be demonstrated below, when combinations are determined by the bidders, auction outcomes are "unbiased" (i.e., the auction does not favor one type of bidder over another). However, when the auctioneer pre-specifies allowable combinations, it can unwittingly disadvantage some bidders relative to others. Note that if the Commission were to permit bids on only single items, auction outcomes would be biased in favor of those that wanted small combinations. In short, any limitations on combinations can bias auction outcomes.

2/ Some audience members accompanied the other nine bidders to their respective remote locations to view the auction.

outbid the current "winning bid" and thereby achieve the optimal efficient allocation of the 54 items.

The Caltech researchers indicated that the AUSM software could be altered quickly for use in the PCS auctions, especially in instances where relatively few licenses are being auctioned. For example, the Caltech software could be used on very short notice to conduct a combinatorial auction for the eleven national narrowband licenses. Similarly, experts from Caltech stated that the AUSM software could be altered to handle the auction of the 102 broadband Major Trading Area (MTA) licenses (Blocks A and B) within a reasonable period of time.[3/] With additional time, the Caltech group could alter its software to handle larger groups of licenses (500 Basic Trading Area (BTA) licenses at a time, for example).[4/]

3/ Because Blocks A and B are so similar within a given MTA, altering the software is largely a matter of doubling the number of items in the present software. It should be noted that the reason the demonstration used 54 licenses instead of 102 is not because of software limitations, but because the valuations created for the experiment did not provide for sufficient competition among the ten bidders for all 102 licenses. If Caltech had ten more remote bidding sites available for the demonstration, the demonstration would have involved 108 licenses. Note also that 54 licenses were used instead of 51 in order to simplify the problem of generating bidder valuations. This, too, was in no way a limitation of the software, but a limitation of the competitive environment that NTIA created for experimental purposes.

4/ Some participants at the demonstration, however, expressed concern that as the number of the licenses increases, it becomes more difficult for the bidders to sort through an important feature of AUSM known as the stand-by queue. The stand-by queue enables a bidder to publicly announce via a computer bulletin board its willingness to pay a certain price for a designated combination. Bids in the stand-by queue, by definition, are <u>not</u> part of the revenue-maximizing allocation.

Installing software that can accommodate combinatorial bidding in an electronic bidding network is also achievable within a reasonable period of time. At the NTIA/Caltech conference, GTE, the Pacific Stock Exchange, and Cantor Fitzgerald explained how a secure bidding network is available for conducting PCS auctions. Caltech indicated that it could enter into a consortium with such firms to conduct the auction.

In short, the NTIA proposal stands out among others because its feasibility has been demonstrated. Moreover, as discussed in Section V, our proposal has performance characteristics in a variety of experimental settings that are superior to the other major auction proposals . Sequential auctions produced relatively inefficient allocations in a variety of experimental environments. Similarly, the performance of a "simultaneous-independent" auction[5/] appears quite sensitive to the type of bid withdrawal rule employed and the bidding environment in which it was tested.[6/]

Caltech indicates that its software could be altered to enable bidders to sort through the queue relatively easily, even for large numbers of licenses. For example, in the 54-item demonstration, the software enabled bidders to sort quickly through the queue by region.

5/ For purposes of this document, a "simultaneous-independent" auction is one in which bidders can only submit bids on individual licenses.

6/ We do not suggest that simultaneous-independent mechanisms are generally undesirable, but rather that more experimental work needs to be done on bid withdrawal rules. Similarly, additional experimental work on stopping rules for AUSM and for simultaneous-independent mechanisms would be useful. We note that these experiments could coincide with development of the software necessary to conduct the auction.

III. Clarifications Regarding NTIA's Proposal

Before discussing theoretical and experimental issues, we wish to respond to reply comments regarding two important issues. The first is whether a bidder in the proposed combinatorial auction would be able to deduce the price at which its bid would become part of the bid or set of bids that currently is winning -- that is, the "provisional revenue maximizing allocation". As these commenters phrased it, did NTIA's proposal offer bidders sufficient "price transparency"?[7]

We remain convinced that the price transparency offered by AUSM is sufficient to produce efficient allocations. As demonstrated at Caltech, at any point in the auction, the current provisionally accepted allocation is displayed on the computer screens of all bidders. The provisional allocation indicates each combinatorial bid that has been accepted, the amount of the bid, and the identity of the bidder. If a bidder wished to submit a type of combinatorial bid that has already been provisionally accepted, it would merely consult the provisional allocation for the appropriate price.

7/ See, e.g., Barry J. Nalebuff & Jeremy I. Bulow, "Response to PCS Auction Proposals" at 9-10 (attached to Reply Comments of Bell Atlantic Personal Communications, Inc. in PP Docket No. 93-253 (filed Nov. 10, 1993)) ("Nalebuff & Bulow"). Unless otherwise indicated, all subsequent citations to "Comments" or "Reply Comments" shall refer to pleadings filed in PP Docket No. 93-253.

Suppose the bidder wished to submit a type of combinatorial bid that was not already part of the provisionally accepted allocation. The bidder would search through the auction's stand-by queue, which is displayed on its computer screen, to find other combinatorial bids that did not overlap with its own, and that, when added to its bid, would bump other bids out of the provisionally accepted allocation.[8/] In the 54-item auction demonstration in January, bidders (Caltech students) used the stand-by queue to figure out how they could combine their bids with those of other bidders to "knock out" provisionally accepted bids and achieve the most efficient allocation.[9/]

We emphasize that, during the course of the experiment, these students calculated their strategies by hand (i.e., they had no computing resources available to them) and had been acquainted with the 54-unit environment for only a week. Actual bidders in the PCS auctions presumably could be trained to use this software

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8/ In the demonstration, the bidders did their own searching and calculating. We note, however, that AUSM could be altered to do the searching and the calculating for the bidders. In the 54-unit example, the bidders did not require this feature to achieve the efficient allocation.

9/ Some commenters have suggested that the huge number of potential combinations could make a combinatorial auction too complex for bidders. See, e.g., R. Preston McAfee, "Auction Design For Personal Communications Services: Reply Comments" at 14-16 (attached to Reply Comments of PacTel Corp.) ("McAfee"). Under NTIA's proposal, an easy way to handle this problem is to limit the number of bids that any one bidder can have in the stand-by queue at any time.

effectively, especially in environments with relatively few licenses to be auctioned.[10/]

The second point to be clarified is the use of the term "iterative" in describing the EICA. In informal communications with NTIA, some parties expressed concern that bidding would proceed too quickly for them to make informed bidding decisions if conducted in a continuous (i.e., oral-like) fashion. In light of these concerns, we now believe that a reasonable way for the auction to operate would be continuously for several hours a day, with overnight pauses. This offers two major advantages. First, bidders would have ample time (e.g., overnight) to consider and update their respective strategies and to confer with their bidding partners. Second, because bids would not arrive in large batches, but one at a time, the AUSM software would be assured of finding the current revenue maximizing allocation.[11/] By contrast, if bids arrived in a large batch, sorting through all bids to find the correct provisional allocation could place an unnecessary burden on the software.[12/]

10/ Because of time constraints, attendees at the Caltech conference had only a limited amount of time to observe the 54-unit demonstration. Increased exposure to the software presumably would improve bidders' dexterity.

11/ When bids arrive continuously, the probability that any two will arrive at exactly the same instant is zero. This provides a sequence in which bids are processed by the algorithm.

12/ Another way to think about this problem is that if bids do not arrive one at a time, the algorithm must sort through all possible sequences in which the bids could have arrived to

IV. PCS Assignment Mechanisms: Non-Combinatorial Versus Combinatorial Auctions[13/]

Commenters generally agree that the Commission should, in selecting an auction mechanism, choose that auction mechanism that maximizes economic efficiency. Economic efficiency is maximized when PCS licenses are assigned to those bidders that value them the highest. In general, placing PCS licenses in the hands of such bidders will generate the greatest social benefit. As shown by Dr. Ledyard, the ability of a non-combinatorial auction to assign such licenses efficiently depends upon two features of the PCS bidding environment. Both of these features -- package-induced returns to scale and partial overlaps in the preferences that bidders have for combinations of PCS licenses -- appear to be important elements of the PCS auction environment. Because of the likely presence of these two features, both a sequential auction and a simultaneous-independent auction will have difficulty assigning PCS licenses to bidders that value them most.

Two different and separate factors contribute to this difficulty. First, by not allowing bidders to submit package bids, both sequential and simultaneous-independent auctions expose

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find the correct provisional allocation. If the sequence is known, a bid submitted at time (t) is compared to the allocation at time (t-1) to determine whether the bid should be part of the current allocation. If the sequence is unknown, the algorithm has no time (t-1) allocation to use for purposes of comparison.

13/ The material presented in this section is based largely on the research conducted by Dr. John Ledyard of Caltech.

bidders to financial risk in attempting to acquire a package of licenses. Second, given the valuations bidders have for PCS licenses, the possibility exists that there may not be a set of prices for the individual PCS licenses that satisfy the necessary conditions for the efficient assignment of such licenses. The following discussion describes these problems more formally.

A. Package-Induced Returns to Scale

The ability of a non-combinatorial auction to assign PCS licenses efficiently depends, in part, upon the degree to which there are returns to scale in owning multiple PCS licenses.[14/] Such returns to scale are present when the value a bidder places on a particular PCS license depends upon what other, for instance, geographically adjacent spectrum licenses it owns.[15/]

There appears to be general agreement among the commenters that package-induced returns to scale will be an important element

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14/ We have adopted Dr. John Ledyard's terminology in this section. Dr. Ledyard's phrase "returns to scale from packaging" is equivalent in meaning to the phrase "value interdependency" used in NTIA's previous work on this topic. See Mark Bykowsky & Robert J. Cull, "Issues in Implementing a Personal Communications Services Auction" at 58 (attached to Comments of NTIA) ("NTIA Staff Paper"). Both phrases refer to the synergies in PCS license value that stem from owning multiple PCS licenses.

15/ Geographic adjacency of PCS licenses may not be necessary in some cases. A cellular telephone company may obtain returns to scale in owning a package of non-adjacent PCS licenses because it may be able to combine such licenses with spectrum it owns in its cellular telephone service area.

of the PCS license bidding environment.[16] For instance, Milgrom and Wilson have observed that "value interdependency" may be the result of: (1) the desire of users to "roam" across PCS license boundaries; and (2) returns to scale that may be present as a result of fixed investments incurred by the PCS service provider.[17] Another source of such interdependency is the lower transactions costs associated with a firm's superior ability to resolve signal interference problems caused by transmissions from geographically adjacent licenses.

Many economic analyses in the record assume, either explicitly or implicitly, that such returns to scale from packaging exist. Indeed, several commenters assume that such returns create the

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16/ As NYNEX observes:

> [t]here can be no doubt that aggregation of licenses will take place. It will happen because the public will insist on it. The development of regional and national networks by cellular carriers and the development of a national ESMR network by Nextel are illustrative of what will likely occur in PCS markets.

Reply Comments of NYNEX at 9. See also R. Weber, "Comments on FCC 93-455: Notice of Proposed Rule Making: A Proposed Auction Methodology for the Allocations of PCS Licenses" at 2 (attached to Comments of Telephone and Data Systems); Comments of Ameritech at 4; Comments of Nextel at 9; Nalebuff & Bulow, supra note 7, at 26 n.21.

17/ See Paul Milgrom & Robert Wilson, "Replies to Comments on PCS Auction Design" at 9-10 (attached to Reply Comments of Pacific Bell and Nevada Bell) ("Milgrom & Wilson"). According to PacTel, value interdependencies appears to be an important element of the bidding environment for narrowband PCS licenses as well. See Letter from Kathleen Abernathy, PacTel, to William Cantor, Acting Secretary, FCC, Attachment at 2 (Jan. 25, 1993).

possibility that bidders may either default or may wish to withdraw their bids as a result of bidding too aggressively for individual PCS licenses in an attempt to obtain a collection of such licenses.[18/] We agree with the judgment of these parties, undoubtedly informed by practical experience, that value interdependencies will be an important element of the PCS bidding environment.

1. Theoretical Analysis

At the NTIA/Caltech conference, Dr. Ledyard showed that, under certain circumstances, the existence of such returns to scale will cause a non-combinatorial auction to assign items in an inefficient manner. We describe his analysis below. Table 1 describes a set of hypothetical bidder valuations for spectrum licenses A, B, and C, and different combinations of such licenses. For purposes of simplicity, the value of the packages is equal to the sums of their individual components. Suppose some entity must assign these licenses, through a non-combinatorial auction, to those bidders that value them the highest.

18/ See McAfee, supra note 9, at 8; Milgrom & Wilson, supra note 17, at 6.

TABLE 1: HYPOTHETICAL VALUATIONS - No Returns to Scale

Bidder	(ABC)	(AB)	(BC)	(AC)	A	B	C
#1	160	110	100	110	60*	50	50
#2	165	105	110	105	55	60*	50
#3	175	100	125	125	50	50	75*

* Denotes the economically efficient assignment.

In this environment, a combinatorial auction that permits bidders to submit package bids is not needed to maximize economic efficiency. A non-combinatorial auction can solve the problem and provide an unbiased outcome. The bidders with the highest valuations for each license will obtain such licenses at a price approximately equal to the second highest valuation.[19/] This solution, which involves Bidder #1, Bidder #2, and Bidder #3 receiving licenses A, B, and C, respectively, yields the highest total value (195), and revenue of approximately 155.[20/]

19/ Such an assignment has the important characteristic of being an "equilibrium assignment." In this instance, an assignment is an equilibrium assignment if, given existing prices, no bidder has an incentive to increase its price. The concept of an equilibrium assignment plays an important part in the analysis presented in Section IV-B.

20/ Olson and Porter provide evidence that a simultaneous-independent auction can efficiently assign (near 100 percent efficiency) licenses in this simple environment. See Mark Olson & David Porter, An Experimental Examination into the Design of Decentralized Methods to Solve the Assignment Problem With and Without Money, 4 Econ. Theory 11-40 (1994). The environment examined by Olson and Porter is mildly different from the likely PCS bidding environment. In their

Now, suppose all three bidders experience returns to scale in packaging licenses A and B together, and moreover, the entity responsible for designing the auction uses a simple auction to assign licenses A, B, and C.[21/] Table 2 describes an environment with returns to scale in the package (AB).

TABLE 2: HYPOTHETICAL VALUATIONS - Returns to Scale in (AB)

Bidder	(ABC)	(AB)	(BC)	(AC)	A	B	C
#1	250	200*	100	110	60	50	50
#2	200	150	110	105	55	60	50
#3	250	175	125	125	50	50	75*

* Denotes the economically efficient assignment.

Observe that economic efficiency is maximized when Bidder #1 obtains licenses A and B, and Bidder #3 obtains license C. We can analyze the difficulty a simultaneous-independent auction may have in efficiently assigning such licenses by considering the price constraints on P(A), P(B), and P(C) that must be satisfied if the

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experiments, participants desired only one item, whereas in the PCS environment, at least some bidders will wish to acquire multiple items (i.e., PCS licenses).

21/ The assumption that all bidders experience returns to scale in the same package affects the economic analysis. The manner in which this assumption affects the analysis is described in Section IV-B.

economically efficient assignment is to be an equilibrium assignment.[22/]

$$55 \leq P(A) \leq 150 \text{ (for Bidder \#1)}$$

$$60 \leq P(B) \leq 140 \text{ (for Bidder \#1)}$$

$$50 \leq P(C) \leq 75 \text{ (for Bidder \#3)}$$

$$175 \leq P(A) + P(B) \leq 200 \text{ (for Bidder \#1)}$$

$$200 \leq P(A) + P(B) + P(C) \leq 275 \text{ (for Bidders \#1 \& \#3)}$$

First, in order for Bidder #1 to receive license A, its bid must be equal to or exceed 55, the second highest stand-alone valuation for license A. Observe that, in this case Bidder #1 does not have to bid in excess of the first highest stand-alone valuation because Bidder #1 has that valuation. In addition, Bidder #1's bid must not exceed 150, which measures its maximum willingness-to-pay for license A, given that its stand-alone value for license B is 50. The reasoning is similar regarding license B. In order for Bidder #1 to obtain license B, its bid must equal or exceed the highest stand-alone valuation for license B (60). Moreover, its bid must not exceed 140, which measures its maximum willingness-to-pay for license B, given that its stand-alone value for license A is 60. A price constraint also applies to license C. To obtain license C, Bidder #3 must submit a bid that exceeds 50,

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22/ Recall that bidders are only allowed to submit bids for individual licenses (i.e., no package bidding).