District: Embracing Local Markets in Truthful Spectrum Double Auctions

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June 30, 2011

Why spectrum exchange market?

Legacy wireless providers → Sellers

Own the majority of spectrum

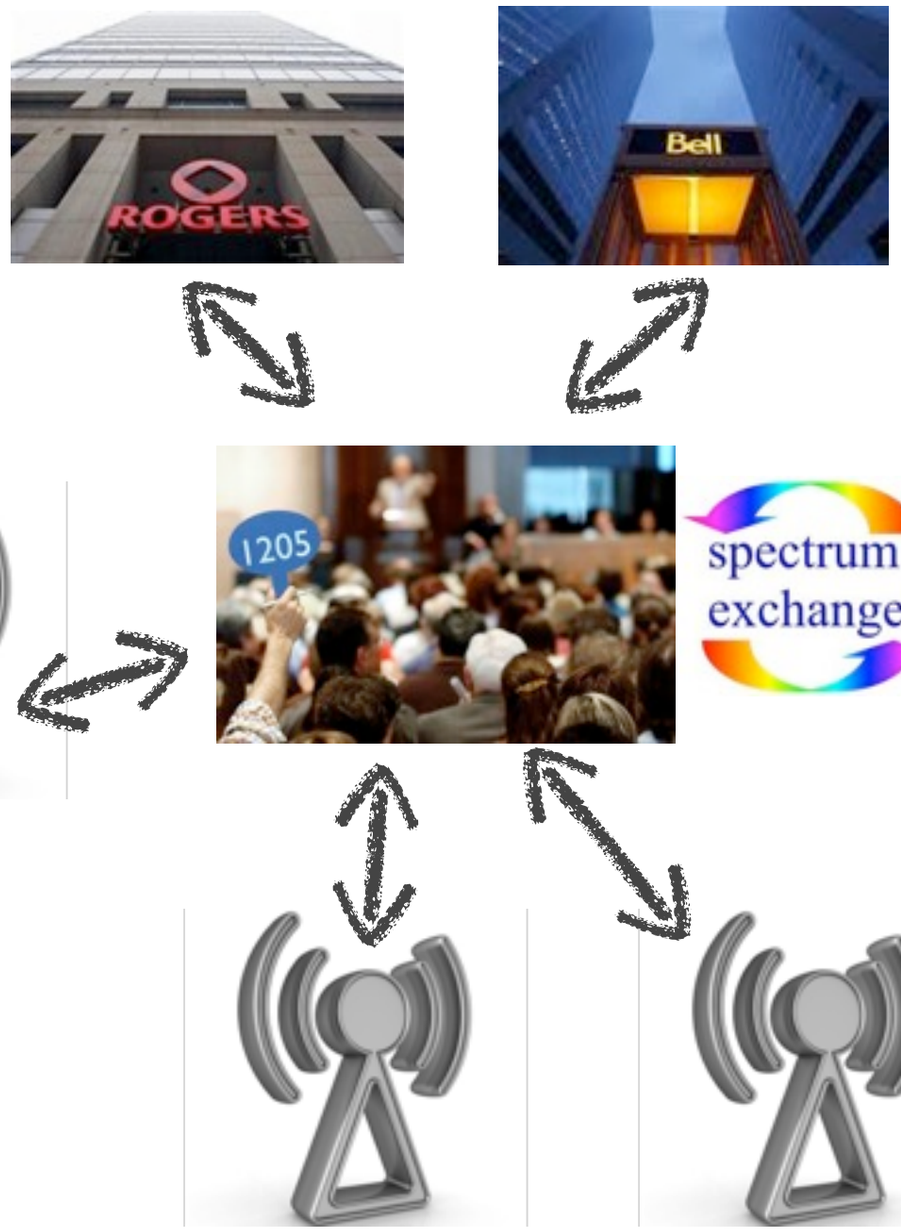
But cannot fully utilize them

New wireless providers → Buyers

Thirst for spectrum resources

Spectrum exchange market

Help to match transactions



Local resource

Spectrum is a local resource traded in local markets

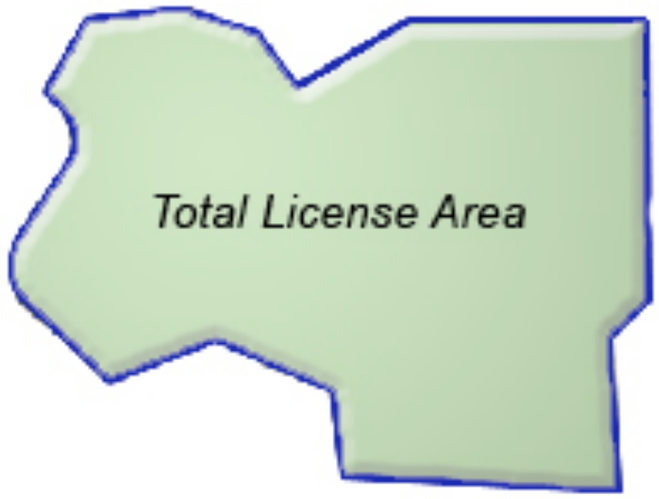
Spectrum license has a geographical region (local area)

Sellers own spectrum license in some regions

Take advantage of locality

Whole sale

Offer an entire license for sale



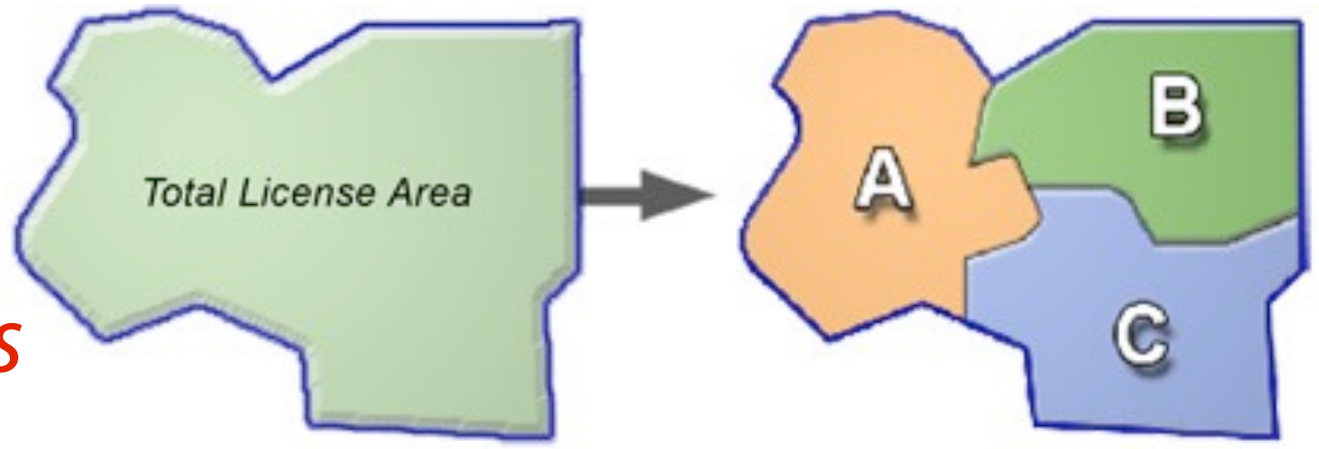
Partitioning

Partition entire license area into pieces

Sell any of them

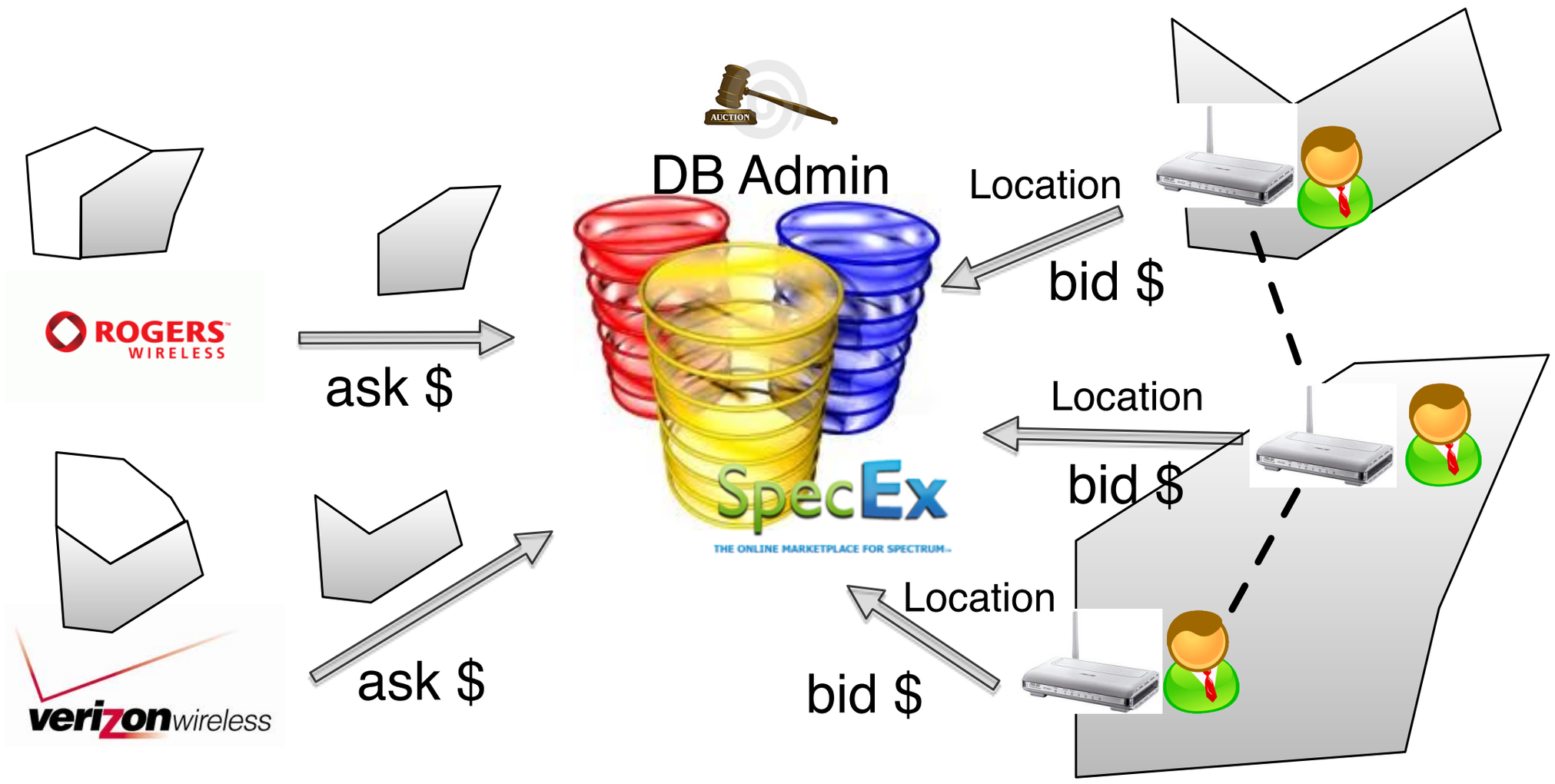
Benefits: Increase utilization

Both are supported in practical exchange markets (e.g., www.specEx.com)



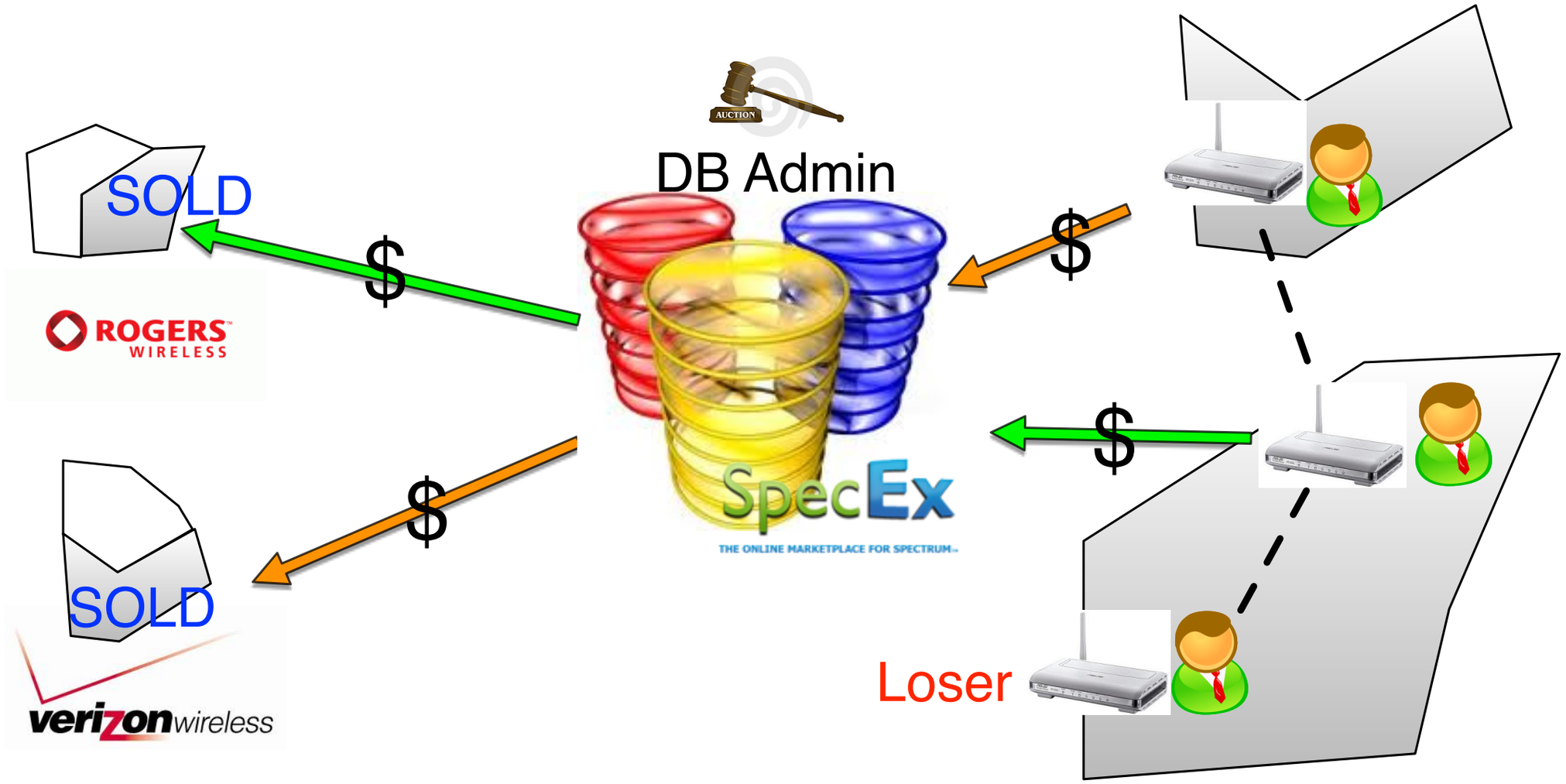
Practical database-driven spectrum markets

Bidding



Practical database-driven spectrum markets

Trade assignments



Make sure the assigned trades are within local markets and conflict-free

Basic economic properties of double auctions

Budget balance

Total payments to sellers $\leq$ total charges to buyers

Truthfulness

All sellers and buyers submit their true valuations

Individual rationality

Buyer pays less than its bid

Seller receives more than its ask

A gap between reality and literature

All proposed spectrum auctions are based on global markets

Sellers' spectrum is *globally* available to all buyers

Whole sale only, no license *partitioning* allowed

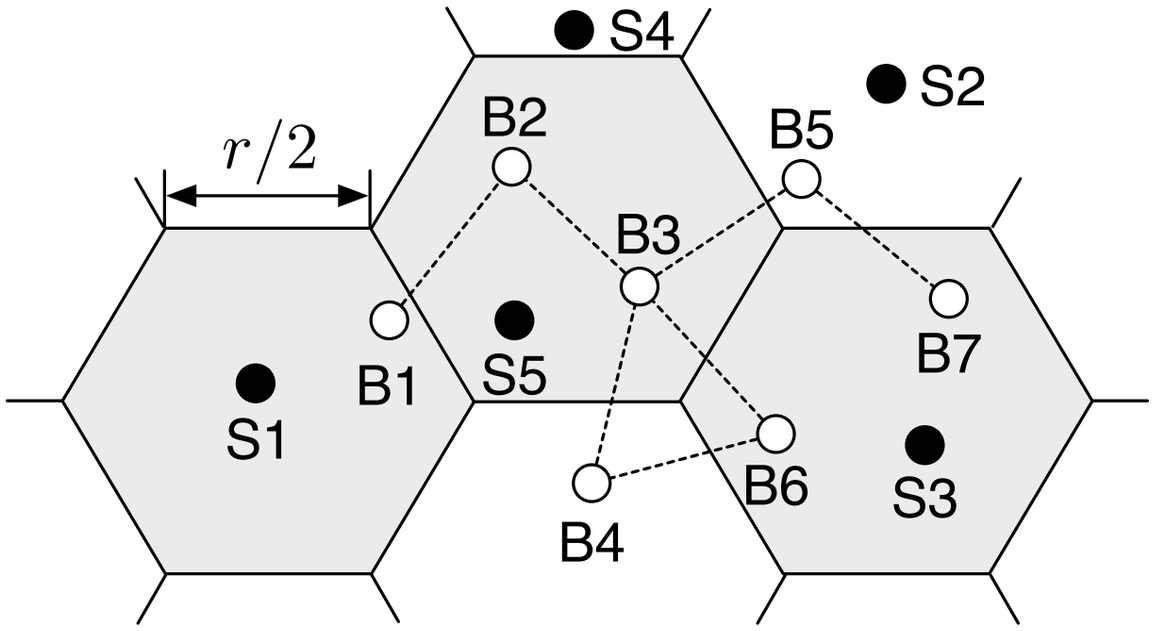
	Auction type	Budget balance	Truthfulness	Individual rationality	Spectrum reuse	Market type
VERITAS, *MobiCom'08*	Single	--	Yes	Yes	Yes	Global
Jia et al., *MobiHoc'09*	Single	--	Yes	Yes	Yes	Global
TRUST, *INFOCOM'09*	Double	Yes	Yes	Yes	Yes	Global
TODA, *DySpan'10*	Double	Yes	Yes	Yes	No	Global
Xu et al., *INFOCOM'10*	Double	Yes	Yes	Yes	No	Global

Market locality challenges

Auction efficiency

η = # of winning buyers / # of total buyers

Direct extension either breaks economic properties or results in low efficiency



Direct extension to TRUST

Our goal:

A spectrum double auction with
local markets and high efficiency

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District

	Auction type	Budget balance	Truthfulness	Individual rationality	Spectrum reuse	Market type
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Xu et al., *INFOCOM'10*	Double	Yes	Yes	Yes	No	Global
District, SECON'11	Double	Yes	Yes	Yes	Yes	**Local**

Two designs

District-U

Uniform pricing: all winning buyers/sellers face the same price

No *a priori* information needed

District-D

Price discrimination: different winners face different prices

Require *a priori* information

	A priori info	Efficiency	Budget balance	Truthfulness	Individual rationality	Spectrum reuse	Market type
District-U	No	Medium	Always	Yes	Yes	Yes	Local
District-D	Yes	High	In expectation	Yes	Yes	Yes	Local

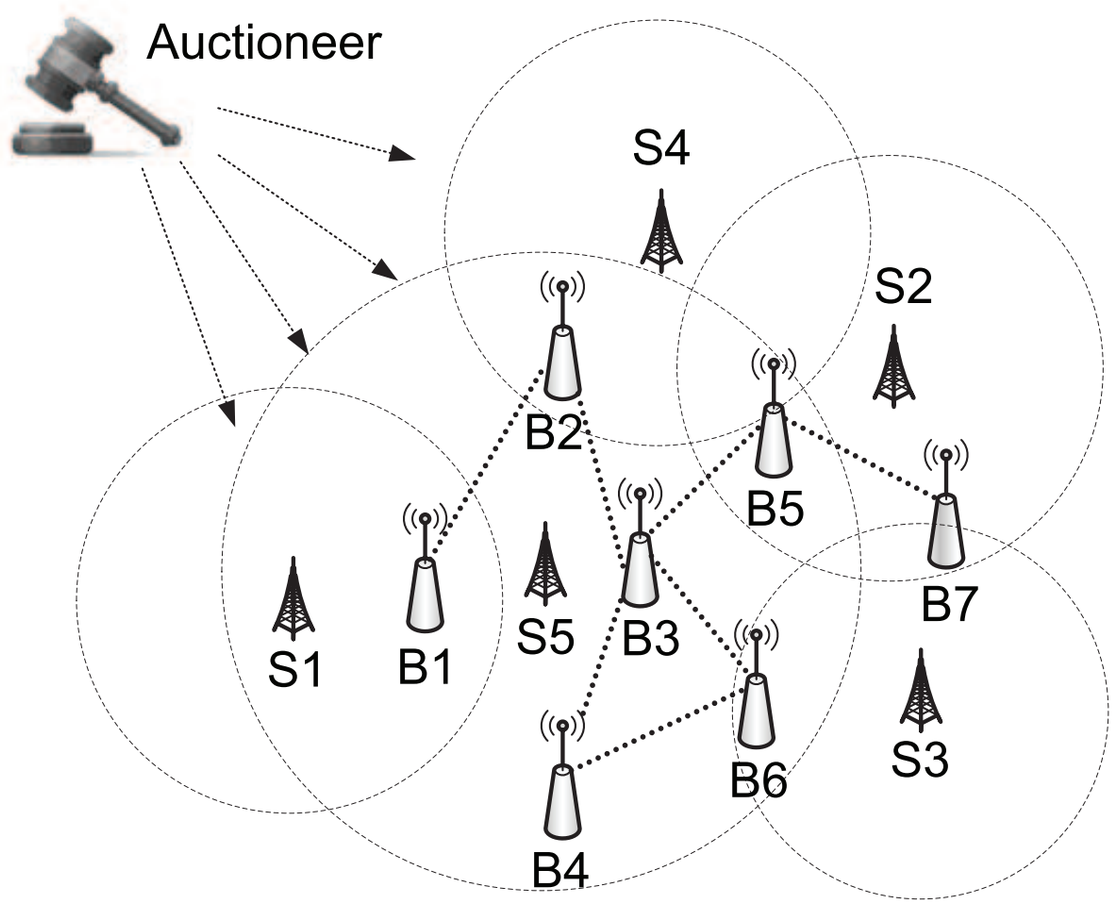
District-U

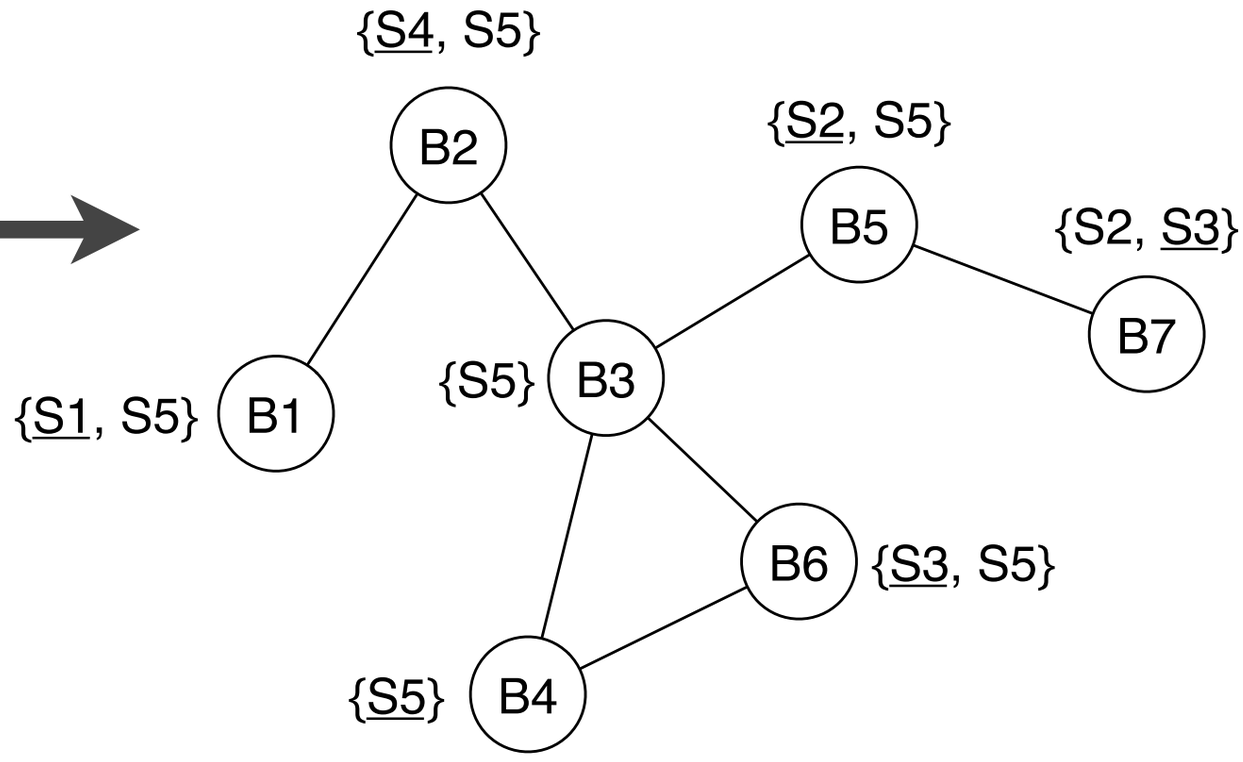
District-U

The trade matching is equivalent to graph colouring if no economic properties are considered

Node = buyer

Colour = seller





Guarantee economic properties

Use *trade reduction* to explicitly remove unprofitable transactions, i.e., remove nodes and colours from the graph

Colour the remaining graph to assign transactions

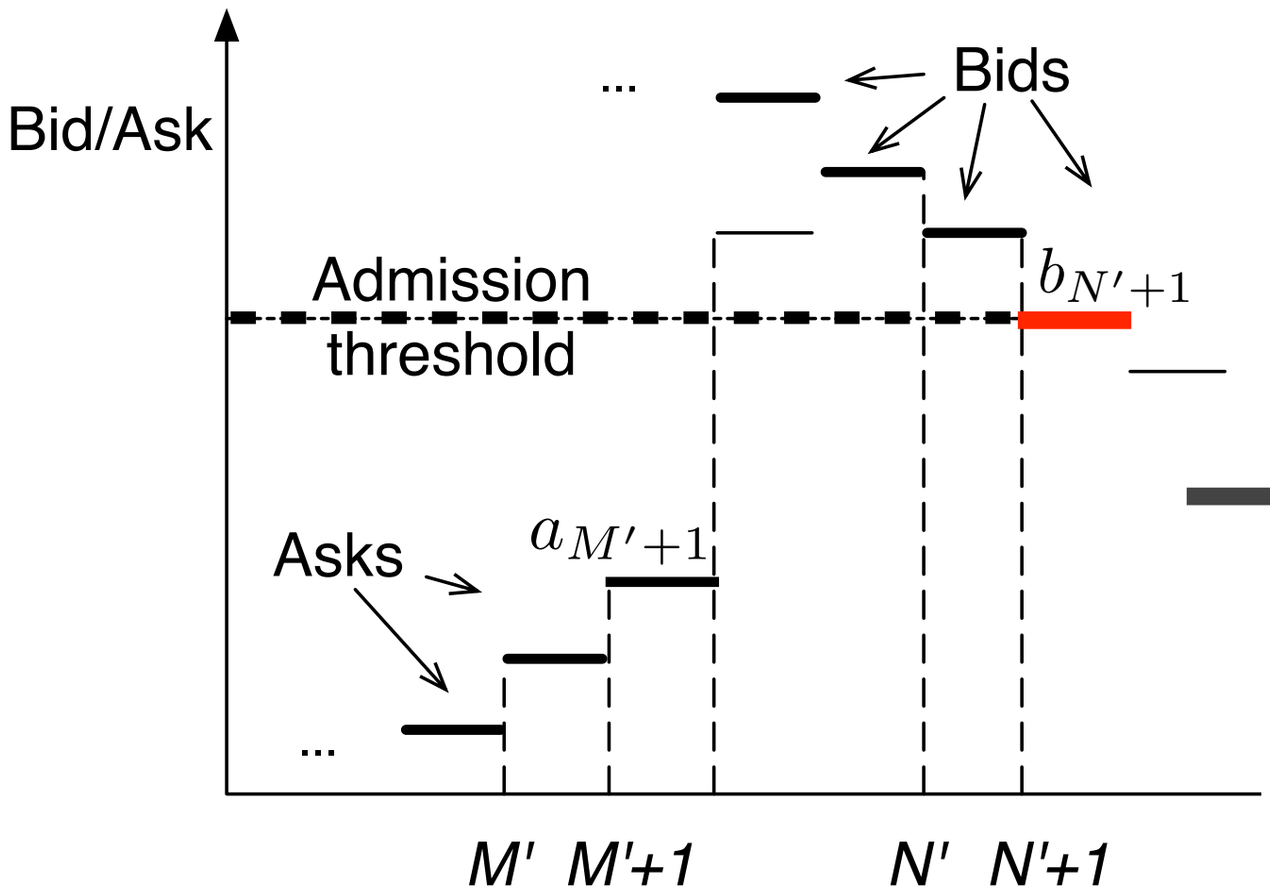
Calculate the uniform prices for winning buyers/sellers

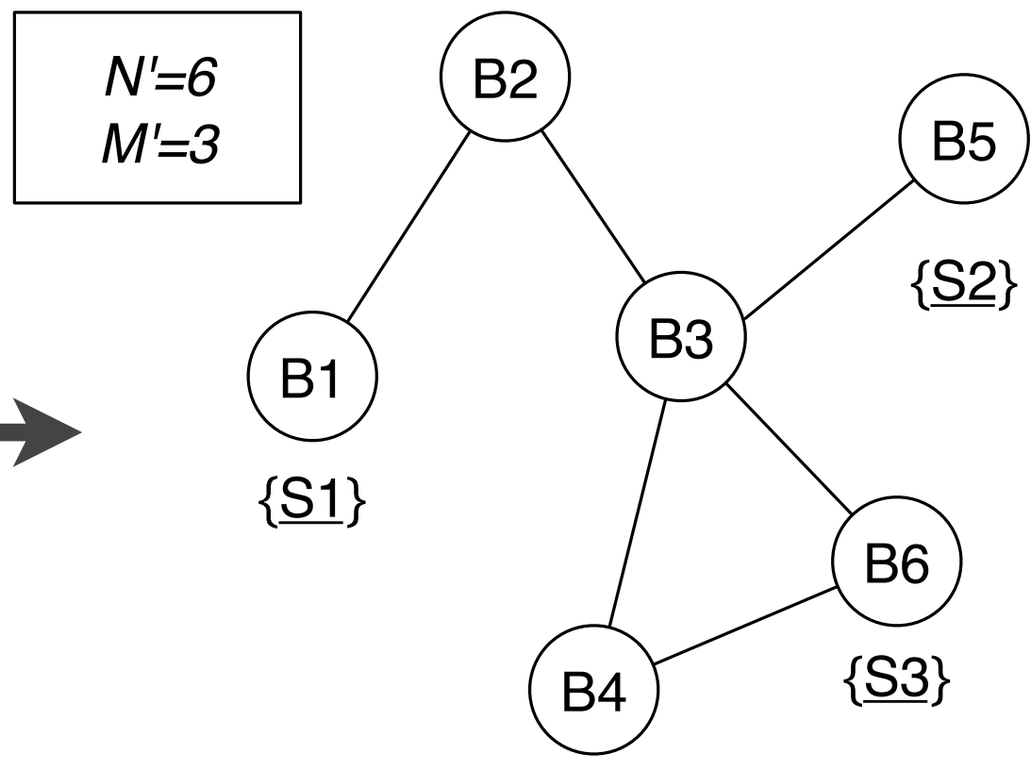
Trade reduction

A predefined admission rate *r*

For *N* buyers, we admit top $N' = N \cdot r$

Use (*N'*+1)-th bid as an admission threshold for sellers

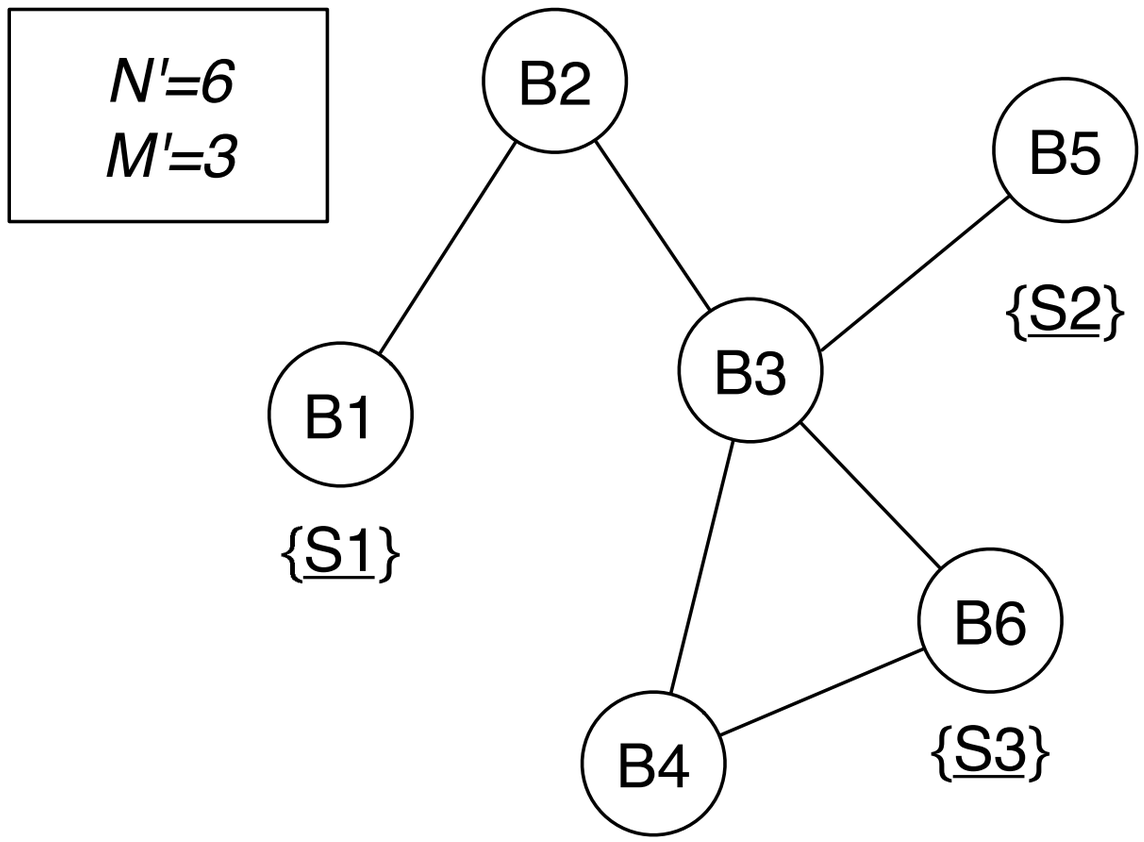




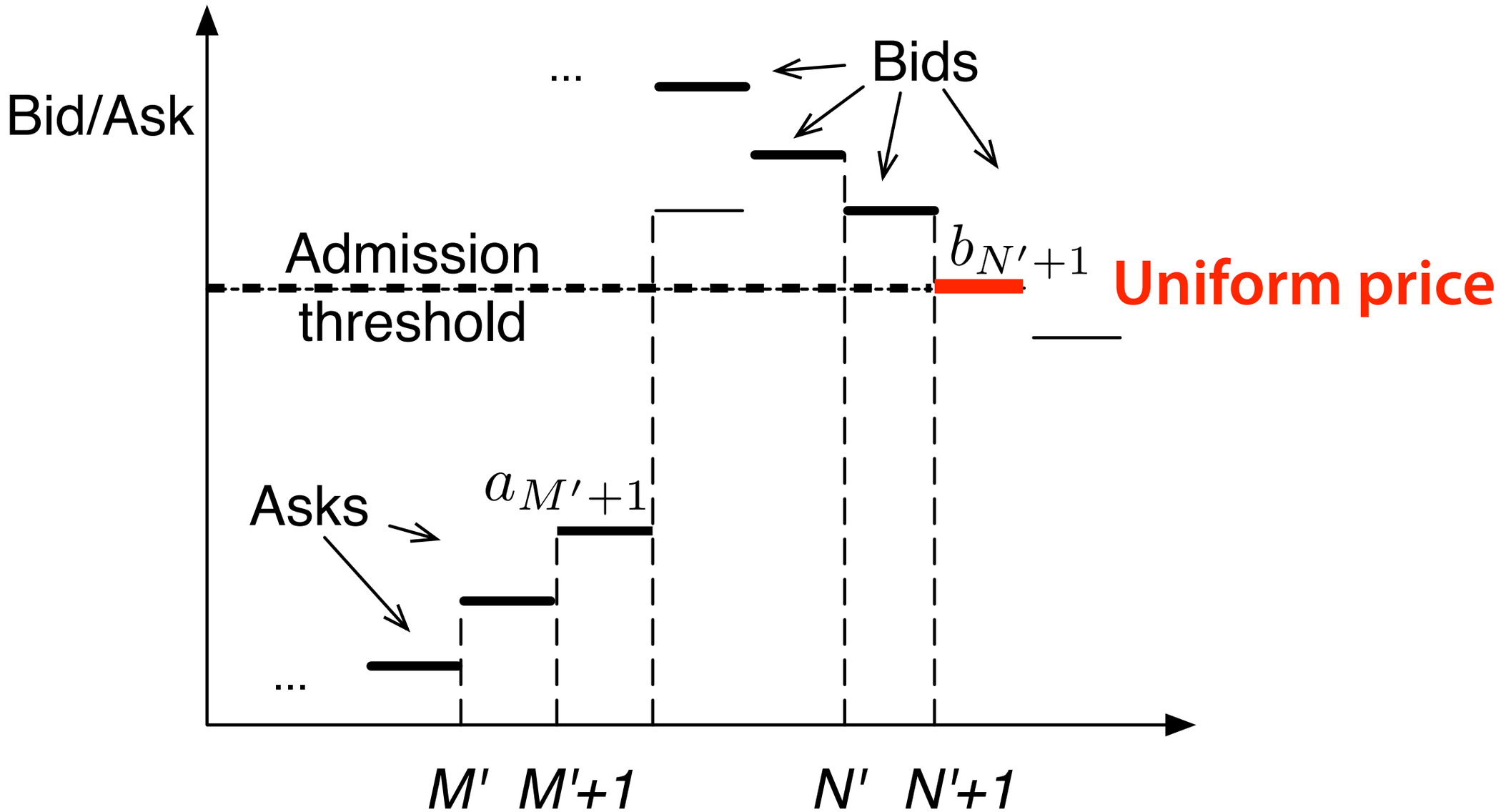
Colour the remaining graph

Assign transactions using *graph colouring*

Any deterministic graph colouring algorithm is accepted



Calculate uniform prices



District-D

	A priori info	Efficiency	Budget balance	Truthfulness	Individual rationality	Spectrum reuse	Market type
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District-D

If bid distributions are known, we have a high-efficiency solution

Extend Myerson's *Revenue Equivalence Theorem* to double auctions

Spectrum auction design $\Longleftrightarrow$ weighted graph colouring

Node *n* has a weight: buyer *n*'s virtual valuation $\phi_n(b_n)$

Colour *m* has a weight: seller *m*'s virtual valuations $\psi_m(a_m)$

Weighted sum of a colouring: auctioneer's revenue

$$W(G) = \sum_{n=1}^{N} \phi_n(b_n) \cdot x_n - \sum_{m=1}^{M} \psi_m(a_m) \cdot y_m$$

District-D (cont'd)

Budget balance $\Longleftrightarrow$ **Non-negative weighted sum**

High efficiency $\Longleftrightarrow$ **colour as many nodes as possible**

Winner determination

Greedily colour a graph while maintaining a non-negative weighted sum

Pricing

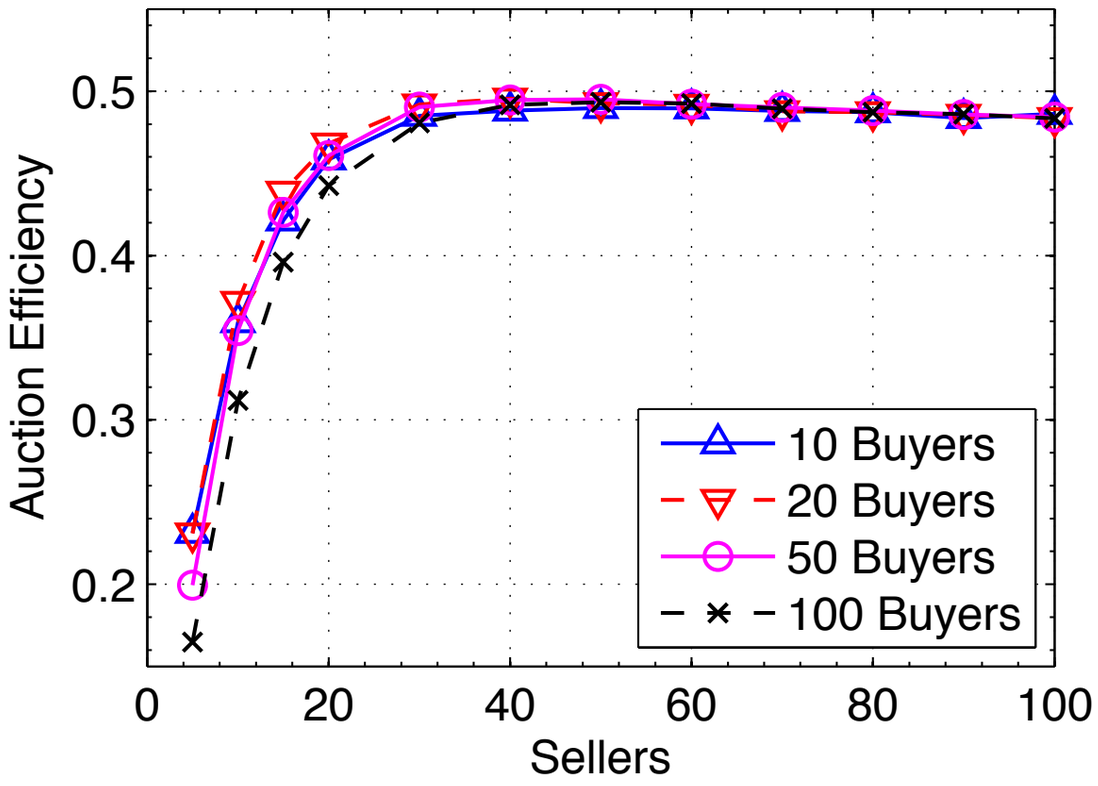
Calculate critical price for each winner

Different winners face different prices

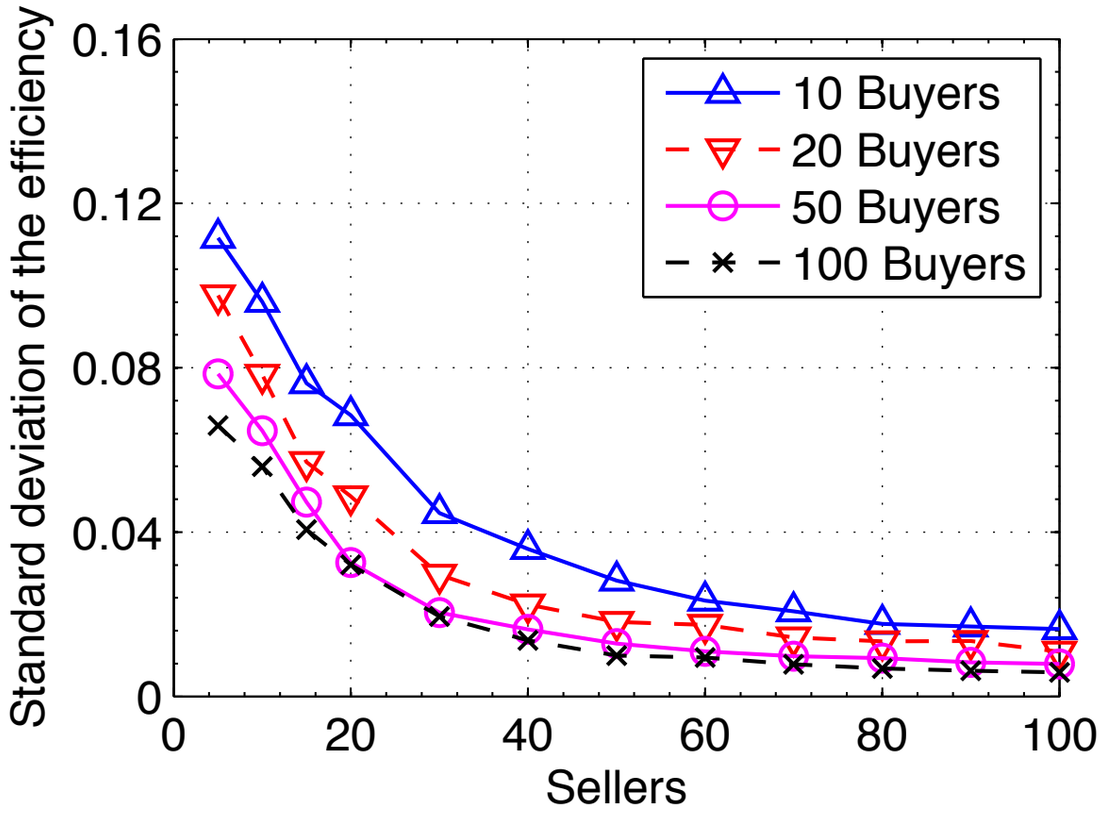
Evaluations

District-U

Predefined admission rate = 50%

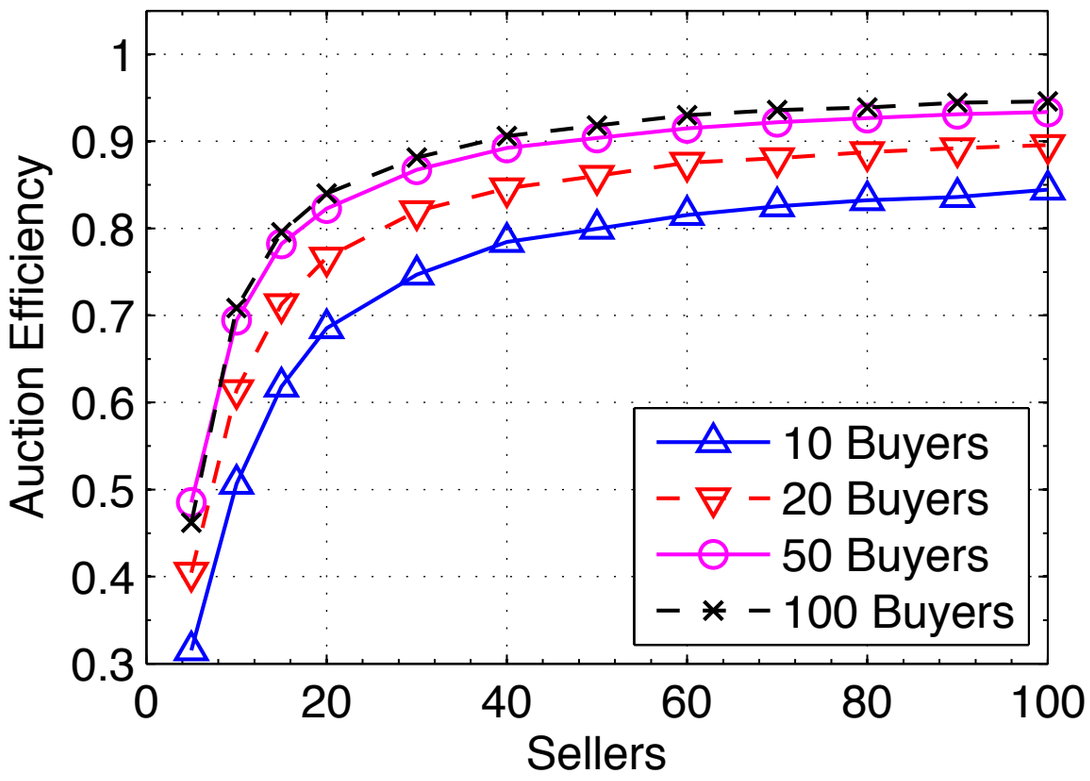


(a) Mean auction efficiency η.



(b) Standard deviation of the auction efficiency.

District-D



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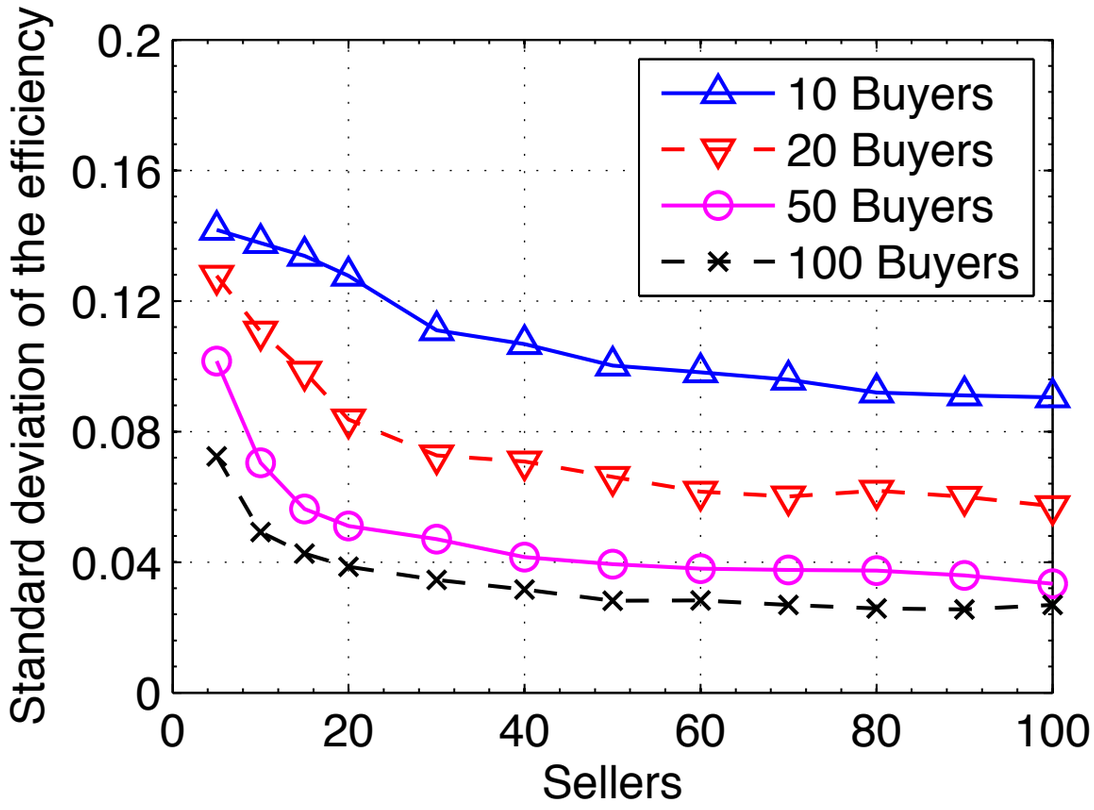

(b) Standard deviation of the auction efficiency.

Conclusions

District is a set of truthful spectrum double auctions supporting local markets

District-U

Achieve moderate level of efficiency

Suitable for a starting mechanism if no prior info is available

District-D

A more efficient mechanism if bid distributions are known

Auctioneers can start with *District-U*, and then switch to *District-D* when prior info is available

Thank you!