An Efficient Double Auction Mechanism for On-Demand Transport Services in Cloud-Based Mobile Commerce*

Lexin Zhou
College of Management
Guizhou University
Guiyang, Guizhou 550025, China
sci.lxzhou@gzu.edu.cn

Haiping Xu
Computer and Information Science Department
University of Massachusetts Dartmouth
Dartmouth, MA 02047, USA
hxu@umassd.edu

***Abstract*—Current cloud-based solutions of mobile commerce (m-commerce) for on-demand transport services, such as Uber and Didi Dache, uses a take-it-or-leave-it market mechanism, in which passengers and drivers have no option but to accept or reject given market prices determined by transport companies. Such a market mechanism does not consider the actual needs of passengers and drivers, e.g., high-urgency situations of passengers and different operating cost of vehicles, which are valuable for determining a reasonable market value of a trip. In this paper, we introduce a double auction mechanism for on-demand transport services, which allows multiple passengers and drivers to submit their bids simultaneously. In a double auction, with bids from both passengers and drivers, the marketplace can fairly determine a reasonable price based on the current supply and demand of the market. The proposed approach, which extends the McAfee's mechanism, ensures that honesty is a dominant strategy for bidders with winning preferences. It is different from existing market mechanisms for transport services as it allows users to specify their own prices based on the actual cost of transport services as well as their urgency situations.**

Keywords—m-commerce; mobile cloud computing; on-demand transport service; double auction mechanism; winning preference

I. Introduction

Cloud-based mobile commerce (m-commerce) for on-demand transport services have shown to be useful and convenient for both passengers and drivers. With such services, private car owners can register to be drivers of an on-demand transport service market, such as Uber and Didi Dache, and share their cars (not fully used goods) with passengers. While organizing an on-demand transport service market, transport companies may use different ways of pricing. For example, Didi Dache has used a fixed unit price mechanism; while in Uber service and the recent implementation of Didi Dache, dynamic pricing mechanisms were adopted. A dynamic pricing method typically sets a base price for transport services, which can be adjusted based on the demand and supply of the current market. However, there are drawbacks of the dynamic pricing approach. For example, Uber enacts surge pricing during peak travel times, and as a result, passengers' fare could be double, triple, or even up to seven times of the normal price. Because the passengers and drivers can only accept whatever prices are offered, the current on-demand transport service market is merely a take-it-or-leave-it market. Since the passengers and drivers are not allowed to report their actual valuation or cost of a trip, the method of dynamic pricing does not reflect the different situations of the traders, where some passenger might be far more urgent than others to use a car, and some driver might be willing to accept certain orders for more trading opportunities, which could be much cheaper than that can be offered by other drivers. Using existing dynamic pricing approaches, transport service companies may arbitrarily raise prices for profiteering and exploiting their customers. For instance, when Uber jacked up prices during a snowstorm in New York in December 2014, there was an eruption of complaints, and Uber finally agreed to limit fare hikes to 2.8 times normal fares [1]. Therefore, there is a pressing need to design a reasonable pricing mechanism for the on-demand transport market. In this paper, we introduce a double auction trading mechanism for the transport market, which allows passengers and drivers to submit their bids and asks, respectively. Different from the McAfee's mechanism [2], in our approach, all valuable profitable trades are guaranteed to go through for efficient passengers and drivers, who deserve to win based on their bid values. In addition, there is no surplus by the marketplace at the stage of trading, which benefits the passengers and drivers for reasonable costs. The double auction mechanism of on-demand transport service market provides a better pricing mechanism by considering passengers and drivers' personal valuation of transport services or estimated cost of trips into the pricing procedure. To support honesty to be a dominant strategy, we define the concept of *winning-preference bidders*, who always try their best to win auctions. By conducting experiments, we demonstrate that in our approach, honesty is a desirable strategy for auction bidders.

In the past decades, a substantial amount of work has been done to implement double auctions. McAfee proposed a single unit double auction mechanism with dominant strategies for both buyers and sellers [2]. The proposed approach is not quite efficient because the least valuable profitable trade may be prohibited by the mechanism. In addition, the mechanism allows the market maker to make an amount of profit from the bidders, though it could be asymptotically small. Huang *et al.* designed a multi-unit double auctions mechanism with honesty strategies for both buyers and sellers in e-markets [3]. The mechanism always leaves an amount of profit for market makers, but when the number of bidders becomes infinitely

* This material is based upon work supported by the National Natural Science Foundation of China under grant number 71461003.

978-1-5090-6325-3/17 $31.00 © 2017 IEEE
DOI 10.1109/MobileCloud.2017.37

large, the percentage of the surplus taken by the market maker converges to zero. In addition, the mechanism is not efficient enough as it allows losing one valuable trading opportunity. In contrast, we introduce a double auction mechanism for transport services, which guarantees that all valuable profitable trades are placed, and leaves no surplus for the market maker. Note that in order to reduce waiting time, we allow a limited number of participants in each auction, thus losing valuable trading opportunities is not acceptable and considered a significant weakness in existing approaches.

The market efficiency and pricing of on-demand transport services have been studied by many researchers. Zeng and Oren researched dynamic taxi pricing strategies, which take into account the likelihood of picking up additional passengers at a passenger's destination after a trip [4]. By modeling the system as a Markov Decision Process (MDP), an optimal strategy can be identified for specific domains. Gan *et al.* challenged two limitations in optimizing taxi market efficiency: one is that the existing approaches cannot be scaled up efficiently, and the other one is that they cannot address complex real-world market situations. To address these issues, they used the FLORA novel algorithms to scale up the model far more efficiently than existing algorithms, and further introduced FLORA-A algorithms to solve the taxi system efficiency optimization problems with arbitrary scheduling constrains [5]. Egan *et al.* decomposed the on-demand transport service market into approximately homogeneous sub-markets in accordance with trip distance, and used the McAfee double auction mechanism for the trading in the sub-markets [6]. Since the mechanism requires a passenger to report the details of a trip including the route and the journey distance before taking a cab, their approach greatly reduced the scope of the mechanism that could be applied in. Meanwhile, the auction mechanism based on journeys with similar distances also affects the market flexibility. Since the market is divided into many sub-markets, many potential deals may become impossible. In contrast, our mechanism is based on the unit price of a trip, which is flexible for the passengers and drivers to choose the destination and the route. Thus, our approach is far more technically practical and commercially viable. In addition, comparing to existing approaches, our approach does not incur any unpredictable surplus to the market maker, and guarantees that no valuable trading opportunity will be lost.

II. On-Demand Transport Service Market

As the market price of a transport service changes with the demand and supply, adopting a dynamic pricing strategy would be more reasonable. To provide passengers and drivers with reference market prices, suggested prices for transport services can be calculated based on historical transactions. However, the reference market prices may change due to factors such as demand peak, seasons, weather conditions and so on. In our approach, we assume that either the reference market prices are given, or the passengers and drivers are capable of evaluating the prices of transport services without the reference ones; thus, how to calculate the reference market prices based on historical transactions is beyond the scope of this paper.

The existing approaches for on-demand transport services do not consider private evaluations of transport services among different traders. Each passenger may have his own urgency level to use a transport service. For example, a passenger who needs to go to the hospital immediately, or a passenger who does not want to be late for an important business meeting, shall be willing to pay a higher fee than other regular passengers. On the other hand, regular passengers who are not in an urgent situation to catch a cab would be willing to wait a longer time for a cheaper price. Similarly, different drivers may also have different estimates of the cost for a trip. When private cars are registered to be members of a on-demand transport service market, due to different cost estimates, drivers may charge differently for a given service. For example, some drivers might want to secure more orders for a stable income by asking for cheaper prices than others; while others may prefer to taking less deals but with higher asking prices. To address the traders' need for a dynamic pricing mechanism based on traders' private information, we introduce a framework for a cloud-based double-auction marketplace for on-demand transport services with multiple passengers and drivers. As shown in Fig. 1, we can see that the marketplace is organized in the clouds to take advantages of cloud computing, where web services can be easily deployed and are accessible anywhere from any mobile devices such as smart phones and tablets. Multiple passengers and drivers form a double auction, where they can send their mobile bids and mobile asks, respectively, to the auction marketplace though their mobile devices. With an effective double auction mechanism, the market maker efficiently determines the winners of the auction as well as the trading price. Then all auction participants are notified accordingly, and the winners (passenger and drivers) can start their trades for the transport services.

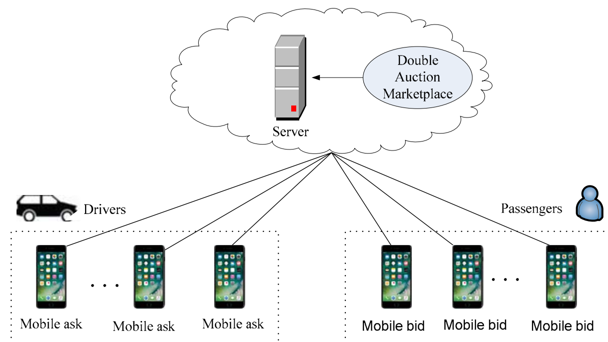

Fig. 1. Cloud-based double auction for on-demand transport services

Note that the trading price of a double auction is determined by the bidding prices of the passengers and drivers, which automatically reflect the changes of economic situation affected by factors such as gas price, employment rate, available transport methods, economic prosperity or recession, and so on. By allowing drivers and passengers to influence the trading price dynamically, both of them are benefited from a reasonable trading price that matches with their valuation of transport services, and thus more drivers and passengers will be attracted into the market. On the other hand, existing transport markets such as Uber, do not allow users to determine or influence the trading prices at all. They dynamically change prices and expect that surge prices may encourage more drivers to go online as the increase in price is proportionate to demand. However, as evidenced in recent research, surge pricing will not necessarily increase the supply timely; instead, it may deplete drivers in adjacent areas, and unfortunately result in worse service quality in those areas [7].

III. An Efficient Double Auction Mechanism

In order to take passengers' and drivers' personal valuation of transport services into consideration, we introduce an efficient double auction mechanism for on-demand transport services. The mechanism not only allows multiple passengers and multiple drivers to simultaneously submit their bids, but also ensures that honesty is a dominant strategy for traders with winning preferences.

A. The Bidding Model

Assume there are n passengers with bidding prices b_i, i =1, 2, …, n, and m drivers with asking prices s_j, j =1, 2, …, m participating in a double auction. Sort the bidding prices and asking prices descendingly and ascendingly into $b_1 \geq b_2 \geq \dots \geq b_n$ and $s_1 \leq s_2 \leq \dots \leq s_m$, respectively, as show in Fig. 2. We further assume the auction takes a few minutes (e.g., 5 minutes) to complete. This is reasonable as the passengers and drivers can typically wait for that long before knowing whether they win the auction as well as how much the trading price is.

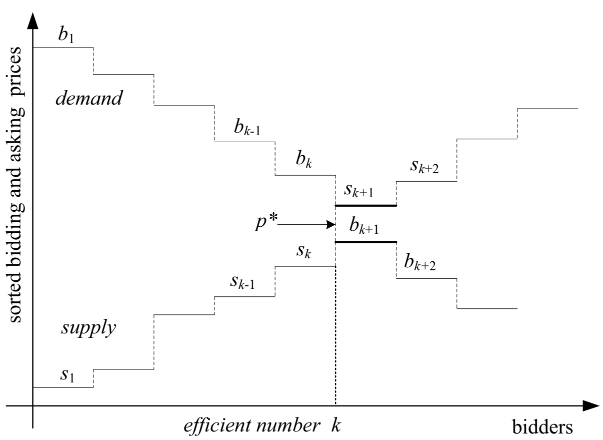

Fig. 2. The allocation and pricing of double auction

As shown in Fig. 2, in order to determine who win the auction, we find the positive integer k, called the *efficient number* of trades, that meets the following requirements:

$b_k \geq s_k$ and $b_{k+1} < s_{k+1}$, where $1 \leq k \leq min(m, n)$

That is where the passengers' demand curve and the drivers' supply curve get across in Fig. 2. All k passengers and k drivers with bidding prices b_1, …, b_k and asking prices s_1, …, s_k, respectively, are called *efficient* bidders, and thus, they shall win the auction. Note that when $s_1 > b_1$, there will be no crossing point between passengers' bidding prices and drivers' asking prices. In this case, the auction fails and there is no trading. In a different scenario, when no bidding price is less than any asking price (including the special case when all passengers and drivers have the same bidding and asking prices), the efficient number k cannot be found because the requirement $b_{k+1} < s_{k+1}$ cannot be satisfied. To deal with these cases, we introduce fictitious bidders with bidding price b_{n+1} and/or asking price s_{m+1} as follows:

if $n < m$ then $b_{n+1} = s_n - 0.01$
else if $n > m$ then $s_{m+1} = b_m + 0.01$
else $b_{n+1} = s_n - 0.01$, $s_{n+1} = b_n + 0.01$

That is, when no bidding price is less than any asking price, the fictitious buyer b_{n+1} and/or seller s_{m+1} ensures the demand and supply curves get across once. Therefore, it guarantees that we can always find the efficient number k in a double auction such that k passengers' bidding price are no less than k drivers' asking prices.

B. Winning-Preference Bidders

A bidder may have a preference for either winning or profit. In this paper, we focus more on strategies that facilitate a bidder to win an auction. We now define a winning-preference bidder as follows.

Definition: A *winning-preference bidder* is a bidder who tries his best to win an auction with non-negative utility. In a case when a bidder with a winning preference has a conflict between winning an auction and increasing his utility, winning the auction is a more rational decision for the bidder.

Let the lower bound price $lb = max(s_k, b_{k+1})$ and the upper bound price $ub = min(b_k, s_{k+1})$. We define the trading price $p^* = (lb+ub)/2$. Since there must be an overlapping between the two ranges $[s_k, b_k]$ and $[b_{k+1}, s_{k+1}]$, it is guaranteed that p^* exists. It also ensures that $p^* \in [s_k, b_k]$ and $p^* \in [b_{k+1}, s_{k+1}]$, i.e., $p^* \in [s_k, b_k] \cap [b_{k+1}, s_{k+1}]$. Fig. 2 and Fig. 3 show two scenarios of calculating p^*, where $s_k < b_{k+1}$ and $s_k > b_{k+1}$, respectively.

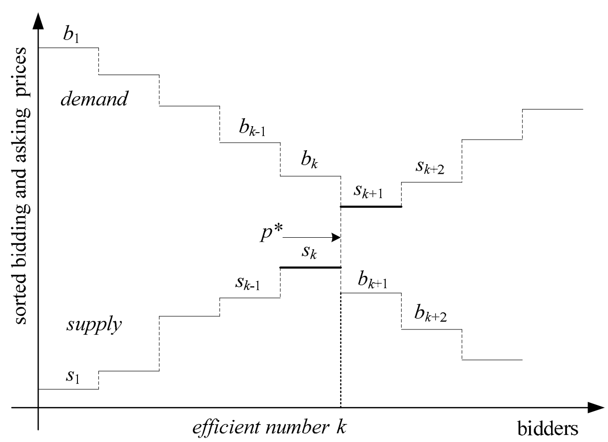

Fig. 3. Calculation of trading price p^* when $s_k > b_{k+1}$

All traders with bidding prices b_1, …, b_k and asking prices s_1, …, s_k shall trade using the same trading price p^*.

Theorem 1: *Honesty is a dominant strategy for all passengers and drivers with winning preferences.*

Proof: Let rb_i be passenger p_i's reservation price, where the reservation price rb_i is defined as the real valuation of the unit mileage cost of a trip taken by passenger p_i. Passenger p_i is said to be an honest bidder if he places a bid that equals to his reservation price. In the following, we show that when passenger p_i chooses to either overbid or underbid, he may face the risk of having less utility than the case when he bids honestly. Note that if a passenger is rational, when the trading price is higher than his reservation price, the passenger shall not choose to trade due to negative utility. This is also true for a driver. We now show honesty is a dominant strategy for passenger p_i with winning preferences. In other words, when a passenger chooses to overbid or underbid, the utility will not increase or may increase but with a risk of losing the auction.

Case 1: *A passenger may consider overbidding if losing an auction with an honest bid*

If passenger p_i placed an honest bid, i.e., $b_i = rb_i$, and lost the auction, we must have $b_i = rb_i < b_k$, and $rb_i \leq b_{k+1}$. In this case, passenger p_i's utility $u(p_i) = 0$. In order to win the auction, passenger p_i may consider overbidding on the auction. Let's see if it might bring any benefit to passenger p_i by doing so. There are two scenarios when the passenger wins the auction by overbidding.

a) Passenger p_i's overbidding results in a new pair of passenger and driver winning the auction, so there will be k+1 pairs of passenger and driver winning the auction. In this case, b_{k+1} will be moved to position k+2 after reordering all passengers' bidding prices (i.e., $b'_{k+2} = b_{k+1}$), where b'_{k+2} is the bidding price at position k+2 after reordering. The mechanism requires that $b'_{k+1} \geq s_{k+1}$ and $b'_{k+2} < s_{k+2}$ for determining the efficient number k. Since the mechanism guarantees that the trading price $p^* \in [s_{k+1}, b'_{k+1}]$, we have $p^* \geq s_{k+1} > b_{k+1} \geq rb_i$. Passenger p_i will have his new utility $u(p_i) = rb_i - p^* < 0$.
b) Passenger p_i's overbidding results in another passenger losing the auction, so there will still be k pairs of passengers and drivers winning the auction. In this case, the original passenger p_k must be the one who lost the auction, and b_k moves to position k+1 after reordering all passengers' bidding prices (i.e., $b'_{k+1} = b_k$), and $p^* \in [b'_{k+1}, s_{k+1}]$, where $b'_{k+1} < s_{k+1}$. Thus, we have $p^* \geq b'_{k+1} = b_k$. Therefore, $p^* \geq b_k \geq b_{k+1} \geq rb_i$. Passenger p_i will have his new utility $u(p_i) = rb_i - p^* \leq 0$.

Note that if passenger p_i does not win the auction when overbidding, his utility will not increase. By analyzing the above scenarios, we can see that if passenger p_i chooses to overbid for winning when he has lost an auction with an honest bid, he will not increase his utility; instead, there is a chance that he receives negative utility when winning the auction.

Case 2: *A passenger may consider overbidding if winning an auction with an honest bid*

In the second case, if passenger p_i placed an honest bid, i.e., $b_i = rb_i$, and won the auction, we must have $b_i = rb_i \geq b_k$. Since the mechanism guarantees that $p^* \in [s_k, b_k]$, so $p^* \leq b_k \leq rb_i$. In this case, passenger p_i's utility $u(p_i) = rb_i - p^* \geq 0$. Now suppose passenger p_i overbid on the auction for whatever reasons, p^* may increase due to a possibly larger upper bound of the range $[s_k, b'_k]$. Therefore, passenger p_i's utility $u(p_i)$ will not increase as a result of overbidding; instead, it may possibly decrease. As such, overbidding is not a good strategy for passenger p_i.

To summarize Case 1 and Case 2, no matter a passenger wins or loses an auction when placing an honest bid, if the passenger chooses to overbid, he may face the risk of having less utility comparing with the strategy of bidding honestly. Therefore, for passenger p_i, the strategy of overbidding is worse than that of bidding honestly.

Case 3: *A passenger may consider underbidding if losing an auction with an honest bid*

In the third case, we consider underbidding. If passenger p_i placed an honest bid, i.e., $b_i = rb_i$, and lost the auction, we must have $b_i = rb_i < b_k$, and $rb_i \leq b_{k+1}$. In this case, passenger p_i's utility $u(p_i) = 0$. Now suppose passenger p_i chooses to underbid on the auction by placing a bid $b_i < rb_i$, he will not win the auction; thus, passenger p_i's utility $u(p_i)$ will not increase.

Case 4: *A passenger may consider underbidding if winning an auction with an honest bid*

On the other hand, if passenger p_i placed an honest bid, i.e., $b_i = rb_i$, and won the auction, we must have $b_i = rb_i \geq b_k$. In this case, passenger p_i's utility $u(p_i) = rb_i - p^* \geq 0$ because $p^* \leq b_k \leq rb_i$. Now suppose passenger p_i chooses to underbid on the auction in order to receive more utility. As passenger p_i does not know the value of b_{k+1}, he may accidentally place a bid $b_i < b_{k+1}$, which leads to a result of losing the auction. When this happens, passenger p_i's utility $u(p_i)$ drops to 0. Since passenger p_i is a bidder with winning preference, when there is a conflict between winning the auction and increasing his utility, winning the auction will be a more rational decision for him. Therefore, in this case, he should not choose to receive more utility with a risk of losing the auction.

In summary, comparing with the strategy of bidding honestly, a passenger who chooses to underbid will either have no increase of his utility, or may have a risk of losing the auction. Therefore, for passenger p_i, the underbidding strategy is worse than that of bidding honestly.

Since the strategy of bidding honestly is a better strategy than both of the overbidding and underbidding strategies, honesty is a dominant strategy for all passengers with winning preferences. Due to the similar reasoning, honesty is also a dominant strategy for all drivers with winning preferences.

Theorem 2: *The proposed double auction mechanism is individually rational.*

Proof: A mechanism with honesty strategy is individually rational if for each trader t_i, the equilibrium expected utility $u_i \geq 0$. In other words, the difference between the valuation of a passenger (or the cost of a trip valuated by a driver) and the trading price must not be negative. Let passenger p_i and driver d_j be a pair of two winners of an auction, where d_j provides transport service for passenger p_i. Let the distance of the journey be L_{ij}, then the utilities of passenger p_i and driver d_j are $(rb_i - p^*) \times L_{ij}$ and $(p^* - rs_j) \times L_{ij}$, respectively. Since the proposed double auction mechanism guarantees that $rb_i \geq p^* \geq rs_j$, the utilities of passenger p_i and driver d_j are ensured to be no less than zero. Note that in the case of not wining an auction, a trader has a payoff of zero [8]. Therefore, the proposed double auction mechanism meets the individual rational principle, which allows the passengers and drivers to participate in auctions without the worry of negative utility.

IV. SIMULATIONS AND EXPERIMENTAL RESULTS

With a sufficient number of passengers and drivers participating in on-demand transport markets, we can reasonably assume the passengers' bidding prices and the drivers' asking prices follow the normal distribution $N(\mu_1, \sigma^2)$ and $N(\mu_2, \sigma^2)$, respectively. To automatically generate bidding prices and asking prices that follow the distributions, we developed a software tool in Java, which can determine the winners of a double auction and calculate the trading price p^* of the auction using the proposed auction mechanism described in Section III.A. In the following experiments, we set the expected bidding price $\mu_1 = 2.2$ and the expected asking price $\mu_2 = 1.8$. This is practical because in a dynamic market, the expected bidding price shall be higher than the expected asking prices to ensure an effective supply and demand. Furthermore, in each simulated auction, we randomly generate the numbers of passengers and drivers. Each auction may contain at most 20 bidders; therefore, the number of participants in an auction is limited, and the participants do not have to wait for too long for an auction to be ready and conducted.

A. Impact of Standard Deviation on Auction Results

The standard deviation σ may be changed when more market information has been captured by traders. The more market information (e.g., historical trading records) available, the smaller σ will be. In this experiment, we study the impact of decreasing σ on the successful rate of the bidders as well as the auction trading price. The successful rate of bidders in an auction is defined as $2k/(m+n)$, where k out of n passengers (or m drivers) win the auction. For L simulated auctions, the average successful rate sr_{avg} and the average trading price p^*_{avg} can be calculated as in Eq. (2) and Eq. (3).

$$sr_{avg} = \frac{1}{L}\sum_{i=1}^{L} 2k_i/(n_i+m_i) \tag{2}$$

$$p^*_{avg} = \frac{1}{L}\sum_{i=1}^{L} p^*_i \tag{3}$$

where in i-th auction, k_i is the efficient number of trades, n_i and m_i are the numbers of passengers and drivers, respectively, and p^*_i is the trading price. The experimental results with $L = 100$ simulated auctions are illustrated in Fig. 3 and Fig. 4.

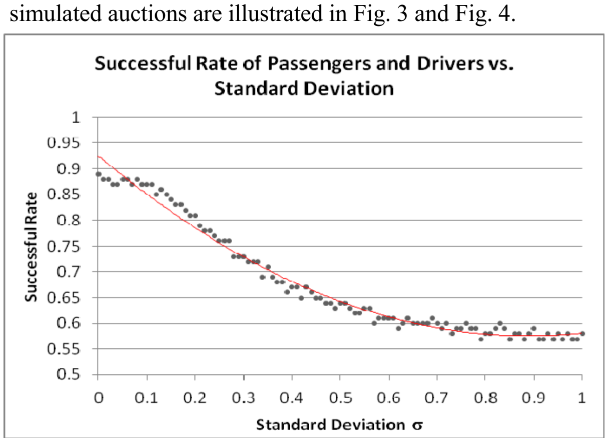

Fig. 3. The impact of standard deviation on average successful rate

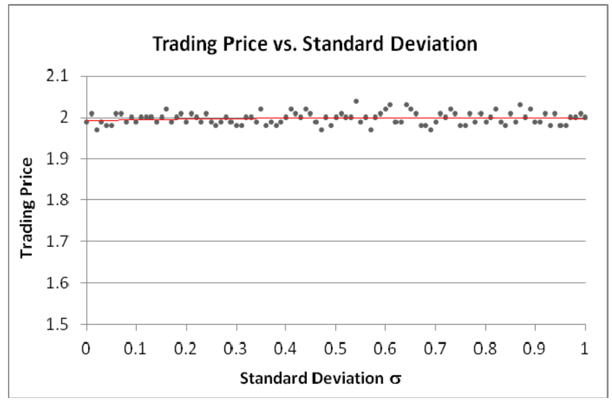

Fig. 4. The impact of standard deviation on average trading price

From the figures, we can see that the average trading price of 100 simulated auctions are affected weakly by the changing of σ; while the average successful rate of traders increases when σ becomes smaller (i.e., decreases when σ becomes larger). This is because the smaller σ is, the higher probability that a passenger's bidding prices is higher than a driver's asking prices due to the settings of the expected passengers' bidding price $\mu_1 = 2.2$ and the expected drivers' asking price $\mu_2 = 1.8$. In this case, the efficient number k becomes larger, and thus, the winning rate of the traders increases. On the other hand, since μ_1 and μ_2 stay the same, the trading price shall have no obvious change when σ changes. From this simulation, we may conclude that when the traders know more about the transport market, their chances of winning the auctions increase, but the trading prices will not be obviously affected.

B. A Passenger's Overbidding Strategy

To increase the chances of winning an auction, a passenger may choose to overbid. To analyze this situation, we consider a special passenger who has an emergency to use a car, e.g., going to hospital or attending an important business meeting. In this experiment, we set $\mu_1 = 2.2$ and $\sigma_1 = 0.5$ for passengers, and $\mu_2 = 1.8$ and $\sigma_2 = 0.5$ for drivers. For each simulation, we run L =100 auctions, and in each auction, we randomly select a special passenger who overbids with a certain rate α, e.g., when $\alpha = 1.2$, the selected passenger places a bid that is 1.2 times of the normal bidding price. The average successful rate of the special passenger in L auctions can be calculated as in Eq. (4).

$$sr_{avg} = \frac{1}{L}\sum_{i=1}^{L} n_i, \text{ and } n_i = \begin{cases} 1, & \text{when } \alpha b_{sp} \geq p^*_i \\ 0, & \text{when } \alpha b_{sp} < p^*_i \end{cases} \tag{4}$$

where b_{sp} is the normal bidding price of the special passenger sp in i-th auction, α is the overbidding rate, and p^*_i is the trading price of the auction. Note that when n_i=1, the special passenger sp wins the auction; otherwise, sp loses the auction. The average trading price can be calculated as in Eq. (3). Fig. 5 and Fig. 6 show the impact of a passenger's overbidding strategy on his successful rate and the average trading price, respectively. From Fig. 5, we can see that when a special passenger takes an overbidding strategy in an emergency situation, the successful rate of the special passenger (i.e., the probability of winning the auction) increases significantly.

According to the simulation, when the overbidding rate is about 1.5, the probability of winning an auction becomes very close to 1. This observation could be very useful for passengers who do not have enough experience of placing overbids, and it suggests that an overbidding rate of 1.5 is usually sufficient for a passenger to win an auction in an emergency situation.

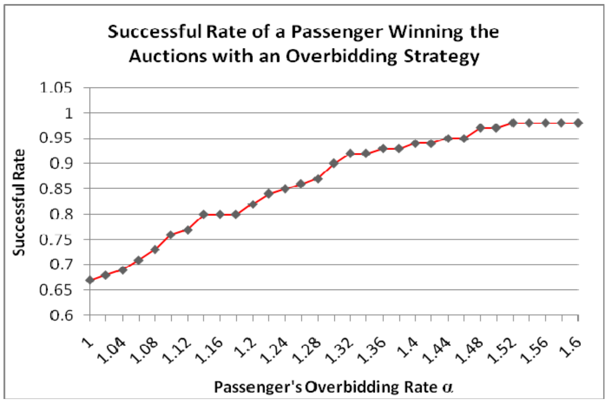

Fig. 5. The impact of overbidding on average successful rate

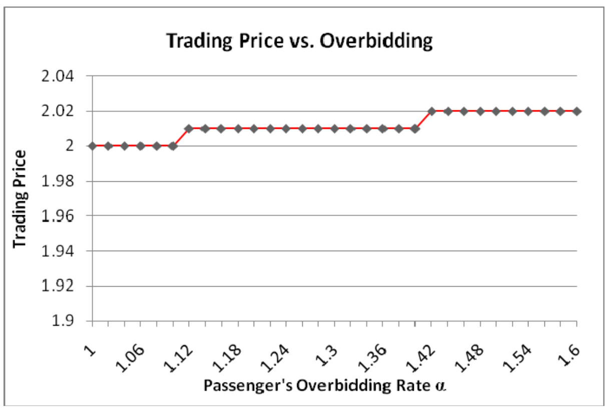

Fig. 6. The impact of overbidding on average trading price

Meanwhile, according to Fig. 6, the average trading price of 100 simulated auctions that involve special passengers only increases insignificantly, which is about one or two cent. Thus, our mechanism allows for passengers to overbid with a reasonable overbidding rate to obtain a higher priority of getting a cab in a timely manner. Note that although taking an overbidding strategy increases the chances of winning an auction, based on the analysis presented in Section III.B, the utility of the special passenger may become negative. Therefore, overbidding is not suggested for normal passengers as it is generally not a good strategy.

The above analysis also applies to drivers who have special needs (e.g., to secure a stable income in financial difficulties) for more trading opportunities. For those drivers, an underbidding strategy may effectively increase their chances of winning the auctions but with possible negative utility.

V. Conclusions and Future Work

In this paper, we introduced a double auction mechanism in cloud-based on-demand transport markets, which supports allocation of passengers and drivers based on their bidding prices, and determines a uniform trading price for each auction. In our approach, multiple passengers and drivers can place their bids of unit prices simultaneously in order to win an auction. The mechanism is efficient as it guarantees all valuable profitable trades to be made, and meanwhile, it leaves no surplus for the market maker. We showed that our mechanism met some key desirable properties, such as honesty strategy for the winning-preference bidders and individually rational decisions. The experimental results show that our approach allows passengers to get transport services in emergency situations by placing overbids with reasonable chances of having negative utility.

In future work, we will further study traders with profit-preference and their relationship with winning-preference bidders. We will compare our approach with other auction mechanisms, such as Vickrey–Clarke–Groves (VCG) auction mechanism, which allows for the selection of a socially optimal solution from a set of possible outcomes [9][10]. Finally, to demonstrate the feasibility and efficiency of our approach, we will implement it as cloud services with clients on mobile devices, and show how existing transport markets for on-demand transport services can be improved.

References

[1] D. Rushe, “Taxi app Uber agrees to cap 'surge pricing' during New York blizzard,” *The Guardian*, January 2015. Retrived on September 29, 2016 from https://techcrunch.com/2015/01/26/uber-will-cap-surge-pricing-during- northeast-snow-storm/

[2] R. P. McAfee, “A dominant strategy double auction,” *Journal of Economic Theory*, vol. 56, no. 2, 1992, pp. 434-450.

[3] P. Huang, A. Scheller-wolf, and K. Sycara, “Design of a multi-unit double auction e-market,” *Computational Intelligence*, vol. 18, no. 4, 2002, pp. 596-617.

[4] C. Zeng and N. Oren, “Dynamic taxi pricing,” In *Proceedings of the 21st European Conference on Artificial Intelligence (ECAI 2014)*, Prague, Czech Republic, August 18-22, 2014, pp. 1135-1136.

[5] J. Gan, B. Am, and C. Miao, “Optimizing efficiency of taxi systems: scaling-up and handling arbitrary constraints,” In *Proceedings of the 2015 International Conference on Autonomous Agents and Multiagent Systems (AAMAS ’15)*, May 4-8, 2015, Istanbul, Turkey, pp. 523-531.

[6] M. Egan, M. Schaefer, M. Jakob, and N. Oren, “A double auction mechanism for on-demand transport networks,” In *Proceedings of the 18th International Conference on Principles and Practice of Multi-Agent Systems (PRIMA 2015)*, October 26-30, 2015, Bertinoro, FC, Italy, LNCS, vol. 9387, pp. 557-565.

[7] N. Diakopoulos, “How Uber surge pricing really works,” *The Washington Post*, April 17, 2015. Retrieved on September 22, 2016 from https://www.washingtonpost.com/news/wonk/wp/2015/04/17/how-uber-surge-pricing-really-works/

[8] V. Krishna, *Auction Theory*, Second Edition, Academic Press, 2009, pp. 66-67.

[9] N. Nisan and A. Ronen, “Computationally feasible VCG mechanisms,” In *Proceedings of the 2nd ACM Conference on Electronic Commerce (EC 2000)*, October 17 - 20, 2000, Minneapolis, MN, USA, pp. 242-252.

[10] P. Cramton, Y. Shoham, and R. Steinberg (Eds.), *Combinatorial Auctions*, The MIT Press, 2006.