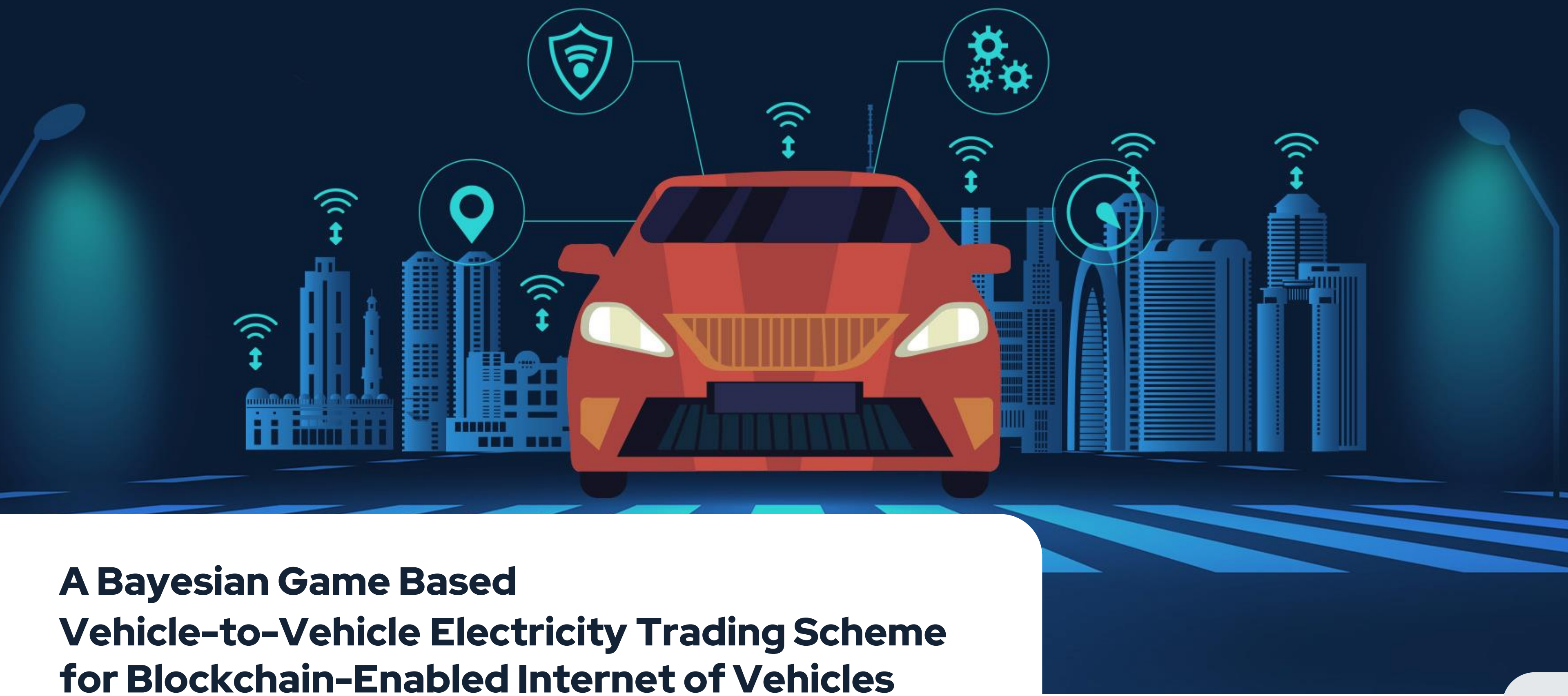
Thanason 63070701614
Sorawit 63070701615

CPE 612
Game Theory

https://ieeexplore.ieee.org/document/9078882/



A Bayesian Game Based Vehicle-to-Vehicle Electricity Trading Scheme for Blockchain-Enabled Internet of Vehicles

1 Introduction

A Bayesian Game Based Vehicle-to-Vehicle Electricity Trading Scheme for BIoV

Peer-to-Peer electric trading

- Normally, people buy energy or electricity from the charging station for EV
- In the era of Blockchain, we can **sell electricity** to other people using smart meter and smart contract **without middleman**

Price mechanism

- It is **hard to acquire** the full information in the decentralized network timely, due to that communication and computation load grow exponentially with network size

In this paper

- To build a blockchain **infrastructure** that can enable vehicle-to-vehicle (V2V) electricity trading
- To create an **electricity trading scheme** which can find the optimal pricing for the trading

The Bayesian game is adopted

- In the blockchain system, It is not trivial to acquire the full information. So, it becomes an **incomplete information game** between buyer and seller in trading

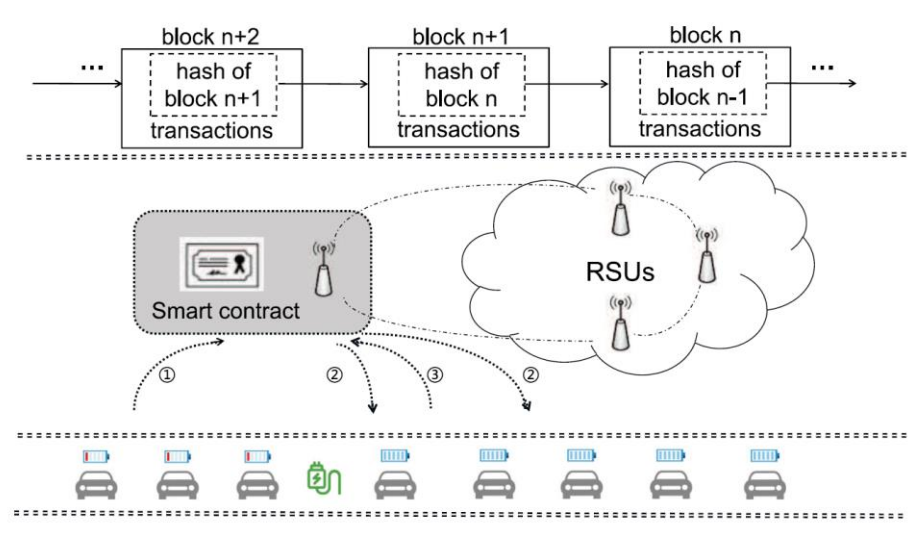
- Finding the optimal pricing under the **linear strategic equilibrium** which maximizes the utilities of both sides of electricity transaction, which stimulates the electric vehicle.

2

System description

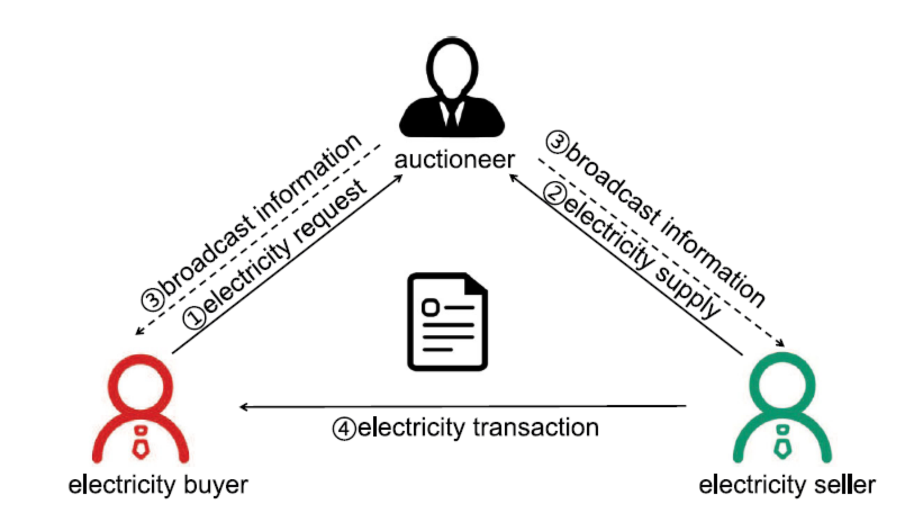
A Bayesian Game Based Vehicle-to-Vehicle Electricity Trading Scheme for BIoV

System architecture



- Buyer and seller will send its request to the system to build the smart contract
- RSU (roadside unit) is another role for this system.
- Computing device located on the roadside that provides connectivity to vehicle

Process of electricity trading



1. Buyer sends a request to auctioneer (RSU)
2. Seller receives it and reply to auctioneer
3. Auctioneer will broadcast the information
4. Transaction will be created and find the optimal price for both

3

BAYESIAN-GAME-BASED TRADING SCHEME

A Bayesian Game Based Vehicle-to-Vehicle Electricity Trading Scheme for BIoV

Look at a request.

Electricity request of buyer i

v_i is electricity price proposed by buyer
where $v_i \in [v_i^{min}, v_i^{max}]$

v_i^{min} is electricity lower bound price
v_i^{max} is electricity upper bound price

*controlled by auctioneer

Electricity reply of seller j

c_j is electricity price proposed by seller
where $c_j \in [c_j^{min}, c_j^{max}]$

c_j^{min} is electricity lower bound price
c_j^{max} is electricity upper bound price

*controlled by auctioneer

Finding optimal price.

Assume that the pricing of both parties satisfies the **linear strategic equilibrium**

Price function

buyer i :

$$P_{ij}(v_i) = \alpha_b + \beta_b v_i.$$

seller j :

$$R_{ji}(c_j) = \alpha_s + \beta_s c_j.$$

Optimal bidding for buyer

$$\max_{P_{ij}} \left[v_i - \frac{1}{2}(P_{ij} + E[R_{ji}(c_j)|P_{ij} \geq R_{ji}(c_j)]) \right] \cdot Prob\{P_{ij} \geq R_{ji}(c_j)\},$$

Optimal bidding for seller

$$\max_{R_{ji}} \left[\frac{1}{2}(R_{ji} + E[P_{ij}(v_i)|P_{ij}(v_i) \geq R_{ji}]) - c_j \right] \cdot Prob\{P_{ij}(v_i) \geq R_{ji}\},$$

Finding optimal price.

Optimal bidding for buyer

means that under the condition that the buyer's bid is not lower than the seller's bid,

$$\max_{P_{ij}} \left[v_i - \frac{1}{2}\left(P_{ij} + \boxed{E[R_{ji}(c_j) | P_{ij} \geq R_{ji}(c_j)]}\right)\right] \cdot Prob\{P_{ij} \geq R_{ji}(c_j)\},$$

Finding optimal price.

Optimal bidding for seller

$$\max_{R_{ji}} \left[\frac{1}{2}\left(R_{ji} + \boxed{E[P_{ij}(v_i) | P_{ij}(v_i) \geq R_{ji}]}\right) - c_j\right] \cdot Prob\{P_{ij}(v_i) \geq R_{ji}\},$$

means that under the condition that the buyer's bid is not lower than the seller's bid, *Proof:* Assuming that c_j, v_i are evenly distributed over their respective intervals, then $Prob\{P_{ij} \geq R_{ji}(c_j)\}$ in (3) can be obtained as

$$Prob\{P_{ij} \geq R_{ji}(c_j)\} = Prob\{P_{ij} \geq \alpha_s + \beta_s c_j^{\text{min}}\} = \frac{P_{ij} - \alpha_s - \beta_s c_j^{\text{min}}}{\beta_s(c_j^{\text{max}} - c_j^{\text{min}})}, \quad (7)$$

and $E[R_{ji}(c_j)|P_{ij} \geq R_{ji}(c_j)]$ in (3) can be obtained as

$$E[R_{ji}(c_j)|P_{ij} \geq R_{ji}(c_j)] = \int_{\alpha_s+\beta_s c_j^{\text{min}}}^{P_{ij}} \frac{x dx}{P_{ij} - \alpha_s - \beta_s c_j^{\text{min}}} = \frac{1}{2}(\alpha_s + \beta_s c_j^{\text{min}} + P_{ij}). \quad (8)$$

Similarly, $Prob\{P_{ij}(v_i) \geq R_{ji}\}$ and $E[P_{ij}(v_i)|P_{ij}(v_i) \geq R_{ji}]$ in (4) can be respectively obtained as

$$Prob\{P_{ij}(v_i) \geq R_{ji}\} = Prob\{\alpha_b + \beta_b v_i^{\text{max}} \geq R_{ji}\} = \frac{\alpha_b + \beta_b v_i^{\text{max}} - R_{ji}}{\beta_b(v_i^{\text{max}} - v_i^{\text{min}})}, \quad (9)$$

$$E[P_{ij}(v_i)|P_{ij}(v_i) \geq R_{ji}] = \int_{R_{ji}}^{\alpha_b+\beta_b v_i^{\text{max}}} \frac{x dx}{\alpha_b + \beta_b v_i^{\text{max}} - R_{ji}} = \frac{1}{2}(\alpha_b + \beta_b v_i^{\text{max}} + R_{ji}). \quad (10)$$

Substitute the (7), (8) and (9), (10) into (3) and (4) respectively. Combine them with the (1) and (2), P_{ij}^* and R_{ji}^* are derived. The proof is finished. ■

Finding optimal price.

Bayesian equilibrium:

$$P_{ij}^{*} = \frac{1}{12} v_i^{\max} + \frac{1}{4} c_j^{\min} + \frac{2}{3} v_i \, ,$$

$$R_{ji}^{*} = \frac{1}{12} c_j^{\min} + \frac{1}{4} v_i^{\max} + \frac{2}{3} c_j \, .$$

Finding optimal quantity.

$$\mathcal{P}1: \quad \max_{b_i, s_j} \sum_{i=1}^{I} U(b_i) - \sum_{j=1}^{J} C(s_j), \tag{11}$$

$$s.t. \quad b_i^{\min} \leq \sum_{j=1}^{J} b_{ij} \leq b_i^{\max}, \tag{12}$$

$$s_j^{\mathrm{t}} - \sum_{i=1}^{I} (1+\rho_j) s_{ji} \leq s_j^{\mathrm{r}}, \tag{13}$$

$$b_{ij} = s_{ji} \geq 0, \tag{14}$$

where

$$U(b_i) = w_i ln \left(\sum_{j=1}^{J} b_{ij} - b_i^{\min} + 1 \right), \tag{15}$$

$$C(s_j) = l_1 \sum_{i=1}^{I} \rho_j (s_{ji})^2 + l_2 \sum_{i=1}^{I} \rho_j s_{ji}. \tag{16}$$

$$\mathcal{P}2: \quad \max_{b_i, s_j} \sum_{i=1}^{I} \sum_{j=1}^{J} [T_{ij} \ln b_{ij} - T_{ij} s_{ji}],$$

$$s.t. \quad (12),\ (13),\ \text{and}\ (14). \tag{17}$$

Objective: solve P1 and P2.

Finding optimal quantity.

Theorem 2: The optimal transaction volume $\{b_{ij}^*, s_{ji}^*\}$ achieving the maximum social welfare can be derived by

$$b_{ij}^* = s_{ji}^* = \frac{Tr_{ji} - l_2\rho_j}{2l_1\rho_j}. \tag{18}$$

$$\begin{aligned} F_1(b_i, s_j, \alpha, \beta, \gamma, \delta, \lambda, \mu) &= \sum_{i=1}^{I} U(b_i) - \sum_{j=1}^{J} C(s_j) \\ &+ \sum_{i=1}^{I} \alpha_i \left(b_i^{\min} - \sum_{j=1}^{J} b_{ij} \right) + \sum_{i=1}^{I} \beta_i \left(\sum_{j=1}^{J} b_{ij} - b_i^{\max} \right) \\ &+ \sum_{j=1}^{J} \gamma_i \left[s_j^{\mathrm{t}} - \sum_{i=1}^{I} (1+\rho_j) s_{ji} - s_j^{\mathrm{r}} \right] \\ &+ \sum_{i=1}^{I}\sum_{j=1}^{J} \lambda_{ij}(b_{ij} - s_{ji}) - \sum_{i=1}^{I}\sum_{j=1}^{J} \mu_{ij} b_{ij}, \end{aligned} \tag{19}$$

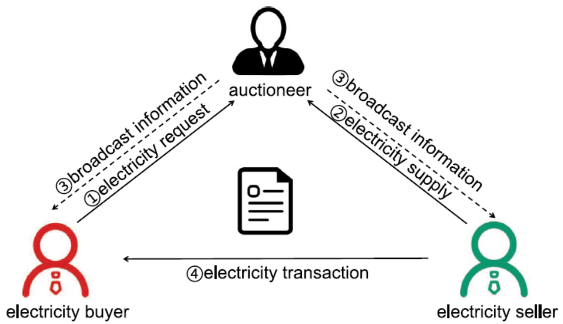
$$\begin{aligned} \nabla_{b_{ij}} F_1(b_i, s_j, \alpha, \beta, \gamma, \lambda, \mu) = {} & \frac{w_i}{\sum_{j=1}^{J} b_{ij} - b_i^{\min} + 1} \\ & - \alpha_i + \beta_i - \lambda_{ij} - \mu_{ij} = 0. \end{aligned} \tag{20}$$

$$\begin{aligned} \nabla_{s_{ji}} F_1(b_i, s_j, \alpha, \beta, \gamma, \lambda, \mu) = {} & -2l_1\rho_j s_{ji} - l_2\rho_j \\ & - (1+\rho_j)\gamma_j - \lambda_{ij} = 0. \end{aligned} \tag{21}$$

$$\begin{aligned} \nabla b_{ij} F_2(b_i, s_j, \alpha, \beta, \gamma, \lambda, \mu) = {} & \frac{T_{ij}}{b_{ij}} \\ & - \alpha_i + \beta_i - \lambda_{ij} - \mu_{ij} = 0. \end{aligned} \tag{22}$$

$$\begin{aligned} \nabla s_{ji} F_2(b_i, s_j, \alpha, \beta, \gamma, \delta, \lambda, \mu) = {} & -Tr_{ji} \\ & - (1+\rho_j)\gamma_j - \lambda_{ij} = 0. \end{aligned} \tag{23}$$

$$P_{ij}^{*} = \frac{1}{12}v_i^{\max} + \frac{1}{4}c_j^{\min} + \frac{2}{3}v_i,$$
$$R_{ji}^{*} = \frac{1}{12}c_j^{\min} + \frac{1}{4}v_i^{\max} + \frac{2}{3}c_j.$$



Algorithm 1: V2V Electricity Trading Algorithm.

Input: $\{b_i^{\min}, b_i^{\max}, v_i^{\min}, v_i^{\max}, v_i\}_{i=1}^{N}$, $\{s_j^{\min}, s_j^{\max}, c_j^{\min}, c_j^{\max}, c_j\}_{j=1}^{M}$
Initialization: $c^{\max}$, $v^{\min}$
Output: $\{T_{ij}, b_{ij}\}$

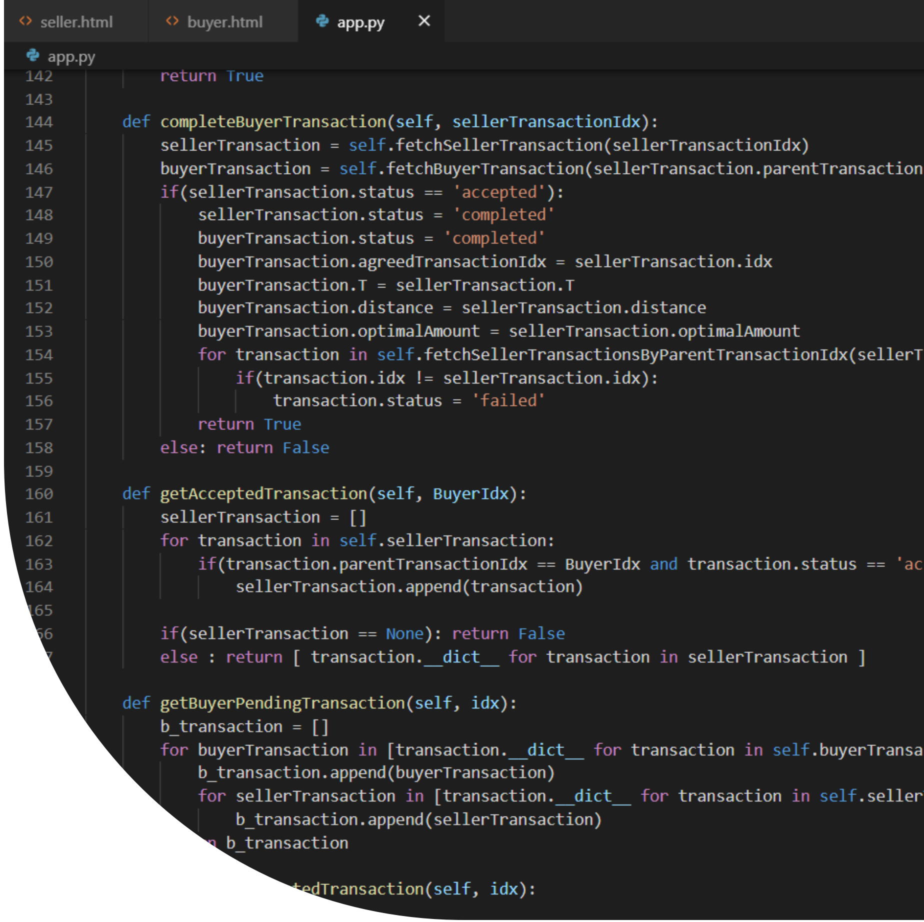
for $i = 1 \to N$ **do**
  for $j = 1 \to M$ **do**
    if $c^{\max} \leq c_j^{\max}$ or $c_j \notin [c_j^{\min}, c_j^{\max}]$ **then**
      seller j needs to resubmit the bid.
    end if
    if $v_i^{\min} \leq v^{\min}$ or $v_i \notin [v_i^{\min}, v_i^{\max}]$ **then**
      buyer i needs to resubmit the bid.
    end if
    if $c^{\max} \geq c_j^{\max}$ and $v_i^{\min} \geq v^{\min}$ **then**
      Solve (3) and (4), the optimal biding prices $\{P_{ij}^{*}, R_{ji}^{*}\}$ that achieve the Bayesian equilibrium can be obtained.
      if $P_{ij} \geq R_{ji}$ **then**
        $T_{ij} = (P_{ij} + R_{ji})/2$
      else
        The transaction between buyer i and seller j is not valid.
      end if
    end if
    Solve the problem $\mathcal{P}1$ and $\mathcal{P}2$ according to T_{ij} to get the optimal trading volume $\{b_{ij}^{*}, s_{ji}^{*}\}$.
  end for
end for
return $\{T_{ij}, b_{ij}\}$

4 Implementation

A Bayesian Game Based Vehicle-to-Vehicle Electricity Trading Scheme for BIoV

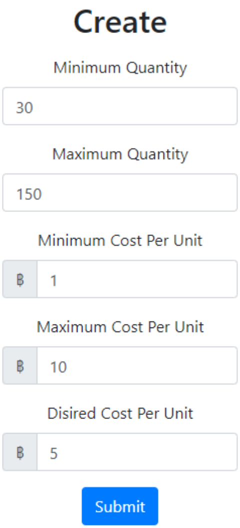
Implement

- Use **Python** for creating system that buyer and seller and interact
- Not use real blockchain as a system

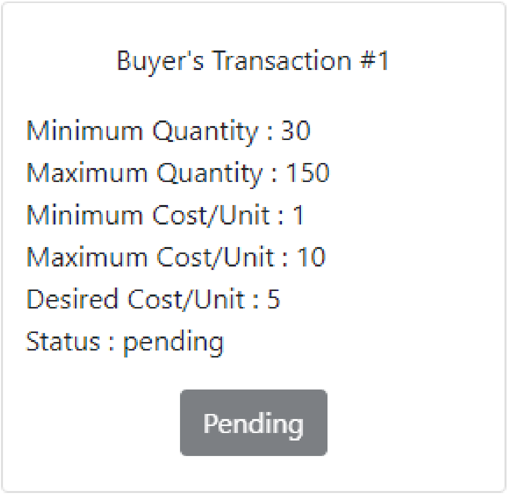


Visit: https://github.com/titlethanason/V2V_ElectricSharing

Buyer create request.



Buyer create request



Wait Seller response

Seller response. (Failed)

Pending

Buyer's Transaction #1

From BuyerIdx : 3.48 km.
From BuyerIdx : 1
Minimum Quantity : 30
Maximum Quantity : 150
Minimum Cost/Unit : 1
Maximum Cost/Unit : 10
Desired Cost/Unit : 5
Status : pending

Accept

Choose Buyer request

Buyer's Transaction #1

Minimum Quantity: 50

Maximum Quantity: 100

Minimum Cost Per Unit: ฿ 5

Maximum Cost Per Unit: ฿ 15

Disired Cost Per Unit: ฿ 10

Submit

Response back

Transaction failed

if $P_{ij} \geq R_{ji}$ **then**
$T_{ij} = (P_{ij} + R_{ji})/2$
else
The transaction between buyer i and seller j is not valid.

Seller's Transaction #6

Distance : 4.08 km.
Optimal Price/Unit(T) : None
Buyer's Optimal Price/Unit(P) : 7.92
Seller's Optimal Price/Unit(R) : 10
Optimal Quantity : None
RefBuyerTransactionIdx : 1
Status : failed

System compute

Seller response. (Success)

Pending

Buyer's Transaction #1

From BuyerIdx : 3.48 km.
From BuyerIdx : 1
Minimum Quantity : 30
Maximum Quantity : 150
Minimum Cost/Unit : 1
Maximum Cost/Unit : 10
Desired Cost/Unit : 5
Status : pending

Accept

Choose Buyer request

Buyer's Transaction #1

Minimum Quantity
10

Maximum Quantity
170

Minimum Cost Per Unit
฿ 1

Maximum Cost Per Unit
฿ 12

Disired Cost Per Unit
฿ 4

Submit

Response back

Transaction success
Wait Buyer to response

Seller's Transaction #6

Distance : 3.48 km.
Optimal Price/Unit(T) : 6.585
Buyer's Optimal Price/Unit(P) : 7.17
Seller's Optimal Price/Unit(R) : 6
Optimal Quantity : 88
RefBuyerTransactionIdx : 1
Status : accepted

System compute

Buyer choose.

Pending/Accept

Buyer's Transaction #1

Minimum Quantity : 30
Maximum Quantity : 150
Minimum Cost/Unit : 1
Maximum Cost/Unit : 10
Desired Cost/Unit : 5
Status : pending

Pending

Seller's Transaction #3

Distance : 7.35 km.
Optimal Price/Unit(T) : 4.46
Seller's Idx : 3
Buyer's Optimal Price/Unit(P) : 4.92
Seller's Optimal Price/Unit(R) : 4
Optimal Quantity : 112
RefBuyerTransactionIdx : 1
Status : accepted

Confirm

Seller's Transaction #6

Distance : 3.48 km.
Optimal Price/Unit(T) : 6.585
Seller's Idx : 4
Buyer's Optimal Price/Unit(P) : 7.17
Seller's Optimal Price/Unit(R) : 6
Optimal Quantity : 88
RefBuyerTransactionIdx : 1
Status : accepted

Confirm

Seller's Transaction #8

Distance : 4.08 km.
Optimal Price/Unit(T) : 9.835
Seller's Idx : 5
Buyer's Optimal Price/Unit(P) : 11.67
Seller's Optimal Price/Unit(R) : 8
Optimal Quantity : 56
RefBuyerTransactionIdx : 1
Status : accepted

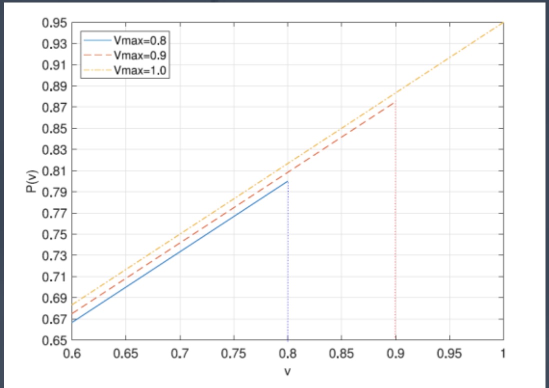
Confirm

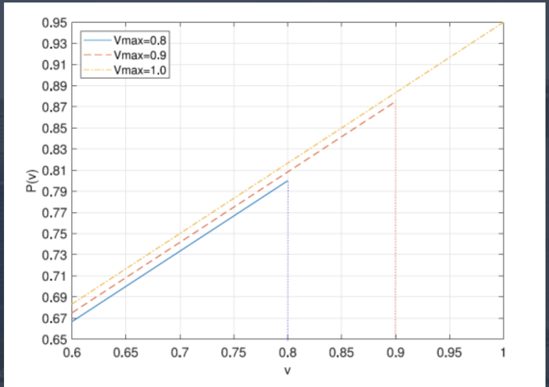
5 Demo

A Bayesian Game Based Vehicle-to-Vehicle Electricity Trading Scheme for BIoV

Transaction Price Based on Bayesian Game

- The prices is influenced by c_j^{min} and v_i^{max}
- When the electricity buyer reduces v_i^{max}, the probability of unsuccessful transaction will increase due to the lower price
- When the electricity seller reduces c_j^{min}, the probability of successful transaction will also increase





Conclusion

- a V2V electricity trading scheme based on blockchain technology has been designed and created

- the Bayesian game-based pricing scheme has been designed to deal with the incomplete information sharing in the blockchain system.

- From the scheme, the optimal pricing under the linear strategic equilibrium is obtained which maximizes the utilities of both sides of electricity transaction

THANK YOU