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# Uberization of NOMA Wireless Network Resource Sharing: A Driver-Passenger Game-Theoretic Approach

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***Abstract*—Non-Orthogonal Multiple Access (NOMA), is considered as a potential solution for resource sharing in wireless multimedia networks because of its high spectral efficiency. In this research, we propose a new pricing scheme to uberize the NOMA network between users in the same resource block, leveraging the ride-sharing concept for better NOMA resource allocation. The pricing scheme between different users is similar to the Uber/Lyft ride-sharing system where the driver and passenger make a deal and share the power, time frame and frequency spectrum resource provided by the base station. The NOMA passenger user pays some virtual payment for wireless riding and the NOMA driver user is rewarded for willing to sharing the resource block after paying commission to the base station. The utility functions of users are derived based on the quality of wireless multimedia. The pricing and power allocation strategy is to make both driver and passenger users achieve their maximum utilities by deriving game-theoretic Nash Equilibrium. The simulation results show that the proposed NOMA ubertization game solution has potential improvement of system utility performance comparing with the orthogonal multiple access (OMA) pricing strategy.**

***Index Terms*—Non-orthogonal multiple access network, pricing strategy, shared riding system, quality of experience, Stackelberg game, Nash Equilibrium.**

## I. INTRODUCTION

Non-Orthogonal Multiple Access (NOMA) has shown higher network capacity potentials to accommodate tremendous data traffic in future generations of wireless networks [1], [2]. Compared to conventional Orthogonal Multiple Access (OMA) networking schemes, the key distinguishing feature of NOMA is its support of multiple users rather than one single user utilizing orthogonal resource slots with the aid of non-orthogonal resource allocation. Therefore, the basic idea of NOMA technique is serving multiple users in the same wireless resource [3], [4]. With the benefit of this concept, NOMA promotes better resource usage efficiency compared to OMA techniques.

Fig. 1 illustrates a typical power resource sharing scenario in NOMA. Super-position coding and successive interference cancellation are two significant technical components: at the transmitter side, different users' signals are directly superimposed using super-position coding and then detected and demodulated at the receivers using successive interference cancellation [5]. In this way, the spectral efficiency can be enhanced at the cost of an increased receiver complexity compared to conventional OMA network. Additionally, it is widely recognized based on information theory that non-orthogonal multiplexing using superposition coding at the transmitter and SIC at the receiver outperforms the system capacity in classical orthogonal multiplexing. The perceived service satisfaction by the user or quality of experience (QoE), as optimized objective function in this paper, is a key pillar of resource allocation in wireless systems.

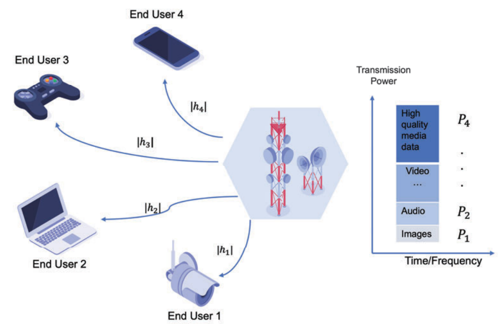


Fig. 1. Non-orthogonal multiple access multimedia network

In this research, we propose a new concept to uberize NOMA pricing strategy for networking access inspired by ride-sharing scheme. The philosophy is to reward the NOMA driver user who is willing to share its resource block with the passenger user and bear interference from the passenger user. The power originally given for one user is shared by both users in this situation.

Although NOMA has gained significant attention from the wireless communications community, the pricing strategy for wireless users is still open issue [6]. Very little research has been conducted for pricing service in NOMA. In [7], pricing the NOMA resource blocks using game theory was studied. A QoE-optimized communication power allocation approach for downlink wireless video service is proposed in [8]. In [9], the NOMA power requisition problem is modeled as a Cournot competition game. The virtual resource allocation and caching strategies are studied in [10]. Authors in [11] explore the

TABLE I
SUMMARY OF NOTATIONS AND PARAMETERS

| | |
|---|---|
| $\sigma^2$ | The variance of normalized AWGN. |
| $B$ | The frequency bandwidth of the NOMA system. |
| ${h_i}^2$ | The channel gain of the $i-th$ downlink. |
| ${R_i}^2$ | Transmission data rate of the $i-th$ user. |
| $P_i$ | Transmission power for the $i-th$ user. |
| $P_{total}$ | The total power amount of a resource block. |
| $U_i$ | Utility of the $i-th$ user. |
| $\alpha$ | The payoff parameter for $QoE$. |

impact of pricing on spectrum fragility and overall network performance. The concept of uberization and ride sharing in generic wireless networks are studied in [12], [13].

In the OMA network, there are some smart pricing schemes correlated to quality of network service rather the data quantity [14]. Benefited from this idea, resources such as power from the base station could be efficiently allocated to a number of users. Inspired on this idea, the utility functions in this research are also built based on QoE of network users. Optimizing utilities of users by pricing the services and finding out the optimal power allocation solution for users are the main goal of this NOMA uberization scheme.

The remainder of the paper is organized as follows: In section II, we describe the system model and mathematically formulate the utility functions for passenger and driver users. In Section III, the optimization problem of utility is formulated as a two-stage Stackelberg game. Simulation and discussions are presented in Section IV. The conclusion is outlined in Section V. Key notations and parameter declarations are summarized in Table. I.

## II. System Model

### A. Uberization of NOMA Pricing

In this section, we present a new pricing strategy for NOMA inspired by Uber/Lyft ride-sharing scheme. We assume the NOMA user with longer distance to base station is the "driver", and the user with shorter distance is the passenger. Typically in NOMA, the shorter distance user could generate interference to the longer distance user, but not the other way round. Thus the burden of pricing is shifted from the base station to users in one resource block. The two users in a single resource block can make deal in a way similar to ride-sharing where passengers pay for drivers' shared resource, and the driver is rewarded for its resource-offering behavior. For simplicity, we consider a minimalistic NOMA network with a base station and two users (one passenger user and one driver user) as shown in Fig. 2. We assume the farther user is the driver and the nearer user is the passenger in the model.

Compared with a single resource block serving one user in OMA network, more users can share the power resource in one NOMA block. In this situation, rather than playing games between new coming users with the base station, shall the passenger user give payment to the existing driver user for resource sharing? If so, how to price the service shared by the existing user in the existing resource block? How to

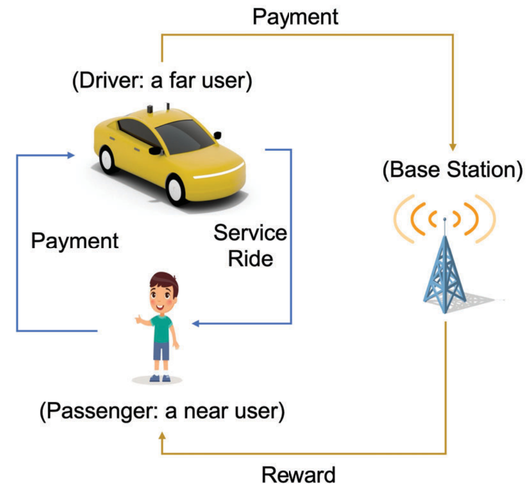


Fig. 2. Ride-sharing NOMA networking access pricing scheme

allocate the power resource to the new passenger user in order to maximize each user's revenue?

We put up a new pricing and power allocation scheme based on ride-sharing concept in NOMA networking access to address this issue. A new sharing concept is applied to pricing scheme between users in a resource block in the NOMA network rather than pricing game between end users and the base station. The pricing scheme between different users is similar to an Uber shared riding system where the taxi driver and passenger utilize the same resource block. The passenger gives a payment for shared-riding offered by the driver while the driver user attains utility from the passenger as well as service from the base station.

In this strategy, the deal making is shifted from the base station to users in the resource block regarding power sharing. Once the deal is made, the multimedia data for these users are superposition-coded and broadcast to both users within a resource block. The power originally allocated to one user (i.e. the driver) is shared by both users (i.e. the driver and the passenger) in this situation. From the view of utility, the leader of the game gets the utility from two aspects: the service provided by base station and payment from other users; the follower users get the utility from the service shared by the leader user. To be specific, the service of network is measured based on the quality of multimedia service rather than the traffic rate of data. Quality of experience $(QoE)$ is to measure end users' satisfaction about multimedia services, usually defined by transmitting data rate, network delay or other resources like system bandwidth. In the following sections, we will set up the formula of $QoE$ and then discuss the utility functions of different network users.

### B. Quality of experience $(QoE)$ model in NOMA network

We follow the generalized downlink transmission model of NOMA network demonstrated in Fig. 1. There are $N$ mobile users sharing the same resource block with the same frequencies, time slots and subcarrier channels. Let $hi$ denote the wireless channel gain for user $i$.

$$0 < |h_1|^2 \leq |h_2|^2 \leq \cdots \leq |h_N|^2 \tag{1}$$

Base station sends signals containing different users' messages to end users $user_i$ with power $P_i$ and the sum of power is fixed $\sum_{i=1}^{N} P_i = P_{total}$.

The transmission rate of the $i$th end user is represented by the Shannon-Hartley theorem as

$$R_i = B\log_2\left(1 + \frac{P_i |h_i|^2}{\sum_{k=i+1}^{N} P_k |h_i|^2 + \sigma^2}\right) \tag{2}$$

in which $B$, $P_i$, $h_i$ and $\sigma$ respectively denote the bandwidth of user's channel, the power allocated for the user, the Rayleigh fading channel gain and the channel noise power.

$QoE$ is the measure of mobile social users' satisfaction and service quality offered by the base station. In this research, we present a $QoE$ model by defining the obtained data transmission rate of R, retaining the following properties [15]:

- $Q(R)$ is positive.
- $Q(R)$ is concave with respect to $R$.
- $Q(R)$ is continuous and twice differentiable for $R$.

Due to the feature of multimedia rate-distortion theory, we present a QoE model impacted by the obtained transmitting data rate. The mobile users QoE follows the logarithmic law and QoE function can be modeled in the logarithmic form for applications of multimedia task.

*Definition 1:* For a NOMA resource block sharing by $n$ users numbered by distance denoted as $user_1, user_2, .., user_i, .., user_N$. The quality of service of $user_i$ provided by the base station is defined as

$$\begin{aligned} QoE_i &= \alpha\log_2(1 + R_i) \\ &= \alpha\log_2\left(1 + B\log_2\left(1 + \tfrac{P_i|h_i|^2}{\sum_{k=i+1}^{N} P_k|h_i|^2+\sigma^2}\right)\right) \end{aligned} \tag{3}$$

where $\alpha$ represents the payoff parameter.

### C. Utility of the passenger user

The NOMA passenger user buys its service from the NOMA driver users instead of purchasing service directly from the base station. The objective is to boost its utility and offer a payment for sharing its power in the same resource block offered by the driver user. The driver user could have utilized an independent resource block in OMA network, but is now sharing the same resource block with the new passenger user. This makes more resources available for other users, and thus the base station should give the driver user rewards for such sacrifice, bearing interference from the passenger user.

*Definition 2:* In the NOMA resource block shared by two users as a farther user(driver) and a nearer user(passenger), the utility of the nearer user is defined as $U_1$,

$$U_1 = \alpha\log_2\left(1 + \mathrm{Blog}\left(1 + \frac{P_1 |h_1|^2}{\sigma^2}\right)\right) + y_2 P_{\text{total}} - y_1 P_1 \tag{4}$$

The cost portion is formulated as a function of virtual price $y_1$ paid by the passenger user proportional to the amount of power P1 purchased to utilize the NOMA resource block. The base station issues a reward formulated as a function of cost $y_2$ times the amount of power in a single resource block $P_{total}$.

### D. Utility of the driver user

The driver user's utility is from two parts: the revenue from the passenger user and the service provided by the base station. The cost paid by the driver user is a linear cost function formulated as cost $y_2$ times the amount of power $P_{total}$ purchased to utilize the NOMA resource block.

*Definition 3:* In the NOMA resource block shared by two users as a farther user(driver) and a nearer user(passenger), the utility of the farther user is defined as $U_2$,

$$\begin{aligned} U_2 = \alpha\log_2\left(1 + B\log_2\left(1 + \frac{(P_{total} - P_1)|h_2|^2}{P_1 |h_2|^2 + \sigma^2}\right)\right) \\ + y_1 P_1 - y_2 P_{\text{total}} \end{aligned} \tag{5}$$

The income function is formulated as a linear function of revenue and cost. The revenue is formulated as y1 given by the passenger user proportional to the amount of power P1. While the cost function consisting of network service and riding service is formulated as a function of cost y2 times the power amount of a single resource block Ptotal.

In the shared resource block, the two NOMA users negotiate a deal for their resource allocation and pricing their solution without the help of the base station. The driver user shares its power resource to the passenger as an offer similar to shared riding, and gets the payment from the passenger user. From the view of utility, the driver user gets the utility from the network service and shared riding payment from the passenger user.

## III. Stackelberg Game and Nash Equilibrium Analysis

After formulating the utility of different users in the uberized ride-sharing NOMA pricing framework, we are going to find out the Nash Equilibrium solution for users in order to maximize their utilities. Specifically, we are going to figure out the solution to the problem with two users in a NOMA network: what is an optimal pricing strategy for the driver to set the price for passenger and what is an optimal power purchasing strategy for passengers to maximize their utility?

It is assumed that both users are rational and selfish. The main goal for them in this pricing game is to maximize their profits subtracted by their costs, formulated as the value of utility. The framework of pricing and power allocation in the previous section can be formulated into a two-stage Stackelberg game, being solved by finding the Nash Equilibrium state. The Stackelberg leadership model is a strategic game in economics with leader-follower interaction, where the leader knows the follower's strategy and both of game players are rational and selfish, with an objectives to maximize their utilities.

In the ride-sharing NOMA pricing scheme, we consider the passenger user as the follower to build up the relationship of optimal power and payment allocation, while driver user is considered as the leader in the game to decide sharing power quantity. In this game, the equilibrium point is a stable state where both players achieve the optimal utility and will not deviate as long as they are still rational. To derive the Stackelberg equilibrium solution, we solve the utility optimization problem of both the passenger and the driver users.

Firstly, we use the backward induction to find out the best response for a passenger user. The data rate of a wireless user $R_i$ is a monotonic increasing function of power $P_1$. The second derivative of $D_1$ respect to $P_1$ to always negative the first derivative being non-negative for all $P_1$ values, which is shown in equation (6) and (7).

$$\frac{\partial R_i}{\partial P_i} = \frac{B\left(\frac{|h_i|^2}{\sum_{k=i+1}^{N} P_k \left|_i\right|^2 + \sigma^2}\right)}{\ln 2\left(1+\frac{P_i|h_i|^2}{\sum_{k=i+1}^{N} P_k|h_i|^2+\sigma^2}\right)} = \frac{B|h_i|^2}{\ln 2\left(\sum_{k=i}^{N} P_k|h_i|^2+\sigma^2\right)} \quad (6)$$

$$\frac{\partial^2 R_1}{\partial^2 P_1} = \frac{-B\,|h_1|^4}{\ln 2\left(P_1\,|h_1|^2+\sigma^2\right)^2} < 0 \quad (7)$$

The utility function $U_1$ is concave with respect to $P_1$ since The two-level logarithmic $D_i$ model when subtracted by a linear cost function introduces concavity to the utility equation.

The first order derivative is a monotonically decreasing function and the function $U_1(P_1)$ have a maximum value in a fixed value range. Deriving the first derivative of $U_1$ respect to $P_1$ to zero can get the relationship between the optimal power amount shared to the passenger and the optimal price $y_1$ to make the deal.

### A. Best response of driver user

The relationship between the optimal shared power and the optimal price can be acquired by setting the first order derivative of utility function U1 equal to zero. Referring to two properties below, the utility function of the driver user could get an attainable optimal value in a way similar to [14].

$Property$ 1: A continuous real function on a closed interval must contain a maximum value and a minimum value.

$Property$ 2: The utility function of driver $U_2$ has a maximum value on the closed interval $[P_{min}, P_{max}]$.

In order to establish the relationship between power and utility, replace $y(P_1)$ with $y_1$ in the utility of the driver user shown in equation (5). From the Property 1 and Property 2, we can find out the optimal power $P_{opt}$ using global searching method in a fixed power range. Finally we insert $P_{opt}$ in $y(P_1)$ and get passenger' best response for the optimal price $y_{opt}$.

### B. Stackelberg game theoretic equilibrium algorithm

Based on the analysis mentioned above, a ride-sharing inspired pricing and power allocation algorithm to derive the Nash equilibrium point is proposed in Algorithm 1.

**Algorithm 1** Shared-riding pricing implementation-Stackelberg Game

1: **Initialization**:
Initialize the cost parameters $\alpha$. Define the channel parameters: channel bandwidth $B$, interference for two users' channel $h1$ and $h2$ and channel noise $\sigma$, the total power amount for a resource block $P_{total}$. Choose the simulation step size $X$.
2: **Searching for the NE solutions:**
**Iteration:** Initialize $U_{max}$=0;
Calculate $y(p_1)$ using passenger's derived strategy:
get $y(p_1)$ that makes $\partial U_1/\partial P_1 = 0$;
Let $P_1 = linespace[0, P_{max}, X]$
**While** $i = 1 : X$ **do**
  Calculate the utility of the driver user $U_2$:
  **if** $U_{\mathrm{SP}} > U_{max}$ **then**
    Set $U_{max} = U_1$;
    Set $P_{opt}$ that obtains $U_{max}$
    return $P_1$ = $P_{opt}$
  **end if**
**end while**
$y_{opt}$ = $y(p_1)$;
Return $RESULT$.
3: **Output**:The optimal power shared to the passenger user $P_{opt}$ and the optimal price $y_{opt}$.

TABLE II
THE VALUE RANGE OF PARAMETERS IN THE SIMULATIONS

| Symbol | Value Range |
|---|---|
| $\sigma^2$ | $10^-18W/hz$ |
| ${h_i}^2$ | $[10^-16, 10^-12]W/hz$ |
| $P_{total}$ | $[0.1, 1]$ |
| $\alpha$ | 5 |

## IV. Simulation Study

In this section, simulation studies are presented to show the efficiency of the new ride-sharing pricing scheme. We compare the performance of ride-sharing power allocation scheme in NOMA network with traditional pricing schemes predominantly used in OMA network. The transmission data rate and average $QoE$ gain are used to measure the performance. The values and ranges of parameters in the simulation are given in Table II.

In the previous section, we mathematically proved that the utility of the passenger is always concave due to the two-level logarithmic QoE model. Thus there is one, and only one, maximum utility of driver user if the amount of shared power changes. The utility of driver user with different channel conditions is shown in the Fig. 3. As the distance from the base station to passenger and driver users increases, the ratio of signal power to the noise power $(SNR)$ difference of their channels increase from $10dB$ to $30dB$. The attained optimal power is the power gaining the maximum value of utility $(U_2)$ for the driver user.

If the total available power amount $P_{total}$ is fixed, as the value of $SNR$ changes, different amount of optimal power $(P_1)$ is shared with the passenger user from the driver user. Under different $SNR$ conditions, the driver user could figure out different amounts of optimal power to share with the passenger user. We can find that, if the channel gain of two users is closer, more power should be shared to the passenger

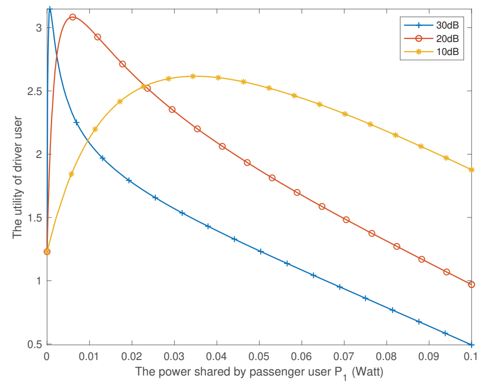


Fig. 3. The utility of driver user with different channel SNR conditions

user for the maximum revenue. As the difference of $SNR$ grows larger, the power allocation is more unbalanced between two users.

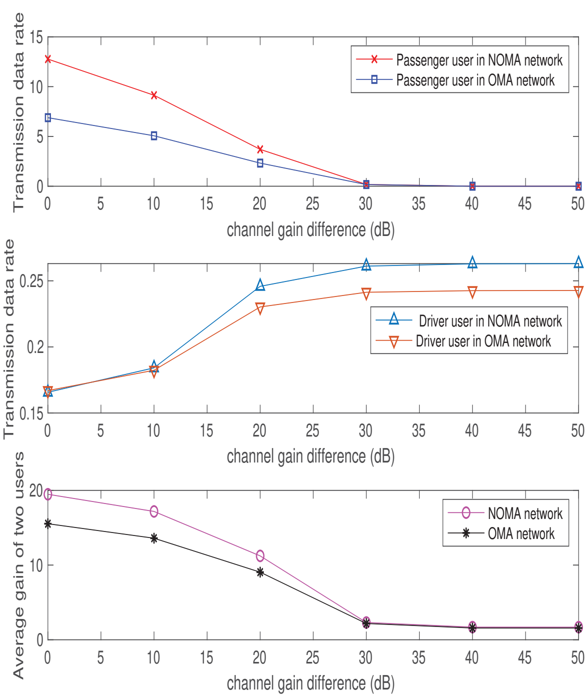


Fig. 4. (a) The transmission data rate of passenger user in different channel conditions; (b) The transmission data rate of driver user in different channel conditions; (c) The average gain of two users in different channel conditions

In the same way, we can observe the optimal shared power in different SNR changing from $0$ to $50dB$ and then obtain the transmitting data rate of the two users sharing power optimally in these situations. The performance of new power allocation scheme for NOMA network is compared with the conventional strategy for OMA network in Fig. 4. The transmission data rate and average utility gain is used to measure the performance of this pricing strategy in NOMA network. In the OMA network, the bandwidth is evenly shared with the two users. We can find out that both the passenger user and driver user utilize higher data rates and also achieve larger gains in NOMA network. When the total power is fixed but the $QoE$ of two channels change, this uberized price-power allocation scheme shows better performance in NOMA network with higher average $QoE$ gain.

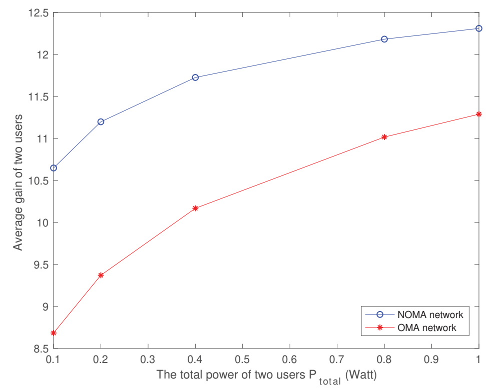


Fig. 5. Comparing average channel gain of two users in NOMA network with in OMA network

Fig. 5 shows that the average $QoE$ gain in NOMA network is higher than OMA network. In this case study the channel condition is fixed and the channel gain difference between two wireless links is $25$ $dB$. The total power increases from $0.1$ watt to $1.0$ watt. Then the average gain of two users when they are both allocated the optimal power in OMA and NOMA networks are compared. Considering this wholistic comparison scenario, the uberization of NOMA wireless resource shows considerable potentials than traditional OMA scenarios.

## V. Conclusion

In this paper, we proposed a new pricing scheme to uberize NOMA resource sharing between users inspired by the Uber/Lyft driver-passenger ride-sharing concept. The uberization of NOMA pricing is designed in a way similar to the Uber/Lyft shared riding system where the driver offers its car to the passenger and receives virtual rewards for compensation. A Stackelberg Game theory solution is developed to find the Nash Equilibrium between the two users in order to share the NOMA resources. Simulation study shows the uberization of NOMA network with ride-sharing inspired pricing scheme has potential to achieve higher efficiency for resource allocation.

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