

Article

Contract Theory-Based Incentive Mechanism for Full Duplex Cooperative NOMA with SWIPT Communication Networks

Zhenwei Zhang^{1,*} , Hua Qu^{1,2}, Jihong Zhao³ and Wei Wang¹¹ School of Electronic and Information Engineering, Xi'an Jiaotong University, Xi'an 710049, China² School of Software Engineering, Xi'an Jiaotong University, Xi'an 710049, China³ School of Telecommunication and Information Engineering, Xi'an University of Posts and Telecommunications, Xi'an 710061, China

* Correspondence: denisberg29@gmail.com

Abstract: Cooperative Non-Orthogonal Multiple Access (NOMA) with Simultaneous Wireless Information and Power Transfer (SWIPT) communication can not only effectively improve the spectrum efficiency and energy efficiency of the wireless networks but also extend the coverage. An important design issue is to incentivize a relaying center user to participate in the cooperative process and achieve a win-win situation to both the BS and the center user. Some private information of the center users are hidden from the BS in the networks. We apply a contract theory-based incentive mechanism under such asymmetric information scenario to incentivize center user to join the cooperative communication to maximize the BS's benefit utility and to guarantee the center user's expected payoff. A matching theory-based Gale-Shapley algorithm is proposed to obtain the optimal strategy with low computation complexity. Simulation results indicated the network performance of our proposed cooperative transmission is much better than the conventional NOMA transmission and the benefit utility of the BS with the stable match strategy is nearly close to that of the complete channel state information multi-users scenario while the center users get the satisfied expect payoffs.

Keywords: Contract Theory, Incentive Mechanism, Cooperative NOMA, SWIPT, Full Duplex

1. Introduction

Both Non-Orthogonal Multiple Access (NOMA) and Simultaneous Wireless Information and Power Transfer (SWIPT) have been recognized as important enabling technologies for data explosive next generation wireless communication networks. we investigate the coexistence of these two new important technologies with cooperative communication and full duplex which can extend the BS coverage area, enhance the system capacity, and enormously increase the spectrum and energy efficiency of the wireless communication networks.

The concept of cooperative NOMA with SWIPT was initially proposed in [1,2], the center user in the NOMA cluster can act as a relay to decode and forward the edge user's data, and use power splitting to harvest energy from the same received signal. Full duplex enabled cooperative communication was studied by [3–5], it can massively improve the sum transmission data rate of the NOMA cluster when the self-interference (SI) at the relaying center user is well cancelled. However, since the cooperating center users are inherently rational and selfish, their private network information are not willing to be shared with others, how to incentivize users with asymmetry information to participate in the cooperative communication is still a challenging issue to be solved.

Contract theory is widely used in economics with asymmetric information to design contracts between employer and employee [6,7]. The asymmetry information refers to the fact that the employer does not know exactly the characteristics of the employee. Using contract theory-based incentive mechanism model, the employer can overcome the asymmetric information and efficiently incentives the employee by offering a contract with performance requirement and corresponding reward. With the survey of Contract theory, zhang[8] demonstrated its effectiveness to design incentive mechanisms for wireless application scenarios. In contract theory model, participants are offered well designed rewards based on their performances, and the objective problem is to maximize the employer's payoff or utility. The objective problem is usually formulated with the incentive compatibility constraint that the employee's expected payoff is maximized and the individual rationality constraint that the employee's payoff under this contract is not below its reservation payoff .

1.1. Related work

Contract theory is widely used in content sharing and delivery problem in Device-to-Device(D2D) communication. Chen[9], introduced contract theory to provide effective and distinctive incentive mechanism to reduce computation and communication cost in device-to-device communication which has advantages in high data transmission rate, spectrum efficiency and energy efficiency. Chen[10], proposed a incentive mechanism to optimize the operator's expected profit from motivating content sharing D2D communication with guaranteed service quality in both complete and incomplete information scenarios. Satisfying individual rationality and incentive compatibility, the proposed greedy algorithms with low complexity obtain fast solutions for contract design based on local optimization. Yang[11], proposed a contract-based allocation mechanism to optimize the benefits of the principal sending users and the contract agents cooperative users. Formulating both contract parties' utility function, considering the social relationships, maximum benefits can be obtained under the control of the BS by a stable match algorithm with user preference. Zhang[12], used contract theory for introducing incentive mechanisms D2D sharing problem under information asymmetry, where the BS as an employer to offer contracts to UEs to hire it as employees to fulfill the content transmission task. The users can be efficiently reward according to the performance to participate in D2D communication.

Contract theory is also widely used in cooperative relay network, such as our proposed cooperative communication mode that can effectively improve the wireless spectrum efficiency and extend the network coverage. Relay nodes with selfish characteristics may acquire the asymmetry network information of the various nodes' location and mobility, channels' conditions and other factors. Zhao[13], proposed a contract-theoretic model to incentives the relay nodes with static and dynamic information to participate in cooperative communication and maximize the source's utility under the multiple information scenarios. By introducing a monitoring node to effectively incentives the potential relay nodes to cooperate in the cooperative communication network, Zhao[14], investigated the various monitoring strategies of contract-theoretic relay incentive mechanism under the dual asymmetric information scenario to achieve the better source's utility. To capture the dynamic characteristic of the relay nodes' cooperative information during the long-term cooperation, Zhao[15], introduced two dynamic contract mechanisms into long-term relay incentive with different relay nodes' relay information structures to maximize the source's expected utility. Nazari[16], applied a contract theoretic framework over the decode-and-forward parallel cooperative relay wireless networks to formulate an incentive compatible contract to stimulate relays to cooperate to improve the utility of the source node. Hasan[17], use contract theory to tackle the problem of relay selection under asymmetric information in OFDM-based cooperative wireless system, proposed a heuristic relay selection scheme to solve the maximizing capacity nonlinear non-separable knapsack problem in each sub-carrier under a budget constraint. Liu[18], proposed a contract-based principal-agent framework to a cognitive-radio-based wireless relaying networks by designing a pricing mechanism leading to a win-win situation between the source nodes and relay nodes.

In recent years, contract theory is studied in NOMA scenarios. Li[19], proposed a price-based power allocation scheme for a cell downlink NOMA system using stackelberg game to jointly investigate the utility maximization of the BS by pricing and users by power allocation. Tang[20], proposed a contract-based incentive mechanism together with an mobile relay selection scheme for multi-channel cooperative NOMA systems under asymmetric information, which strikes a good balance between performance and complexity.

Contract theory is also applied to energy transfer or energy trading field. Li[21], used a contract approach to study the power allocation and pricing issue for SWIPT in a downlink cellular network, where a monopoly mobile network operator (MNO) gains revenue from providing both information and energy transfer for its subscribers under incentive compatibility and individual rationality constraints. Hou[22], developed incentive mechanisms under complete and asymmetric information for the wireless energy trading in radio frequency energy harvesting based internet of things systems, concluded that the performance with the incentive mechanism under asymmetric information is better than the exist stackelberg game under complete information scenario. Liu[23], proposed a contract theory based on wireless energy harvesting in order to maximize the transfer

efficiency of source node. Liu[24], used contract theory to design incentive mechanism and proposed an energy trading method based on ESP wireless power supply.

1.2. Our contribution

Fundamentally, the proposed full duplex cooperative NOMA and SWIPT communication mode through the energy transfer to incentivize the relaying center user to participate in the cooperative process in intrinsic. Motivated By the above findings, we design the incentive mechanisms with contract theory under the asymmetric information situation to incentives the relaying center user to participate in full duplex cooperative NOMA and SWIPT communication networks. The BS can get the maximum benefit utility while guaranteeing the edge user and center user's transmission rates. The center user can get extra energy transfer as the payoff to participate in the cooperative communication. The contributions of this work are fourfold:

1) In the full duplex cooperative NOMA and SWIPT communication networks, we designed a contract-theory based incentive mechanism to encourage central users to participate in cooperative transmission. The type of the contract is determined by the channel state information of the relay user's two transmission stages.

2) Under the asymmetric information scenario, based on adverse selection of contract theory based incentive mechanism, BS obtained contract price (Sub-channel transmission power) in the complete channel information which was regarded as the upper bound of the asymmetric information scenario. The asymmetric channel information is estimated by BS to design the contract to achieve the maximum payoff utility.

3) Receiving the contract from the BS, the center users with asymmetric information adopted the optimization method of power allocation to evaluate the extra energy transferred from the BS, and gave the feedback to the BS to confirm the contract execution.

4) In the multi-user and multi-channel scenario, the preference lists of center user and edge user participating in cooperative transmission are established. The BS used the stable matching strategy [25,26] to design the contracts to achieve the maximum stable benefits while satisfying the expected payoffs of each center user.

2. System model

We consider a multi-paired users cooperating communication networks with one base station (BS), coverage with M edge users and N ($M=N$) relaying center users. Each full duplex downlink cooperative NOMA with SWIPT communication consists one center user and one edge user. Due to the strong obstruction (large scale fading) between the BS and the edge users, the BS needs to incentivize the center users as relay to cooperative communication with the edge user in NOMA to satisfy the data rate requirement. we assume that each relaying center user provided with one receive antenna and one transmission antenna, working in full duplex mode with perfect SIC.

The BS transmits the information data to the cooperative communication users in k th sub-channel using superposition coding (SC) technology. The relaying center user with good channel condition receives the signal from the BS, and uses power splitting (PS) technology in SWIPT with β for energy harvest, and $1 - \beta$ for information decoding. Concurrently, it uses self-interference cancellation technology to subtract the edge user information and acts as a relay to decode-and-forward (DF) it. The edge user receives the signal from the BS and the cooperative relaying center user, then decodes the information in the maximal-ratio combining (MRC) mode. A full-duplex cooperative NOMA and SWIPT communication network consists two transmission stages as:

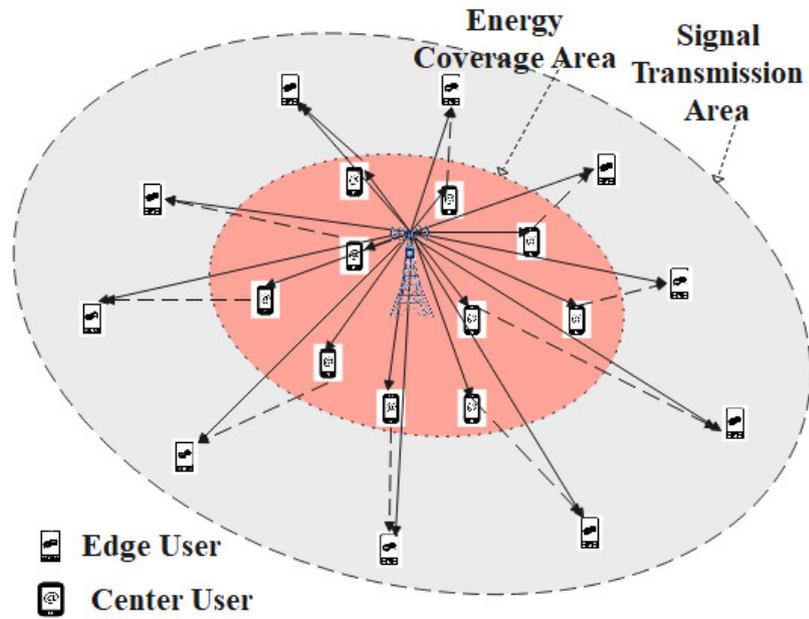


Figure 1. Edge users and center users distribution in Sub-6G networks

2.1. Direct Transmission Stage:

The observation at relaying center user n is given by[1]:

$$y_{sn}^k = \sum_{i=\{n,m\}} \sqrt{p_i^k (1 - \beta_{sn}^k)} H_{sn}^k x_i^k + \sqrt{p_{rn}^k} H_{rn}^k x_m^k \frac{(T - \tau)}{T} + n_n^k \quad (1)$$

where k means that the BS's transmission to the cooperative users in the k th sub-channel, p_i^k is the transmit power allocated to users in the k th subchannel, H_{sn}^k models the channel gain from the BS to the relaying center user n , n_n^k is the additive white Gaussian noise (AWGN) with variance σ^2 , H_{rn}^k models the self-interference fading channel gain. We assume $|p_n^k|^2 + |p_m^k|^2 = p^k$ and $|p_n^k|^2 = p^k \omega_n^k$, $|p_m^k|^2 = p^k (1 - \omega_n^k)$. x_n and x_m are the transmission signals for the relaying center user and the edge user. p_{rn}^k is the transmit power for relaying transmission to the edge user m . τ is the time delay at relaying center user caused by full duplex operation, which can be negligible.

The received SINR at relaying center user n to detect signal x_m of edge user m is given by:

$$\gamma_{sm,n}^k = \frac{p^k H_{sn}^k \omega_{nm}^k (1 - \beta_{nm}^k)}{p^k H_{sn}^k (1 - \omega_{nm}^k) (1 - \beta_{nm}^k) + \kappa p_{rn}^k H_{rn}^k + \sigma^2} \quad (2)$$

We assume the full-duplex self-interference cancellation technology playing an important role that the residual self-interference coefficient κ is smaller than -50dB, with H_{rn}^k is about -10dB, so $\kappa p_{rn}^k H_{rn}^k$ is much smaller than noise and can be neglected.

The received SINR at relaying center user n to detect signal x_n of center user n is given by:

$$\gamma_{sn}^k = \frac{p^k H_{sn}^k (1 - \omega_{nm}^k) (1 - \beta_{nm}^k)}{\kappa p_{rn}^k H_{rn}^k + \sigma^2} \quad (3)$$

At center user n , we assume the capacity of the battery is large enough and the harvested energy transfer is linear with energy conversion coefficient η which is from $0 \sim 1$. In each time slot $T=1$, the harvested energy is represented by:

$$E_n^k = \eta \beta_{nm}^k p^k H_{sn}^k \quad (4)$$

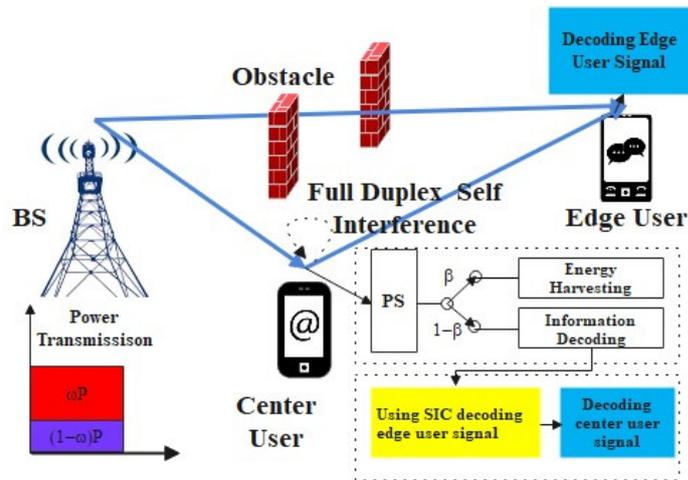


Figure 2. Full duplex cooperative NOMA and SWIPT communication mode

2.2. Cooperative Transmission Stage:

The observation at edge user m is given by:

$$y_{sm}^k = \sum_{i=\{n,m\}} \sqrt{p_i^k(1-\beta_{nm}^k)} H_{sm}^k x_i^k + \sqrt{p_{rn}^k} x_m^k G_{nm}^k \frac{(T-\tau)}{T} + n_m^k \quad (5)$$

Using MRC, edge user m combines the signals from the BS and the cooperative relaying center user n , the SINR at edge user m to detect x_m is as follows:

$$\gamma_{sm,MRC}^k = \frac{p^k H_{sm}^k \omega_{nm}^k}{p^k H_{sm}^k (1-\omega_{nm}^k) + \sigma^2} + \frac{p_{rn}^k G_{nm}^k}{\sigma^2} \quad (6)$$

3. Contract Formulation

A contract is composed of the BS transmission power and the contract type with the cooperative communication requirement. The whole process of the contract formulation consists of three phases[13]: service requesting and CSI interaction, contract design and confirmation, contract execution, as described in Fig.3.

Phase 1: *service requesting and CSI interaction*. Edge users and center users request data transmission services with minimum data requirement at the same time, then the BS requests the CSI between the users and BS.

Phase 2: *contract design and confirmation*. The BS would design and offer the contract $\Phi_{nm}^k = (p^k, \theta_m^k)$ based on the contract theory based incentive mechanism to maximize its payoffs while satisfy the center user's expected utility in the full duplex NOMA and SWIPT cooperative communication process. Receiving the contract, with the complete channel state information, the relaying center user optimizes the coefficients of the full duplex cooperative NOMA with SWIPT model to satisfy the data rate requirements of both cooperative users and to get the maximum payoffs. It will decide to accept or drop the contract?

Phase 3: *contract execution*. If the relaying center user accepts the contract, it replies the BS with the optimal cooperative transmission coefficients. Then the BS executes the contract to meet the data rate requirements of edge users and center users and gets rewards from the users. The relaying center user would get extra transferred energy from the radio frequency signals from the BS in the cooperative transmission process as its payoff.

3.1. BS's benefit utility:

The edge and center users would apply a fixed data rate service from the BS and pay the corresponding reward for it. The BS is well known of all the CSI between BS and users, but it has no knowledge of the CSI among the center users and edge users. The aim of the BS is to incentivize more center users to participate in cooperative transmission with the edge users to decrease the

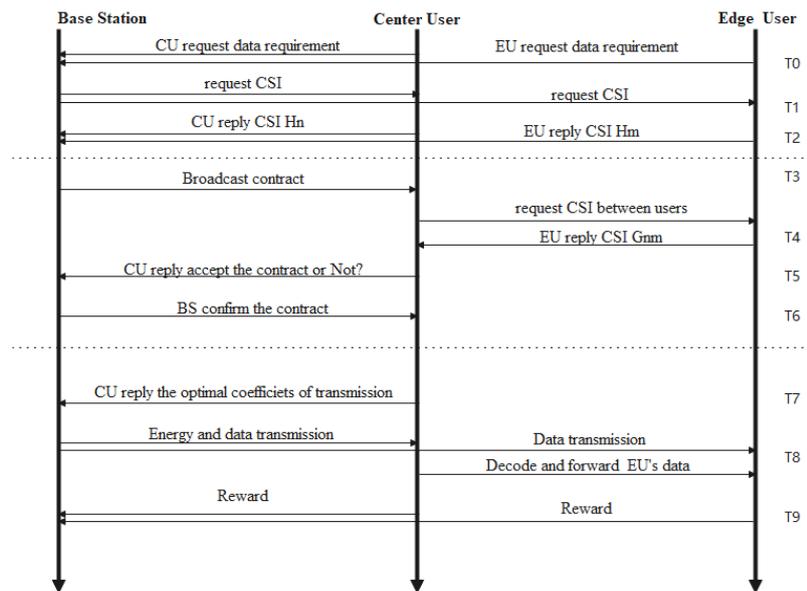


Figure 3. The process diagram of contract formulation

transmission power and get the maximum network profit utility. It will offer a contract set to center users to achieve the data rate requirements of the edge users. If a contract is accepted by multiple center users, the BS would decrease contract price (the transmission power) until only one relaying center user can accept it, and scarcely have payoff. The BS's benefit utility can be defined as,

$$U_{BS} = \lambda \cdot \sum_{k=1}^K (R_n^k + R_m^k) - c \cdot \sum_{k=1}^K p^k \quad (7)$$

Where R_n^k and R_m^k are the transmission data rate requirement of the center user and edge user in the k th channel respectively. Without loss of generality, λ is the unit price of the requirement data rate, c is the unit cost of the BS transmission power.

3.2. Relaying center user's payoff:

Owing to the rational and selfish of the users, once the center user receives the contract, it would optimize the coefficients $(\omega_{nm}^k, \beta_{nm}^k)$ of the cooperative communication to maximize its own utility and then reply to the BS to accept or drop it. The utility of the relaying user is,

$$U_{nm}^k = c \cdot (E_n^k - P_{rn}^k T) = c \cdot (\eta \beta_{nm}^k p^k H_{sn}^k - P_{rn}^k) \quad (8)$$

Where $E_n^k = T \eta \beta_{nm}^k p^k H_{sn}^k$ is harvested energy of center user n in the k th subchannel using power splitting in SWIPT. And P_{rn}^k is easy to get by the given contract after getting the optimize coefficients $(\omega_{nm}^k, \beta_{nm}^k)$.

3.3. The optimal coefficients for each given contract

The decoded data rate of each part in the full duplex cooperative NOMA and SWIPT communication network are given as,

$$\begin{cases} R_{sm,n} = \log \left(1 + \frac{p^k H_{sn}^k \cdot \omega_{nm}^k (1 - \beta_{nm}^k)}{p^k H_{sn}^k (1 - \omega_{nm}^k) (1 - \beta_{nm}^k) + \sigma^2 + \kappa p_{rn}^k H_{rn}^k} \right) \\ R_{sn} = \log \left(1 + \frac{p^k H_{sn}^k (1 - \omega_{nm}^k) (1 - \beta_{nm}^k)}{\sigma^2 + \kappa p_{rn}^k H_{rn}^k} \right) \\ R_{sm,MRC} = \log \left(1 + \frac{p^k H_{sm}^k \cdot \omega_{nm}^k}{p^k H_{sm}^k (1 - \omega_{nm}^k) + \sigma^2} + \frac{p_{rn}^k G_{nm}^k}{\sigma^2} \right) \end{cases} \quad (9)$$

Characterization 1. *The maximize payoffs of a relaying center user when it receives a contract is with the optimization power allocation coefficient $(\omega_{nm}^k, \beta_{nm}^k)$ to a Karsh-Kuhn-Tucker point that $R_{sm,MRC} = R_m^{\min}$, $R_{sm,n} = R_{sn} = R_n^{\min}$.*

Proof. The proof can be found in Appendix A. \square

According to characterization 1, let $\gamma_m = 2^{R_m^{\min}} - 1$ and $\gamma_n = 2^{R_n^{\min}} - 1$, we can get the optimized coefficients, when: $p^k \geq \frac{(\gamma_m \gamma_n + \gamma_m + \gamma_n) \sigma^2}{H_{sn}^k}$ is satisfied:

$$\omega_{nm}^{k*} = \gamma_m (\gamma_n + 1) / (\gamma_m \gamma_n + \gamma_m + \gamma_n) \quad (10)$$

$$\beta_{nm}^{k*} = 1 - (\gamma_m \gamma_n + \gamma_m + \gamma_n) \sigma^2 / (p^k H_{sn}^k) \quad (11)$$

Then the payoff of the n th relaying center user from the cooperative communication with the m th edge user is redefined as,

$$U_{nm}^k = c \cdot (E_n^k - P_{rn}^k T) = c \cdot \eta \beta_{nm}^k H_{sn}^k (p^k - \Pi_m^k \cdot \theta_m^k) \quad (12)$$

$$\Pi_m^k = \gamma_m - \frac{p^k H_{sm}^k \omega_{nm}^k}{p^k H_{sm}^k (1 - \omega_{nm}^k) + \sigma^2} \quad (13)$$

We defined the contract type of the relaying center user cooperative communication with edge user m as:

$$\theta_m^k = \sigma^2 / (\eta H_{sn}^k G_{nm}^k). \quad (14)$$

Which suggests that the stronger multipliers of the channel gains from the BS to the relaying center user and from the relaying center user to the edge user, the lower the type is. Without of generality, we assume there are totally M types of edge users cooperatively communicating with one relaying center user n in channel k . we denote the set of types as $S = (\theta_1^k, \theta_2^k, \dots, \theta_M^k)$ with $|S| = M$ and $\theta_1^k \leq \theta_2^k \leq \dots \leq \theta_M^k$.

3.4. IR and IC constraints of contract

Since the relaying center users are rational and selfish, the designed contract $\Phi_{nm}^k = (p^k, \theta_m^k)$ should be feasible and satisfy the following individual rationality (IR) and incentive compatibility (IC) constraints[12]. The IR condition requires that the received energy of each relaying center user should compensate the cost when it participates in the cooperative communication. The IC condition ensures that the relaying center user automatically selects the contract item with maximizing the relaying center user's payoff. If a contract satisfies the IR and IC constraints, we refer to the contract as a feasible contract.

Definition 1. (IR constraints) *the contract item that a relaying center user signing for its type should ensure a non-negative payoff:*

$$U_{nm}^k = c \cdot \eta \beta_{nm}^k H_{sn}^k (p^k - \Pi_m^k \theta_m^k) \geq 0, \forall \theta_m^k \in S \quad (15)$$

Definition 2. (IC constraints) *the payoff of the relaying center user is maximized when signing for its type.*

$$(p_m^k - \Pi_m^k \theta_m^k) \geq (p_{m'}^k - \Pi_{m'}^k \theta_{m'}^k), \forall \theta_m^k, \theta_{m'}^k \in S, m < m' \quad (16)$$

4. Problem formulation

We aim to find feasible contract sets that maximizes the expected profit utility of the BS, the problem is formulated as (P1),

$$\begin{aligned} \max U_{BS} &= \sum_{k=1}^K \sum_{n=1}^N \sum_{m=1}^M \alpha_{nm}^k \left(\lambda \cdot (R_n^k + R_m^k) - c \cdot P^k \right), \\ \text{s.t. } \max U_{nm}^k &= c \eta \beta_{nm}^k H_{sn}^k (p_n^k - \Pi_n^k \theta_n^k), \\ IC : (p_m^k - \Pi_m^k \theta_m^k) &\geq (p_{m'}^k - \Pi_{m'}^k \theta_{m'}^k), \\ IR : U_{nm}^k &= c \cdot \eta \beta_{nm}^k H_{sn}^k (p_m^k - \Pi_m^k \theta_m^k) \geq 0, \\ SINR : R_n^n &\geq R_n^{\min}, R_{mn}^n \geq R_m^{\min}, R_m^{mrc} \geq R_m^{\min}. \end{aligned} \quad (17)$$

The P1 is a Mixed-Integer Nonlinear Programming (MINLP) problem, $\alpha_{nm}^k=1$ is the index of the edge user M and relaying center user N which are cooperative communication in the k th subchannel. The problem is divided into power allocation and user pairing two sub-problems. In the power allocation sub-problem, we use the contract theory-based incentive mechanism to maximize the BS's profit utility while maximizing the relaying center users' payoffs. In the user pairing sub-problem, we use the matching theory with Gale-Shapley algorithm, the computation complexity is much lower than that of the global searching algorithm.

5. Incentive Mechanism for power allocation of the contract

For the power allocation sub-problem, we can transform the problem as (P2),

$$\begin{aligned} \max U^k &= \lambda \cdot (R_n^k + R_m^k) - c \cdot (P^k - P_N^{noma}) \\ \text{s.t. } \max U_{nm}^k &= c \cdot \eta \beta_{nm}^k H_{sn}^k (p_m^k - \Pi_m^k \theta_m^k), IC, IR, SINR. \end{aligned} \quad (18)$$

Where P_N^{noma} is the fraction transmission power to satisfy the QoS of the center user n, which is fixed in the conventional NOMA and our proposed full duplex cooperative NOMA and SWIPT communication networks, and P_N^{noma} is easy to get that $P_N^{noma} = \gamma_n \sigma^2 / H_{sn}^k$.

5.1. Complete Channel information scenarios

We consider the complete information scenario as the upper-bound of the optimization.

Lemma 1. For the optimal feasible contract set $\Phi_{nm}^k = (p_m^k, \theta_m^k)$ with the complete information scenario, the IR constraints in eq. 8 are equivalent to $U_{nm}^k = 0$.

we assume, the optimal contract set $\Phi_{nm}^k = (p_m^k, \theta_m^k)$ with power as,

$$p_m^k = \left(-\alpha_n^1 + \sqrt{(\alpha_n^1)^2 + 4\gamma_n H_{sn}^k H_{sm}^k \alpha_n^2} \right) / \left(2\gamma_n H_{sn}^k H_{sm}^k \right) \quad (19)$$

where $\Delta = (\gamma_m \gamma_n + \gamma_m + \gamma_n)$, $\alpha_m^1 = \Delta \cdot \sigma^2 (H_{sn}^k - \gamma_n H_{sm}^k) - \gamma_m \theta_m^k H_{sn}^k H_{sm}^k$ and $\alpha_m^2 = \Delta \cdot \sigma^2 (\theta_m^k \gamma_m H_{sn}^k -$

5.2. Incomplete Channel information scenarios

Lemma 2. For the optimal feasible contract set $\Phi_{nm}^k = (p_m^k, \theta_m^k)$, the following condition holds: $p_m < p_{m'}$ if and only if $\theta_m < \theta_{m'}$.

$$P_1^k \leq P_2^k \leq \dots \leq P_m^k; \theta_1^k \leq \theta_2^k \leq \dots \leq \theta_m^k \quad (20)$$

Algorithm 1 Power allocation optimization algorithm of center user in complete/incomplete information Scenarios.

Input: Contract $\Phi_{nm}^k = (p^k, \theta_m^k)$ accepted from BS to cooperative transmission to edge user m .

The required data rate of edge user R_m^{\min} and center user R_n^{\min} .

Output: Accepted or Not ? Cooperative transmission coefficient $(\omega_{mn}^k, \beta_{mn}^k)$.

Let $\gamma_m = 2^{R_m^{\min}} - 1$ and $\gamma_n = 2^{R_n^{\min}} - 1$, and $\Delta = (\gamma_m \gamma_n + \gamma_m + \gamma_n)$, get the up-bound and low-bound cooperative transmission power by: $P_{up}^k = \Delta \sigma^2 / H_{sm}^k$, $P_{low}^k = \Delta \sigma^2 / H_{sn}^k$.

if $P^k \leq P_{up}^k$ and $P^k \geq P_{low}^k$ **then**

Get the optimal edge user power coefficient by:

$$\omega_{nm}^{k*} = \gamma_m(\gamma_n + 1) / (\gamma_m \gamma_n + \gamma_m + \gamma_n)$$

Get the optimal center user's energy efficient coefficient by:

$$\beta_{nm}^{k*} = 1 - (\gamma_m \gamma_n + \gamma_m + \gamma_n) \sigma^2 / (p^k H_{sn}^k)$$

In complete scenarios:

Get the optimal power transmission for full duplex cooperative NOMA and SWIPT communication by:

$$p_m^k = \frac{-\alpha_m^1 + \sqrt{(\alpha_m^1)^2 + 4\gamma_n H_{sn}^k H_{sm}^k \alpha_m^2}}{2\gamma_n H_{sn}^k H_{sm}^k}$$

where $\alpha_m^1 = \Delta \cdot \sigma^2 (H_{sn}^k - \gamma_n H_{sm}^k) - \gamma_m \theta_m^k H_{sn}^k H_{sm}^k$, $\alpha_m^2 = \Delta \cdot \sigma^2 (\theta_m^k \gamma_m H_{sn}^k - \Delta \cdot \sigma^2)$.

In incomplete scenarios:

Get the optimal power transmission for the n th type contract relaying center user by:

$$p_M^k = \frac{-\alpha_m^1 + \sqrt{(\alpha_m^1)^2 + 4\gamma_n H_{sn}^k H_{sm}^k \alpha_m^2}}{2\gamma_n H_{sn}^k H_{sm}^k}$$

for $m \geq 2$ **do**

Get the optimal power transmission for the n th type contract relaying user through recursion by:

$$p_{m-1}^k = \frac{-\alpha_{m-1}^1 + \sqrt{(\alpha_{m-1}^1)^2 + 4\gamma_n H_{sn}^k H_{sm}^k \alpha_{m-1}^2}}{2\gamma_n H_{sn}^k H_{sm}^k}$$

where $\alpha_{m-1}^1 = \Delta \sigma^2 (H_{sn}^k - \gamma_n H_{sm}^k) + \theta_{m-1}^k H_{sm}^k (U_{nm}^k / \eta - \gamma_m H_{sn}^k)$,

$\alpha_{m-1}^2 = \Delta \sigma^2 (\theta_{m-1}^k \gamma_m H_{sn}^k + U_{nm}^k / \eta - \Delta \sigma^2)$, $U_{nm}^k = c \cdot (\eta \beta_{nm}^k p^k H_{sn}^k - P_{rn}^k)$.

then $m = m - 1$;

end for

return Accept the contract with the transmission power p^k and coefficient $(\omega_{mn}^{k*}, \beta_{mn}^{k*})$;

else

The BS only can use NOMA transmission mode to satisfy the QoS of both edge user and center user.

end if

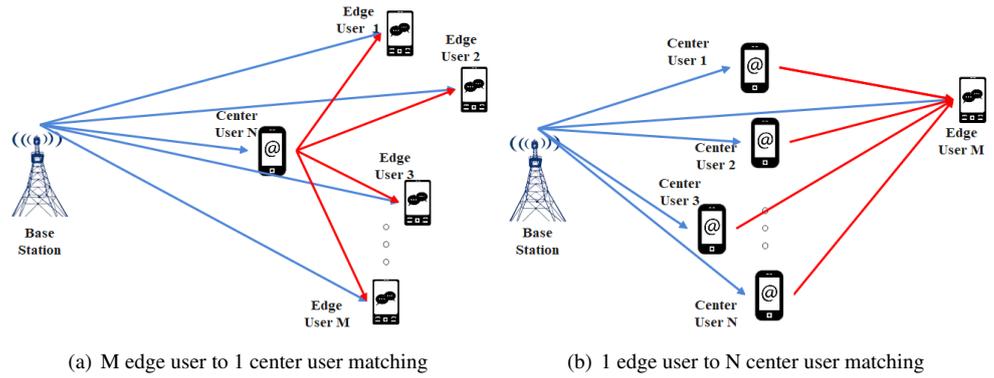


Figure 4. Stable Matching Scenarios

Lemma 3. (IC Transitivity) For the optimal feasible contract set, suppose the lemma2 condition holds, and the IC constraints are equivalent to:

$$p_1^k - \Pi_1^k \theta_1^k \geq p_2^k - \Pi_2^k \theta_2^k \geq \dots \geq p^k - \Pi_M^k \theta_M^k \quad (21)$$

Theorem 1. The contract $\Phi_{nm}^k = (p_{nm}^k, \theta_m^k)$ is feasible when the following conditions holds:

- 1) $p_1^k \leq p_2^k \leq \dots \leq p_M^k$
- 2) $m = M, p_m^k - \Pi_m^k \theta_m^k = 0$
- 3) $m \leq M, p_{m-1}^k - \Pi_{m-1}^k \theta_{m-1}^k \geq p_m^k - \Pi_m^k \theta_m^k = U_{nm}^k$

To optimize the P2, the unique and optimal power allocation is:

$$p_M^k = \frac{-\alpha_m^1 + \sqrt{(\alpha_m^1)^2 + 4\gamma_n H_{sn}^k H_{sm}^k \alpha_n^2}}{2\gamma_n H_{sn}^k H_{sm}^k} \quad (23)$$

$$p_{m-1}^k = \frac{-\alpha_{m-1}^1 + \sqrt{(\alpha_{m-1}^1)^2 + 4\gamma_n H_{sn}^k H_{sm}^k \alpha_{m-1}^2}}{2\gamma_n H_{sn}^k H_{sm}^k} \quad (24)$$

where $\Delta = \gamma_m \gamma_n + \gamma_m + \gamma_n, \alpha_{m-1}^1 = \Delta \sigma^2 (H_{sn}^k - \gamma_n H_{sm}^k) + \theta_{m-1}^k H_{sm}^k (U_{nm}^k / \eta - \gamma_m H_{sn}^k)$, $\alpha_m^2 = \Delta \sigma^2 (\theta_{m-1}^k \gamma_m H_{sn}^k + U_{nm}^k / \eta - \Delta \sigma^2)$, and U_{nm}^k is get from eq.11

The detail of the incentive mechanism for power allocation is in Algorithm 1.

6. Stable matching for multiple user scenarios

Above on the contract theory based incentive mechanism, the BS applies a feasible contract set to the relaying center user for each edge user, and we get the feasible contract set with the center user' preference list in the descent recursion order.

At the BS side, the BS calculates benefit utility U_m for cooperative communication with edge user m and can get the edge user's preference list in the descend recursion order.

$$U_m = \lambda \cdot R_m^k - c \cdot (p^k - p_N^{oma}) \quad (25)$$

As mentioned, there may be multiple edge users competing for the same cooperative relaying center user in the networks, simultaneously, the same center user may be selected as the optimal relaying user by multiple edge users. This competition conflict will cause contract delivery to fail. Therefore, we introduce the user preference for the relaying center user's adverse selection on the basis of matching theory with Gale-Shapley (GS) algorithm [27,28], which mainly emphasizes the matching stability and usually is used to solve the stable marriage matching between men and women. Then with the feasible contract set offered to the center users, we can get the preference list

of each edge user. Based on the specific scenario proposed in this paper, their respective preference lists are arranged in descending order. After several round of matching, the conflict can be avoided and a stable matching for optimal contract delivery can be obtained. The detail of the GS matching algorithm is summarized as in Algorithm 2.

Algorithm 2 Gale and Shapley Stable Matching Algorithm with Preference.

Set up cooperative relaying center user's preference list PLC; $\forall n_k \in N$;

Set up edge users' preference list PLE; $\forall m_k \in M$;

Set up a list of unmatched edge users $\mathcal{UM} = \{m_k, \forall m_k \in M\}$;

while \mathcal{UM} is not empty **do**

m_k proposes to the cooperating relaying center user n_k that locates first in its list, $\forall m_k \in \mathcal{UM}$

if n_k receives a proposal from $m_{k'}$, and $m_{k'}$ is more preferred than the current hold m_k **then**

n_k holds $m_{k'}$ and rejects m_k ;

$m_{k'}$ is removed from \mathcal{UM} and m_k is added into \mathcal{UM} ;

else

n_k rejects $m_{k'}$ and continues holding m_k ;

end if

end while

The computation complexity of the stable matching with GS algorithm is N^2 with the worst case, that is $N \log(N)$ with average case and that is N with the best case, which is much more efficiency than the global search method.

7. Discussion

In the simulation, assume the relaying center users and edge users are randomly distribution deployed in the area of 20 ~ 50 and 50 ~ 100 meters euclidean distance to the BS respectively. The distance dependent pass loss model follows [1]. The detail of the coefficients are in Table 1. All the simulation results are averaged over 1000 independent channel realizations.

Table 1. Simulation parameters in Sub-6G networks

Parameter	Definition	Value
P	Base Station Transmission Power	1 ~ 46dBm
p^k	Sub Channel Transmission Power	1 ~ 30dBm
p_c	Electricity Circuit Power Consumption	10dBm
d_{sn}	Distance between center user to BS	20 ~ 50m
d_{sm}	Distance between edge user to BS	50 ~ 100m
d_{nm}	Distance between edge user to center user	50 ~ 120m
θ_{mn}	Deviation angle from edge user to center user	0 ~ 90°
ω	Power allocation coefficient to edge user	0 ~ 1
β	Energy transmission coefficient to center user	0 ~ 1
κ	Self-interference cancellation residual coefficient	-80dB ~ 0dB
η	Energy transfer efficiency	0.5 ~ 1
B	Sub-6G network channel Bandwidth	10MHz
σ^2	Noise power per unit bandwidth	-174dBm/Hz

7.1. Discuss the cooperative NOMA SWIPT transmission mode in complete channel information scenario

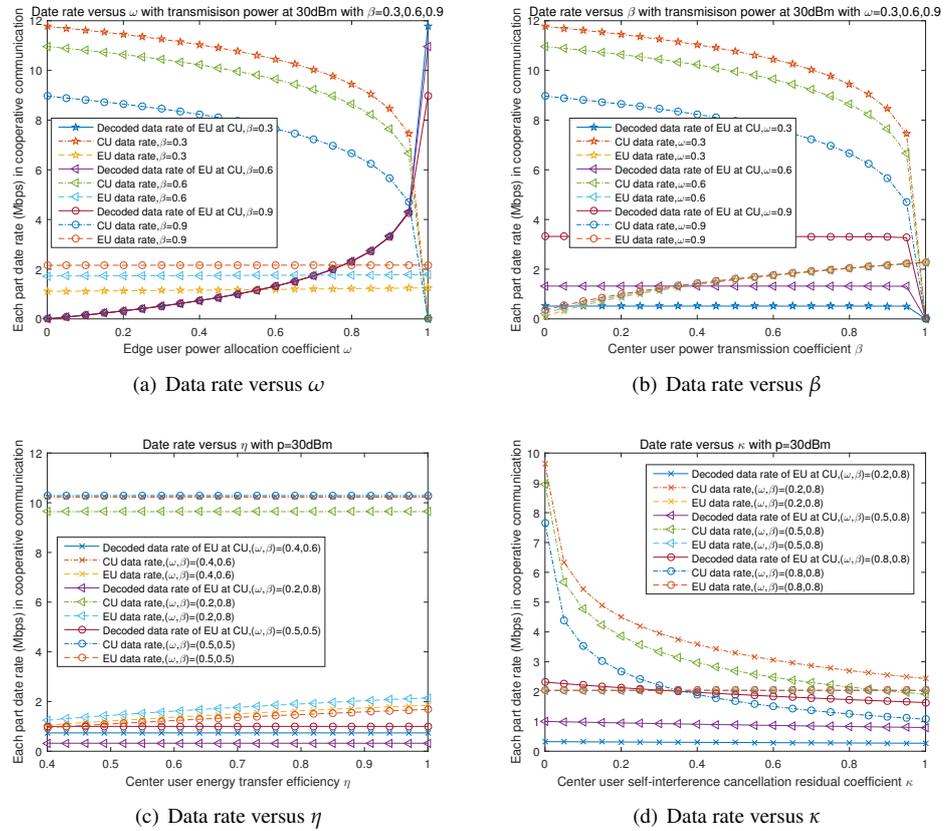


Figure 5. Three decoded data rates versus cooperative network coefficients

Fig.5 discusses the network transmission performance of Full Duplex NOMA and SWIPT cooperative transmission in Sub-6G networks with different transmission coefficients. Fig.5a discusses the relation of three decoded transmission rates with the edge user's power allocation coefficient ω . The transmission power of the sub-channel is set at 30dBm (1w), the distance of center user and edge user to BS is 20 meters and 80 meters, their deviation angel is $\delta = 30^\circ$, the center user's energy transfer coefficients β is set as 0.3, 0.6, 0.9, the center user's energy transfer efficiency η is set as 0.9, we neglect the impact of full duplex self-interference.

Fig.5a indicates, with the increase of edge user's power allocation coefficient, center user's decoded transmission rate is monotonically decreasing, the rate of center user decoding edge user's transmission rate is slowly monotonically increasing, the edge user's decoded transmission rate is accelerated monotonically increasing. Fig.5b discusses the relation of three decoded rates with the energy transfer coefficient. The edge user power allocation coefficient is set as 0.3, 0.6, 0.9, other coefficients is set same as fig.5a. Fig.5b indicates, with the increase of center user's energy transfer coefficient, center user's decoded transmission rate is monotonically decreasing, the rate of center user decoding edge user's transmission rate is slowly monotonically decreasing, the edge user's decoded transmission rate is monotonically increasing. Fig.5c discusses the relation of three decoded rates with the full duplex self-interference cancellation residual coefficient. The coefficients pair are set as (0.2,0.8),(0.5,0.8),(0.8,0.8) respectively. Fig.5c indicates, with the increase of full duplex self-interference cancellation residual coefficient, the edge user's decoded transmission rate is unchanged, the rate of center use decoding edge user's transmission rate is slowly monotonically decreasing, and the center user's decoded transmission rate is accelerated monotonically decreasing. Fig.5d discusses the relation of three decoded rates with center user's energy transfer efficiency η . The coefficients pair (ω, β) is set as (0.4,0.6),(0.2,0.8),(0.5,0.5). Fig.5d indicates, the increase of

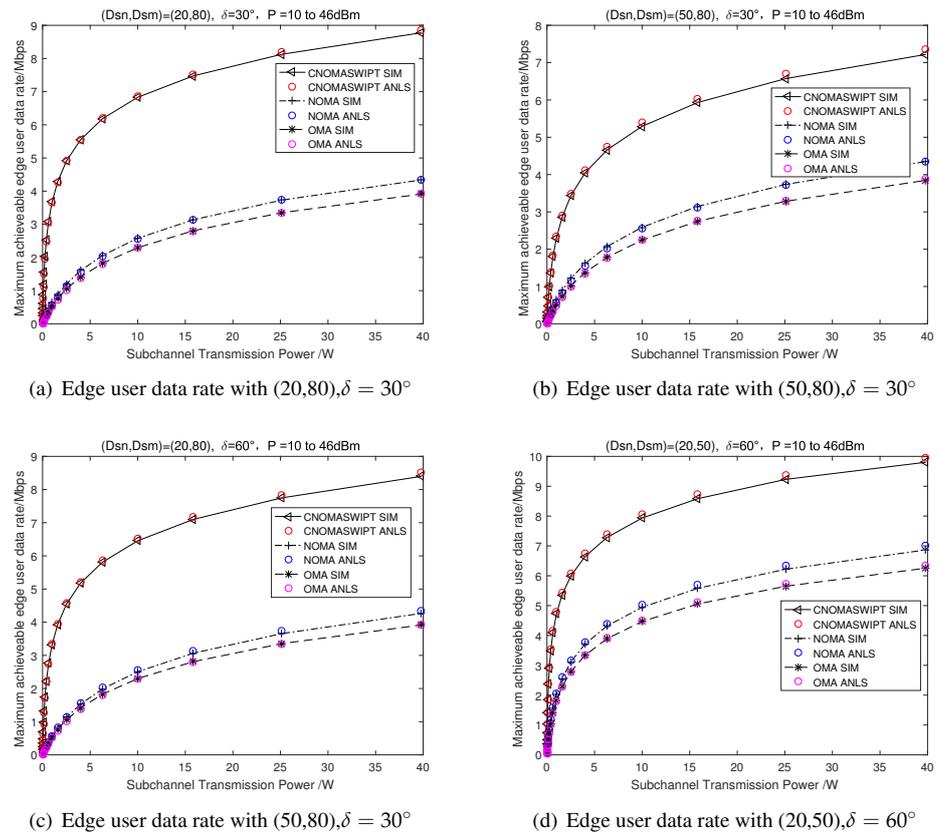


Figure 6. Achievable edge user data rate /Mbps with $R_n^{min} = 2Mbps$

center user's energy transfer efficiency is only positively increasing with the edge user's decoded transmission rate.

Fig.6 discusses the relation of the maximum achievable rate of edge user with the transmission power in four group cooperative transmission matched user pairs. Compared the edge user's achievable transmission rate of the proposed full duplex NOMA and SWIPT cooperative transmission, conventional NOMA transmission, OMA transmission with the transmission power increase from 10dBm to 46dBm. Fig.6a discusses then scenario with the distance of center user and edge user to BS are (20,80) meters, and the deviation angel is $\delta = 30^\circ$. Fig.6b discusses the corresponding scenario is $(20,80), \delta = 30^\circ$; Fig.6c discussed the corresponding scenario is $(20,80), \delta = 60^\circ$; Fig.6d discusses the corresponding scenario is $(20,50), \delta = 60^\circ$.

Fig.6 indicates, in four group scenarios, the simulation result (SIM) is approximate to the theoretical analysis result (ANLS), with error less than 0.2%. With the increase of transmission power, under the different scenarios and different transmission modes, the edge user's transmission rate is monotonically increasing. When the transmission power is 25dBm, for example in Fig.6a, the maximum edge user rate is 8.2Mbps in full duplex NOMA and SWIPT cooperative transmission mode, which is 127% better than that in NOMA mode with 3.6Mbps and 147% better than that in OMA mode with 3.3Mbps. Comparing the four group scenarios, the distribution positions of center user and edge user have a great influence on the edge user's achievable maximum transmission rate in full duplex NOMA and SWIPT cooperative transmission mode. The transmission rate in conventional NOMA mode and OMA mode is only related to the CSI between the user and BS.

7.2. Discuss the contract type in complete channel information scenario

Fig.7 is the histogram of contract type value with the change of the center user and edge user's distribution position according to eq. 7. Fix the distance between center user and BS, and between edge user and BS, under three different user pairs scenarios, Fig.7a indicates the contract type value

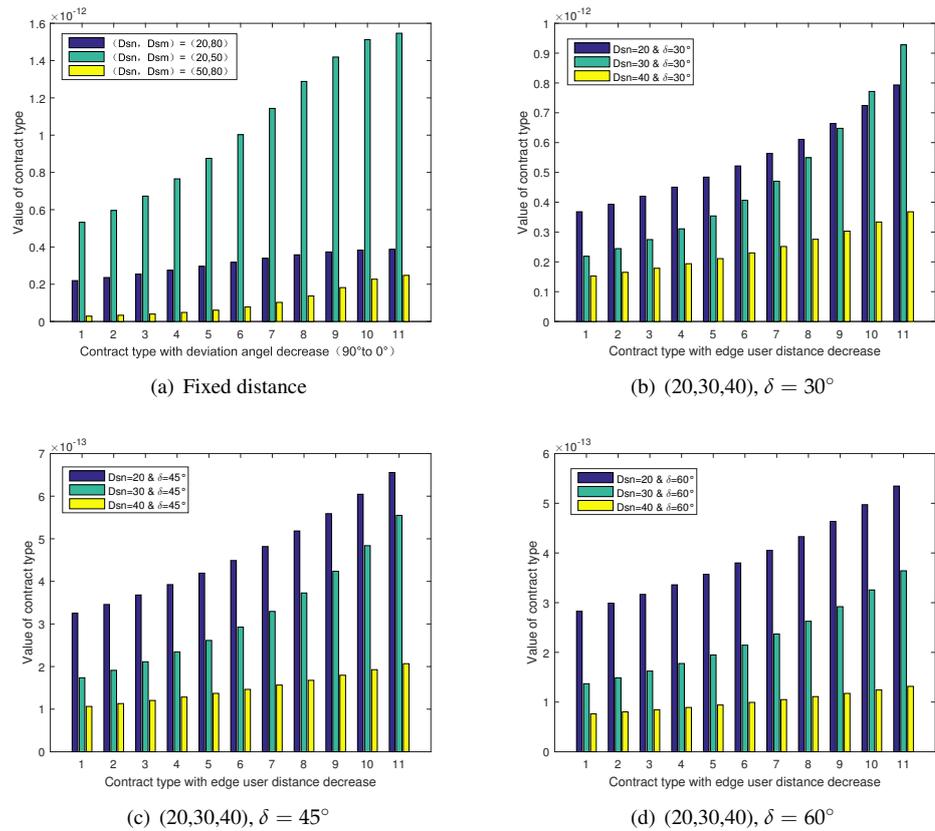


Figure 7. Contract type with edge user distribution

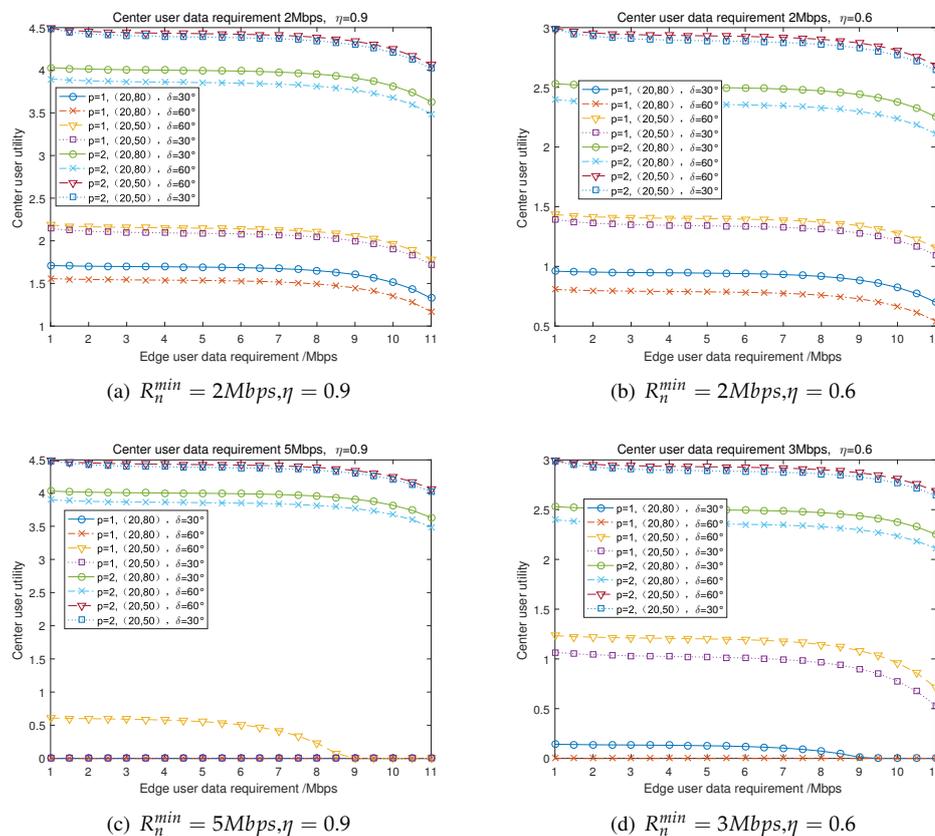


Figure 8. Center user utility with fixed transmission power in cooperative communication

(a)(b)
 Complete
 Complete
 $R_n^{min} =$
 $2Mbps, \eta =$
 0.9
 $\eta =$
 0.7

Figure 9. BS utility in complete CSI scenarios

is increasing with the decrease of the deviation angel among center user, edge user and BS, which is satisfied the IC constrain in eq. 10.

Fig.7b, Fig.7c, Fig.7d separately set the deviation angel among center user, edge user and BS as $\delta = 30^\circ, 45^\circ, 60^\circ$, under the three scenarios with the distances between the center user and BS are 20, 30, 40 meters, the simulation results indicates then contract type value is increasing with the decrease of the distance between then edge user and BS, which is also satisfied the IC constrain in eq.10.

The transmission power are set as 1W (30dBm) and 2W (33dBm) respectively in the contract, under different center user transmission rate requirement and energy transfer efficiency, under different center user and edge user distribution positions, Fig.8 discusses the center user's utility(payoffs) versus the edge user's transmission rate requirement. Fig.8a is corresponding to the scenario with $R_n^{min} = 2Mbps, \eta = 0.9$, Fig.8b is corresponding to the scenario with $R_n^{min} = 2Mbps, \eta = 0.6$, Fig.8c is corresponding to the scenario with $R_n^{min} = 5Mbps, \eta = 0.9$, Fig.8d is corresponding to the scenario with $R_n^{min} = 3Mbps, \eta = 0.6$. Fig.8 indicates, with the increase of edge user's transmission rate requirement R_m^{min} , center user's utility is monotonically decreasing. after a threshed point, center user's utility is accelerated decreasing to 0, which means the full duplex cooperative NOMA and SWIPT transmission mode cannot satisfy the demand of the user data rate. Comparing the four group scenarios, it indicates that the higher center user's transmission rate requirement would significantly decrease its utility, meanwhile the energy transfer efficiency would significantly affect its utility.

Set the center user transmission rate requirement as R_n^{min} , energy transfer efficiency are $\eta = 0.9$ and $\eta = 0.7$ respectively. Fig.9 discusses the BS utility(benefit) versus edge user transmission rate requirement, comparing three group full duplex NOMA and SWIPT cooperative transmission with one group conventional NOMA transmission in complete channel state information scenario. Fig. 9 indicates, when the edge user transmission rate requirement R_m^{min} is low, the BS utility in conventional NOMA transmission mode is better than the proposed full duplex NOMA and SWIPT cooperative transmission with utility 0. Increase R_m^{min} , conventional NOMA transmission mode cannot satisfy the user's transmission rate requirement, and proposed cooperative transmission mode can get increased utility until a threshed. Then the BS utility in proposed cooperative transmission mode would accelerated decrease to 0, which means it cannot satisfy the $R_n^{min} = 2Mbps$ too. Comparing Fig.9a and Fig.9b, higher energy transfer efficiency can get higher BS utility in completely CSI scenario.

7.3. Discuss the center user and BS's utility in incomplete channel information scenario

Set center user transmission rate requirement R_n^{min} , center user utility(payoffs) are 0.5 and 1 respectively, energy transfer efficiency are $\eta = 0.9$ and $\eta = 0.7$ respectively, Fig.10 discusses the BS utility(benefit) versus edge user's transmission rate requirement in four group incomplete CSI scenarios. The other coefficients same as in Fig.9. Fig.10 indicates, under different group incomplete CSI scenario, with lower edge user's transmission rate requirement R_m^{min} , BS would prefer conventional NOMA transmission mode. Using the proposed cooperative transmission mode, BS would get increased utility with the increase of edge user's transmission rate requirement until a threshold, then get accelerated decrease utility to 0(cannot satisfy the user rate requirement). Under the incomplete CSI scenarios, comparing the four groups, it indicates that high center user utility would decrease the BS utility, and the energy transfer efficiency has greater affection to BS utility. This would demand researchers to continue to study and develop the chips and circuits technology

(a)(b)(c)(d)
 CCCCCU
 utttttttt-
 ittytyty
 0.6.51
 wwwttttth
 ttttttttt=
 0.9.7.7

Figure 10. BS utility in incomplete CSI scenarios

to improve the energy conversion efficiency, to make it widely available to meet the diverse needs of wireless power transfer scenarios.

7.4. Discuss the BS's utility in multi-cooperative users Sub-6G networks

The discussion above is all about the contract design and transmission power auction in the cooperative transmission process of the BS to incentivize the center user to anticipate in the cooperative communication with one edge user. Then, we discuss the multi-user scenarios with M edge users and N center users applying the data rate requirement to BS at the same time. To get more utility to accomplish the user's data requests, the BS needs to design $M*N$ contracts to incentivize the center user to anticipate the cooperative transmission.

Considering a scenario with 10 center users and 10 edge users (equal to 10 contract types to one center user), Fig.11a and Fig.11b present the histogram of the center user utility and BS utility, which get from the cooperative transmission in full duplex NOMA and SWIPT cooperative transmission mode when center user accepts the contract from the BS. Each color histogram means the utility get from the cooperative transmission from different edge user to the center user. The utility with 0 means the two matched users cannot satisfy the cooperative transmission demand after the pre-processing.

For a single center user, cooperative transmission with different edge user can get different utility (payoffs). According to Fig.11a, each center user can get its cooperative edge user's preference list PL_m by the utility in descending order. Meanwhile, to satisfy each edge user's demand and decrease the power consumption with full duplex cooperative NOMA and SWIPT transmission, BS can get its cooperative center user's preference list PL_n by the utility (benefit) in descending order from Fig. 11b. Implementing the same contract, the utility obtained by center user and BS are inversely related. BS getting more utility through collecting asymmetric information means the center user anticipating in the cooperative transmission under the incomplete CSI condition getting less utility which is in extra transferred energy representation.

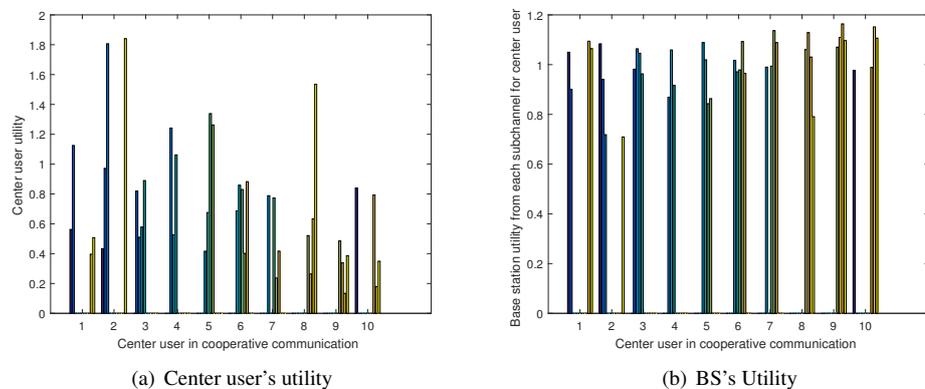


Figure 11. Multi-cooperative users Scenario

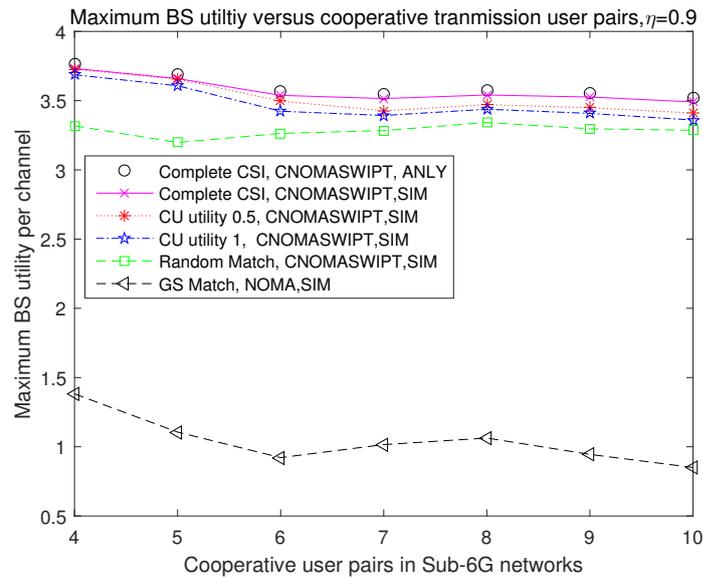


Figure 12. Base station profit utility versus the increase of the cooperate cluster number

Considering the conflict that the center user and BS only select its best preference list cooperative user under the multi-user scenarios, resulting the transmission failure and get utility loss, BS design contracts of the multi-user incentive mechanism by GS match theory algorithm to get the maximum stable utility.

Set $R_n^{min} = 2Mbps$, $R_m^{min} = 2Mbps$, $\eta = 0.9$, Fig.12 discusses the maximum average BS utility versus the cooperative transmission user pairs from 4 to 10, in the BS coverage areas in five transmission and matching strategies. Such as complete CSI with full duplex NOMA and SWIPT cooperative transmission, CU utility is 0.5 and 1, random match and conventional NOMA transmission.

Fig.12 indicates BS utility get from the proposed GS stable matching algorithm in full duplex NOMA and SWIPT cooperative transmission is near to the optimal utility in analysis with less than 0.2% loss, get 8% utility gain better than the random match algorithm, 3.3% utility gain better than the scenario of CU utility is 0.5, 4.9% utility gain better than the scenario of CU utility is 1, and more than 200% utility gain better than the scenario of using conventional NOMA transmission. When user pairs number is small, the average BS utility with GS match algorithm has big fluctuation, which would tend to be stable under different scenarios. Only the average BS utility with conventional NOMA transmission has major fluctuation owing to the channel utility being zero that the transmission mode cannot satisfy the matched user pair's data requirement.

Under the incomplete CSI scenarios, the average BS utility is much better than that with Random matching strategy and with conventional NOMA transmission strategy. Random matching strategy gets less average BS utility owing to some matched user pairs required extra power consumption resulting in the BS utility from that channel decreased. Although the average BS utility in Fig.12 has the lowest average utility, it is still much better than the conventional OMA transmission mode to satisfy the two cooperative users' data rate requirements at the same time.

8. Conclusion

This paper proposed a contract theory-based incentive mechanism to solve the problem of power allocation and cooperative user pairing with asymmetric information in full duplex cooperative NOMA and SWIPT transmission communication in single BS multi-user scenario.

In the design process of the contract, the benefit of the BS is based on the premise of meeting the data rate requirement of users and getting the corresponding reward. The BS serving more users at the same time means more benefit, and its cost is corresponding to the consumed transmission power. The central user can obtain extra transferred energy from the BS by participating in the full duplex NOMA and SWIPT cooperative transmission process through asymmetric information. To guarantee the maximum stable benefit by executing the contracts to meet the users' requirement, the

BS designs the contracts using GS matching theory with the preference cooperating list to each edge user. And center users have to make concessions to meet their own expected payoffs.

The simulation results show that the edge user's data rate in the full duplex cooperative NOMA and SWIPT transmission is much higher than the conventional NOMA transmission in the low transmission power range; the types of contracts are positively correlated with the channel states of the central user, the BS and the edge user. The improvement of energy conversion efficiency can make the BS consume less transmission power to ensure cooperative transmission and obtain greater benefits. In the multi-user scenario, the BS adopts the stable matching strategy to design the contract, which can not only make the BS get better benefit, but also make the center users get expected payoffs.

Abbreviations

The following abbreviations are used in this manuscript:

CT	Contract Theory
BS	Base Station
CU	Center User
EU	Edge User
NOMA	Non-Orthogonal Multiple Access
OFDMA	Orthogonal Frequency Division Multiple Access
SWIPT	Simultaneous Wireless Information and Power Transfer
FD	Full Duplex
CSI	Channel State Information
SINR	Signal Interference Noise Ratio
SI	Self-Interference
DF	Decode and Forward
IC	Incentive Compatibility
IR	Individual Rationality
GS	Gale and Shapley

Author Contributions: Conceptualization, Z.Z.; methodology, Z.Z.; software, Z.Z. & W.W.; validation, H.Q., J.Z.; writing—original draft preparation, Z.Z.; writing—review and editing, Z.Z., W.W.; supervision, H.Q.; All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Nature Science Foundation of China under Grant 61531013 and by the National Science and National Key R&D Program of China under Grant 2018YFB1800300.

Data Availability Statement: The data presented in this study are available through contracting the corresponding author denisberg29@gmail.com.

Acknowledgments: We thank XXX & XXX for discussion.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A.

prove of characterization 1. We assume $(\omega_{nm}^{k*}, \beta_{nm}^{k*})$ are optimal coefficients to maximizate the relaying center user's payoff $U_{nm} = c(\eta\beta_{nm}^k H_{sn}^k p^k - p_{rn}^k)$ and not a Karsh-Kuhn-Tucker point. It is obvious that $R_{sm,n}, R_{sn}, R_{sm,MRC}$ are convex and concave funntions respect to $p^k, \omega_{nm}^k, \beta_{nm}^k$ and p_{rn}^k . There are two cases, 1) $R_n(\omega_{nm}^{k*}, \beta_{nm}^{k*}) > R_n^{min}$, we can increase ω_{nm}^k and make $R_n = R_n^{min}$, then p_{rn}^k can decrease to satisfy $R_{sm,MRC} = R_n^{min}$, which would increase the payoff of U_{NM} . 2) $R_{sm,n}(\omega_{nm}^{k*}, \beta_{nm}^{k*}) > R_n^{min}$, we can increase β_{nm}^k to make $R_n = R_n^{min}$, which would increase the payoff of U_{nm} . Above on case 1 and case 2, it is contradiction to our assumption. \square

References

1. Liu, Y.; Ding, Z.; ElKashlan, M.; Poor, H.V. Cooperative non-orthogonal multiple access with simultaneous wireless information and power transfer. *IEEE Journal on Selected Areas in Communications* **2016**, *34*, 938–953.

2. Xu, Y.; Shen, C.; Ding, Z.; Sun, X.; Yan, S.; Zhu, G.; Zhong, Z. Joint beamforming and power-splitting control in downlink cooperative SWIPT NOMA systems. *IEEE Transactions on Signal Processing* **2017**, *65*, 4874–4886.
3. Zhong, C.; Zhang, Z. Non-orthogonal multiple access with cooperative full-duplex relaying. *IEEE Communications Letters* **2016**, *20*, 2478–2481.
4. Liu, H.; Kim, K.J.; Kwak, K.S.; Poor, H.V. Power splitting-based SWIPT with decode-and-forward full-duplex relaying. *IEEE Transactions on Wireless Communications* **2016**, *15*, 7561–7577.
5. Wu, W.; Yin, X.; Deng, P.; Guo, T.; Wang, B. Transceiver design for downlink SWIPT NOMA systems with cooperative full-duplex relaying. *IEEE Access* **2019**, *7*, 33464–33472.
6. Bolton, P.; Dewatripont, M.; others. *Contract theory*; MIT press, 2005.
7. Zhang, Y.; Han, Z. *Contract Theory for Wireless Networks*; Springer, 2017.
8. Zhang, Y.; Pan, M.; Song, L.; Dawy, Z.; Han, Z. A survey of contract theory-based incentive mechanism design in wireless networks. *IEEE wireless communications* **2017**, *24*, 80–85.
9. Chen, Y.; He, S.; Hou, F.; Shi, Z.; Chen, J. An efficient incentive mechanism for device-to-device multicast communication in cellular networks. *IEEE Transactions on Wireless Communications* **2018**, *17*, 7922–7935.
10. Chen, Y.; He, S.; Hou, F.; Shi, Z.; Chen, J. Promoting device-to-device communication in cellular networks by contract-based incentive mechanisms. *IEEE Network* **2017**, *31*, 14–20.
11. Yang, P.; Zhang, Z.; Yang, J.; Wang, X. Incorporating user willingness in contract-based incentive mechanism for D2D cooperative data forwarding. *IEEE Access* **2018**, *6*, 54927–54937.
12. Zhang, Y.; Song, L.; Saad, W.; Dawy, Z.; Han, Z. Contract-based incentive mechanisms for device-to-device communications in cellular networks. *IEEE Journal on Selected Areas in Communications* **2015**, *33*, 2144–2155.
13. Zhao, N.; Liu, R.; Chen, Y.; Wu, M.; Jiang, Y.; Xiong, W.; Liu, C. Contract design for relay incentive mechanism under dual asymmetric information in cooperative networks. *Wireless Networks* **2018**, *24*, 3029–3044.
14. Zhao, N.; Chen, Y.; Liu, R.; Wu, M.; Xiong, W. Monitoring strategy for relay incentive mechanism in cooperative communication networks. *Computers & Electrical Engineering* **2017**, *60*, 14–29.
15. Zhao, N.; Liang, Y.C.; Pei, Y. Dynamic contract incentive mechanism for cooperative wireless networks. *IEEE Transactions on Vehicular Technology* **2018**, *67*, 10970–10982.
16. Nazari, B.; Jamalipour, A. Relay selection scheme for cooperative communication networks using contract theory. 2013 19th Asia-Pacific Conference on Communications (APCC). IEEE, 2013, pp. 757–762.
17. Hasan, Z.; Bhargava, V.K. Relay selection for OFDM wireless systems under asymmetric information: A contract-theory based approach. *IEEE Transactions on Wireless Communications* **2013**, *12*, 3824–3837.
18. Liu, Y.; Zhong, X.; Yan, Y.; Wang, J.; Saad, W. Contract theory for incentive mechanism design in cooperative relaying networks. International Conference on Wireless Algorithms, Systems, and Applications. Springer, 2014, pp. 302–312.
19. Li, C.; Zhang, Q.; Li, Q.; Qin, J. Price-based power allocation for non-orthogonal multiple access systems. *IEEE Wireless Communications Letters* **2016**, *5*, 664–667.
20. Tang, R.; Cheng, J.; Cao, Z. Contract-based incentive mechanism for cooperative NOMA systems. *IEEE Communications Letters* **2018**, *23*, 172–175.
21. Li, H.; Wang, Z.; Zhang, X. A contract-based pricing mechanism for simultaneous information and energy transfer. 2017 IEEE Globecom Workshops (GC Wkshps). IEEE, 2017, pp. 1–6.
22. Hou, Z.; Chen, H.; Li, Y.; Vucetic, B. Incentive mechanism design for wireless energy harvesting-based Internet of Things. *IEEE Internet of Things Journal* **2017**, *5*, 2620–2632.
23. Liu, C.; Peng, H.; Lu, W.; Xu, Z.; Hua, J. Contract Theory Based on Wireless Energy Harvesting with Transmission Performance Optimization. International Conference on Machine Learning and Intelligent Communications. Springer, 2018, pp. 400–408.
24. Liu, C.; Lu, W.; Peng, H.; Hu, S.; Gao, Y. Energy Trading Scheme Based on Contract Theory in Cooperative Relay Network. 2019 15th International Wireless Communications & Mobile Computing Conference (IWCMC). IEEE, 2019, pp. 997–1001.
25. Islam, M.T.; Taha, A.E.M.; Akl, S.; Abu-Elkheir, M. A stable matching algorithm for resource allocation for underlaying device-to-device communications. 2016 IEEE International Conference on Communications (ICC). IEEE, 2016, pp. 1–6.
26. Xu, M.; She, F.; Wu, K.; Jiang, M. Bilateral contract based incentive matching for device-to-device content sharing. 2020 54th Annual Conference on Information Sciences and Systems (CISS). IEEE, 2020, pp. 1–6.
27. Gu, Y.; Zhang, Y.; Pan, M.; Han, Z. Matching and cheating in device to device communications underlying cellular networks. *IEEE Journal on Selected Areas in Communications* **2015**, *33*, 2156–2166.
28. Chang, W.; Jau, Y.T.; Su, S.L.; Lee, Y. Gale-Shapley-algorithm based resource allocation scheme for device-to-device communications underlaying downlink cellular networks. 2016 IEEE Wireless Communications and Networking Conference. IEEE, 2016, pp. 1–6.