Chapter 4

Multi-unit Auctioning Based Resource Allocation Technique for Semi-Distributed Cooperative Network

The approaches of resource allocation, discussed in chapter 3, are applicable to centrally controlled network like cellular network where the relays are installed by the service providers. The cooperation would be more attractive if nodes cooperate with each other without the need of specially installed relay. Multi-unit auctioning technique is presented in this chapter which encourages nodes, by offering compensation in terms of virtual currency, to become the relay. This technique eliminates the need of specially installed relays and reduces the computation burden of the central controller. Proposed multi-unit auction technique is based on revelation of demand curve parameters by the source nodes. Modelling of this technique is done and verified with the aid of extensive simulations. This technique is compared with conventional clock auctioning technique. It is also checked that the proposed technique also satisfies the theoretic properties of auction.
4.1 Auctioning Techniques for Resource Allocation

Auction is the game of incomplete information in which a buyer is unaware of the valuation of the goods by the other buyers (Fudenberg) (Osborne) (Vazirani). In this method, the information, in the form of bids, are sent from the potential buyers to seller, showing their willingness to pay. The outcome in terms of who will receive how much is determined solely on the basis of the received information (Zavlanos). Auction can be sealed bid or open bid (Krishna). In the sealed bid auction, the bid of a buyer is not known to the others. In open auction, all the potential buyers are aware of bids of all other buyers and accordingly they can modify their bids for the next cycle. In open bid auction, price can be ascending (or descending) in which the bid prices increase (or decrease) in step till all the units are sold. The sealed bid auction can be first price, in which the buyer willing to pay the maximum, wins and pay the highest. It can be second price, in which buyer willing to pay the maximum, wins and pay the second highest. Apart from these basic types, many variants of auctions are available in the literature (Krishna).

Auctioning is employed for resource allocation by considering source nodes as a buyer and relay nodes as a seller of ‘cooperation’. The sources are unaware of the price at which the relay would sell units of power and number of units of power available with the relay for sell. At the same time the relay is unaware of the demand of the power from one or more sources. The source would not like to pay more than the benefit which it gets from the cooperation. If relay demands too high price, source would not buy any power from it. On the other hand, if relay announces very low price, the source would buy all the units of power, which results in sub-optimal revenue for the relay. In (Baidas) (Mukherjee) (D. G. Yang) (D. X. Yang), ascending / descending auction has been considered in which negotiation takes place step by step between the source and the relay which results in large delay in establishing cooperation. This delay is not at all appropriate in case of time varying wireless channel.

In this chapter, the interaction between network nodes is modelled as a buyer-seller market employing a single round, multi-unit auctioning mechanism based on revelation of demand curve parameters. To reduce the time needed in negotiation process, the requirement of the source is represented as demand curve. When there are multiple buyers with different demands
and multiple sellers with different supply, the allocation can be done using supply–demand curve based market clearing strategy. It has been demonstrated in (Sandholm, Market clearability) (Sandholm, Optimal clearing of supply/demand curves). It results in low complexity and less overheads; compared to clock-auction based techniques. The uniqueness of the work presented in this chapter is that the interaction between the source and the relay is based on the source demand curve and available supply with relay. The objective of allocation is to maximize the revenue earned by the relay. The relay are given two options to charge the price: non-discriminatory (uniform) and discriminatory. This technique is semi-distributed in which the source finds the suitable partner (or relay) locally. The management of virtual currency is done by the central controller in order to avoid probable malfunctioning by the nodes. The central controller maintains the balance of virtual currency and informs each node from time to time. By employing this technique, the data rate of source nodes is increased and power is saved. This technique requires fewer overheads and results in less delay compared to clock-auctioning technique (Baidas) (Mukherjee).

4.2 System Model

There are $M$ wireless nodes with a single antenna communicating with the common destination in the network. All the nodes are given equal virtual currency in the beginning to trade for getting cooperation from the nodes in the vicinity. Nodes can increase the balance of currency by cooperating with the needy nodes and spent it when they are in need. Access point maintains the balance of the virtual currency and informs all the nodes from time to time. The decision to cooperate is taken by the nodes but the accounting of currency is done by the central controller to avoid malpractices by the nodes. Out of $M$ nodes, the node having good channel with the destination but does not have its own data to send, acts as a relay. The node having data to send but not having good channel with the destination, acts as a source. Amplify and forward relay protocol is assumed due to its simplicity. Each node is assumed to have channel state information between the relay and itself and destination and itself, respectively. Achievable maximum data rate by the source with the cooperation of one or more relays and phases required for establishment of cooperation are presented in following subsections.
4.2.1 Maximum Achievable Data Rate with Cooperation

For Amplify and forward protocol, the maximum achievable data rate with cooperation can be given by (3.15). If multiple relays are ready to help the source and if the source has sufficient virtual currency to make payment to multiple relays, then the source may choose the relays to help and take benefit of higher diversity order (Liu). In multiple relay scenario, (3.15) can be modified as

\[ R_{iK}^C = \frac{1}{2} \log_2 \left( 1 + \frac{1}{\sum_{j=1}^{K} \frac{\Gamma_{SRj} \Gamma_{R_jD}}{\Gamma_{SRj} + \Gamma_{R_jD} + 1}} \right) \]  

(4.1)

(Notations carry the meaning as defined in Table 3.1)

where \( j = \{1,2,\ldots,K\} \) number of relays cooperating to a source and \( R_{iK}^C \) is the data rate achieved by source \( i \) with \( K \) relays. One relay may help one or more sources by giving its power and in return, the relay charges certain revenue to the sources. The relay wants to allocate the power so that it can take maximum benefit of good channel condition and maximize its revenue.

4.2.2 Phases for Establishing Cooperation

To establish the successful cooperation, the nodes negotiate with each other. We have considered relay-centric scenario. Therefore, the nodes in need of cooperation i.e. source nodes send demand curve parameters to relay and relay makes decision about the price and units of power to be allocated to each source which can maximize relay revenue. Multi-unit auctioning mechanism involves following steps:

I. In the beginning of the block, the sources that cannot achieve their desired transmission rate, generate a demand function showing its maximum requirement of power from the relay and its ability to pay. (The analytical model of the same is developed in the next section)
II. The node that wants to act as relay receives the requests. It calculates the units of power and price per unit that can maximize its revenue and informs it to the corresponding sources.

III. If the demand of the source is more than the spare resources available with the relay, it is rejected.

IV. Relay informs clearing price and units of power to sources which can maximize relay revenue.

V. Sources start communication cooperatively and get higher data rate as per (3.15).

VI. The allocation of power to the sources by the relay remains the same for the given block.

VII. At the beginning of new block, the cooperating nodes continue with the same power and price by sending a signal to each other. If anyone wants to leave or change the trade generates fresh demand and supply.

The mechanism to generate demand functions by the sources and choosing optimum allocation by the prospective relay is presented in the following section.

4.3. Multi-Unit Auctioning Mechanism

The source nodes buy power from relay to increase data rate. In return, source nodes have to pay price per unit of power to the relay node. The relay node utilizes its power to retransmit source nodes’ signal. The trade becomes successful only when both the nodes are able to earn benefit out of it. Utility of source and relay are formulated in the following sub-section. As per the theory of auction, the successful auction must possess certain properties as described below.

4.3.1 Properties of Auction

Auction is the mechanism to do trade between the buyer and seller. An efficient design of auction mechanism must satisfy the following important properties:
A. Truthfulness: For all the buyers, the dominating strategy is to reveal its true valuation of the object while putting the bid.

B. Budget-Balance: Price paid to the seller is equal to or smaller than the price taken from the buyers in case of auction when the auction is done in the presence of an auctioneer.

C. Individual Rationality: Buyers and sellers, both can get benefit by participating in auction

D. System efficiency: The benefit obtained by all the participants is maximized as a result of allocation.

A validation check for these properties with regard to the proposed auction mechanism is carried out in section 4.3.5.

4.3.2 Utility of Source and Relay

Utility of the source and utility of the relay can be defined as the benefit gained by each one by participating in cooperation. The utility of the source \( i \) depends on two factors – increase in data rate due to cooperation and total revenue paid to the relay. The utility of the relay depends on unit price of power and total units of power sold to the sources. Consider \( N \) sources in need of cooperation from the potential relay. The benefit acquired by the source node \( i, \forall i = \{1, 2, 3, \ldots, N\} \) is expressed as a utility function, \( U_{Si} \) and can be computed as

\[
U_{Si} = \mu \ast (R_i^C - R_i^{NC}) - (\Theta \ast \Pi_i) \tag{4.2}
\]

where, \( R_i^C \) is the transmission rate achieved as a result of cooperation, \( R_i^{NC} \) is the transmission rate of the direct path, \( \Theta \) is the price per unit of power charged by the relay and \( \Pi_i \) is the units of power purchased by the source \( i \). \( \mu \) is the scaling parameter for comparing increase in transmission rate with price (Wang).
The utility of the relay can be modelled as

\[ U_R = \sum_{i=1}^{N} \Theta \ast \Pi_i \]  

(4.3)

The source has to determine how much power it desires to purchase at a particular price. Moreover, the source is completely unaware about the utility of the other sources. Utility of the relay is the total revenue generated as a result of selling surplus units of power. The prime objective of the relay is to maximize its revenue.

In ascending price clock-auction (Baidas), as the relay gradually increases its price, the demand of the source goes down. The deal is struck at when the demand matches with the supply. The price at which the relay agrees to sell power is called market clearing in auction terminology. Determining market clearing price is a computationally complex task (Mukherjee) (D. G. Yang) (Baidas). The market clearability can be done in most efficient manner when the buyers/sellers project their demand/supply in the form of demand/supply curves (Sandholm, Market clearability) (Sandholm, Optimal clearing of supply/demand curves). The sources express their demand in the form of price-power demand curve. The demand curve can be step for fixed data rate users and linear or exponential for variable data rate users. In this work, linear curve for variable data rate user and step for fixed data rate users are assumed.

When large number of sources ask for the cooperation, it is not possible for the relay to fulfil the requirement of all of them completely. In that case, relay starts increasing the price which results in reduction of the demand. When demand and supply matches, the auctioning is accomplished. The delay incurred in the process of reaching an optimum solution is very large and increases communication overheads also. In time varying wireless channels with mobile nodes, the optimum allocation would no longer remains optimum. The practical approach is to implement a technique having fewer overheads, less delay and allocate the resources proportionally. In the following section, we have developed a technique to establish cooperation with proportional power allocation to sources, incurring less delay and having reduced overhead.
4.3.3 Determination of Power Allocation to Sources

When a source realize that it is not possible to achieve its targeted data rate on direct S-D link, it generates the demand of units of power necessary to reach the target. It also mention its capability of pay after considering the balance of virtual money possessed by it. Relay gets such information from many sources and determines the revenue maximizing allocation, considering availability of power. Modelling of this trade and evaluation of revenue maximizing allocation for is presented in following sub-sections.

4.3.3.1 Demand Curve of a Source

The source demands power from the relay for relaying its information. The demand of the source is high, if price per unit of power is small. As price per unit of power increases, the demand of source decreases. This is because as per (4.2), if source buys power at higher price, the benefit in data rate would be less compared to price paid. Hence, source wants to avoid this situation. The demand of the source is represented as linear demand curve.

\[ \Pi_i = -\alpha_i \ast \Theta + \beta_i \]  

(4.4)

where \( \alpha_i \) is the slope of the line and \( \beta_i \) is the maximum units of power source wants to utilize if price is minimum. The demand curve shows the price as a function of units of power \( \Theta(\Pi) \). If demand of the source is cleared at price \( \Theta \) per unit of power, the source receives \( \Pi \) units of power at price \( \Theta \) per unit of power. The utility of the relay is the revenue earned i.e. \( \Pi \ast \Theta(\Pi) \). Negative sign of the curve indicates that demand decreases with increase in the price.

In the beginning, each source calculates \( \alpha_i \) as,

\[ \alpha_i = R_i^{tar} / (R_i^{tar} - R_i^{NC}) \]  

(4.5)

where \( R_i^{tar} \) is the maximum targeted rate the source wants to achieve and \( R_i^{NC} \) is the rate achieved by the source \( i \) in non-cooperative mode. We define a parameter \( \beta_i \) for source \( i \) which
represents the estimate of the additional units of the power required from relay to achieve the targeted rate under the cooperative mode. It can be estimated as,

\[
\beta_i = \frac{p^{req}_{max}}{}
\]  

(4.6)

where \(p^{req}_{max}\) is the maximum units of power required from relay.

The relay can charge from the source either the non-discriminatory price or the discriminatory price. In non-discriminatory price, the relay would assign different units of power to different sources at the same price per unit of power. In discriminatory price, the relay charges different price per unit of power to different sources. In the following sub section, we have presented the optimization problem with an objective to maximize the relay revenue for both the pricing techniques. The comparison of pricing techniques is presented in simulation results. We have also analysed the applicability of these pricing technique based on the demand of the sources.

4.3.3.2 Maximizing relay revenue with non-discriminatory price

Each interested source, \(i\), \(i = \{1,2,\ldots N\}\) sends only two parameters \(\alpha_i\) and \(\beta_i\) to the relay. The relay calculates the aggregate demand from the individual demands as,

\[
\Pi_{aggre} = \sum_{i=1}^{N}(-\alpha_i \star \Theta + \beta_i)
\]  

(4.7)

Utility of the relay is the total revenue of the relay, \(\Omega\), which can be computed from (4.3) and (4.7) as,

\[
\Omega = \sum_{i=1}^{N}(-\alpha_i \star \Theta^2 + \beta_i \star \Theta)
\]  

(4.8)

The objective of the relay is to maximize its revenue \(R\). The optimization problem for relay revenue can be formulated as A1.
\[
\max \Omega = \max \sum \Pi_i \cdot \Theta \\
\text{subject to}
\]

(i) \[\Pi_i = -\alpha_i \cdot \Theta + \beta_i\]

(ii) \[\sum \Pi_i \leq \Pi_{\text{max}}\]

where \(\Pi_{\text{max}}\) is the maximum power available with relay for cooperation.

The condition for maximum revenue can be established by differentiating (4.8) with respect to \(\Theta\), it yields

\[\Theta_{\text{max}} = \sum \beta_i / 2 \sum \alpha_i\]  \hspace{1cm} (4.9)

and

\[\Pi_{\text{aggregate}} = \sum \beta_i / 2\]  \hspace{1cm} (4.10)

The amount of maximum revenue can be found by putting the value of \(\Theta\) in (4.8) as

\[\Omega_{\text{max}} = \sum \beta_i^2 / 4 \sum \alpha_i\]  \hspace{1cm} (4.11)

It can be seen from (4.11) that relay calculates clearing price to yield maximum revenue from parameters \(\alpha_i\) and \(\beta_i\) of the sources.

\textbf{4.3.3.3 Maximizing Relay Revenue with Discriminatory Pricing}

In discriminatory pricing technique, the relay charges each source differently based on the urgency of source to buy power. Let \(\Theta_i\) be the price per unit power charge by relay source \(i\).

The optimization problem for relay revenue can be formulated for discriminatory price as,
\[
max \Omega = \max \sum \Pi_i \ast \Theta_i \quad [A2]
\]

subject to

(i) \[\Pi_i = - \sum \alpha_i \ast \Theta_i + \sum \beta_i\]

(ii) \[\sum \Pi_i \leq \Pi_{max}\]

The above problem can be rewritten as \(\min - \sum \Pi_i \ast \Theta_i\). It is a two-variable optimization problem and can be solved using Lagrangian multipliers [subh1] [subh2]. Applying Lagrangian multipliers to the objective function \(A2\) yields

\[
\min \left( \left( \frac{\Pi_i^2}{\sum \alpha_i} \right) + \left( \frac{\sum \beta_i \Pi_i}{\sum \alpha_i} \right) \right) + \Lambda \left( \Pi_{max} - \sum \Pi_i \right) \tag{4.12}
\]

where, \(\Lambda\) is the Lagrangian multiplier. Solving (4.12) gives

\[
\Lambda = \frac{2 \ast \Pi_{max} + \sum \beta_i}{\sum \alpha_i}
\]

Substituting the value of \(\Lambda\), optimum price and quantity for each source can be obtained as

\[
\Theta_i = - \left( \frac{\beta_i}{2} \right) + \left( \frac{\alpha_i}{2} \right) \ast \left( \frac{2 \ast \Pi_{max} + \sum \beta_i}{\sum \alpha_i} \right) \tag{4.13}
\]

and

\[
\Pi_i = \left( \frac{\beta_i}{2 \ast \alpha_i} \right) + \frac{1}{2} \ast \left( \frac{2 \ast \Pi_{max} + \sum \beta_i}{\sum \alpha_i} \right) \tag{4.14}
\]

The relay, in this method allocates power by keeping the demand from all the sources in mind. i.e. source with higher demand will be charged more and vice-versa. One important characteristic of discriminatory pricing is that it gives degree of fairness among sources. The power is allocated to all the sources so that the difference in the maximum and minimum data rate achievable by the sources reduces.
4.3.3.4 Power allocation for fixed data rate users

There are certain applications which require fixed data rate. In such cases, the source’s demand curve becomes step i.e., it either wants full or none. With the limited resources, the relay chooses source/s which can maximize its revenue and the request from other sources are rejected. This optimization problem for revenue maximization for fixed data rate can be formulated as

\[ \text{max} \sum \theta_i \times x_i \]  \hspace{1cm} \text{[A3]} \]

subject to

(i) \( \sum \pi_i \times x_i \leq \pi_{max} \)
(ii) \( x_i \in \{0,1\} \)

In the above problem \( x_i = 1 \) indicates that the source \( i \) is selected and assigned the power fully as per its demand and \( x_i = 0 \) indicates that the relay has denied the demand of source \( i \).

4.3.4 Algorithm for Multi-unit Auctioning Process

In this proposed mechanism, the source is the buyer and the relay is the seller of power for retransmission. Both the nodes prefer to maximize their benefit. Source node likes to maximize the data rate and reach its target and relay node wants to maximize the revenue. The step by step procedure for establishing successful cooperation is as follows:

i. Source \( i \) generates a tuple \((\alpha_i, \beta_i)\) where \( \alpha_i \) and \( \beta_i \) are calculated from (4.5-4.6).

ii. On receiving \( \alpha_i \) and \( \beta_i \) from all the participating sources, relay generates aggregate demand curve based on (4.7).

iii. The relay calculates price and units of power to maximize its revenue from (4.9-4.10) for non-discriminatory price and for discriminatory price from (4.13-4.14).

iv. Relay chooses the appropriate pricing technique based on maximum revenue.
v. Relay selects sources which contribute to maximize relay revenue.
vi. Selected sources confirm allocation by sending signal to the relay and the destination.
vii. In the beginning of new block (or frame), if demand changes, the whole process is repeated otherwise sources and relay follow the same allocation.

4.3.5 Validation Check for Auction Properties

The auction mechanism is required to satisfy certain properties as described in 4.3.1. The proposed auction mechanism fulfils those properties in the following manner.

A. Truthfulness: In the proposed technique, each source has to reveal its requirement and its ability to pay truly. The smaller value of slope of the curve indicates higher requirement of the power by the source. The relay allocates more power to it and the source has to pay more. Conveying smaller value of slope to get more power by the source may result in negative utility as per (4.2). Also, the source is unaware of the competition so the source has to reveal its true valuation for getting relay cooperation.

B. Budget-Balance: This technique is without the aid of any centralized auctioneer so the price paid by the sources directly goes to the relay i.e. price paid by the buyer is the same as the price asked by the seller. So it is budget balanced.

C. Individual Rationality: Here, source decides the amount of power which can result in positive utility and relay decides price and units of power which can maximize its utility. Both the nodes are rational decision makers and makes decision to increase their individual utilities.

D. System efficiency: This is the relay centric auction in which relay maximizes its revenue by allocating units of power to the sources in need. However, the sources are not able to get all the units of power as required from one relay. The process for
exactly equalizing demand and supply units of power is time consuming and computationally complex. Looking at the time varying nature of the wireless channel and variable data rate application of the sources, it is a practical approach to allocate the power as quickly as possible with minimum overheads and complexity. The sources can definitely increase the transmission rate with the help of one relay. The same technique can be further modified to model multi source-multi relay scenario in which the sources would be able to get the desired number of units as per its requirements.

4.4 Performance Evaluation and Discussion

The performance of the proposed technique is checked with the help of extensive simulations. Data rates of individual sources with both type of pricing technique are found out and compared. Revenue maximizing allocation and power allocation under both the pricing schemes are also computed. Amount of power saved by source nodes are calculated to demonstrate the benefit of cooperation.

4.4.1 Simulation Environment

The wireless nodes communicating with a common access point are distributed randomly in the given area. Three sources S1, S2 and S3 and one relay R communicating with access point D are considered as shown in Fig 4.1. All the three sources are at equal distance from the destination. The distance between each source and the relay is also assumed to be same. The target data rate of the source are 0.22, 0.25 and 0.28 units, respectively. For the sake of simplicity, path loss channel model with path loss exponent 3 is considered for simulation. This technique is also applicable for random channel model. The negotiation occurs between sources and relay at the beginning of new block. If channel does not change rapidly, the same negotiation can be continued for longer duration of time. Otherwise, at the beginning of each new block, the negotiation can be changed.
For the sake of simplicity, the channel coefficients are assumed to be dependent on distances between the nodes. The power transmitted by all the sources $P_{s_j} = 1$ units, $\forall j = \{1, 2, 3\}$.

4.4.2 Analysis of Power Allocation Based on Aggregate Demand Curve

Three sources S1, S2 and S3 have different targeted transmission rates. Being not able to achieve it on their own with maximum power limitation, they calculate their demand function and broadcast it to get help from neighbouring node. The interested relay node R gets such request from one or more than one source. It calculates units of power to be allocated and price per unit of power which can maximize its revenue for that aggregate demand. The sources whose demand is too high, would be denied cooperation. The plot in Fig 4.2 shows demand of each source, aggregate demand curve and revenue maximizing allocation by the relay.
Source 1 demands for 0.66 units of power, source 2 wants 0.94 units of power and source 3 demands 1.325 units of power from relay to reach their target data rate, if the price from the relay is minimum. As the price increases, the demand of the source reduces. The slope of the demand curve is determined by the difference between the target data rate and data rate of direct source to destination link as per (4.5). Sources broadcast the slope of demand curve, $\alpha_i$ and maximum units of power required at minimum price $\beta_i$. Relay considers the demands which can be served by it. Using (4.7), the relay calculates aggregate demand and determine non-discriminatory revenue maximizing allocation with the help of optimization problem [A1].

It also calculates revenue maximizing allocation with discriminatory price with the help of optimization problem [A2]. Fig 4.2 shows that the relay allocates 1.47 units of power at 0.32 per unit of power. At the point of revenue maximization, relay offers 0.14 units of power to source 1, 0.46 units of power to source 2 and 0.87 units of power to source 3. The objective of relay in not to allocate power to satisfy the aggregate demand of sources completely but the
relay wants to maximize its revenue from the cooperation. Relay has another option to use optimization problem [A2] to determine different price and units of power for different sources, depending upon their individual and relative demand. Fig 4.3 shows units of power and price per unit of power for each source as per (4.13) and (4.14). In this case, source 1 would get 0.34 units of power at the price of 0.19 per unit of power, source 2 would get 0.47 units at the price of 0.30 per unit and source 3 would get 0.67 units of power at 0.45 per unit of power. As the need of source 3 is more, relay charges more per unit of power and allocates less units of power. Source with less demand would get power at less price and the moderate demand source gets nearly same power in both the cases. One source with very high demand prevents other sources from getting sufficient help of the relay in non-discriminatory pricing scheme. In discriminatory pricing scheme, relay takes benefit of demand curve of the source with the highest demand, which indicates that the source is ready to pay high price. Therefore, the relay allocates fewer units of power at higher price to it as per the demand curve. In this case, the source with the lowest demand would also get significant power at lesser price than the non-discriminatory case.

4.4.3 Evaluation of Utility of source and relay

Sum of the utility of the all the source and the relay as mentioned in (4.2, 4.3) show that the utility of the relay can be maximized by determining the price per unit of the power and maximum units of power to be allocated for sources. Utility of source and relay as a function of price for non-discriminatory pricing scheme is depicted in Fig 4.3. The utility of the source is minimum at the point where the utility of the relay is maximum. It is because the technique discussed here is relay centric, where sources compete to get cooperation of relay. It is also possible to devise source centric technique where multiple relays compete to cooperate with the source and earn virtual currency. In that case, the utility of the source would be maximum and relay would be minimum at the point of trade.
Fig 4.3 Revenue maximizing allocation for discriminatory pricing

Fig 4.4 Price per unit vs. Utility of source and relay
4.4.4 Analysis of Source Data Rate in Cooperation

The data rate achieved by the sources in direct transmission is not sufficient so sources choose relay and buy power from the relay. Relay allocates power to re-transmits sources’ signal as per non-discriminatory or discriminatory pricing schemes. In each case, sources would get different relay power and hence get different data rate. The data rate achieved by the sources without cooperation, their target data rate and data rate with non-discriminatory price and discriminatory price are shown in Fig 4.4. Percentage increase in data rate due to cooperation in both pricing schemes is depicted in Fig 4.5. It is evident from Fig 4.5 that all the sources are able to increase the achievable data rate with the help of the relay. As per our assumption, the target data rate of source 1 is the lowest and that of source 3 is the highest. As all the sources are assumed at the same distance from the destination and the relay; and the power available with each source is the same, the no-cooperation data rate of all the sources are the same.

All the sources can achieve higher data rate then no-cooperation data rate in both pricing schemes. Percentage increase in data rate of all the three sources are shown in Fig 4.6. The sources get 0.09 units data rate in no-cooperation mode. The data rate is increased to 0.13, 0.19 and 0.24 units in the case of non-discriminatory pricing for the source 1, source 2 and source 3, respectively. In case of discriminatory pricing scheme, the sources get 0.17, 0.19 and 0.22 units, respectively. The data rate of source 1 increases by 30.2 % and 47.2% with non-discriminatory and discriminatory pricing schemes, respectively. Source 2 is able to increase the data rate by 53.2% in non-discriminatory and 53.7% in discriminatory pricing scheme. Source 3 gets maximum resource to increase its data rate by 63.1% in case of non-discriminatory and 59.3% in discriminatory pricing scheme. The source with higher demand as source 3 gets more benefit in non-discriminatory scheme whereas the source with lower demand benefited more in discriminatory pricing scheme. Source 2 with intermediate demand is indifferent between any of the two pricing schemes.
Fig 4.5 Comparison of data rates

Fig 4.6 Increase in data rate with cooperation, %
Fig 4.5 and 4.6 show that sources get higher data rate with cooperation in the range of 30.2% to 63.1%.

4.4.5 Comparison of Non-Discriminatory Price and Discriminatory Price Allocation

In Fig 4.2, the relay allocates different units of power to the sources by charging all the sources at equal price. But the relay can earn more revenue by allocating different units at different price to the sources. Fig 4.3 shows allocation of different power at different price to the sources. Fig 4.7 and Fig 4.8 show units of power allocated to each source and corresponding price per unit of power charged by user under non-discriminatory pricing and discriminatory pricing schemes, respectively.

Source 1, 2 and 3 get 0.14, 0.46 and 0.87 units of power in non-discriminatory pricing scheme, respectively. All the sources gets power at the same price of 0.31 in this case. In case of discriminatory pricing scheme, relay gives more units to nearer user with less price and allocates less power to farther user at more price. As a result, source 1, 2 and 3 get 0.34, 0.47 and 0.67 units at a price per unit power of 0.19, 0.30 and 0.45 respectively. The sources would get power and price per unit depending on the competition among the sources. The revenue earned by relay is shown in Fig 4.9. Relay earns more revenue from source1 by allocating more units at less price and source3 by allocating less units at more price to sell the units of power to maximize revenue. The relay earns 11% more total revenue in discriminatory pricing. The relay has to decide whether to go for discriminatory or non-discriminatory pricing scheme. However, the relay’s decision of discriminatory price may not be in favour of sources with higher demand as it would get less power with more price. The willingness of sources for the type of pricing scheme and choice pricing scheme by the relay depend on urgency of cooperation to sources and monopoly of the relay. If there exists more relay, the relay may switch to uniform price to attract source with high demand.
Fig 4.7 Power allocated under non-discriminatory and discriminatory schemes

Fig 4.8 Price / unit of power paid by the each source
4.4.6 Analysis of Source Power Saving

The cooperation between the sources and the relay results in saving of the power. It is assumed that all the sources have limited power of 1 unit. The sources try to achieve their target data rate with the help of relay. The relay allocates power to each of them to maximize own revenue. The amount of power allocated by the relay for retransmitting the source signal would result in higher data rate compared to no-cooperation data rate. Total power spent in cooperative mode is source power of 1 unit plus relay power. If relay does not cooperate with source and source attempts to achieve the data rate same as its cooperative data rate on its own, it has to spent more power. The source has two choices: either to transmit more power or to buy help of the relay. If source chooses the second option, it can save power. The saving of the power by the source extends its battery life and reduces interference in the network. Table 4.1 shows the saving of power with the units of the power assigned in non-discriminatory pricing scheme and discriminatory pricing scheme.
In the case of non-discriminatory pricing, the relay allocates 0.14 units to source 1, 0.46 units to source 2 and 0.87 units to source 3. Therefore, total power spent in cooperation is 1.14 units, 1.46 units and 1.87 units by source 1, source 2 and source 3, respectively. With that the sources achieve 0.13, 0.19 and 0.24 units, respectively. The sources have to spend power 1.46 units, 2.22 units and 2.22 units, respectively to achieve the same data rate in non-cooperation mode. As a result, source 1, source 2 and source 3 are able to save 21.9%, 34.2% and 15.8% of the power. Similarly, with the discriminatory price, the sources achieve data rate of 0.17, 0.19 and 0.22 units for which they need 1.95 units, 2.25 units and 2.25 units of power in non-cooperation mode. In cooperation mode, the sources get cooperation of 0.33 unit, 0.47 unit and 0.87 unit from the relay. As a result, source 1, source 2 and source 3 successfully save 31.8%, 34.7% and 16.9% of power.

4.4.7 Analysis of Effect of Node Mobility on Resource Allocation

In the mobile environment, the location of node and hence the distance between the nodes changes frequently. This in turn affects the channel and thereby the aggregate demand and power allocation. To demonstrate the effect of mobility on the power allocation and revenue clearly, two sources with equal target data rate are considered. One source is located at the normalized distance of 25 units from the destination. Another source is assumed to move 22 units to 28 units from the destination. The distance between the relay and both the sources are
assumed to be constant. Fig 4.10 shows the aggregate demand curve and revenue maximizing allocation for different positions of the moving source. As one of the source moves away, its demand for relay power to achieve target increases thereby reduces the slope of the aggregate demand curve. When the demand of one source is high, relay could maximize its revenue by allocating 1.08 units of power at 0.37 unit price per unit of power. On the other hand, when that source comes closer, relay could maximize the revenue by allocating 0.79 units of power at 0.22 unit price per unit of power.

As far as, revenue maximization is concerned, relay tries to choose discriminatory pricing. Discriminatory pricing ensures that even when both the sources having same target data rate and same distances with relay, relay would not get less revenue than that with non-discriminatory pricing scheme. If the relay has monopoly, it would charge as per discriminatory pricing. In the scenario, when more relays are ready to help the sources, a relay can attract sources by choosing non-discriminatory pricing scheme.

![Fig 4.10 Revenue maximizing allocation with one source moving](image-url)
4.4.8 Comparison of Computational Complexity

The computational complexity of the proposed technique is less compared to classical ascending or descending clock auction (Wang). In clock auction technique, the sources send their bids to demand number of units of power. If the units demanded by all the sources are more than available power with relay, relay increases the price. In next iteration, the sources generate their new demand at the increased price and again relay checks for available units and revenue generated. If the units demanded by the sources are less than the available units of power with relay, the relay decrease the price in order to increase the demand of the sources. The price is increased or decreased in steps. The time taken to click the deal between the sources and the relay depends upon the difference between the available power with the relay and demand of the sources and the step size in which the price increases or decreases. In order to maximize the revenue, the computational complexity required in clock auction is of the order of $O(N) \times I(\phi)$ where, $N$ is the total number of nodes and $I(\phi)$ is the number of iteration as a function of step size ($\phi$). In proposed technique, the relay does not try to sell all the units of power. The efforts of selling all the units of power incurs delay due to rounds of negotiations. The demand of the source changes continuously due to time varying wireless channel and mobility. Power available with the relay also reduces as it spends power to cooperate with sources. In such situation, the proposed technique, relay allocates power in single shot and the sources improves the data rate compared to no-cooperation mode. The sources cannot reach the target data rate with the help of only one relay. However, the sources may buy power from more than one relay to reach the target data rate. The computational complexity of this sub-optimal negotiation process is of the order of $O(I)$. Thus, substantial reduction in computational complexity is achieved in the proposed technique.
4.5 Conclusion

Semi distributed multi-unit auctioning technique based cooperation stimulation has been presented in this chapter. The objective of power allocation is to maximize the revenue earned by the relay in form of the virtual currency and thereby encourages it to stick to cooperation. The node which acts as relay maximizes its revenue by allocating units of power to sources for retransmitting their signal. From the implementation point of view, sources in need of cooperation are required to compute and convey only two parameters $\alpha_i$ and $\beta_i$ to relay, based on which relay decides the units of power to be allocated to sources and corresponding prices. The transaction of virtual currency and updating of accounts of the nodes is the only task done by the central controller. Two pricing schemes have been considered – Non-discriminatory and discriminatory. Simulation results shows an increase in source data rate compared to direct transmission in the range of 30.2% to 63.1% in case of non-discriminatory pricing scheme and 47.2% to 59.3% in discriminatory pricing scheme. Non-discriminatory scheme assigns power in proportion of the demand of the source whereas discriminatory pricing scheme assigns power to minimize the difference between the maximum and minimum achievable data rate by the sources. For the system model considered for simulation, the relay could earn 11% more revenue in case of discriminatory pricing scheme. The sources are able to save 15.8% to 34.2% power in case of non-discriminatory and 16.9% to 34.7% power in case of discriminatory pricing scheme. There would be no difference in revenue if two sources having the same channel condition demand the same power from the relay. The computational complexity of this technique is of the $O(1)$ and is substantially low as compared to that of clock auctioning technique. The allocation approach presented in this chapter can be easily applied to fixed data rate users where relay helps only some sources whose demand can be fulfilled completely. The remaining sources are denied the cooperation.