1. RESEARCH OBJECTIVES

- In relay-based cooperative communication, long link breaks into two or more shorter links, using relay nodes.
- Precise resource allocation helps to further improve performance of the system.
- Relay nodes only allocate power to the source, if the source node reimburses them well.

By taking the derivative of $U_k(P_k, \zeta)$ with respect to $P_k$, the optimal power allocation to the source node by relay $k$ obtained as

$$P_{k}^{*} = \frac{A_k B_k Y + \sqrt{X^2 + 4XW}}{2X} - B_k$$

Where

$$X = 1 + \sum_{l=1}^{K} A_l$$

$A_k = \frac{P_{k-l} + c_{rl}^2}{\max{\{\zeta_l, \zeta\}}}$

$B_k = \frac{P_{k-l} + c_{rl}^2}{\max{\{\zeta_l, \zeta\}}}$

$W = \frac{\sum_{l=1}^{K} \sqrt{A_l B_l}}{\max{\{\zeta_l, \zeta\}}}$

Relay Node Utility Function

- The utility of the source node is the payment it receives minus its cost of cooperation
- Utility of the relay node can be defined as $U_{t_k} = \zeta_k P_{k}^{*} - c_{rl} P_{t_k}$
- $c_{rl}$ is cost of channel for transferring data
- The objective of the relay node is to maximize its utility $\max \{\zeta_k - c_{rl}\}$

4. PROPOSED ALGORITHM

Distributed Contract-Auction Algorithm

- Price of power at each relay node is favorable to change with dynamic network condition
- The cooperation among nodes is considered as integrated contract and auction process.
- Source node designs contract and offers it to the relays
- Relay nodes may be interested to bid for the price announced by the source. A relay may bid for a higher price to increase its utility, or bid for a lower price to increase its chance of being selected as relay
- Source node is principle (designs contract) and buyer (buys power from relays)
- Relay node is agent (accepts or rejects contract) and seller (sells power to the source)

Algorithm 1 Distributed contract-auction algorithm

1. Source node broadcasts the contract, including its demand for SNR and initial price of power for each type of relay $\zeta = \{\zeta_1, \zeta_2, ..., \zeta_K\}$. The vector of prices announced by the $K$ relay nodes

2. Interest relay nodes reply to the source node by accepting a contract pair.

3. If the relay which bids for the lowest price is different from the source, then relay $k$ bids for a higher price.

4. These relays announce their bid in a form of a new price vector $\zeta = \{\zeta_1, \zeta_2, ..., \zeta_K\}$ to the source node.

5. Source accepts the lowest bid, calculates the optimal power lesson from that relay and communication starts.

3. UTILITY FUNCTIONS

Source Node Utility Function

- The utility function of the source node is $U_s(P, \zeta) = a R_s c_d(P) - \sum_k \zeta_k P_{t_k}$

$\zeta = \{\zeta_1, \zeta_2, ..., \zeta_K\}$ is the vector of prices announced by the $K$ relay nodes

- The source node objective is to maximize its utility subject to power constraint at each relay node

$$\max \{U_s(P, \zeta) = a R_s c_d(P) - \sum_k \zeta_k P_{t_k}\}$$

subject to: $0 \leq P_{t_k} \leq P_{t_k}^{\max}$, $\forall k \in \{1,2,...,K\}$

The power demand of the source node from relay node is a function of the announced price as well as the price announced by the other relay nodes.

Since relays are bidding competitively, restricting the number of bidders can raise the price and benefit the sellers (relays).

2. CONTRACT THEORY

- Channel gain of the link between relay $k$ and destination is defined as $\Theta_k$ or type of relay $k$ which is hidden from other nodes
- The basic contract is in the form of

$$C = \{(P_k, \zeta_k) : \forall k \in \Theta\}$$

$P_k$ is demand of the source node for SNR from relay of type $\Theta_k$

$\zeta_k$ is the price per unit of power

The contract should be individually rational. This means that the assigned price per unit of power should be higher than the cost of channel

$$\zeta_k - c_{rl} \geq 0, \forall k \in \Theta$$

The contract should be incentive compatible. That is, a relay receives the highest utility by revealing its type truthfully

$$\Gamma_k (\zeta_k - c_{rl}) \geq \Gamma_l (\zeta_l - c_{rl}), \forall k, l \in \Theta$$

3. UTILITIES

Relay Node Utility Function

- The utility of the source node is the payment it receives minus its cost of cooperation
- Utility of the relay node can be defined as $U_{t_k} = \zeta_k P_{k}^{*} - c_{rl} P_{t_k}$
- $c_{rl}$ is cost of channel for transferring data
- The objective of the relay node is to maximize its utility $\max \{\zeta_k - c_{rl}\}$

4. PROPOSED ALGORITHM

Distributed Contract-Auction Algorithm

- Price of power at each relay node is favorable to change with dynamic network condition
- The cooperation among nodes is considered as integrated contract and auction process.
- Source node designs contract and offers it to the relays
- Relay nodes may be interested to bid for the price announced by the source. A relay may bid for a higher price to increase its utility, or bid for a lower price to increase its chance of being selected as relay
- Source node is principle (designs contract) and buyer (buys power from relays)
- Relay node is agent (accepts or rejects contract) and seller (sells power to the source)

Algorithm 1 Distributed contract-auction algorithm

1. Source node broadcasts the contract, including its demand for SNR and initial price of power for each type of relay $\zeta = \{\zeta_1, \zeta_2, ..., \zeta_K\}$. The vector of prices announced by the $K$ relay nodes

2. Interest relay nodes reply to the source node by accepting a contract pair.

3. If the relay which bids for the lowest price is different from the source, then relay $k$ bids for a higher price.

4. These relays announce their bid in a form of a new price vector $\zeta = \{\zeta_1, \zeta_2, ..., \zeta_K\}$ to the source node.

5. Source accepts the lowest bid, calculates the optimal power lesson from that relay and communication starts.

5. SIMULATION RESULTS

- Above figure shows the price per unit of power exponentially decreases when maximum available relay power at each relay node increases.

6. CONCLUSIONS

- This work provides a distributed solution for power allocation and price assignment problems.
- The distributed algorithm integrates contract theory and auction mechanism.
- The designed contract elicits the private information of relay nodes.
- The participation of the relay nodes are voluntary and the interaction between nodes are very limited.