Cooperative ARQ with Fairness via Vickrey Auction-Based Spectrum Leasing

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***Abstract*—Cooperative automatic repeat request (ARQ) communication has been studied as a way to improve reliability of networks compared to conventional ARQ transmission scheme. We consider cooperative ARQ via Vickrey auction-based spectrum leasing, which is a communication scheme with a decentralized mechanism that motivates other non-cooperative nodes to participate as relay nodes in cooperative ARQ. Conventional researches of this model did not focus on fairness for amount of traffic flows among relay nodes' data. In this paper, we propose a new protocol considering this fairness by making autonomous-decentralized decision based on behavioral economic by each relay node evaluating own degree-of-satisfaction according to their acquired profits up to previous time auction. With computer simulation, we show that our proposal protocol has superiority to conventional schemes from the viewpoint of throughput and fairness index.**

I. INTRODUCTION

Recently, cooperative communication has been moved into the limelight with the one of the emerging transmission strategies for future wireless networks [1]. As its name suggests, it is the technology for increasing reliability by making neighbor multi-nodes cooperate mutually.

In [2], to satisfy desired quality-of-service (QoS) constraints, ARQ is introduced into decode-and-forward (DF) cooperative communication. These cooperative ARQ protocols are promising techniques that provides a synergy between two important communication paradigms, cooperation and opportunistic resource allocation. In particular, a source-destination link applying this protocol might hand over possible retransmissions to one of the available neighboring nodes that are able to decode the original transmission; thus, the cooperative transmission is prescribed only if needed in an opportunistic fashion [2]. Despite this attractive property, implementation of cooperative ARQ protocols is often discussed [3], since the underlying assumption that relays unconditionally assist communications without any benefit, is unrealistic for regular users' mobile terminals. Given the above, in [4], authors alleviated the assumption that available relays are willing to assist the ongoing transmission in an altruistic fashion, and proposed an incentive mechanism for cooperation based on spectrum leasing. Specifically, incentive for relaying nodes is given by the possibility for the source to lease a portion of the retransmission slots for the traffic of retransmitting relay node in exchange for cooperative retransmission. To further leverage gains from opportunistic transmission and obtain a fully decentralized solution, the relays (now motivated to cooperate) compete for the retransmission slot by trying to make the best retransmission offer (i.e., reliability), while simultaneously satisfying some reliability requirements for transmission of their own data in case of offer acceptance. Effective selection of relay retransmissions is performed using auction theory, with the source in the role of the auctioneer, the relays acting as the bidders, the retransmission slot as the bidding item and the retransmission reliability as the selection criteria. The idea of this spectrum leasing via cooperation was originally proposed in [5]. The protocol in [4] can be seen as a further elaboration on the ideas of [5] to offer a fully distributed solutions by exploiting cooperative ARQ and auction theory. In particular, owing to its many attractive properties (as discussed in section II), authors employ Vickrey auction [6] to study the system performance.

In [4], under a situation that relay nodes' layout (or channel condition) is lacking in uniformity, despite significant bias for traffic flows among relay nodes' data would occur, fairness for amount of traffic flows among relay nodes' data was not considered. In this paper, we propose a new protocol considering this fairness by making autonomous-decentralized decision based on behavioral economic by each relay node evaluating own degree-of-satisfaction according to their acquired profits up to previous time auction. To show the effectiveness of this idea, using computer simulation, we discuss the comparison of throughput and fairness.

The rest of the paper is organized as follows: We start with explanations of system model and communication protocols, and we bring up the issues of conventional scheme and sets up our study's objective in section II. In section III, our proposed scheme is presented. In section IV, simulation results are shown. Finally, section V concludes this paper.

II. SYSTEM MODEL

A. SYSTEM MODEL

We consider a cluster of nodes consisting of a source node 'S', an access point node 'AP', and N (potential) relay nodes '$\{\mathrm{R}_k\}_{k=1}^{N}$' that have their own data D_k to transmit towards AP. We assume that S's data D_0 has a retransmission protocol (ARQ) but $\{\mathrm{D}_k\}$ do not have it. We suppose that time is slotted by duration T, each node is all half-duplex and multiple access scheme is time division. DF is used as a relay strategy. As shown in Fig. 1, protocol consists of data-sharing phase (Phase 1) and retransmission phase (Phase 2) [4].

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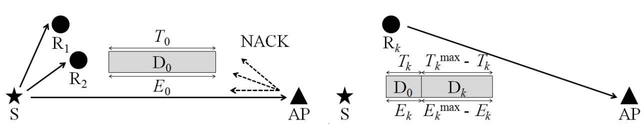
Under the constraint of D_k's minimum reliability $q_k^{\min}$, R_k are interested in transmitting D_k to AP. Reliability is defined as the probability that transmission is successful. If S-AP transmission misses, upon receiving a negative acknowledgement (NACK) from AP, in order to increase the retransmission reliability and thus reduce the overall number of (re)transmissions, S is willing to lease its retransmission slot, provided that the awarded R_k, besides transmitting D_k, will also use it for the retransmission of D_0. More specifically, S awards the retransmission slot to R_k that decoded D_0 and offers to provide the largest retransmission reliability, and particularly larger than the reliability achievable by S alone. Here, S needs to share information for reception status of D_k with R. On the other hand, $\{\mathrm{R}_k\}$ compete for access by trying to make the best retransmission offer to S, while simultaneously maximizing the reliability for transmission of D_0 in case of the offer acceptance under the constraint on $q_k^{\min}$. This interaction between the S and independent $\{\mathrm{R}_k\}$ can be conveniently cast in the auction-theoretic framework, with retransmission slot as the bidding item, retransmission reliability as the selection criteria, S in the role of the auctioneer, and $\{\mathrm{R}_k\}$ as the bidders competing for access to retransmission slot. We consider Vickrey auction as auction protocol.

B. COMMUNICATION PROTOCOL



(a) Phase 1 (data-sharing phase) (b) Phase 2 (retransmission phase)

Fig. 1. Communication protocol: (a) D_0 transmission (broadcast) from AP under NACK (b) Retransmission interval in casse R_k wins the auction

In Phase 1 (Fig. 1(a)), S transmits D_0 to not only AP but also each R_k. If AP fails to receive D_0, AP sends NACK to S and each R_k. Upon receiving NACK from AP, S determines the retransmission reliability p_0 achievable with no help from any R_k and sets it as the reserve price and auctions the retransmission slot. The retransmission reliability p_0 is estimated using a training sequence embedded in the NACK. Assuming coding at the Shannon limit for a given target rate of S-AP link, $C_{\mathrm{S}}^{\mathrm{tar}}$, achievable rate of S-AP link, C_{S}, estimated (current) channel of S-AP link, $\hat{h}_{\mathrm{S}}$, which is availbale at S by analyzing a training sequence embedded in the NACK, actual channel of S-AP link, h_{S}, transmission energy of S, E_{S}, channel variance of S-AP link, σ_{S}^2, and temporal correlation parameter, ρ, which is detailed in section IV-A, this p_0 is described as

$$p_0 = 1 - F_{\chi^2}\left\{\frac{2^{C_{\mathrm{S}}^{\mathrm{tar}}}-1}{\sigma_{\mathrm{S}}^2 E_{\mathrm{S}}}, \frac{|\rho \hat{h}_{\mathrm{S}}|^2}{\sigma_{\mathrm{S}}^2}\right\}, \qquad (1)$$

where $F_{\chi^2}\{x,\mu\}$ is the cumulative distribution function (CDF) of the noncentral chi-square distribution with 2 degrees of freedom and noncentrality parameter μ, taken at value x. During the S's transmission, $\{\mathrm{R}_k\}$ attempt to decode D_0 and, in case of successful decoding and NACK from AP, calculate and submit the optimal bid for the auctioned retransmission slot, p_k^*. This p_k^* is retransmission reliability of D_0 and estimated from the training sequence in the NACK. We assume, without loss of generality, that $\{\mathrm{R}_k\}$ that could decode D_0 and are eligible for the auction are indexed as $\{\mathrm{R}_k\}_{k=1}^n$, where $n \leq N$ denotes the number of such nodes. R_k is interested in relaying D_0 to attain the opportunity to transmit its own traffic as reliably as possible, with a minimum tolerated reliability $q_k^{\min}$. Utility function reflecting these goals can be assigned to R_k as follows:

$$\begin{aligned} u_k(\{T_i,E_i;t_i\}_{i=1}^n) &= (q_k(T_k,E_k;t_k) - q_k^{\min}) \\ &\cdot 1\left\{(p_k(T_k,E_k;t_k) = \max(p_0, p_i(T_i,E_i;t_i)_{i=1}^n)\right\}, \end{aligned} \qquad (2)$$

where the indicator function $1\{\cdot\}$ equals 1 or 0 according to whether its argument is satisfied or not, $q_k(T_k,E_k;t_k)$ is the retransmission reliability of D_k, $\{T_k,E_k\}$ is a parameter for R_k's resource allocation (T_k sec is retransmission slot for the retransmission of D_0 and E_k J/(channel symbol) is retransmission energy for the retransmission of D_0), and t_k is a parameter characterizing, respectively R_k, such as $q_k^{\min}$, $E_k^{\max}$ and others. This says that, if R_k wins the auction, he acquires $q_k - q_k^{\min}$ as utility, whereas otherwise the utility is 0. It is well known that Vickrey auction has a dominant strategy equilibrium (DSE), a concept that poses the strongest requirement in terms of robustness [6]. Vickrey auction admits a DSE with the strategies chosen so that the utility (profit) is on the margin of indifference as to whether the player wins the auction or not. Applying this principle to the utility (2), it is clear that in the DSE the following needs to be satisfied (an accurate proof is presented in [4]):

$$q_k(T_k,E_k;t_k) = q_k^{\min}. \qquad (3)$$

Thus, maximization of the utility (2) is attained when R_k chooses the pair $\{T_k,E_k\}$ so as to maximize $p_k(T_k,E_k;t_k)$, under the constraint (3). At this time, p_k becomes a bid submitted to S, p_k^*, and this is defined as:

$$\begin{aligned} p_k^* = \max_{T_k,E_k} p_k(T_k,E_k;t_k),\ \text{s.t. } q_k(T_k,E_k;t_k) = q_k^{\min}, \\ 0 < T_k < T_k^{\max},\ 0 < E_k < E_k^{\max}, \end{aligned} \qquad (4)$$

where $T_k^{\max}$ and $E_k^{\max}$ are maximum retransmission time and energy for the retransmission of D_0, respectively.

Below, we describe the computation of this p_k^*. To elaborate, we start with the expressions for the reliabilities p_k and q_k. These are defined as the probability of successful transmission, given target rate for D_0 of R_k-AP link, $C_{\mathrm{S}_k}^{\mathrm{tar}}$, target rate for D_k of R_k-AP link, $C_{\mathrm{R}_k}^{\mathrm{tar}}$, and the current channel of R_k-AP link, $\hat{h}_{\mathrm{R}_k}$, available at R_k by analyzing a training sequence embedded in the NACK:

$$p_k = \Pr\{C_{\mathrm{S}_k} \geq C_{\mathrm{S}_k}^{\mathrm{tar}} | \hat{h}_{\mathrm{R}_k}\}, \qquad (5)$$

$$q_k = \Pr\{C_{\mathrm{R}_k} \geq C_{\mathrm{R}_k}^{\mathrm{tar}} | \hat{h}_{\mathrm{R}_k}\}, \qquad (6)$$

where C_{S_k} and C_{R_k} are the rates achievable of D_0 and D_k by R_k during duration T_k and $T_k^{\max} - T_k$, respectively:

$$C_{\mathrm{S}_k} = T_k \log_2\left(1 + |h_{\mathrm{R}_k}|^2 \frac{E_k}{T_k}\right), \qquad (7)$$

$$C_{\mathrm{R}_k} = (T_k^{\max} - T_k)\log_2\left(1 + |h_{\mathrm{R}_k}|^2 \frac{E_k^{\max} - E_k}{T_k^{\max} - T_k}\right). \qquad (8)$$

h_{R_k} is actual channel of R_k-AP link. Applying constraint $q_k = q_k^{\min}$ of (3) to (6) and (8), we have

$$q_k^{\min} = 1 - F_{\chi^2}\left\{ \frac{(T_k^{\max} - T_k)\left(2^{\frac{C_{\mathrm{R}_k}^{\mathrm{tar}}}{T_k^{\max}-T_k}} - 1\right)}{\sigma_{\mathrm{R}_k}^2 (E_k^{\max} - E_k)}, \frac{|\rho \hat{h}_{\mathrm{R}_k}|^2}{\sigma_{\mathrm{R}_k}^2} \right\}. \tag{9}$$

Here, $\sigma_{\mathrm{R}_k}^2$ is channel variance of R_k-AP link. We thus obtain from (9) the following relation between optimization parameters T_k and E_k in (4) that satisfy $q_k = q_k^{\min}$:

$$E_k(T_k) = E_k^{\max} - \frac{(T_k^{\max} - T_k)\left(2^{C_{\mathrm{R}_k}^{\mathrm{tar}}/(T_k^{\max}-T_k)} - 1\right)}{\sigma_{\mathrm{R}_k}^2 F_{\chi^2}^{-1}\{1 - q_k^{\min}, |\rho \hat{h}_{\mathrm{R}_k}|^2/\sigma_{\mathrm{R}_k}^2\}} \quad \text{s.t. } 0 < T_k < T_k^{\max},\ 0 < E_k < E_k^{\max}, \tag{10}$$

where $F_{\chi^2}^{-1}\{x, \mu\}$ is the inverse of the CDF of the noncentral chi-square distribution with 2 degrees of freedom and noncentrality parameter μ, taken at value x.

Similarly to (9), exploiting (5) and (7), p_k, which is the objective function in (4), becomes:

$$p_k = 1 - F_{\chi^2}\left\{ \frac{T_k\left(2^{C_{\mathrm{S}_k}^{\mathrm{tar}}/T_k} - 1\right)}{\sigma_{\mathrm{R}_k}^2 E_k(T_k)}, \frac{|\rho \hat{h}_{\mathrm{R}_k}|^2}{\sigma_{\mathrm{R}_k}^2} \right\}, \tag{11}$$

where the relation $E_k(T_k)$ is given by (10). By (4) and (11), we can conclude that a bid submitted to S, p_k^*.

In Phase 2 (Fig. 1(b)), auctioneer S decides winning relay $\mathrm{R}_{\breve{k}}$ ($\breve{k}$ denote the index of the winning relay) as $\breve{k} = \arg\max_k p_k^* \cdot 1\left(\max_k p_k^* \geq p_0\right)$.

Second-price $\breve{p}_{\breve{k}}$ that sets up based on the following equation is submitted to $\mathrm{R}_{\breve{k}}$ from S:

$$\breve{p}_{\breve{k}} = \begin{cases} \max\left\{p_0, \max\limits_{k \neq \arg\max_k p_k^*} p_k^*\right\} & \text{, if } \breve{k} = 1, \cdots, n, \\ p_0 & \text{, if } \breve{k} = 0. \end{cases} \tag{12}$$

As shown in Fig. 2, $\mathrm{R}_{\breve{k}}$ can re-adjust its transmission parameters $\{T_k, E_k\}$ by maximizing its reliability $q_{\breve{k}}$ while guaranteeing the required D_0's reliability $\breve{p}_{\breve{k}}$. Under the situation of each NACK, by repeating the above auction, the retransmission route (i.e. $\mathrm{R}_{\breve{k}}$-AP) changes each time, and thus efficient retransmissions can be achieved.

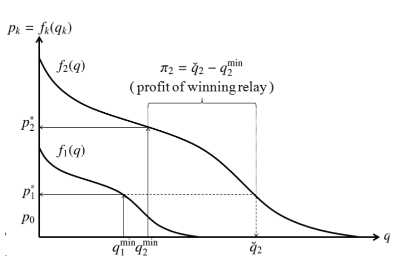


Fig. 2. Summary of the auction process with mapping $p_k^* = f_k(q_k^{\min})$ and profit of the winning relay $\breve{q}_{\breve{k}} - q_{\breve{k}}^{\min}$ ($N = n = 2$ and $p_2^* > p_1^* > p_0$ with $\breve{k} = 2$ and $\breve{p}_{\breve{k}} = p_1^*$).

C. ISSUES AND OBJECTIVE

We have the notion that this model has the following two problems. 1) Use of Profit: As shown in Fig 2, each R gains a profit in auction as shown in Fig 2. However, in conventional scheme, he could not at all make good use of this profit to determine own strategy in the next action. 2) Fairness: Fairness for amount of traffic flows among each D_k is not considered.F Under the constraint that R_k can not transmit D_k unless he wins the auction, when layout of R_k (or channel condition) is lacking in uniformity, $\mathrm{R}_{\breve{k}}$ is lacking in uniformity, too. Therefore, significant bias for traffic flow among each D_k would occur. Then, in a situation that relay nodes' layout (or channel condition) is lacking in uniformity, the objective of this study is improvement of this fairness of traffic flow among each D_k by flattening this bias by exploiting acquired profits for each R_k in jth ($j = 1, 2, \cdots$) auction up to the last ($(j-1)$th) auction.

III. PROPOSED PROTOCOL

The basic idea of our proposal is that R_k which is not gaining much profit in auction are in a better position to win in next auction and R_k which is gaining much profit in auction are in a worse position to win in next auction, and it helps traffic flow among D_k equalize.

Our proposed utility function is defined as:

$$u_{k,j}(\{T_i, E_k; t_i\}_{i=1}^n) = (q_{k,j}(T_k, E_k; t_k) - q_{k,j}^{\min}) \cdot 1\{p_{k,j}(T_k, E_k; t_k) = \max(p_{0,j}, p_{i,j}(T_i, E_i; t_i)_{i=1}^n)\}, \tag{13}$$

where $q_{k,j}(T_k, E_k; t_k)$ is the retransmission reliability of D_k in the jth auction and $q_{k,j}^{\min}$ is the D_k's minimum reliability in the jth auction, which is defined as variables (functions) depending on acquired profits up to the last ($(j-1)$th) auction as follows:

$$q_{k,j}^{\min} = \left[q_{k,j-1}^{\min} + \eta_{k,j-1}\xi_{k,j-1}\right]_{q_k^{\min,\min}}^{q_k^{\min,\max}} \quad (j = 2, 3, \cdots,) \tag{14}$$

where $q_{k,1}^{\min} = q_k^{\min}$, $q_k^{\min,\max}$ is a maximum possible value of $q_{k,j}^{\min}$, $q_k^{\min,\min}$ is a minimum possible value of $q_{k,j}^{\min}$, and thus $[x]_{x^{\min}}^{x^{\max}}$ is defined as $[x]_{x^{\min}}^{x^{\max}} = x^{\min}$ $(x < x^{\min})$, x $(x^{\min} \leq x \leq x^{\max})$, $x^{\max}$ $(x^{\max} < x)$.

$\xi_{k,j-1}$ in (14) denotes a degree-of-satisfaction for R_k according to the acquired profits of $(j-1)$th auction, and this is defined as a function depending on the profits acquired by each R in the $(j-1)$th auction as follows:

$$\xi_{k,j-1} = \begin{cases} \pi_{k,j-1}, & \text{if } \quad k = \breve{k} \\ -\pi_{\breve{k},j-1}/(n-1), & \text{if } \quad k \neq \breve{k} \end{cases} \tag{15}$$

where $\pi_{k,j-1}$ is the profits that R_k acquires on $(j-1)$th auction as shown in Fig. 2, and thus $\pi_{k,j} = \breve{q}_{k,j} - q_{k,j}^{\min}$.

$\eta_{k,j-1}$ in (14) denotes a corrective coefficient for degree-of-satisfaction $\xi_{k,j-1}$, and this is defined as a function depending on absolute value of slope of a curve of function $p_{k,j-1}^* = f_{k,j-1}(q_{k,j-1}^{\min})$, $\delta_{k,j-1} = \left|\frac{\mathrm{d}p_{k,j-1}^*}{\mathrm{d}q_{k,j-1}^{\min}}\right|$, as shown in Fig. 3 as follows:

$$\eta_{k,j-1} = 1 - \frac{\delta_{k,j-1}}{\delta_{k,j-1} + 1}. \tag{16}$$

Here, From Fig. 3, we can see that domain of $\delta_{k,j-1}$ is $(0,\infty)$. $\eta_{k,j-1}$ is the function which has 1 and 0 at both limits of this domain, as follows:

$$\eta_{k,j-1} \rightarrow \begin{cases} 1, & \text{if} \quad \delta_{k,j-1} \rightarrow 0, \\ 0, & \text{if} \quad \delta_{k,j-1} \rightarrow \infty. \end{cases} \tag{17}$$

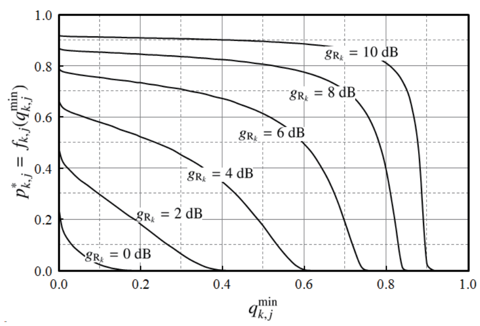


Fig. 3. Corresponding bid $p^*_{k,j} = f(q^{\min}_{k,j})$ in jth auction, for $g_{\mathrm{R}_k} = 0, 2, 4, 6, 8, 10$ dB, $|\hat{h}_{\mathrm{R}_{k,j}}| = \sqrt{\pi g_{\mathrm{R}_k}}/2$, and $\rho = 0.75$.

When $\delta_{k,j-1}$ takes small value, from Fig. 3, since, unless $q^{\min}_{k,j-1}$ takes a large shift, $p^*_{k,j-1}$ takes a little shift, $\xi_{k,j-1}$'s impact on renewing of $q^{\min}_k$ expressed in (14) must be greater. On the other hand, when $\delta_{k,j-1}$ takes large value, from Fig. 3, since, unless $q^{\min}_{k,j-1}$ only takes a small shift, $p^*_{k,j-1}$ takes a large shift, $\xi_{k,j-1}$'s impact on renewing of $q^{\min}_k$ expressed in (14) must be less. Here, from (17), if absolute value of slope function $p^*_{k,j-1} = f_{k,j-1}(q^{\min}_{k,j-1})$ takes large value, the corrective coefficient, $\eta_{k,j-1}$, takes small value. Therefore, we can see that the degree-of-satisfaction $\xi_{k,j-1}$'s impact on renewing of $q^{\min}_k$ expressed in (14) become less. On the other hand, from (17), if $p^*_{k,j-1} = f_{k,j-1}(q^{\min}_{k,j-1})$ takes small value, $\eta_{k,j-1}$ takes large value. Therefore, we can see that $\xi_{k,j-1}$'s impact on renewing of $q^{\min}_k$ expressed in (14) become greater. This is the role of the corrective coefficient $\eta_{k,j-1}$.

Details of this proposal are described below. 1) From (15), it can be seen that $\mathrm{R}_{\breve{k},j-1}$ (R_k which wins in $(j-1)$th auction) evaluates degree-of-satisfaction as positive value according to own profit gained in $(j-1)$th auction, and R_k which loses in $(j-1)$th auction evaluates degree-of-satisfaction as negative value according to wining relay $\mathrm{R}_{\breve{k},j-1}$'s profit gained in $(j-1)$th auction. 2) From (14), we can see that if $\xi_{k,j-1}$ has positive (negative) value, $q^{\min}_{k,j}$ become larger (smaller) in renewing to $q^{\min}_{k,j}$ from $q^{\min}_{k,j-1}$. At this time, by $\eta_{k,j-1}$ considering $\delta_{k,j-1}$, $\xi_{k,j-1}$'s impact on this renewing is adjusted to optimal value. 3) From (3) and (13), we can understand that $q^{\min}_{k,j}$ becomes smaller (larger), $q_{k,j}$ becomes larger (smaller). 4) From the shape of the function of Fig. 2 and intuition, we can understand that the more $q^{\min}_{k,j}$ increases (decreases), $p_{k,j}$ (i.e., ditto with $p^*_{k,j}$) decreases (increases), intuitively. From the above, we can see that since R_k which is not gaining much profit before $(j-1)$th auctions tend to have larger p^*_k, he could tend to win in jth auction, and on the contrary, since R_k which is gaining much profit before $(j-1)$th auction tend to have smaller p^*_k, he could tend to lose in jth auction Thus, varying $p^*_{k,j}$ according to the degree-of-satisfaction for each R_k would be lead to flattening of chance of winning for each R_k, and fairness for amount of traffic flows among each D_k could improve. This is the mechanism of our proposal.

In this protocol, each R_k needs to know profit gained for wining relay, $\pi_{\breve{k},j-1}$, and they can know this information based on the following protocol. (i) When $\mathrm{R}_{\breve{k}}$ sends $p^*_{\breve{k},j-1}$ to S, it sends not only a bid, but also $\pi_{\breve{k},j-1}$. (ii) When S sends $\breve{k}$ and $\breve{p}_{\breve{k}}$ to each R_k, S sends not only these, but also $\pi_{\breve{k},j-1}$.

IV. PERFORMANCE EVALUETION

A. SIMULATION PARAMETERS

We compared three transmission schemes: "Conventional" is the conventional auction based scheme without considering fairness explained in Section II; "Random" is the scheme in which retransmission node is selected at random from S and $\{\mathrm{R}_k\}$ in every NACK; "Proposal" is our proposed scheme considering fairness explained in Section III. In Conventional, Random and Proposal, traffic data are D_0 and each D_k, respectively.

Our computer simulation parameters are shown as follows. Network with one S node, one AP node, and 8 R nodes which successfully decode D_0 ($n = 8$) is assumed. Transmission energy for S, E_0, is 1 J/(channel symbol). The time constraints, $T^{\max}_k$, are 1 sec and the energy constraints, $E^{\max}_k$, are 1 J/(channel symbol). The single-sided spectral density of the independent white Gaussian noise at the receivers is normalized to unity, $N_0 = 1$ W. Bandwidth is 1 Hz. The target rate of D_0's transmission of the original transmission, $C^{\mathrm{tar}}_{\mathrm{S}}$, is 1 bps and D_k's it, $C^{\mathrm{tar}}_{\mathrm{R}_k}$, is 1 bps, respectively. Maximum number of retransmission is four times. Minimum reliability $q^{\min}_k$ is 0.4, $q^{\min,\min}_k = 0.01$, $q^{\min,\max}_k = 0.99$.

We assume that each link experiences i.i.d. block Rayleigh fading, and block length is as long as a time slot (i.e. $T^{\max}_k$). Delay between the (re)transmission slots is large enough to assume uncorrelated block fading. The channel power gains of respective links are $g_{\mathrm{S}} = E[|h_{\mathrm{S}}|^2]$ and $g_{\mathrm{R}_k} = E[|h_{\mathrm{R}_k}|^2]$. We consider $g_{\mathrm{R}_1} = g_{\mathrm{S}}$ and $g_{\mathrm{R}_{k+1}} = g_{\mathrm{R}_k} + 0.5$, and this indicates $\{\mathrm{R}_k\}$ (channel) layout is lacking in uniformity Channel variation during the interval between the estimation instance and the consequent (re)transmission slot is accounted for and modeled through a temporal correlation parameter ρ, as in, e.g., [8]. Notice that delay between the downlink channel estimation and the following (re)transmission slot is not negligible but still much smaller than the delay between (re)transmissions, in order for block-fading to hold. The actual channel $h \in h_{\mathrm{S}}, \{h_{\mathrm{R}_k}\}^n_{k=1}$ during the (re)transmission slot is outdated with respect to the channel at the receiving time interval $\hat{h} \in \hat{h}_{\mathrm{S}}, \{\hat{h}_{\mathrm{R}_k}\}^n_{k=1}$ (with correlation ρ) and the corresponding modeling is $h = \rho\hat{h} + \omega$ where $\hat{h} \sim \mathcal{CN}(0, g), g = E[|h|^2]$ and $\omega \sim \mathcal{CN}(0, \sigma^2)$ is the innovation term (due to the outdated knowledge) with variance $\sigma^2 = (1-\rho^2)g$. We assume that each node knows the noise power and that the channel estimations are ideal and $\rho = 0.75$.

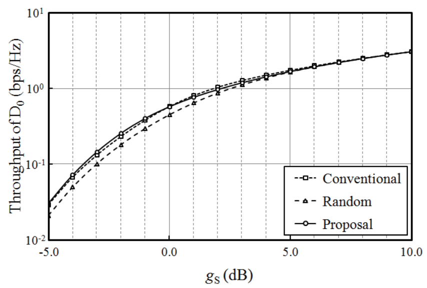


Fig. 4. $g_{\rm S}$ vs. throughput of $\rm D_0$ for the three schemes; Conventional, Random and Proposal.

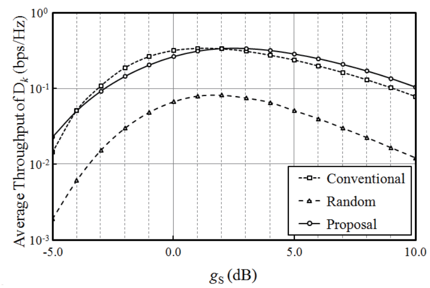


Fig. 5. $g_{\rm S}$ vs. average throughput of $\{{\rm D}_k\}_{k=1}^n$ for the three schemes; Conventional, Random and Proposal.

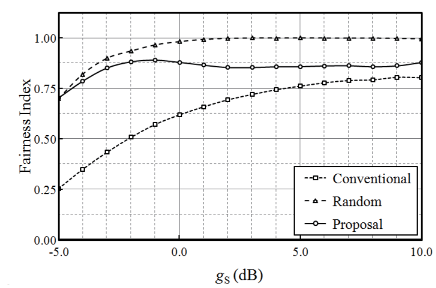


Fig. 6. $g_{\rm S}$ vs. fairness index performance for the three schemes; Conventional, Random and Proposal.

B. SIMULATION RESULTS

First, Fig. 4 shows channel power gain between S-AP, $g_{\rm S}$ vs. throughput of S's data, $\rm D_0$, for the three schemes; Conventional, Random and Proposal. From this figure, Conventional and Proposal have greater throughput than Random. In this result, we can confirm the effectiveness of auction based resource allocation. It shows that Conventional and Proposal have approximately comparable throughput, and we understand it is little impact on throughput of $\rm D_0$ that variation of p_k^* owing to changes in $q_k^{\min}$. This is because Vickrey auction-based resource allocation can achieve optimal allocation of resources according to the value of q_k^{min}.

Second, Fig. 5 shows channel power gain between S-AP, $g_{\rm S}$, vs. average throughput of R's data, $\{{\rm D}_k\}_{k=1}^n$, for the three schemes; Conventional, Random and Proposal, where vertical axis is defined as $\sum_{k=1}^n C_{{\rm R}_k}/n$. The shape of these performances are seen to be a convex shapes. This is owing to the following reasons: (i) Under the low channel gain, because most of the (re)transmission does not succeed, average throughput of $\{{\rm D}_k\}$ degrades; (ii) Under the high channel gain, because the number of (re)transmission decreases, average throughput of $\{{\rm D}_k\}$ degrades. Conventional and Proposal have greater throughput than Random.

Thirdly, Fig. 6 shows $g_{\rm S}$ vs. fairness index performance for the three schemes; Conventional, Random and Proposal. This index is known and described as Jain's fairness index and it is defined as $(\sum_{k=1}^n C_{{\rm R}_k})^2/(n \cdot \sum_{k=1}^n C_{{\rm R}_k}^2)$ [9]. The fairness index of a system ranges from 0 to $1/n$, with 0 being totally unfair and $1/n$ being totally fair. In this simulation, because we assume $n = 8$, lower bound of fairness index performance is 0.125. From Fig. 6, naturally, we can see that Random has greatest fairness index performance. Proposal has greater fairness index performance than Conventional. This is because, by using index obtained by evaluating degree-of-satisfaction according to their acquired profits, each $\rm R_k$ makes autonomous-decentralized decision based on behavioral economic, and this decision leads to a fair opportunity to win. Thus, we understand that Proposal using degree-of-satisfaction according to their acquired profits has a positive impact for fairness improvement.

From these three figures (Figs. 4, 5 and 6), we have led to the following conclusions: While Random has the excellent fairness index performance, in both throughput performances ($\rm D_0$ and $\{{\rm D}_k\}_{k=1}^n$), Random is inferior to Conventional and Proposal. Therefore, we can confirm the effectiveness of auction based resource allocation. In addition, Proposal has improved fairness index performance as compared with Conventional, without little degradation of throughput of both $\rm D_0$ and $\{{\rm D}_k\}_{k=1}^n$. Therefore, we can confirm the effectiveness of our proposed scheme.

V. CONCLUSION

We propose a new protocol for Cooperative ARQ with fairness of amount of traffic flows among each ${\rm D}_k$ via Vickrey auction-based spectrum leasing by making autonomous-decentralized decision based on behavioral economic by each relay node evaluating own degree-of-satisfaction according to their acquired profits up to previous time auction. By computer simulation, we confirm that compared with conventional scheme, our proposed schme improves fairness without causing little degradation in both throughput of $\rm D_0$ and average throughput of $\{{\rm D}_k\}$.

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