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Relay selection mechanism for user cooperation networks using a game-theoretic approach

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In this paper, we propose a new mechanism for selecting the most suitable partner in a cooperative wireless communication system, using a type of game called the Bidding game. Among all the previous researches in cooperative communications employing a similar game concept, none of them considered how relays are selected, but rather how power is allocated among the relays or sources. In this game, in which the conventional theories of economic bidding are applied, the cooperative communication network is modeled as a single-user, multi-relay system in which the source acts as the auctioneer while the relays or partners act as the bidders in the game. The resource being auctioned here is power, and the relay which offers the highest bid in terms of price is selected, allocated power and also given an incentive (for helping) by the source node. This paper shows that there is a linear relationship between the utility achievable by a source node and the selection of a suitable partner for the cooperative process by that node. Simulations are run to verify and validate our proposed scheme.

Key words: Auction, bidding game, cooperative communication, utility.

INTRODUCTION

Cooperative communication or user cooperation has, over the last decade, been seen as a promising signal transmission technique aimed at exploiting spatial diversity gains over single antenna nodes in wireless communication networks (Alonso-Zarate et al., 2009). In this technique, several nodes act as partners or relays and share their resources to forward other nodes' data to the destination. It has also been ascertained that this cooperation gives a significant improvement in system performance and reliability over the non-cooperative systems (Baidas and MacKenzie, 2011b). To fully take hold of the benefits of cooperative diversity or communication, appropriate partner selection and an efficient resource allocation are very essential, because, apart from the fact that these aid in harnessing the benefits of cooperative diversity, the actual performance of cooperative communication as a whole depends on them.

Recently, several works have dealt with the issue of partner selection and resource allocation in cooperative communications. These works are found to be in two categories namely, centralized systems (Ng and Wei, 2007; Wenbing et al., 2010; Yuan et al., 2010) and decentralized systems (Beibei et al., 2009; Bletsas et al., 2006; Li et al., 2010; Lingjie et al., 2011; Niyato et al., 2009; Savazzi and Spagnolini, 2007; Shaolei and Van der Schaar, 2011; Yang et al., 2011). Unlike the centralized systems which require the global channel state information (CSI), and thus incur higher signaling overhead (Yuan et al., 2011), the decentralized or distributed systems are more favorable in practical terms since they require only the local information of the nodes.

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For instance, Bletsas et al. (2006), propose a partner selection scheme for distributed systems based on limited instantaneous SNR. Savazzi and Spagnolini (2007), propose a distributed power control framework for a single-source, multiple relays to optimize multihop diversity.

In the last few years, game theory has grown to be a veritable tool in the analysis of distributed systems due to their autonomous and self-configuring capability. For instance, in Beibei et al. (2009) a non-cooperative game known as Stackelberg game is employed to develop a power allocation algorithm. The network is modeled as a single user, multi-relay system in which the source acts as the buyer and the relays act as the sellers of resource (that is, power). In the work the concept of conventional buying and selling is employed.

Jianwei et al. (2008) develop an auction-based power allocation scheme for a distributed cooperative network. In the work where there are many source nodes and only one relay node, the source nodes act as the bidders while the relay node acts as the auctioneer. This is because the objective of the work is how to allocate power among the many nodes involved, rather than selecting a particular relay node for cooperation. Also the Antonopoulos and Verikoukis (2012) developed a strategy for an *N*-player medium access game for the dissemination of wireless data in a cooperative network.

Yuan et al. (2011) develop a multi-source, multi-relay cooperative network that utilizes the concept of auction for the purpose of optimal allocation of power. In this case however, each user acts as both a bidder and an auctioneer. Baidas and MacKenzie (2011b), proposed a distributed ascending-clock auction-based algorithm for multi-relay power allocation where the source nodes are also many. A design of an auction-based power allocation scheme for many-to-one (multi-user, single-relay) cooperative adhoc networks is implemented in (Baidas and MacKenzie, 2011a).

In this game-based work however, the source node selects the partner node that offers the highest bid in terms of price. Moreover, unlike the works in Baidas and MacKenzie (2011a, 2011b), Jianwei et al. (2008), and Yuan et al. (2011) in which multiple source nodes are employed in implementing resource allocation, we propose a single-user, multi-relay system, which we call single-auctioneer, multi-bidders bidding game for the purpose of selecting the most suitable partner by the source node. It is noteworthy that none of these aforementioned works considered selection of suitable partners for the relaying process; this work therefore intends to propose this new partner selection scheme based on the theory of bidding. Thus the major contribution of this paper is the development of a partner selection scheme using the bidding game whereas the previous auction-based researches as stated above primarily focused on resource allocation in cooperative communications.

SYSTEM MODEL AND PROBLEM FORMULATION

Cooperative system model

The scheme in Figure 1(a) shows a single source node and *N*-relays, which describe our proposed work in which the source node acts as the auctioneer and the *N*-relay nodes act as the bidders in our proposed bidding game. A simple cooperative model is depicted in Figure 1(b) where there is one relay and one source node for the purpose of describing the cooperative process.

In the first time slot or Phase 1, the source node (*s*) in Figure 1(a) broadcasts its information, and is received by the both the partner (*i*) and destination (*d*) nodes as follows:

$$Y_{sd} = \left(P_s G_{sd}\right)^{0.5} X_s + \eta_d \tag{1}$$

$$Y_{sr_i} = \left(P_s G_{sr_i}\right)^{0.5} X_s + \eta_{r_i} \tag{2}$$

where Y_{sd} and Y_{sr} respectively represent the received signal from the source to destination, *d* and from source to relay, *r*. P_s represents the power transmitted from the source node while X_s represents the transmitted data normalized to unit energy. G_{sd} and G_{sr} denote channel gains from *s* to *d* and from *s* to *r* respectively, and the AWG noises are given as η while the noise power is denoted by *n*, which we assume is equal for all links.

During the first time slot, the SNR obtained at the destination node is given as

$$\gamma_{sd} = \frac{P_s G_{sd}}{n} \tag{3}$$

Moreover, during the second time slot, the Y_{sr_i} is amplified and forwarded to the destination node; thus the signal received at the destination during the second time slot is given as

$$Y_{r_i d} = \left(P_r G_{r_i d}\right)^{0.5} X_{r_i d} + \eta'_d \tag{4}$$

where $G_{r_i d}$ is the channel gain from relay to destination nodes while η'_d is the noise received during the second phase, and $X_{r_i d} = \frac{Y_{sr_i}}{\left|Y_{sr_i}\right|}$ is the signal of unit energy that the relay receives from the source node and which it forwards to the destination node.

Now, using $X_{r_i d}$ and Equation (2), we rewrite Equation (4) to obtain the following:

$$Y_{r_i d} = \frac{\left(P_{r_i} G_{r_i d}\right)^{0.5}\left(\left(P_s G_{sr_i}\right)^{0.5} X_s + \eta_r\right)}{\left(P_s G_{sr_i} + n\right)^{0.5}} + \eta'_d \tag{5}$$

And using Equation (5), we obtain the SNR through relaying, at the destination node as follows:

$$\gamma_{sr_i d} = \frac{P_{r_i} P_s G_{r_i d} G_{sr_i}}{n\left(P_{r_i} G_{r_i d} + P_s G_{sr_i} + n\right)} \tag{6}$$

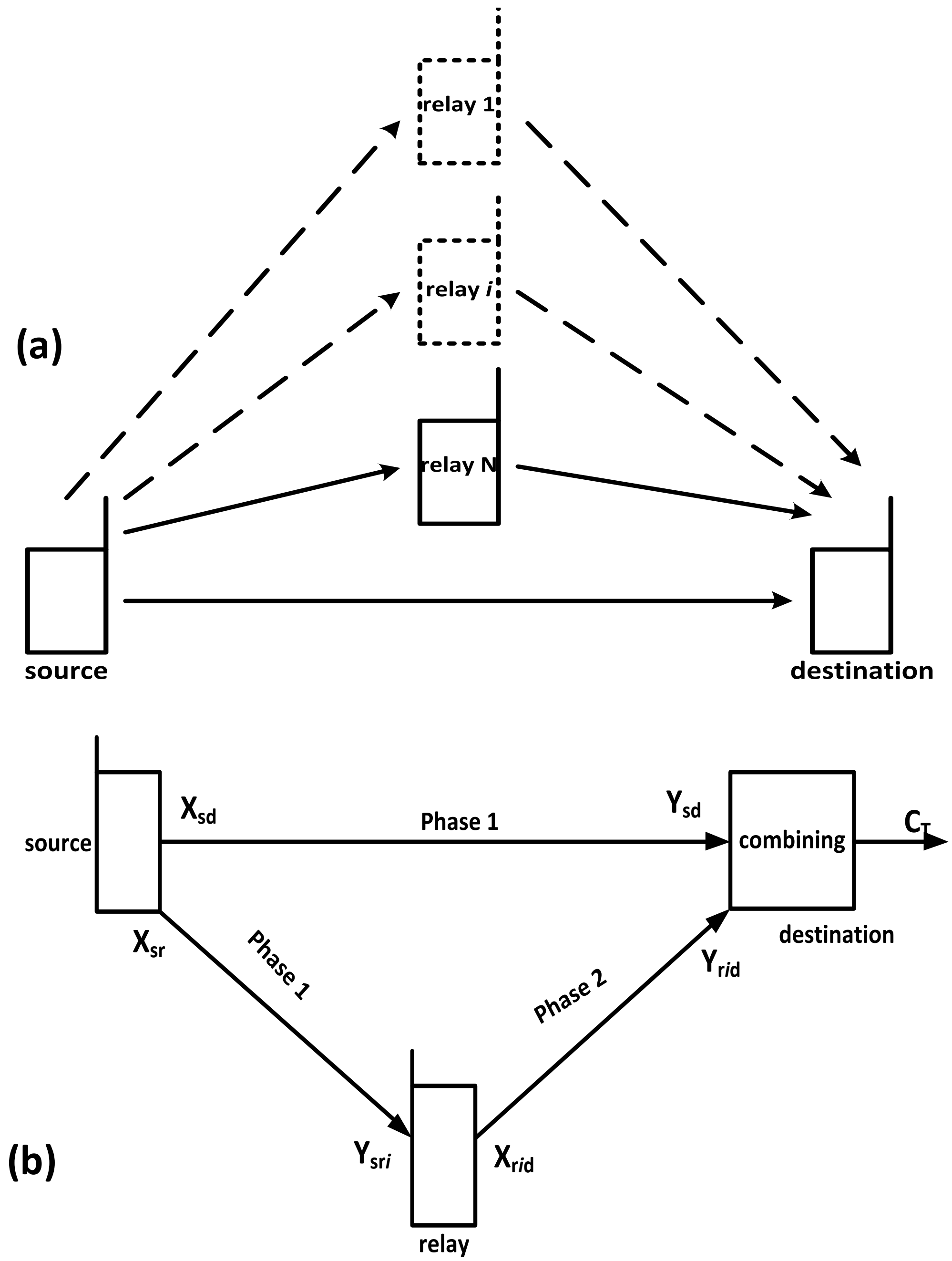

Figure 1. (a) A multi relay representation of a wireless cooperative communication system. (b) System model for a single-relay cooperative network.

Next, the achievable transmission rate C_{sd} at the destination node will then be obtained. In this case from the above analysis, the source will have two options:

Option1: the source node uses only the Phase1 transmission and obtains the rate

$$C_{sd} = W \log_2 (1 + \gamma_{sd}) \tag{7}$$

where *W* is the bandwidth of the transmitted signal

Option 2: the source node uses the two phases, and at the combining output (using MRC), achieves the following achievable rate:

$$C_{sr_i d} = \frac{W}{2} \log_2 (1 + \gamma_{sd} + \gamma_{sr_i d}) \tag{8}$$

It can be seen in Equation (8) that the $\gamma_{sr_i d}$ is the additional SNR increase when compared with the non-cooperative case, that is,

Source node announces the bid threshold B_{th} with price p_{th} to all relays, $r_1, \ldots r_i \ldots r_N$;

Relay r_i announces its bid to the source, with bid price p_i;

Source compares the bid price of r_i with the B_{th}

If bid price p_i of relay $r_i < p_{th}$, relay r_i is rejected,

else it is stored;

Source node compares another relay r_j with price p_j

If $p_j < p_{th}$, relay r_j is rejected;

else it is stored;

if $p_j < p_i$, relay r_j is also rejected,

else it is stored;

Repeat until all relays are checked and their prices compared with the p_{th} ;

The relay with the highest value of bid in term of the price is selected as the cooperating relay and allocated power.

Figure 2. Pseudo-code for the proposed partner selection scheme.

$\Delta SNR \approx \gamma_{sr_id}$.

Comparing option 1 above with option 2, the rate increase obtainable by the source node is given as follows:

$$\Delta C = \max\left\{C_{sr_id} - C_{sd}, 0\right\} \tag{9}$$

We make the assumption that the P_s (source node's power) is fixed and that the power that would be allocated to a particular relay node would be a function of the amount of bid placed by that relay.

Bidding game model

The main essence of a bidding game is auction. An auction is a decentralized economic mechanism for allocation of resources. In an auction, the players are the bidders (r_i) and auctioneers (s), the strategies are the bids (b_i) while allocations (P_{all}) and prices (p_i) are the bids' functions. For our work, the source is the auctioneer who desires to sell bids to the highest bidder, the relay nodes are the bidders who wish to pay for the bids and the good or resource to be bought is the power (P). According to (Han et al., 2012), there are four components which determine the outcome of an auction. These components are (1) the information available to the bidders and auctioneer, (2) the bids placed by the bidders to the auctioneer, (3) the allocation of good or resource by the auctioneer, based on the placed bids, and (4) the payments made to the auctioneer by the bidder after the successful bidding.

In the cooperative scenario being considered here, power is the resource that the bidders (relays) are placing bids for. It is from these bidding relay nodes that the source node would select the partner that offers the highest bid price (the relay that places the highest value in the bid profile).

Modeling the bidding game with these components, we have:

(i) Information, I: The source node (auctioneer) announces a non-negative bid threshold B_{th} and a price $p > 0$ to all relays prior to the commencement of the bidding process;
(ii) Bids, b_i: Relay r_i places a bid (which is a scalar), $b_i \geq 0$ to the source node. After an iterative process to get the highest bidder, the source selects the most suitable relay;
According to (Jianwei et al., 2008), a bidding profile is defined as vector $\mathbf{b} = (b_1, b_2 \ldots b_i \ldots b_N)$ which contains the bids of the relay nodes, where N is the number of relays involved in the game.
(iii) Allocation, P_{all}: The source, after selecting the relay, allocates power P_{all} based on the following:

$$P_{all} = \frac{b_i}{\sum_{j=1}^{N} b_j + B_{th}} P \tag{10}$$

where P is the total transmit power of the relaying partners available for the bidding game.

PROPOSED RELAY SELECTION SCHEME

As described in "system model and problem formulation" part of this work, our work focuses on a single-user, multi-relay network in which we model the source node as the auctioneer and the relay nodes as the bidders; we also mentioned that the good or resource being bided for is power.

The pseudo code for implementing this relay selection is given in Figure 2.

A brief description of the proposed scheme is given as follows: As seen in the pseudo code in Figure 2, the partner selection process is iterative in the sense that the source node compares the bid prices announced by each relay node with its own announced price, p_{th} and rejects any bid price that is less than its own announced price while retaining the one that is higher. It also compares a succeeding bid price with a preceding one, with a view to selecting the higher bid price at every point. The point of convergence in the iteration is the point where an announced bid price is the highest of all the other bids in the network; and the relay presenting such bid is thus selected by the source node and then allocated power for forwarding to the destination node. This selected relay node now happens to be the most suitable to help the source node forward its data to the destination node, based on the concept of bidding being discussed in this work. Another important issue in this type of bidding game is that the source node, upon selecting the suitable relay node, also gives an incentive to the particular relay node for helping it with the forwarding of its data.

One very important criterion in this bidding-based partner selection is summed up in these two components of the game:

(a) For a given price p_{th}, each of the bidders r_i, $\forall i$ determines its demand vector $\left\{p_{s,r_i}\right\}_{i=1}^{N}$, then places or submits a corresponding bid vector $\left\{b_{s,r_i}\right\}_{i=1}^{N}$ to the auctioneer;

(b) For the collected bids from the bidders, the auctioneer determines its own power supply value and announces its preferred bidder (usually the highest bidder) based on the bid prices placed by the bidders.

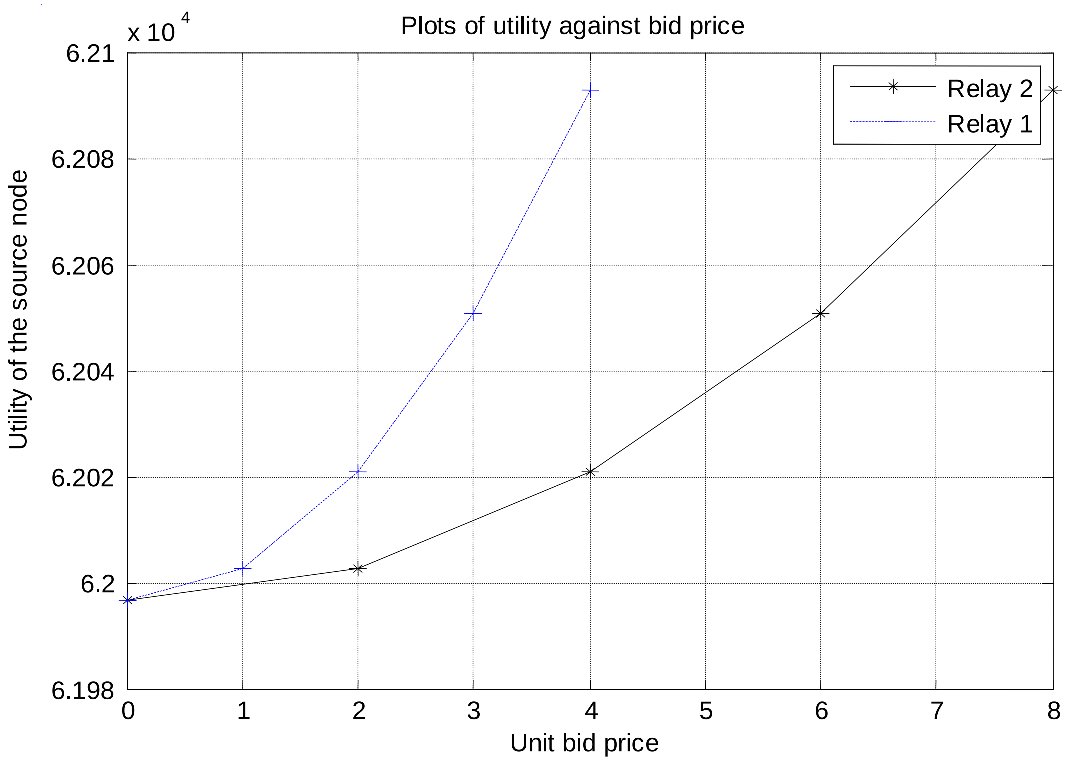

Figure 3. Plots showing the relationship between the source utility and the bid price.

RESULTS AND DISCUSSION

A cooperative communication network consisting of one source node, one destination and two relays is considered. The single destination node is situated at (0, 0) while the relays are randomly located at (0.2, 0.5) for relay 1 and (0.8, 0.6) for relay 2, in a two-dimensional plane topology. The source node is expected to select the highest bidding relay node as its cooperating node from the two relays being considered.

Figure 3 shows plots depicting the relationship between the utility of the source node and the bid prices of the relay nodes. The figure shows that the higher the bid price a relay is willing to pay for the power being auctioned by the source node, the greater the probability of that relay node being selected as the cooperative partner due to a corresponding increase in the utility of the source node. For instance, when the bid price is 2 units, the utility of the source by virtue of relay 1 is 6.2 × 10^4 utils while it is 6.202×10^4 utils by relay 2. In the same vein, when the bid price increases to 4 units, the source node utility resulting from relay 1 is 6.202 × 10^4 utils while for relay 2, it is 6.208×10^4 utils. It can also be seen from the plots that relay 1 will be selected by the source node since it accords a higher utility than relay 2. In Figure 4 however, it is seen that there is convergence to equilibrium after a number of iterations, just as it also shows that at a higher price, there is a corresponding higher utility. This further corroborates our earlier proposition in formulating this game model.

Worthy of note however is the motivation of the relay nodes to participate in the bidding game: In the proposed game, the relay nodes are the bidders while the source node is the auctioneer. The relay nodes are motivated to be part of the game because of the utility they also enjoy, for when they are selected by the source node to help in forwarding data to the destination node, there is also an incentive being paid the relay node for helping the source node in the forwarding process. How do the relay nodes determine their bid prices? Their bid prices are determined by their location on the network. The relay nodes that are better located to give the source nodes the highest utility or pay off tends to place a bid for a high price.

Conclusion

In this work we have been able to propose a new partner selection scheme different from the renowned bidding schemes which have focused principally on resource allocation and left out the selection of suitable partner(s) for the cooperation. The scheme which is modeled as a single-user multi-relay network has the source node acting as the auctioneer in the bidding process while the relays act as the bidders. Our results agree with what

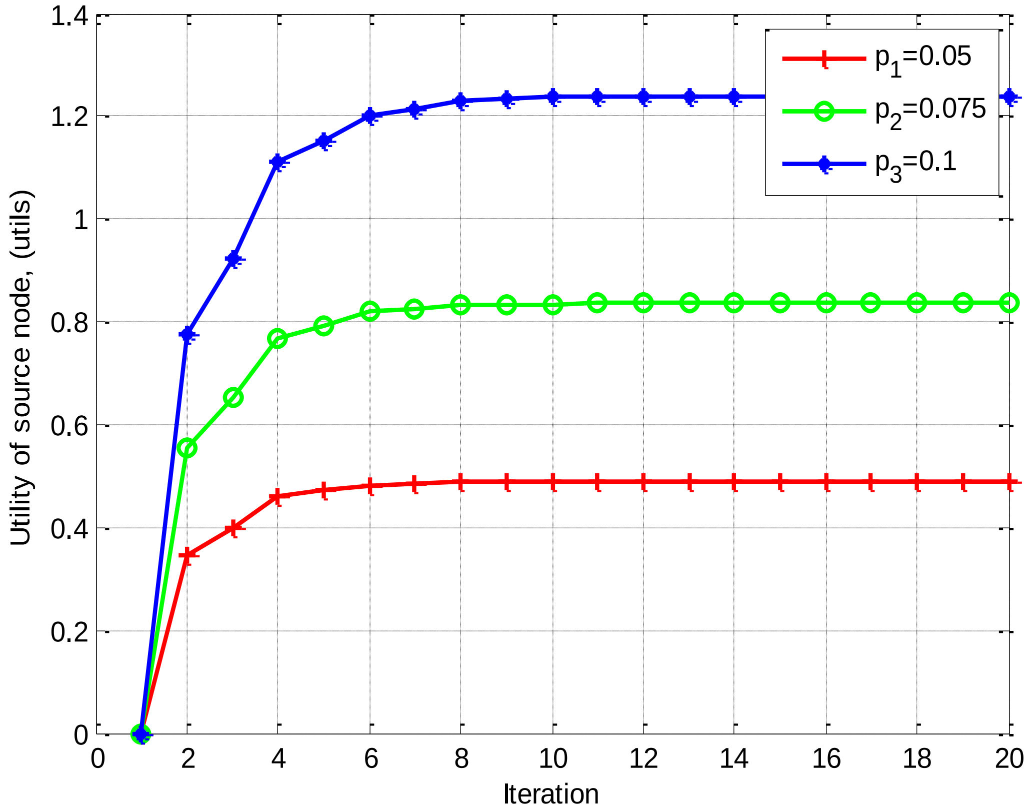

Figure 4. Plots showing the convergence to equilibrium of the utility of the source node.

transpires in the conventional economic bidding practice where the highest bidder goes with the goods and also shows that a relationship exists between the utility obtainable by the source node (which is a function of the bid price) and the selection of the relay node. We furthermore see that the auctioneer (source node) selects the relay that is willing to pay the highest, in terms of the bid price and at the same time provides an incentive to the selected bidder (relay node) for the help the latter is rendering in forwarding the source node's data to the destination node.

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