LoCo – Link: A Low-Complexity Link Selection Algorithm for Delay Mitigation in Asymmetric Two-Hop Networks

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***Abstract*—While buffer-aided relaying improves the diversity of a multi-hop network, its deployment introduces time-delays, thus rendering buffering unreliable for delay-intolerant applications. To alleviate excessive delays, various studies propose delay-aware protocols, but at the expense of reduced diversity, and consequently, increased outage probability. Attempts to maintain the diversity of the system while trying to reduce delays, however, may lead to even higher delays, especially in asymmetric topologies. In this work, we propose a *Low-Complexity* (LoCo) link selection algorithm, herein called $\mathrm{LoCo-Link}$, that aims at reducing packet delays and enhancing the performance of practical asymmetric two-hop networks. The complexity of $\mathrm{LoCo-Link}$ is derived and compared with other state-of-the-art relay selection policies. The performance of the proposed algorithm is evaluated in terms of outage probability, average throughput and average delay, focusing on scenarios with asymmetric links.**

***Index Terms*—Relay selection, buffer-aided relaying, delay, diversity, Markov chains, low-complexity, asymmetric links.**

I. INTRODUCTION

Relaying, an underpinning of multi-hop communications, has attracted a lot of research interest due to the benefits it offers to communications; namely, path-loss is reduced, shadowing is mitigated and link diversity is increased. Building on seminal studies (e.g., [1]) that developed important theoretical frameworks, several relaying techniques have been proposed in the literature. Among those techniques, *Opportunistic Relay Selection* (ORS) [2], [3] and *Buffer-Aided* (BA) relaying [4], [5] have received considerable attention, especially due to their capability of fulfilling the requirements of the *fifth generation* (5G) wireless networks. Regarding ORS, it is known to provide full diversity without requiring multiple orthogonal channels [6], thus promoting spectral and energy efficiency. On the other side, BA relaying increases the *Degrees-of-Freedom* (DoF) of scheduling at the cost of additional delay. The survey in [4] includes numerous protocols that combine ORS and BA relaying (hereinafter called BA ORS protocols), providing performance gains as well as open challenges, which require careful investigation on practical issues, such as, the need for low-complexity implementation and the consideration of practical asymmetric channels.

In recent years, different BA ORS protocols focused on the reduction of the outage probability when a certain amount of delay can be tolerated. The authors of [7] presented a *Hybrid Relay Selection* (HRS) combining non-buffered ORS of [2] and *Max-Max Relay Selection* (MMRS). MMRS selects two different relays in one time-slot, each one having the best *Source-Relay* ($\{S{\rightarrow}R\}$) and *Relay-Destination* ($\{R{\rightarrow}D\}$) link. It was shown that for the delay-unconstrained case, HRS offers equal diversity with non-buffered ORS for lower *Signal-to-Noise Ratio* (SNR) and additional coding gain. Aiming to increase the diversity gain of BA ORS, Krikidis *et al.* [8] proposed the $\mathrm{max-link}$ protocol with adaptive link selection. In $\mathrm{max-link}$, each time-slot is dedicated to either an $\{S{\rightarrow}R\}$ transmission through a non-full relay or to an $\{R{\rightarrow}D\}$ transmission through a non-empty relay. When the number of relays K is large, a diversity gain of $2K$ can be achieved. Also, the case of *Source-Destination* ($\{S{\rightarrow}D\}$) connectivity for $\mathrm{max-link}$ has been studied in [9], providing an efficient framework for switching between direct and relay transmissions. Furthermore, in [10] $\mathrm{max-link}$ was combined with full-duplex relaying in order to improve the throughput without reducing the diversity of the network.

Various works have modified the HRS and $\mathrm{max-link}$ protocols to improve delay performance. The algorithm in [11] was based on the HRS protocol aiming to maintain the queues non-empty and balanced. This is achieved by choosing among the feasible $\{S{\rightarrow}R\}$ ($\{R{\rightarrow}D\}$) links, the ones with the smallest (largest) data queue. Building on the robust nature of $\mathrm{max-link}$, Tian *et al*. proposed a delay-aware version in [12], where selection prioritizes $\{R{\rightarrow}D\}$ transmission even if it doesn't use the strongest link. Results and comparisons with $\mathrm{max-link}$ showed that in the low SNR regime the delay is significantly reduced. More importantly, for high SNR, the delay converges to two time-slots and does not depend on the number of relays or buffer size. Next, the work in [13] uses *Buffer State Information* (BSI) for relay selection. Through centralized coordination, BSI is exchanged and the best relay is selected, requiring that buffers will not be empty or full. Numerical results show that for a buffer size $L \leq 3$ the proposed policy has lower delay than $\mathrm{max-link}$. In addition, in [14] two extensions to $\mathrm{max-link}$ were given that make use of BSI: in the first, a delay-aware version of the $\mathrm{max-link}$ protocol [8] was investigated showing that, while the average delay remains low, the outage probability is increased, as buffers were often empty and relays were excluded

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from selection. In the second algorithm, delay- and diversity-aware $\max-\text{link}$ selection was presented guaranteeing that a plethora of links is available by making sure that buffers are non-empty and so, diversity is not compromised. On the downside, this algorithm tends to distribute packets to multiple relays in order to avoid buffer starvation and as a result, in the case where many relays participate, the delay increases. In [16] the authors present a *Combined Relay Selection* (CRS) policy for small buffer sizes and aim at addressing buffer stability and reducing delay. CRS selects the relay with the shortest buffer length for reception and the relay with the longest buffer length for transmission. Results illustrate that reduced delay can be achieved compared to HRS and $\max-\text{link}$. Other policies deriving from HRS and $\max-\text{link}$ have also been presented. A protocol merging MMRS and $\max-\text{link}$ was presented in [15]. This protocol divides the transmission in odd and even time-slots selecting one relay to receive in an odd time-slot and one relay to transmit in an even time-slot, similarly to MMRS. When selection fails, the protocol searches all the links to avoid outages. Performance evaluation shows that the proposed protocol exhibits lower delay than $\max-\text{link}$ without compromising the diversity order.

In all the aforementioned buffer-aided relaying schemes, only one link is activated at each time slot. The concept of simultaneous use of multiple $\{S\to R\}$ links into the framework of buffer-aided relaying protocols is proposed in [17], where both MMRS and $\max-\text{link}$ are extended to Generalized MMRS (G-MMRS) and Generalized $\max-\text{link}$ (G-ML), respectively, by allowing the source to broadcast packets in the first hop, rather than activating only one relay. Packet delay performance for G-MMRS and G-ML is improved compared to those of MMRS and $\max-\text{link}$, respectively. While the *Channel State Information* (CSI) overhead is reduced for the G-MMRS, this is not the case for the G-ML. Furthermore, in the case of asymmetric channels for which the $\{S\to R\}$ links are better, G-ML overflows. This problem is mitigated by the balanced G-ML, introducing percentages, an approach that is not efficient and does not adapt to the network's conditions.

It is evident that in the majority of works practical considerations, such as low-complexity implementation and asymmetries among the $\{S\to R\}$ and $\{R\to D\}$ links, have not been sufficiently investigated. In this paper, we propose a *Low-Complexity* link ($\text{LoCo}-\text{Link}$) selection algorithm based on two characteristics: *(i)* $\{R\to D\}$ transmissions are prioritized even if there exist $\{S\to R\}$ links with better conditions, thus targeting delay minimization; *(ii)* we allow broadcast transmissions in the $\{S\to R\}$ hop aiming at maintaining the diversity of the network. The combination of $\{R\to D\}$ prioritization and $\{S\to R\}$ broadcast provides a three-fold gain to two-hop communication: 1) delay is reduced since packets already residing in the relays' buffers do not have to wait additional time-slots to be transmitted, 2) diversity is maintained as broadcast offers an efficient way to avoid non-empty buffers, and 3) the complexity of the proposed algorithm is reduced compared to other algorithms, such as [8], [11], [12], [14], since the CSI of the $\{S\to R\}$ links is no longer required.

The remainder of this paper is organized as follows. In Section II, we introduce the system model. In Section III, we present the $\text{LoCo}-\text{Link}$ link selection algorithm and present centralized and distributed implementation as well as a complexity analysis. Next, performance evaluation is provided in Section IV, while conclusions and future directions are given in Section V.

II. SYSTEM MODEL

We investigate a relay-assisted network consisting of one source, S, one destination, D, and a cluster $\mathcal{C}$ of K *Half-Duplex* (HD) *Decode-and-Forward* (DF) relays $R_k \in \mathcal{C}$ ($1 \leq k \leq K$). Due to severe fading, the direct link between the source and the destination does not exist and communication is established via relays. Each relay R_k is equipped with a buffer Q_k of size L denoting the maximum number of data elements that can be stored from the source's transmissions. The system model is depicted in Fig. 1. To transmit data to the relays, the source selects to broadcast its packets and so, depending on channel quality one or more relays might be able to receive them. Fig. 1 illustrates a successful reception with a green tick, while an unsuccessful reception is illustrated by a red x mark.

The quality of the wireless channels is degraded by *Additive White Gaussian Noise* (AWGN) and frequency non-selective Rayleigh block fading according to a complex Gaussian distribution with zero mean and variance σ_{ij}^2 for the $\{i\to j\}$ link. For simplicity, the variance of the AWGN is assumed to be normalized with zero mean and unit variance. The channel gains, $g_{ij} \triangleq |h_{ij}|^2$, are assumed to be exponentially distributed and in general, they are not identically distributed, as is the case of asymmetric topologies. Regarding the CSI availability, it is considered that only *CSI at the receiver* (CSIR) is available, thus allowing low-complexity network coordination.

The source node is assumed to be saturated (it has always data to transmit) and the information rate, when the transmission is successful, is fixed and equal to r_0. Equivalently, a transmission from a transmitter to its corresponding receiver is successful if the SNR of the receiver is greater or equal to a threshold γ_0, called the *capture ratio*. The value of γ_0 depends on the modulation and coding characteristics of the application. So, a transmission from a transmitter i to its corresponding receiver j is successful (error-free) if the SNR of the receiver j, denoted by γ_j, is greater or equal to the *capture ratio* γ_0. The variance of thermal noise at relay R_j is denoted by η_j and it is assumed to be AWGN; in this work, for simplicity of exposition, we assume that η_j is the same on all nodes and equal to η, i.e., $\eta_j = \eta$ for all nodes j. The transmission is divided in time-slots of equal length and at each time-slot, the source S or one of the relays R_k attempts to transmit a packet using a fixed power level P. Therefore, we require that

$$\gamma_j(P) \triangleq \frac{g_{ij}P}{\eta} \geq \gamma_0. \tag{1}$$

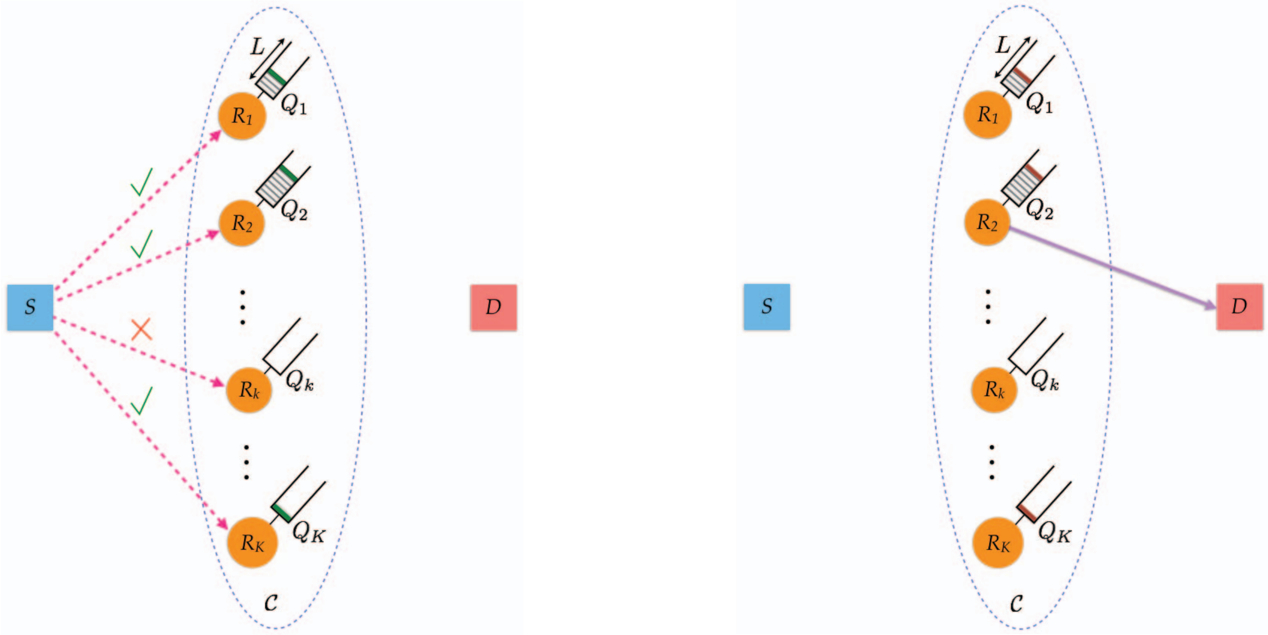

Fig. 1. When no $\{R \to D\}$ link is available, S communicates with D by broadcasting data to a cluster of relays $R_k \in \mathcal{C}$, $k \in \{1, 2, \ldots, K\}$ (left figure). When at least a $\{R \to D\}$ link is neither in outage nor empty, the $\{R \to D\}$ link with the maximum queue length is chosen for transmission (right figure) .

On the contrary, link $\{i \to j\}$ is in outage if $\gamma_j(P) < \gamma_0$, i.e., $\frac{g_{ij}P}{\eta} < \gamma_0$, and the probability of outage is given by

$$p_{\text{out}} = \mathbb{P}\left[g_{ij} < \frac{\gamma_0 \eta}{P}\right].$$

The retransmission process is based on an Acknowledgement/Negative-Acknowledgement (ACK/NACK) mechanism, in which short-length error-free packets are broadcasted by the receivers over a separate narrow-band channel.

As CSIR is assumed, the channel connectivity state is known at each receiver. Let $b_{SR} \triangleq (b_{SR_1}, b_{SR_2}, \ldots, b_{SR_K})$ and $b_{RD} \triangleq (b_{R_1D}, b_{R_2D}, \ldots, b_{R_KD})$ be the binary representation of the feasible links due to the fulfilment of the channel conditions (i.e., if transmission on link R_iD is possible, then $b_{R_iD} = 1$). Similarly, let $q_{SR} \triangleq (q_{SR_1}, q_{SR_2}, \ldots, q_{SR_K})$ and $q_{RD} \triangleq (q_{R_1D}, q_{R_2D}, \ldots, q_{R_KD})$ be the binary representation of the feasible links due to the fulfilment of the queue conditions (i.e., for a $\{S \to R\}$ link the buffer is not full and for a $\{R \to D\}$ link the buffer is not empty). By $\mathcal{F}_{SR}$ and $\mathcal{F}_{RD}$, we denote the sets of $\{S \to R\}$ and $\{R \to D\}$ links that are feasible having cardinalities of F_{SR} and F_{RD} respectively.

III. THE LoCo – Link ALGORITHM

A. Centralized Implementation

The LoCo – Link link selection algorithm aims at improving the performance of buffer-aided relay networks in terms of delay based on a low-complexity implementation. The centralized implementation of the algorithm is as follows:

1) Contrary to max – link, in which the selection of the best link was performed among the $2K$ available ones, LoCo – Link prioritizes the $\{R \to D\}$ link by activating in each time-slot the $\{R \to D\}$ link that is in $\mathcal{F}_{RD}$ and has the maximum queue length. If more than one relays have the same maximum queue length, then a link among them is randomly chosen.
2) If no $\{R \to D\}$ link is available due to severe fading or because all buffers are empty, the source broadcasts its packets to all the relays in the first hop. So, more than one relays forming the set $\mathcal{F}_{SR}$ might be able to receive and store the source's packet. As a result, in the next time-slot, the possibility of activating an $\{R \to D\}$ link is increased compared to the original max – link or the delay-aware algorithm of [12] where only one relay receives the source's packet in the $\{S \to R\}$ link.

The LoCo – Link link selection algorithm for a single time-slot is summarized in Algorithm 1:

Algorithm 1 The LoCo – Link link selection algorithm

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input $\mathcal{F}_{RD}$
if $\mathcal{F}_{RD} = \emptyset$ then
    The source broadcasts its value.
    $Q_j \leftarrow Q_j + 1, \quad \forall j \in \mathcal{F}_{SR}$
else
    $i' = \arg\max_{i \in \mathcal{F}_{RD}} Q_i \qquad (\{R \to D\}$ link)
    if more than one relays have the same maximum queue length then
        $i^*$ is chosen randomly among the set of relays in $i'$.
    else
        $i^* = i'$.
    end if
    $Q_{i^*} \leftarrow Q_{i^*} + 1$
end if
Output Link $\{R_{i^*} \to D\}$ is activated or the set of links in $\mathcal{F}_{SR}$ receive a packet from the source, if $\mathcal{F}_{SR} \neq \emptyset$.
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B. Distributed Implementation

The distributed approach for the link selection process is based on the use of synchronized timers as proposed in [2] and elaborated with queue sizes in [11].

The destination broadcasts a pilot sequence and each relay R_i, for which $q_{R_iD} = 1$, estimates the $\{D \rightarrow R_i\}$ CSI. By assuming that the reciprocity property [18] of antennas holds[1], relays can estimate the $\{R_i \rightarrow D\}$ CSI. From that it can assess whether $b_{R_iD} = 1$. If $b_{R_iD}q_{R_iD} = 1$, then R_i participates in the competition for the slot, but in this case R_i starts a timer from a parameter based on the reciprocal of the buffer size $(Q_i + 1 + \nu_i)^{-1}$. The timer of the relay with the *maximum* buffer size will expire first. In case there exist more than one relays with the same buffer size, ν_i will again guarantee almost surely that the timers will expire on different time instances. The relay with the fastest timer and hence the largest queue size transmits a short duration flag packet, signaling its presence. All relays, while waiting for their timer to expire are in listening mode. As soon as they hear another relay to flag its presence or forwarding information, they back off.

If there is no short duration flag packet it means that $\mathcal{F}_{RD}$ is an empty set. In this case, the source broadcasts a packet and all the relays in $\mathcal{F}_{SR}$ will receive it. All relays that received the packet start a timer from a parameter based on the buffer size $\max\{0, Q_i + \nu_i\}$, where ν_i is uniformly distributed in $(-0.5, 0.5)$. The timer of the relay with the *minimum* buffer size will expire first. In case there exist more than one relays with the same size, ν_i will guarantee almost surely that the timers will expire on different times. The relay with the fastest timer and hence the smallest queue size broadcasts an ACK message, thus confirming reception of the packet by at least one relay. All other relays in $\mathcal{F}_{SR}$, while waiting for their timer to expire, are in listening mode. As soon as they hear another relay to flag its presence they do not need to send any ACK message.

If both sets $\mathcal{F}_{RD}$ and $\mathcal{F}_{SR}$ are empty, then all the links are in outage and no packet is transmitted during that slot.

Remark 1. *Contrary to the algorithms where single link activation is performed in both hops,* $\mathrm{LoCo-Link}$ *demands that the destination will broadcast the successful reception of each packet. This information includes not only one-bit ACK/NACK but the packet ID as well and so, one-bit feedback is not sufficient in* $\mathrm{LoCo-Link}$.

C. Complexity analysis and CSI requirements

For the *distributed* $\mathrm{LoCo-Link}$ protocol (d-$\mathrm{LoCo-Link}$), the destination broadcasts a pilot block to the K relays and each relay carries out the CSI estimation based on the received pilot block. No additional communication is required, as the decisions are taken locally. For the *centralized* $\mathrm{LoCo-Link}$ protocol (c-$\mathrm{LoCo-Link}$), the CSI of the k-th RD channel together with the buffer state are transmitted to the destination by the k-th relay; alternative suggestions (see, e.g., [17]), in which each relay transmits a pilot block to the destination, which then estimates the CSI of the K $\{R \rightarrow D\}$ links, have the problem that the relays have to send the buffer state without knowing the CSI.

The overhead required for the link selection for several protocols, including MMRS and $\max-\mathrm{link}$, was recently investigated and compared in [17] in terms of the number of pilot transmissions, the estimated CSI, and the data transmissions (per link selection). In Table I, we use the same metrics and include the $\max-\mathrm{link}$ and Generalized $\max-\mathrm{link}$ (G-ML) for comparison.

D. Analysis

The theoretical analysis of this work is similar, *mutatis mutandis*, to that of [17]. More specifically, [17] builds on the framework proposed in [8], in which the states of a *Discrete Time Markov Chains* (DTMC) represent all the possible states of the buffers. Unlike [8], however, in which the state of the buffers depends only on the number of packets in each buffer, in this case it also matters whether or not the same packet appears in other buffers as well. This is necessary because a transmission from a relay to the destination might result to the removal of other identical packets from other relays as well. The framework developed by [17] *applies to all algorithms for which the* $\{S \rightarrow R\}$ *link broadcasts its packets*. What changes in our proposed algorithm is the values of the transition probabilities of the DTMC. We omit further analysis since it is redundant.

IV. PERFORMANCE EVALUATION

In this section, the outage and delay performance of $\mathrm{LoCo-Link}$ is evaluated and comparisons with other state-of-the-art schemes are given. More specifically, $\mathrm{LoCo-Link}$ is compared to non-buffered *Best Relay Selection* [2], $\max-\mathrm{link}$ [8], *Delay-Aware* (DA) $\max-\mathrm{link}$ [14], the link selection policy of [12] and the G-ML [17]. In the comparisons, the rate threshold for successful reception is set at $r_0 = 1$ *bit-per-channel use* (BPCU), while $K = 3$ relays are available with each one having a buffer size of $L = 5$ bits. Moreover, two asymmetric topologies are considered where in the first case the average SNR $\bar{\gamma}_{SR}$ of the $\{S \rightarrow R\}$ links is higher than the average SNR of the $\{R \rightarrow D\}$ links $\bar{\gamma}_{RD}$ and their relationship is expressed as $\bar{\gamma}_{RD} = 0.6\bar{\gamma}_{SR}$, while in the second case $\bar{\gamma}_{SR} = 0.6\bar{\gamma}_{RD}$.

Fig. 2 shows the outage probability performance for the case where $\bar{\gamma}_{RD} = 0.6\bar{\gamma}_{SR}$. Due to the asymmetry the probability of buffer overflow is high and one may observe that relay selection policies prioritizing the $\{R \rightarrow D\}$ transmissions can mitigate this phenomenon. Also, G-ML has the worst performance from all the BA policies as broadcasting increases the instances of full buffers. On the contrary, $\mathrm{LoCo-Link}$ alleviates this issue through $\{R \rightarrow D\}$ prioritization and its performance exceeds that of the policy in [12] due to increased diversity in the $\{R \rightarrow D\}$ link selection.

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[1] Reciprocity technically applies only to antennas which operate in a linear medium made of linear materials (e.g., magnetic materials that exhibit hysteresis are not linear). In general, any antenna can be assumed to be a reciprocal device.

	Pilot transmissions			CSI estimations			Data transmissions from relay nodes		
	S	R_j	D	S	R_j	D	$\{S{\rightarrow}R\}$ CSI	$\{R{\rightarrow}D\}$ CSI	buffer states
d-LoCo − Link	0	0	1	0	1	0	0	0	0
c-LoCo − Link	0	0	1	0	1	0	0	K	K
max − link	1	1	0	0	1	K	K	K	K
G-ML	1	1	0	0	1	K	K	K	K

TABLE I
REQUIRED OVERHEADS OF LoCo − Link, max − link AND G-ML PER LINK SELECTION.

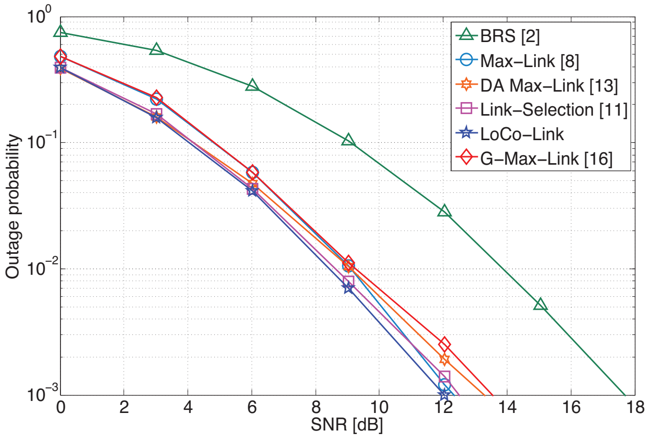

Fig. 2. Outage probability for various policies employing $K = 3$ relays and $L = 5$ buffer size for a topology where $\bar{\gamma}_{RD} = 0.6\bar{\gamma}_{SR}$.

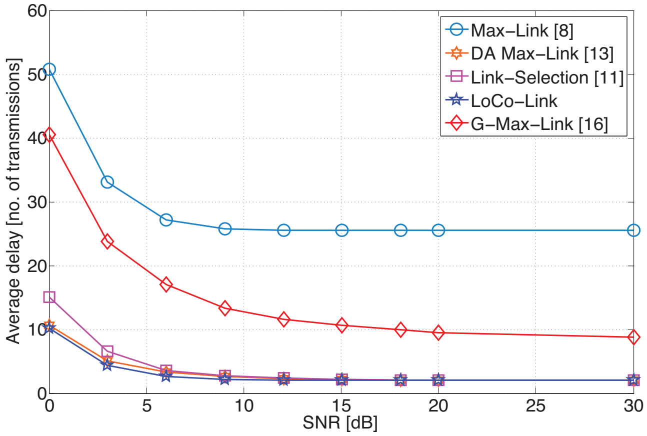

Fig. 4. Average delay for various policies employing $K = 3$ relays and $L = 5$ buffer size for a topology where $\bar{\gamma}_{RD} = 0.6\bar{\gamma}_{SR}$.

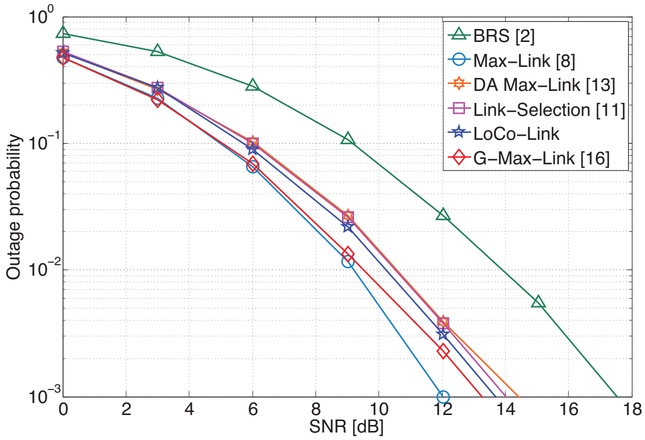

Fig. 3. Outage probability for various policies employing $K = 3$ relays and $L = 5$ buffer size for a topology where $\bar{\gamma}_{SR} = 0.6\bar{\gamma}_{RD}$.

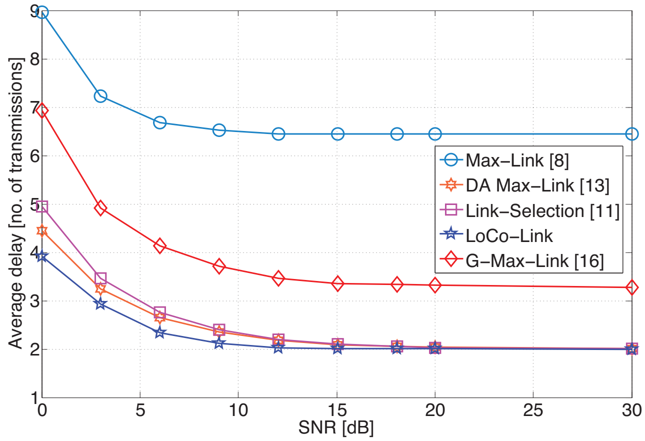

Fig. 5. Average delay for various policies employing $K = 3$ relays and $L = 5$ buffer size for a topology where $\bar{\gamma}_{SR} = 0.6\bar{\gamma}_{RD}$.

Then, Fig. 3 includes outage probability results for a topology where $\bar{\gamma}_{SR} = 0.6\bar{\gamma}_{RD}$. In this topology, the main challenge is to avoid empty buffers as $\{R{\rightarrow}D\}$ transmissions have a higher probability of being selected. So, it is observed that the policies providing $\{R{\rightarrow}D\}$ prioritization perform worse than the policies where the selection of each hop is equiprobable. Nevertheless, LoCo − Link performance is slightly better than DA-max − link and the link selection of [12]. Overall, max − link provides the lower bound on the outage probability as G-ML tends to experience more often buffer overflow instances.

The average delay performance is depicted in Fig. 4 for a topology where $\bar{\gamma}_{RD} = 0.6\bar{\gamma}_{SR}$. In this case, excessive delay might be introduced as the selection of $\{R{\rightarrow}D\}$ transmissions has reduced probability and packets tend to reside for more time-slots in the relays' buffers. However, the policies with $\{R{\rightarrow}D\}$ prioritization overcome this challenge by first searching a transmission from the set of $\{R{\rightarrow}D\}$ links that provide rates above r_0. LoCo − Link has the best delay performance as broadcasting offers increased diversity for the selection of a $\{R{\rightarrow}D\}$ transmission and for high SNR the average delay reaches a value of 2 time-slots, as is the case with [12]. DA-max − link follows closely but it must be noted that it suffers from outages. Also, G-ML has higher delay as packets from the broadcast phase will remain for more time-slots in the buffers.

After, Fig. 5 illustrates average delay curves for a topology where $\bar{\gamma}_{SR} = 0.6\bar{\gamma}_{RD}$. In general, all the schemes exhibit lower delay as the asymmetry allow $\{R{\rightarrow}D\}$ transmissions to be performed at a higher frequency than $\{S{\rightarrow}R\}$ transmis-

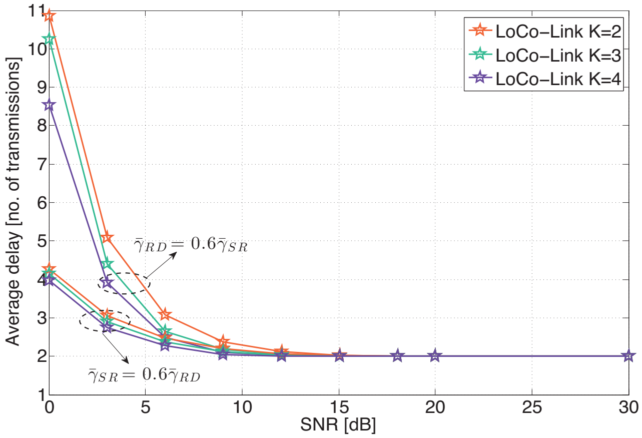

Fig. 6. Average delay for $\mathrm{LoCo-Link}$ employing $K = 2, 3, 4$ relays and $L = 5$ buffer size for both asymmetric topologies.

sions. One may see that $\mathrm{LoCo-Link}$ exhibits minimum delay as broadcasting allows more $\{R \rightarrow D\}$ links to participate in the selection process for this asymmetric case where $\{S \rightarrow R\}$ transmissions are difficult especially in the low and medium SNR regimes, thus resulting in empty buffers. In the high SNR regime, all three policies prioritizing $\{R \rightarrow D\}$ transmissions provide a delay of 2 time-slots. regime.

The final comparison considers the average delay performance for $\mathrm{LoCo-Link}$ for cases when $K = 2, 3, 4$ relays are available with $L = 5$ buffer size for both asymmetric topologies. The results are included in Fig. 6. From the figure it is evident that as the number of relays increases the delay performance in the low and medium SNR regimes improves. It is important to note that in the high SNR regime, increasing the number of relays does not increase the average delay as is the case with $\mathrm{max-link}$ and G-ML that have equiprobable selection of each hop. So, that the addition of more relays allow $\mathrm{LoCo-Link}$ to improve its delay performance for both asymmetric cases.

V. CONCLUSIONS AND FUTURE DIRECTIONS

We proposed $\mathrm{LoCo-Link}$, a low-complexity link selection algorithm that aims at reducing packet delays and enhancing the performance of practical asymmetric two-hop networks, based on two features: firstly, the $\{R \rightarrow D\}$ links are prioritized over the $\{S \rightarrow R\}$ links choosing the feasible link, if there is any, with the largest queue size; secondly, if no transmission can occur from any of the relays, the source broadcasts its packets. The distributed implementation of our algorithm is also discussed and it is based on the use of synchronized timers. The gains of $\mathrm{LoCo-Link}$, as demonstrated in our performance evaluation and complexity analysis, are the following:

1) The average delay is reduced when compared to other current-of-the-art delay-aware algorithms, since packets already residing in the relays' buffers do not have to wait additional time-slot to be transmitted as $\{R \rightarrow D\}$ transmissions are prioritized.
2) The diversity order is not significantly degraded as the broadcasting mechanism offers an efficient way to avoid non-empty buffers and increase the diversity of $\{R \rightarrow D\}$ transmissions.
3) Practicality is promoted as the complexity of the proposed algorithm is reduced compared to other delay-aware algorithms, as the CSI of the $\{S \rightarrow R\}$ links and *CSI at the transmitter* (CSIT) are not required.

Part of ongoing research studies the impact of using ACK/NACK packets that are not error-free in this scheme that is highly reliable on such a mechanism.

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