Relay Selection Methods for Wireless Sensor Networks: Performance-Complexity Tradeoff

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Abstract—This paper analyzes the complexity-performance tradeoff of relay selection (RS) methods for cooperative networks (CoopNet), specially applied to wireless sensor networks (WSNs). The performance-complexity of the classical RS methods such as opportunistic (O-RS), random (R-RS), maximum harmonic mean (MHM-RS), best-worse (BW-RS), max-generalized-mean (MGM-RS) and maximum signal-noise ratio (Max-SNR) have been analyzed by simulation considering one and two hops with increasing number of available relays and set of selected relays as well. The complexity in terms of number of operations and computational time is analyzed in order to confirm the feasibility of the RS methods under the perspective of digital signal processing architecture.

Keywords—CoopNet, relay selection; multiple selection; multiple hop; maximum ratio combining; amplify-and-forward.

I. Introduction

The use of relaying method in wireless communication has been analyzed and widely deployed in the last decade [1]–[3], aiming to take advantage and benefits of the spatial diversity available, for instance in the multiple-input-multiple-output (MIMO) systems, but achieving diversity order greater than one without additional antennas. The multiple copies of the received signal by a set of real or virtual antennas are combined in order to improve the performance and thus increase the system reliability. This strategy mitigates the negative effects of fading by the principle of being statistically less likely all copies arrive simultaneously at the destination profoundly faded.

In cooperative communication, the main retransmission protocols include amplify-and-transmit (AF) and decode-and-transmit (DF), and also as the number of relays available for retransmission and the amount of hops allowed, such as choosing a single relay, or the choice of two or more relays, are used simultaneously or in two or more jumps. The relay selection (RS) method aims to maximise the system performance or reliability, taking into account how many and which relays are simultaneously active in the system.

The RS selection techniques differ in terms of method of search and regarding the selection criterion [4]–[8], since the optimization problem results in a conflicting multi-objective criteria, and therefore these criteria can not always be combined. The RS techniques compared have been chosen to be representative in order to analyze the performance and complexity tradeoff, the main contribution of this work.

Recent works using relay selection in fixed and mobile configuration for multiple relays and multiple hops have been

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reported in [9], [10]; multiple relays allows a better signal-noise ratio (SNR) at the receiver, due to the greater diversity of path and the possibility to reduce the transmitted power of each node by deploying multiple hops configuration between source node (SN) and destination node (DN), since the transmission distance on each hop decreases, as well as the transmitted power involved.

The principal optimization goal in selecting relay methods consist in reducing the network power consumption, mainly in the transmission side, linked to environment concerns, since this process involves non-renewable resources, such as energy and spectrum. The overall power consumption of a WSN is subject to trade-offs and thresholds involving quality-of-service (QoS) issues, such as bit error rate (BER), throughput and maximal tolerable delay, to mention a few. Despite adding complexity, the suitable or even optimal RS method in a cooperative WSN is capable to reduce significantly the overall power consumed by the system, since some percentage of consumed energy is wasted with the circuitry, while the main concern in the optimization process is related just to transmit power only.

II. System Model

In our wireless sensor network (WSN) there is a number a of relays available; these relays make up the set denoted by $\mathcal{A}$, being arranged randomly into a circle which diameter is the distance between the source and destination node (DN). The simplest scenario is realized with single relay in one hop (SR-1h), which is defined by a relay node between the transmitter and receiver [1]–[3].

The model with multiple relay in one hop (MR-1h) can be extended as multi-links aiming to benefit from diversity of positioning or macro-diversity, mitigating large scale or even small channel effects, depending on how the received signals are combined. Multiple relays (MR) are used simultaneously to retransmit information between the SN and DN. Under MR configuration, the BER decreases as the number of selected relays increases, improving the system reliability.

Furthermore, the large scale fading is better addressed deploying multiple relay in two hops (MR-2h) configuration, since multiple serial relays are selected to retransmit the information. Note that in MR-2h configuration, two relays are selected in a sequence of two hops to perform one link between the SN and DN. Thus, more hops are used in order to reach the destination, reducing path loss, despite there is no improvement in the diversity.

The channel is assumed quasi-static with non-line-of-sight (NLOS) propagation, i.e., the amplitudes of the channel coefficients have a Rayleigh distribution, where $|h_{ij}|$ is the fading amplitude value for the $i - j$ link, with i^{th} and j^{th} node could

be a source, relay or destination node. The pathloss between nodes is modeled as in [11]:

$$\varrho_{ij} = \frac{G\lambda^2}{(4\pi)^2 d_{ij}^{\nu}} \cdot \frac{1}{\mathcal{L}N_{\mathrm{f}}} \tag{1}$$

where d_{ij} is the distance in meters between nodes i and j involved in the transmission, ν is the path loss exponent, $G = G_{\mathrm{tx}}G_{\mathrm{rx}}$ is the combined gains for the transmission and reception antennas, $\lambda = \frac{3 \cdot 10^8}{f_c}$ is the carrier wavelength in meters, f_c is the carrier frequency in hertz, $\mathcal{L}$ is link margin and N_{f} is the noise figure of the receiver, which depends on the frequency and the low noise amplifier (LNA) features.

The instantaneous and average SNR at the receiver are:

$$\gamma_{ij} = |h_{ij}|^2 \cdot \frac{\varrho_{ij} P_t}{P_n}, \qquad \text{and} \qquad \overline{\gamma}_{ij} = \frac{\varrho_{ij} P_t}{P_n}, \tag{2}$$

where $\mathbb{E}\left[|h_{ij}|^2\right] = 1$ has been assumed; $P_n = N_0 B$ is the noise power, B is the bandwidth, N_0 is the AWGN power spectral density, and P_t is the transmission power.

A. Single Relay Selection in 1-hop (SR-1h)

The relaying process in WSN system is implemented in half-duplex time slots, since the relay nodes are not able to send and receive information at the same time; besides, it was assumed that each relay node has knowledge of its channel state, while the destination node has perfect knowledge of the channel state of all relays. In the first time slot, the information is broadcast by the source and received by a number of a relays available in the system; the received signal at the ith relay is expressed as:

$$r_i = \sqrt{P\varrho_{si}}h_{si}b + \eta_i \tag{3}$$

where P is the transmitted power from the source node, $h_{si} = |h_{si}|e^{j\theta_i}$ is the complex channel coefficient between the source and i^{th} relay node (S-R$_i$) link; b is the information assumed $M-$QAM modulation, and $\eta_i \sim \mathcal{N}(0; \sigma_n^2)$ represents the Gaussian noise, with zero mean and variance σ_n^2.

In the simplest model of the CoopNet, it is chosen just one relay for retransmission through a specific selection method. The phase of the received signal is corrected as

$$\tilde{r}_i = r_i \cdot e^{-j\theta_i} = r_i \cdot \frac{h_{si}^*}{|h_{si}|} \tag{4}$$

while the received signal is amplified according to the factor

$$\alpha_i = \kappa_i \cdot \frac{\sqrt{P_i}}{\sqrt{P\varrho_{si}|h_{si}|^2 + P_n}} \tag{5}$$

where the binary-valued κ_i indicates either the ith relay is selected to cooperate ($\kappa_i = 1$) with fixed transmitted power P_i or not ($\kappa_i = 0$); hence, the transmitted power of ith relay is $\kappa_i^2 \cdot P_i$. The retransmitted signal by the ith relay arrives at the destination in the second time slot as:

$$r_d = \alpha_i \cdot \sqrt{\varrho_{id}}h_{id}\tilde{r}_i + \eta_d \tag{6}$$

where the Gaussian noise also presents $\eta_d \sim \mathcal{N}(0; \sigma_n^2)$. Correcting the phase of the signal at the destination:

$$y = r_d \cdot e^{-j\phi_i} = r_d \cdot \frac{h_{id}^*}{|h_{id}|} \tag{7}$$

Finally, the information of interest is estimated applying the maximum likelihood (ML) principle:

$$\hat{b} = \arg \quad \min_{\mathrm{b} \in \mathcal{S}} \left\| y - \kappa_i \cdot |h_{id}|\sqrt{P_i\varrho_{id}} \, \mathrm{b} \right\| \tag{8}$$

where $|| \cdot ||$ is the Euclidian distance and b is a symbol-candidate belongs to the constellation set $\mathcal{S}$ from the adopted $M-$QAM modulation.

B. Multiple Relay Selection in 1-hop (MR-1h)

We can explore the relay diversity choosing more relays for retransmission in the second and subsequent time-slots; in this case, $\mathcal{C} \subset \mathcal{A}$ is the subset of selected relays with dimension $c \leq a$; hence, we used c time-slots to receive the relaying signals, one for each relay. In the first time slot of information received by the relays is the same denoted by eq. (3). The chosen relays correct the phase effect as in eq. (4), amplify the information by a factor α_i given by (5), and retransmit the signal at the $t = 1, 2 \ldots c$ time-slot, in which is selected proportionally to $t \propto \gamma_{si}^{-1}$. Hence, the received signal at the destination node in each time-slot is a copy of the original signal with noise enhanced, given by:

$$r_{id} = \alpha_i \cdot \sqrt{\varrho_{id}}h_{id}r_i + \eta_d, \quad i \in \mathcal{C} \tag{9}$$

where set $\mathcal{C}$ is composed by c elements (number of relays). Those c receiver signal copies after phase correction produce:

$$y_i = r_{id} \cdot e^{-j\phi_i} = r_{id} \cdot \frac{h_{id}^*}{|h_{id}|}, \quad i \in \mathcal{C}, \tag{10}$$

which are combined via maximum ratio combining (MRC):

$$y = \sum_{i=1, i \in \mathcal{C}}^{c} y_i \cdot \iota_i, \qquad \text{with} \quad \iota_i = \frac{|g_i|}{\sqrt{\sum_{i=1, i \in \mathcal{C}}^{c} |g_i|^2}}, \tag{11}$$

with $g_i = \sqrt{P_i\varrho_{id}}h_{id}$, and normalised weight factor $\sum_{i=1}^{c} \iota_i = 1$. Finally, the ML detection is given by:

$$\hat{b} = \arg \quad \min_{\mathrm{b} \in \mathcal{S}} \left\| y - \sum_{i=1, i \in \mathcal{C}}^{c} \kappa_i \cdot |h_{id}|\sqrt{P_i\varrho_{id}} \, \iota_i \, \mathrm{b} \right\| \tag{12}$$

C. Multiple Relay Selection in 2 hops (MR-2h)

Two relays k_i and $k_j \in \mathcal{A}$ are chosen through the RS criteria, in order to obtain the best "combined" paths from the source node to i^{th} relay, from the ith relay to j^{th} relay, and finally from the jth relay to destination node. This topology reduces the BER since the signal arrives at the receiver with the higher bit energy than 1-hop topologies (SR-1h and MR-1h). Besides, the MR-2h scheme does not provide additional diversity gain. In the first time-slot, the information is sent by the source to the ith relay as in (3). After correcting the phase effect as in (4), the signal is amplified by a factor α_i given by (5) at i^{th} relay and retransmitting (with power $\kappa_i^2 \cdot P_i$) to the jth relay in the second time-slot:

$$r_j = \alpha_i \cdot \sqrt{\varrho_{ij}}h_{ij}\tilde{r}_i + \eta_j, \tag{13}$$

Again, at the jth relay the effect of phase is corrected as $\tilde{r}_j = r_j \cdot e^{-j\phi_j}$ and in the third time-slot, the signal is retransmitting

to the DN after amplification by a factor α_j:

$$r_d = \alpha_j \cdot \sqrt{\varrho_{jd}} h_{jd} \tilde{r}_j + \eta_d, \qquad (14)$$

Hence, the signal at the DN with the phase of $j - d$ link corrected is

$$y = r_d \cdot e^{-j\varpi_j} = r_d \cdot \frac{h_{jd}^*}{|h_{kd}|} \qquad (15)$$

Finally, the estimated information is obtained applying the ML metric after this two-hops:

$$\hat{b} = \arg \quad \min_{\mathtt{b} \in \mathcal{S}} \left\| y - \kappa_i \kappa_j \cdot |h_{jd}| \sqrt{P_j \varrho_{jd}} \; \mathtt{b} \right\| \qquad (16)$$

III. RELAY SELECTION CRITERIA

When the goal of the relay selection is to reduce transmission errors and thus increase the quality of data received at the destination, RS techniques select relays with better channel gains or are capable to overcome the unfair condition of propagation paths, achieving a SNR that ensures the maximum BER tolerated by the system. Moreover, considering various relaying topologies and scenarios it has been demonstrated [10] that the suitable RS techniques, such as harmonic mean and max-min, have diversity order of a, where a is the number of relays available for selection in the set $\mathcal{A}$, and the simplest technique has the diversity order equal to 1, as for instance the random relay selection method is equivalent to the direct transmission without relaying node.

A. Random Relay Selection (R-RS)

The algorithm randomly selects the relay node for retransmission of the signal. Received a message NACK request from the DN, at each time-slot interval t, the tth relay acts as a auxiliary node. The advantage of R-RS is that the power consumption for retransmission is equally distributed over the relays, and thus the lifetime of all batteries of RNs also decays equally and slower, avoiding the fall of the entire network by just a device without energy [12]. However, the R-RS algorithm selects a relay without considering any additional information; the relay chosen could be far from the destination or, more probable, with an unsuitable channel condition, or both. Moreover, since the power consumption is inversely proportional to the Tx-Rx distance, $\propto d^{-\nu}$, and in general the environment is more critical that line-of-sight (LOS), the pathloss exponent increases as $\nu = 3, 4$ or even more, increasing drastically the power consumption of mobile RNs.

B. Opportunistic Relay Selection (O-RS)

The DN sends a NACK request to all RNs; each relay estimates its channel gain through the NACK message and relays the required source signal in a time $t \propto \frac{1}{\varrho_{id}|h_{id}|}$ [3]. This technique takes advantage of the best channel condition to relay the signal. However if frequently the same relay is selected for its privileged position regarding the destination, it tends to achieve the dead battery condition before the other RNs, compromising the network lifetime.

C. Maximum Harmonic Mean Relay Selection (MHM-RS)

In this method the SR and RD channels condition at each relay is evaluated in order to decide which relay presents the

highest harmonic mean [5]; this criterion is given by:

$$k = \arg \quad \max_{i \in \mathcal{A}} H(P\varrho_{si}|h_{si}|^2, P_i \varrho_{id}|h_{id}|^2), \qquad (17)$$

with harmonic mean (HM) function $H(u,v) = \frac{2uv}{u+v}$. Analogously, for 2 hops, the HM function is given by $\tilde{H}(u,v,z) = \frac{3uvz}{uv+uz+vz}$, while the two selected relays (one for each hop) is obtained as:

$$[k_i, k_j] = \arg \quad \max_{i,j \in \mathcal{A}} H(P\varrho_{si}|h_{si}|^2, P_i \varrho_{ij}|h_{ij}|^2, P_j \varrho_{jd}|h_{jd}|^2), \qquad (18)$$

where $i \neq j$ and P and P_i, P_j are the transmitted power at source and relays i and j, respectively. This criterion requires that the paths have good channel conditions and are not disparate, avoiding that a stretch in a good way to compensate a very bad stretch and take the algorithm to the wrong choice.

D. Best-Worse Selection Criterion (BW-RS)

The best-worse selection technique, as known as max-min criterion, also looking for the best path according to the channel conditions; it seeks the path that combines the best gains of the channel in the branches SR and RD, excluding relays that have unfair channel conditions in one or both branches. For a 1-hop topology, the BW rule will select the kth relay among all possible relays in the set $\mathcal{A}$ as [6]:

$$k = \arg \quad \max_{i \in \mathcal{A}} \min(P\varrho_{si}|h_{si}|^2, P_i \varrho_{id}|h_{id}|^2), \qquad (19)$$

while for 2-hops results:

$$[k_i, k_j] = \arg \quad \max_{i \in \mathcal{A}} \min(P\varrho_{si}|h_{si}|^2, P_i \varrho_{ij}|h_{ij}|^2, P_j \varrho_{jd}|h_{jd}|^2) \qquad (20)$$

E. Max-Generalized-Mean Selection Criterion (MGM-RS)

MGM-RS is a more flexible criterion of selection [4] which combines the choice of the BW-RS with the MHM-RS, being adapted via parameters p, w_1 and w_2, where $p \in \mathbb{R}$, where the larger in module, the greater the difference between the final average; $w_1 \in [0, 1]$ is the weight given to the SR_i link, and $w_2 = 1 - w_1$ is the weight given to the $R_i D$ link. Hence, the MGM selection is formulated as:

$$k = \arg \quad \max_{i \in \mathcal{A}} \mu_{p,w\_}(P\varrho_{si}|h_{si}|^2, P_i \varrho_{id}|h_{id}|^2),$$
$$\text{where:} \quad \mu_{p,w\_}(u,v) = [(w_1 u)^p + (w_2 v)^p]^{\frac{1}{p}} \qquad (21)$$

When $w_1 = w_2 = 0.5$ and $p = -1$ the MGM lies on harmonic mean; besides, when $p = -\infty$, the $\mu_{p,w\_}$ is equivalent to the Best-worse rule. In a same way, for 2-hops results:

$$[k_i, k_j] = \arg \quad \max_{i,j \in \mathcal{A}} \mu_{p,w\_}$$
$$\mu_{p,w\_}(u,v,z) = [(w_1 u)^p + (w_2 v)^p + (w_3 z)^p]^{\frac{1}{p}}, \qquad (22)$$

with $w_1 = w_2 = w_3 = \frac{1}{3}$.

F. Max-SNR

Max-SNR metric chooses the relay with higher end-to-end SNR; for 1-hop and 2-hop topologies the selection problem can be formulates as:

$$\text{(1-hop)} \; k = \arg \quad \max_{i \in \mathcal{A}} \frac{P\varrho_{si}|h_{si}|^2 \cdot P_i \varrho_{id}|h_{id}|^2}{P_n + P\varrho_{si}|h_{si}|^2 + P\varrho_{id}|h_{id}|^2} \qquad (23)$$

$$\text{(2-hop)} \quad [k_i, k_j] = \arg \quad \max_{i,j \in \mathcal{A}} \Gamma_{ij} \qquad (24)$$

$$\Gamma_{ij} = \frac{PP_iP_j\varrho_{si}\varrho_{ij}\varrho_{jd}|h_{si}|^2|h_{ij}|^2|h_{jd}|^2}{P_n(P_j\varrho_{jd}|h_{jd}|^2(P_n + P_i\varrho_{ij}|h_{ij}|^2 + P\varrho_{si}|h_{si}|^2) + P_i\varrho_{ij}|h_{ij}|^2(P_n + P\varrho_{si}|h_{si}|^2) + P_nP\varrho_{si}|h_{si}|^2 + P_n^2)} \tag{25}$$

G. Diversity Order

The order of diversity is an important metric aiming to compare the performance of different RS methods; graphically this can be computed as [13]:

$$\mathcal{D} = -\lim_{\text{SNR}\to\infty} \frac{10 \cdot \Delta \log_{10}\left[\text{BER(SNR)}\right]}{\Delta \text{SNR}_{\text{dB}}} \tag{26}$$

Diversity order achieved by various RS methods is explored in the next section. The diversity order of the R-RS is equal to 1, and for other RS criteria results $1 < \mathcal{D} \le a$. The full diversity for a specific RS method is achieved when $\mathcal{D} = a$.

IV. NUMERICAL RESULTS

The CoopNet scenarios considered vary in the number of hops, with 1 hop (1h) and 2 hops (2h), the available relays a, and the number of selected relays c. The adopted simulation parameters values are listed in Table I. The power allocated to the source node is fixed and equal to the minimum power need to compensate the large-scale fading, i.e. the pathloss term ϱ_{sd} was calculated as in (1) with distance d_{sd}. Accordingly, the power allocated for all relays also is equal and corresponding to the minimum power to compensate the pathloss term, considering half distance between source and destination, i.e., the pathloss term ϱ_* was obtained for the average relay placement, with link distance equal to $d_{sd}/2$; as a result, the fixed and equal power allocated to all RNs is much lower that to the transmit power allocated to the SN.

TABLE I
COOPNET SIMULATION RELAYING SYSTEM PARAMETERS

Parameter	Value
Cooperative Protocol	AF
size of available relay set	$a = 2$ or 4 or 6
size of selected relay $\mathcal{C}$	$c = 1$ or 2
f_c	900 MHz
ν	3
$G = G_{\text{tx}}G_{\text{rx}}$	12 dB
$\mathcal{L}$	8 dB
N_{f}	5 dB
S-D distance	50m
S-R and R-D distance	uniformly distributed, $d_{si}, d_{id} \in [2; 48]$m
N_0	-174 [dBm/Hz]
Bandwidth	$B = 30$ kHz
Average SNR	$\overline{\gamma} \in [0; 30]$ dB
Source Tx Power (fixed)	$P = \overline{\gamma}P_n\varrho_{sd}^{-1}$ [W]
Relay Tx Power (fixed)	$P_i = \overline{\gamma}P_n\varrho_*^{-1}$ [W]
Modulation	BPSK

BER performance versus SNR for different CoopNet topologies and RS methods are depicted in Fig. 1 and 2. In Fig.1, one RS has been considered for retransmission ($c = 1$) when two, four and six relays were available As expected, the diversity order in R-RS method is poor $\mathcal{D} = 1, \forall a$ and lower than the opportunistic methods MHM-RS, MGM-RS, SNR-RS and BW-RS, in which diversity grows with the number of available relays, where full diversity $\mathcal{D} = a$ is achieved. Besides, one can see that the theoretical diversity order can be graphically

confirmed in Fig. 1 with SNR in the range $15 \sim 18$ dB for all available relays, $a \in \{2, 4, 6\}$.
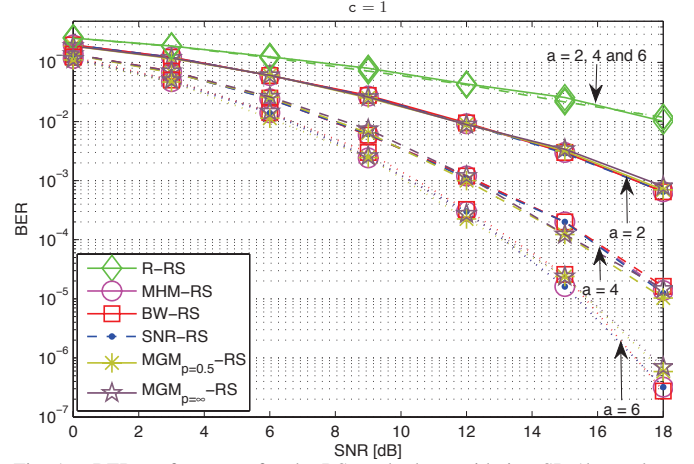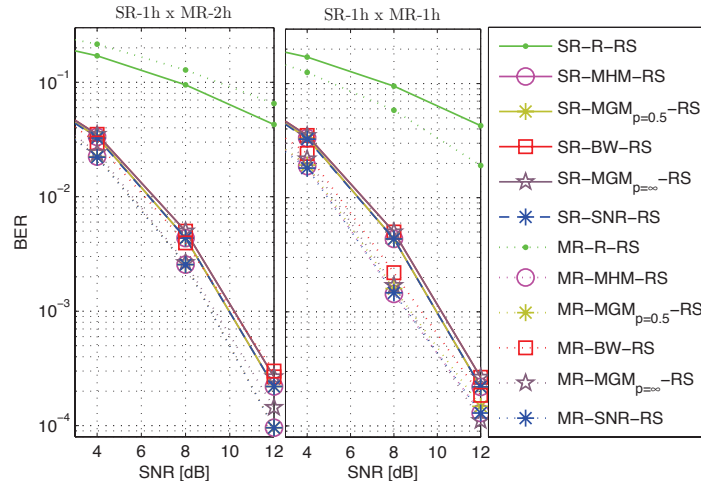

Fig. 1. BER performance for the RS methods considering SR-1h topology

Fig. 2 shows the BER when signal from various relays are combined (MR) based on MRC rule. The R-RS method has a significant improvement in its performance due to the optimal combination of signals on the DN. For the other RS methods since the two best selected signals are the strongest and have no larger energy disparity, the MRC rule turns out to the EGC, which conceptually provides an improvement compared to the signal without further combination, however this improvement is small.

Fig. 2. Performance for the RS methods with MR-1h and MR-2h topology, $a = 6$ and $c = 2$: a) two relays in serial; b) two relays in parallel.

Moreover, BER performance for the topologies with 2 hops MR-2h, just one link topology, where the transmission is helped by two relays, corroborate the no further diversity gain; however, the MR-2h topology enable the signal selection through short distances, which alleviate the pathloss effects, and as a consequence enabling better detection, better BER performance (performance gap regarding SR-1h topologies) for the same transmission power levels available at source (P) and relays (P_i, P_j) nodes.

A. Complexity Analysis

RS methods have been compared regarding the required number of operations, as well their behaviour when the number of hops and relay nodes increase. All RS algorithms were decomposed into basic operation, comparison and exponential operations, since the difference of complexity between them is simply the amount of such computational operations. The complexity expressions were determined for different number of hops, available relays a and selected relays c. Table II expresses those number of operations need with respect to the dominant terms. In addition, Fig. 3 depicts the total number of operations (basic + comparison + exponential operations) for 1, 2 and 3 hops and $a \in [2; 200]$ relays.

TABLE II
NUMBER OF OPERATIONS

Method	Complexity
R-RS	$\mathcal{O}(ch)$ basic
MHM-RS	$\mathcal{O}(\mathrm{h}!a^{\mathrm{h}})$ basic + $\mathcal{O}(\mathrm{h}a^{\mathrm{h}})$ compare
BW-RS	$\mathcal{O}(\mathrm{h}a^{\mathrm{h}})$ basic + $\mathcal{O}(\mathrm{h}a^{\mathrm{h}})$ compare
SNR-RS	$\mathcal{O}(\mathrm{h}a^{\mathrm{h}})$ basic + $\mathcal{O}(\mathrm{h}a^{\mathrm{h}})$ compare
MGM-RS	$\mathcal{O}(a^{\mathrm{h}})$ basic + $\mathcal{O}(a^{\mathrm{h}})$ compare + $\mathcal{O}(a^{\mathrm{h}})$ expon.

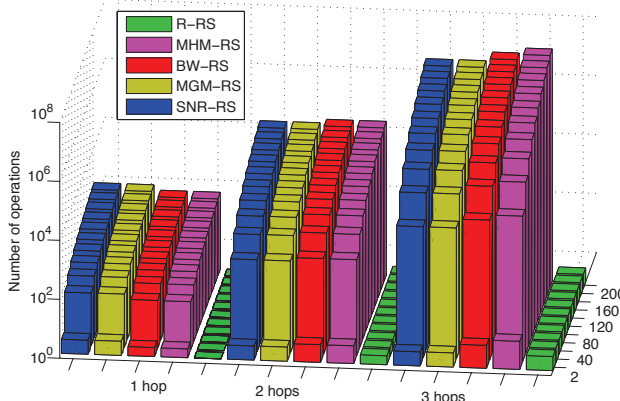a: # relays available in the system; c # relays selected; h # hops

Fig. 3.   Number of basic, comparisons and exponentials operations.
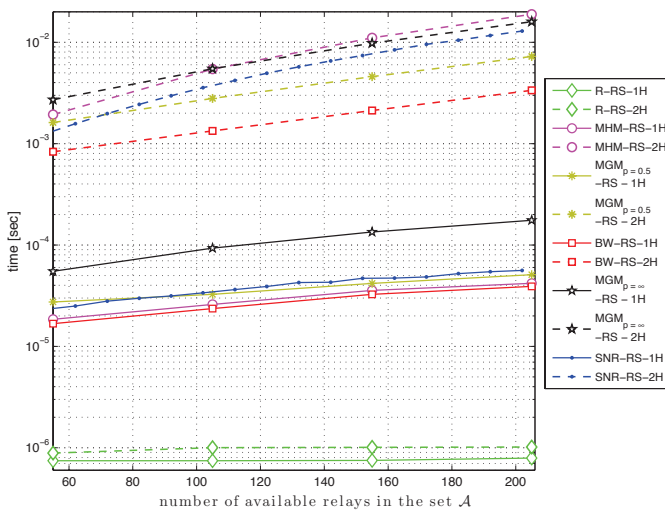

Fig. 4.   Run time in asymptotic conditions *versus* number of available relays.

In general, the RS methods which verify the channel quality of all relays have complexity increasing with the number of available relays and the number of hops, except the R-RS method, which depends on the number of selected relays and

hops, and it results in a marginal increasing with the number of hops (first order dependence). On the other hand, the complexity differences of opportunistic MHM-RS and BW-RS become significant just when $\mathrm{h} > 3$ hops; this difference is due to the factorial term in $\mathcal{O}(\mathrm{h}!a^{\mathrm{h}})$ associated to the basic operations in the MHM-RS. The MGM-RS method is more costly for one hop, but from two or more hops implementation requires less operations than the MHM-RS and BW-RS methods, making it more feasible when h increases, since it is a flexible method equivalent to the BW-RS, even taking more time to perform exponential operations $\mathcal{O}(a^{\mathrm{h}})$ that depends on its parameter p, as depicted in Fig. 4.

V. CONCLUSIONS

The performance-complexity trade-off of the principal RS methods and their behavior on the increasing number of available relays and selected sets, as well as number of hops have been analyzed in this paper. Monte-Carlo simulation results have demonstrated that there are two groups of RS methods in terms of diversity order: MGM-RS, MHM-RS, BW-TS and SNR-RS achieve full diversity order of the size of available relay set a, while random selection method (R-RS) presents no diversity order gain. Furthermore, the relevant number of operation among those RS methods is quite similar, in which the MGM-RS method presents a marginal complexity gain when the number of hops increase.

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