Performance Evaluation of Power-Aware Relay Selection Scheme in Cooperative Wireless Ad-Hoc Networks

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Abstract— Cooperative communication greatly reduced fading but isn't sufficient enough to increase the longevity of network lifetime due to inefficient usage of the node's power. This project was proposed to utilize a Power-aware relay selection scheme (PARS) in selecting the relaying node that best extends the network lifetime and thereby conserves the node's backup power.

The power-aware relay selection scheme (PARS) entails the measurement of the channel state information (CSI) of wireless ad-hoc networks and the estimation of the Optimal power allocation (OPA) for each relay. Then two Power-aware relay selection scheme (PARS) criteria were developed to select the best relay by utilizing both the CSI and the OPA information. The simulations were done under Amplify-and-forward (AF) and Decode-and-forward (DF) modes of cooperation and the Power-aware relay selection scheme (PARS) criteria were examined with the existing OR strategy that only considered the CSI measurements. The result shows that by considering the node's power in relay selection, the network lifetime is greatly improved compared to the OR strategy, and the network lifetime for PARS in DF mode is more energy-efficient than in AF mode due to stricter consideration of channel conditions.

Index Terms— Amplify-and-forward (AF), Channel state information (CSI), Decode-and-forward (DF), Multiple inputs multiple outputs (MIMO), Optimal power allocation (OPA), Opportunistic relaying (OR), Power-aware relay selection scheme (PARS).

1 Introduction

WIRELESS communications are set up without cables covering everywhere. They are becoming increasingly popular and are widely deployed in academic institutions and residences in transmitting and receiving information over some meters to hundreds of kilometers through well-defined channels [1]. Despite this growth, wireless communication is still immature. Issues such as user behavior, security, channel fading, path loss, minimal bandwidth, and limited battery power are a few of the challenging factors and constraints to wireless communications. As a result, various techniques such as equalization, diversity, and channel coding have been employed but inefficiently to solve all the problems i.e. lowering the power consumed by wireless devices [2].

Cooperative communication was proposed by [3] to overcome the impact of the channel on the message received at the destination. It is based on simple terminal relay channels which involve the communication between the transmitter and receiver assisted by a relay node to enrich the rate of transmission of the transmitter and the achievable rate of the receiver. Cooperative communication does not only improve the rendition of wireless relay networks but also provides benefits of diversity without requiring multiple antennas per terminal, by allowing surrounding terminals to collaborate, acting as a virtual MIMO (Multiple inputs multiple outputs) antenna array. The importance of this form of cooperation is that each node requires only one antenna, and by the cooperation of other nodes in the network, a virtual antenna array is fashioned.

The two major classifications of relay selection mechanism based on the way by which the rules are employed are: (Centralized and distributed mechanisms). In centralized mechanism, a central base station harvest and make use of the received information to choose one or more relays for the source to the destination link. Mobile networks where users communicate with a centralized base station creates the attainability of a centralized mechanism.

By comparison, ad-hoc networks don't have a centralized dominance but rather require distributed protocol. Here, each node individually determines whether to cooperate and who to cooperate in agreement to the information transferred between nodes. The distributed algorithm is usually inefficient, but it limits communication overhead and calculation complexity. The cooperative transmission protocol schemes used by relays can either be Amplify-and-forward (AF) or Decode-and-forward (DF) depending on how the received signals are processed at the relay before being sent to the destination [4]. Generally, both amplify-and-forward and decode-and-forward algorithms entail two forwarding phases in a cooperative communication where in the first phase, a transmitter sends the information to its receiver and all potential relays while during the second phase, the relays transmit the information to the destination. The relay can be chosen before a source-destination transmission, which is called proactive relay assignment or selected after a source-destination transmission, named as reactive relay assignment. Cooperative relay selection protocols in wireless ad-hoc networks are categorized into Single relay selection schemes (SRSs) and Multiple relay selection schemes (MRS) [5].

Several relay selection protocols under these two categories have been examined to choose the best relay or node for transmission but in Wireless ad-hoc networks, the nodes are built with limited battery power, therefore, power conservation is necessary for designing the relay selection protocol that helps to increase network lifetime of a node. As a result of this examination and utilization of the Power-aware relay selection scheme (PARS) and other energy-conservation selection schemes, determination of the most energy-efficient route for

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communication nodes selection in cooperative wireless ad-hoc networks will be feasible [6].

2 Wireless ad-hoc networks

Wireless ad-hoc networks are decentralized infrastructure networks equipped with multi-hop relaying and signal processing capabilities and find application in distributed sensor and mobile systems such as smart meters, environmental or industrial monitoring, disaster relief operations, etc. [7]. The network is referred to as ad-hoc due to its independence of preexisting infrastructures, such as routers or access points. Alternatively, each node engages in routing by transferring data for other nodes so the designation of which node will transfer data is done impulsively based on network connectivity and the routing algorithm employed. Usually, nodes using wireless networks are energy-limited, therefore it will be a disadvantage for a node to always receive relay requests [8]. Also, if all nodes choose not to consume energy in relaying, then the network transfer rate will go down impressively. Both these extreme scenarios are injurious to the interest of the user [9]

In these networks, each node is an end system and a router at the same time. The limited energy is then not only used to deliver one's packets to the destinations but also to serve other nodes as message relayer. For example, the availability of malicious nodes in the network can harm the final delivery ratio attained by well-behaving nodes compared to that attained by the nodes that didn't cooperate. On the opposite, too much cooperation can cause much energy consumption because nodes in the middle of the network topology are more used than others in relay operations and this causes a greater drain of their energy compared to that spent by border nodes [10].
A significant feature of ad-hoc networks is that frequent transition in connectivity and link characteristics are inserted due to node mobility and power control practices. Ad-hoc networks can be erected around any wireless technology, including infrared and RF (Radiofrequency) [11].

3 Basics of opportunistic relaying (OR)

Opportunistic relaying (OR) is to select the "best" relay from all the possible and available relays. This was an idea applied to ad-hoc networks with cooperative diversity, in which each user first chooses the best relay from a set of *N* available relays and then makes use of this best relay for cooperation [12]. The relay selection in ad-hoc networks is based on local measurements of the instantaneous channel conditions and requires no knowledge of the global topology information. Considering the scenario in which all nodes can hear each other. The opportunistic relaying OR approach transmission period is divided into three stages.

In the first stage, the potential relays overhear the transmission of a packet from the source and a packet from the destination which allows for the estimation of the channel state information (CSI) between the source (s) and each relay (i), i.e. h_{si}, as well as the CSI between relay (i) and the destination (d), i.e. h_{id}.

In the second stage, on receiving the packets, each potential relay i starts a timer with the parameter h_i, which is a function of the instantaneous channel measurements h_{si} and h_{id}. The best relay has the smallest initial timer value, e.g. node 3 in Figure 1, which expires first and transmits a flag packet to signal its presence. Hearing the flag packet, all the potential relays stop their timers and back off. In [13], two policies were proposed to define the parameter h_i, having the same purpose of selecting the best end-to-end path between the source and the destination.

policy I: it selects the "bottleneck" of the two paths of source-relay and relay-destination. i.e., chooses the relay within the network coverage that requires the minimum channel gain to re-transmit the received packet to the destination.

$$h_i = \min\{H_{si}, H_{id}\} \quad (1)$$

policy II: it uses the harmonic mean of the two links.

$$h_i = 2/(1/H_{si} + 1/H_{id}) \quad (2)$$

where, $H_{si}=|h_{is}|^2$ represent the channel gains of the sender (s) to the relay (i) link

$H_{id} = |h_{id}|^2$ represent the channel gain of relay i to the destination d

h_i is the parameter that represents the channel of the selected best relay

The initial timer value V_i for the relay, i is set to be inversely proportional to h_i, namely,

$$V_i = \lambda / h_i \quad (3)$$

where λ is a constant and has the units of time.

In the third stage, the source and the selected relay cooperatively transmit data to the destination. Such repetition-based cooperation schemes as amplify-and-forward (AF) and decode-and-forward (DF) can be directly applied [14]. The relay in AF mode simply amplifies its received signal and forwards them to the destination, while the relay in DF mode first decodes its received signal and then re-encodes and forwards them to the destination. Spatial diversity is created by combining the two copies of the same data from independent fading channels at the destination [12]. Figure 1 offers graphical instructions for the simple case of the number of nodes N = 6 [15].

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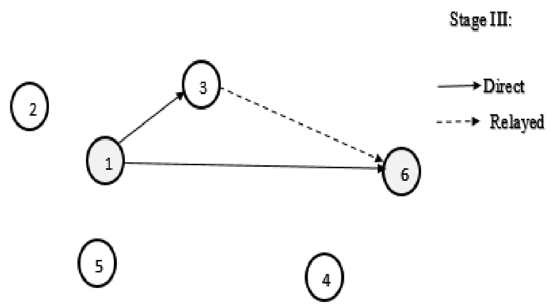

Fig. 1: Illustration of cooperative transmission from node 1 to node 6 using opportunistic relaying: *Stage III*–Cooperative transmission of source and the selected relay.

4 Related works

The capacity of mobile ad-hoc networks can be considered in different aspects. Some researchers have paid attention to the instantaneous throughput of the network, i.e., how many bits can be transmitted in the network in a certain duration, or how many traffic links can be established simultaneously [16]. However, from another point of view, nodes in an ad-hoc network are constrained by battery energy. Thus the network capacity was defined as the ratio of the number of transmitted bits to the energy consumed by this transportation. Here the transportation means end-to-end communication through a multi-hop path. In a multi-hop ad-hoc network, we need to consider the energy consumed by all the intermediate routing nodes.

In [17] the authors gave the network capacity definition as bit per joule. In some specific type of ad-hoc networks such as sensor networks, the traffic is not very heavy, thus the network survivability transmits as much as data before the batteries run out is more important than the network instantaneous throughput. One of the major energy-saving methods is power control. Power control at the Media access control (MAC) layer has been heavily discussed and it is found that power control can save energy significantly. Also, by using different power levels, there is a transition in network connectivity. Research reveals that a lesser transmitting power will lead to more simultaneous transmissions because the co-channel interference is minimized [16]. However, the reduction of transmit power increases hop count from the source to the destination.

Power control is one of the major methods applied in ad-hoc networks to save battery energy. Increasing the transmit power will reduce the average hop count of routes. Since the number of hops is reduced, the end-to-end packet drop rate is potentially reduced. However, increasing the transmit power will increase the energy consumption of a single radio link. Meanwhile, the co-channel interference will also increase thus increase the packet error rate (PER) at a single link. In [18], the authors inspected the Transfer control protocol (TCP) performance of ad-hoc networks by setting different transmit power levels. They established a model to analyze the change of packet error rate (PER) when transmitting power differs. They concluded that a medium power level provides efficient energy rendition in respect of packet retransmission.

However, they inspected the energy performance only over a fixed source destination couple by varying the distance between them. Another argument is the network instantaneous throughput. It is stated that lower transmit power can let more simultaneous transmissions thus the network throughput is increased. However, from a network point of view, for an end-to-end connection, lower transmit power will involve more nodes as routers. Consequently, these nodes have less resource for their traffic thereby reducing the network throughput.

After the analysis of energy performance of ad-hoc networks that utilized transmit power, control was carried out, it was asserted that minimizing the transmit power will not result in the best energy conservation, because the energy taken by receiving a packet is fixed at a single hop. When the transmit power decreases, the energy consumption taken by the receivers becomes more and more significant in implementing an efficient relaying protocol [19].

5 Power-aware relay selection strategies

This research is based on the performance evaluation of the Power-aware relay selection (PARS) scheme in cooperative wireless ad-hoc networks to extend the network lifetime by reducing the overall transmit power to a minimum. The idea of PARS strategies is divided into three parts. Firstly, based on opportunistic relaying (OR), the channel state information (CSI) of the source-relay and relay-destination link utilizing node distance is measured to estimate the channel gain for each relay.

Secondly, each potential relay performs the estimation of optimal power allocation (OPA) which is purposed to reduce the total transmit power by the addition of the minimum transmitting power needed for the source and the minimum transmitting power needed for the relay under both the amplify-and-forward and decode-and-forward relaying scheme. Then, two relay selection criteria are proposed to select the relay that best extends the network lifetime. This differs from the opportunistic relaying (OR) selection policies in [12] which is only based on the instantaneous channel measurements.

Here, PARS criteria take into consideration both the OPA results and the residual power levels of the source and each potential relay. The simulations were done in a Python environment.

5.1 System Model

PARS protocol is considered based on the Opportunistic relaying (OR) model to describe Power-aware relay selection (PARS) [15] strategies in a sequence of three stages. In the first stage, based on Opportunistic relaying (OR) for transmission when determining the relay to cooperate with, each potential relay measures the channel state information (CSI) of the source-relay and relay-destination link using node distance to estimate the channel gain for each relay (h_{si}) which includes the source transmit rate (R_s) and source residual power level (P_{rs}), so that all potential relays can share this information.

The destination also gets the channel state information (CSI) of the source-destination link (h_{sd}) and broadcasts this measurement to other nodes. Using the knowledge of (h_{sd}) will

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help each potential relay i to do the Optimal power allocation (OPA) when combined with their channel gain measurements (h_{si} and h_{id}).

At the beginning of stage II, each potential relay performs the Optimal power allocation, OPA to minimize the total transmit power at the given transmit rate level (R_s).

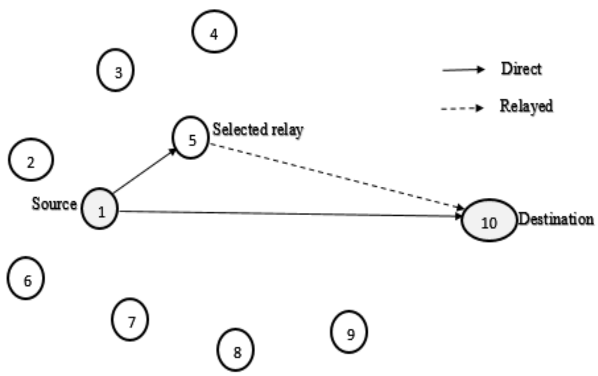

Fig. 2: System model based on the selection and transmission of relay

By applying Shannon's theory, the power consumption of direct transmission from the source to the destination P_s^D is expressed as equation 3.2

$$P_s^D = \frac{\sigma^2\Gamma}{|h_{sd}|^2}(2^{R_s} - 1) \tag{4}$$

For the cooperative transmission, each potential relay i will perform the Optimal power allocation (OPA) by utilizing the channel measurements it has gathered, i.e. h_{sd}, h_{si} and h_{id} whether under Amplify-and-forward (AF) or Decode-and-forward (DF) cooperation scheme.

5.2 Estimating the Optimal power allocation (OPA) under the Amplfy-and-forward (AF) scheme

The mathematical model of the Optimal power allocation (OPA) at the potential relay i under the AF scheme is the addition of the minimum overall transmit power of both the transmitting power consumption of direct transmission for source-relay link $P_s^{C_{AF}}$ and the transmitting power consumption of relayed transmission for the relay-destination link $P_i^{C_{AF}}$ is written as:

$$\min_{P_s^{C_{AF}}, P_i^{C_{AF}}} P_s^{C_{AF}} + P_i^{C_{AF}} \tag{5}$$

subject to:

$$R_s \geq \frac{1}{2}\log_2\left(1 + \frac{P_s^{C_{AF}}|h_{sd}|^2}{\sigma^2\Gamma} + \frac{P_s^{C_{AF}}P_i^{C_{AF}}|h_{si}|^2|h_{id}|^2}{\sigma^2\Gamma\left(\sigma^2 + P_s^{C_{AF}}|h_{si}|^2 + P_i^{C_{AF}}|h_{id}|^2\right)}\right) \tag{6}$$

$$P_s^{C_{AF}} \leq P_t \tag{7}$$

$$P_i^{C_{AF}} \leq P_t \tag{8}$$

$$P_s^{C_{AF}},\ P_i^{C_{AF}} \geq 0 \tag{9}$$

where, $P_s^{C_{AF}}$ is the transmitting power consumption of the direct transmission from source to the relay under AF scheme

$P_i^{C_{AF}}$ is the transmitting power consumption of relayed transmission from the relay i to the destination d under the AF scheme

P_t is the total transmitting power consumption

The optimal solution to the problem resulted to:

$$P_s^{C_{AF}} = \begin{cases} \hat{P}\frac{|h_{sd}|^2}{|h_{si}|^2}\left(\frac{|h_{sd}|^2}{|h_{si}|^2} + \frac{1}{1+\eta}\right)^{-1}, & h_{sd} < h_{id} \\ P_s^D, & h_{sd} \geq h_{id} \end{cases} \tag{10}$$

$$P_i^{C_{AF}} = \begin{cases} \hat{P}\frac{|h_{sd}|^2}{|h_{si}|^2}\left(\frac{|h_{sd}|^2}{|h_{si}|^2} + \frac{1}{1+\eta}\right)^{-1\frac{1}{\eta}}, & h_{sd} < h_{id} \\ 0, & h_{sd} \geq h_{id} \end{cases} \tag{11}$$

where, h_{sd} is the channel again for source-relay link
h_{id} is the channel gain for relay-destination link
h_{si} is the channel gain for source-relay link

And the other two temporary variables are

$$\hat{P} = \frac{\sigma^2\Gamma}{|h_{sd}|^2}(2^{2R_s} - 1) \tag{12}$$

$$\eta = \frac{|h_{sd}|^2 + \sqrt{|h_{sd}|^2|h_{id}|^2 + |h_{id}|^2|h_{si}|^2 - |h_{si}|^2|h_{sd}|^2}}{|h_{id}|^2 - |h_{sd}|^2} \tag{13}$$

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5.3 Estimating the Optimal power allocation (OPA) under the Decode-and-forward (DF) scheme

The mathematical model of the Optimal power allocation (OPA) at the potential relay i under the DF scheme to find the addition of the minimum overall transmit power of both the transmitting power consumption of direct transmission for source-relay link $P_s^{C_{AF}}$ and the transmitting power consumption of relayed transmission for the relay-destination link $P_i^{C_{AF}}$ is written as:

$$\min_{P_s^{C_{DF}},P_i^{C_{DF}}} P_s^{C_{DF}} + P_i^{C_{DF}} \tag{14}$$

subject to:

$$R_s \geq \min\left\{\frac{1}{2}log_2\left(1+\frac{P_s^{C_{DF}}|h_{si}|^2}{\sigma^2\Gamma}\right),\frac{1}{2}log_2\left(1+\frac{P_s^{C_{DF}}|h_{sd}|^2}{\sigma^2\Gamma} + \frac{P_i^{C_{DF}}|h_{id}|^2}{\sigma^2\Gamma}\right)\right\} \tag{15}$$

$$P_s^{C_{DF}} \geq P_t \tag{16}$$

$$P_i^{C_{DF}} \geq P_t \tag{17}$$

$$P_s^{C_{DF}}, P_i^{C_{DF}} \geq 0 \tag{18}$$

where, $P_s^{C_{DF}}$ is the transmitting power consumption of the direct transmission from the source to the relay under the DF scheme

$P_i^{C_{DF}}$ is the transmitting power consumption of relayed transmission from the relay i to the destination d under the DF scheme

The optimal solution to the problem resulted to:
For $h_{sd} < h_{id}, h_{sd} < h_{si}$

$$P_s^{C_{DF}} = \frac{\sigma^2\Gamma}{|h_{sd}|^2}(2^{2R_s}-1)\frac{|h_{sd}|^2}{|h_{si}|^2} \tag{19}$$

$$P_i^{C_{DF}} = P_s^{C_{DF}}\frac{|h_{si}|^2-|h_{sd}|^2}{|h_{id}|^2} \tag{20}$$

For $h_{sd} < h_{id}, h_{sd} < h_{si}$

$$P_s^{C_{DF}} = P_s^D \tag{21}$$

$$P_i^{C_{DF}} = 0 \tag{22}$$

$$P_s^{C_{DF}} = \begin{cases}\hat{P}\frac{|h_{sd}|^2}{|h_{si}|^2}, & h_{sd} < h_{id}, h_{sd} < h_{si}\\ P_s^D, & otherwise\end{cases} \tag{23}$$

$$P_i^{C_{DF}} = \begin{cases}P_s^{C_{DF}}.\frac{|h_{si}|^2-|h_{sd}|^2}{|h_{id}|^2}, & h_{sd} < h_{id}, h_{sd} < h_{si}\\ 0, & otherwise\end{cases} \tag{24}$$

The OPA results show again that cooperation has preconditions, and the channel conditions required for cooperation under the DF scheme are much stricter compared to that of the AF scheme.

6 Simulation Results

The modeling of the Power-aware relay selection scheme (PARS) system model was based on the simulation parameters shown in Table 3.3. The performance evaluations of the PARS strategies were carried out via computer simulations using Python software under both AF and DF cooperation schemes over the Rayleigh fading channel which ensured cooperation in transmission (Direct and relayed transmission). This strategy involved the estimation of Optimal power allocation (OPA) and utilization of the Power-aware relay selection criteria (PARS I and PARS II) to select the best relay that best extends the network lifetime. The network lifetime ($T_{network}$) was modeled as $T_{network} = P_{rs} - P_t^c T$ where P_{rs} is the node initial total power, P_t^c is the total transmitting power consumption needed for the transmission and T is the time required for the data to be transmitted.

The scenario considered was where 10 nodes were randomly distributed in an area of radius normalized to 1. Tests were carried out for each strategy and in every test, each node was given the same initial power level which varied from P=50W to 2P where increased by 0.1P each time.
From the simulations, after comparing the Power-aware relay selection strategies (PARS) with the Opportunistic relay (OR) section policy, it's revealed that the PARS strategies greatly extend the network lifetime by largely reducing the transmitting power to minimal both in the Amplify-and-forward and decode-and-forward modes but in the decode-and-forward mode, the network lifetime tends to be more extended and the node's power tends to be more conserved than in decode-and-forward mode.

Also, the result shows that by increasing the number of nodes for cooperation, the network lifetime decreases due to the increase in power consumption during the Channel state information (CSI) estimation while the Power-aware relay selection (PARS) strategy is more efficient in maintaining the network lifetime than Opportunistic relay (OR) strategy and for the proposed relay selection criteria, PARS criteria II is more efficient than OR criteria.

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Table 1: Performance evaluation of network lifetime against initial total power of node utilizing PARS criterion I, PARS criterion II and OR criterion under AF cooperation scheme

Node initial Power (dB)	Network lifetime (s)		
	PARS Criterion I	PARS Criterion II	OR Criterion
P	2830.278	3006.810	2520
1.1P	2900.970	3076.038	2580
1.2P	2978.670	3153.636	2640
1.3P	3017.904	3206.058	2700
1.4P	3075.360	3254.724	2760
1.5P	3155.076	3350.118	2820
1.6P	3209.214	3380.904	2880
1.7P	3254.850	3505.272	2940
1.8P	3358.944	3518.052	3000
1.9P	3371.616	3572.310	3060
2P	3458.136	3623.112	3120

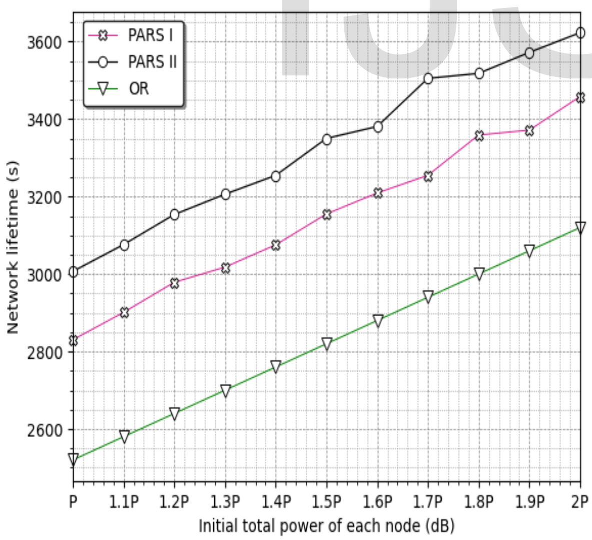

Fig. 3: Network lifetime against initial total power of each node under Amplify-and-forward cooperation

6.1 Performance evaluation of Amplify-and-forward cooperation using PARS criterion I, PARS criterion II and OR criterion against initial total power of nodes

Figure 3 shows the result obtained for the network lifetime against the initial total power of nodes for AF cooperation using PARS relay selection criteria and the OR selection criterion. From the graph, it was observed that by increasing the initial total power of nodes in the network, the network lifetime also increases.

The result also shows that in AF mode, PARS criterion II is more energy-efficient than PARS criterion I at an average of 17.6% which is due to the consideration of the residual power level of each node while the PARS strategies maximized the network lifetime at an average of 49.5% over the OR strategy. At target initial node total power of 1.4P, the value obtained from network lifetime for PARS criterion I, PARS criterion II and OR criteria were 3075.360s, 3254.724s, and 2760s respectively.

Table 2: Performance evaluation of network lifetime against initial total power of node utilizing PARS criterion I, PARS criterion II and OR criterion under DF cooperation scheme

Node initial Power (dB)	Network lifetime (s)		
	PARS Criterion I	PARS Criterion II	OR Criterion
P	3020.970	3199.200	2580
1.1P	3074.250	3254.724	2640
1.2P	3146.712	3324.000	2700
1.3P	3200.400	3373.470	2760
1.4P	3278.658	3441.336	2820
1.5P	3280.488	3454.068	2880
1.6P	3328.056	3466.584	2940
1.7P	3338.340	3494.718	3000
1.8P	3386.358	3554.676	3060
1.9P	3398.550	3621.204	3120
2P	3433.884	3633.858	3180

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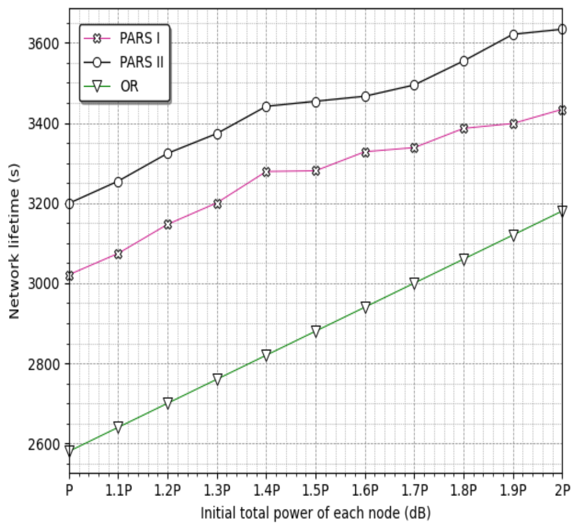

Fig. 4: Network lifetime against initial total power of each node under Decode-and-forward cooperation

6.2 Performance evaluation of Decode-and-forward cooperation using PARS criterion I, PARS criterion II and OR criterion for the initial total power of nodes

Figure 4 shows the result obtained for the network lifetime against the initial total power of nodes for DF cooperation using PARS relay selection criteria and the OR selection criterion. From the graph, it was observed that by increasing the initial total power of nodes in the network, the network lifetime also increases.

The result also shows that under DF mode, PARS criterion II is more energy-efficient than PARS criterion I at an average of 16.2% which is due to the consideration of the residual power level of each node while the PARS strategies maintained the network lifetime at an average of 62.1% over the OR strategy which indicates that the network lifetime is maximized to a larger extent in Decode-and-forward (DF) than in Amplify-and-forward cooperation scheme due to the stricter channel conditions required for cooperation in DF scheme than AF scheme. At target initial node total power of 1.4*P*, the value obtained from network lifetime for PARS criterion I, PARS criterion II and OR criteria were 3278.658s, 3441.336s, and 2820s respectively.

Table 3: Performance evaluation of network lifetime against the number of nodes utilizing PARS criterion I, PARS criterion II and OR criterion under AF cooperation scheme

Number of Nodes	Network lifetime (s)		
	PARS Criterion I	PARS Criterion II	OR Criterion
3	2738.670	2913.636	2400
4	2537.904	2726.058	2220
5	2355.360	2534.724	2040
6	2195.076	2390.118	1860
7	2009.214	2180.904	1680
8	1814.850	2005.272	1500
9	1678.944	1838.052	1320
10	1451.616	1652.310	1140

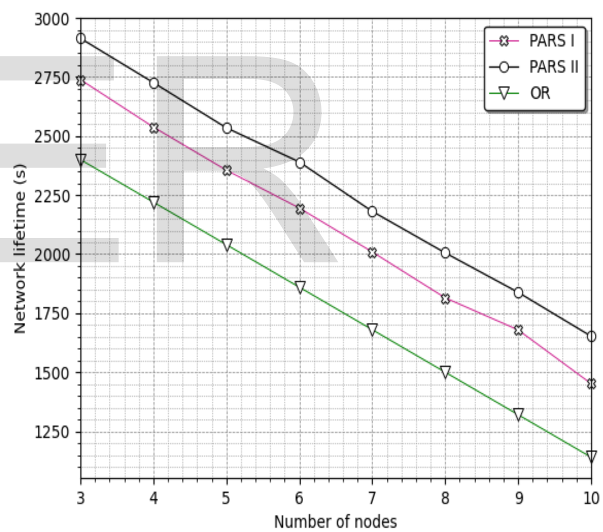

Fig. 5: Network lifetime against the number of nodes under Amplify-and-forward cooperation

6.3 Performance evaluation of Amplify-and-forward cooperation using PARS criterion I, PARS criterion II and OR criterion against the number of nodes

Figure 5 shows the result obtained for the network lifetime against the number of nodes for AF cooperation using PARS relay selection criteria and the OR selection criterion. From the graph, it was observed that by increasing the number of nodes in the network, the network lifetime also decreases which was due to an

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increase in power consumption during the Channel state information (CSI) estimation.

The result also shows that in AF mode, PARS criterion II is more energy-efficient than PARS criterion I at an average of 17.9% which is due to the consideration of the residual power level of each node while the PARS strategies maximized the network lifetime at an average of 49.4% over the OR strategy. At the target number of nodes of 6, the value obtained from network lifetime for PARS criterion I, PARS criterion II and OR criteria were 2195.076s, 2390.118s, and 1860s respectively.

Table 4: Performance evaluation of network lifetime against the number of nodes utilizing PARS criterion I, PARS criterion II and OR criterion under DF cooperation scheme

Number of Nodes	Network lifetime (s)		
	PARS Criterion I	PARS Criterion II	OR Criterion
3	2906.712	3084.000	2460
4	2720.400	2893.470	2280
5	2558.658	2721.336	2100
6	2318.658	2494.068	1920
7	2128.056	2266.584	1740
8	1888.056	2054.718	1560
9	1706.358	1874.676	1380
10	1478.550	1701.204	1200

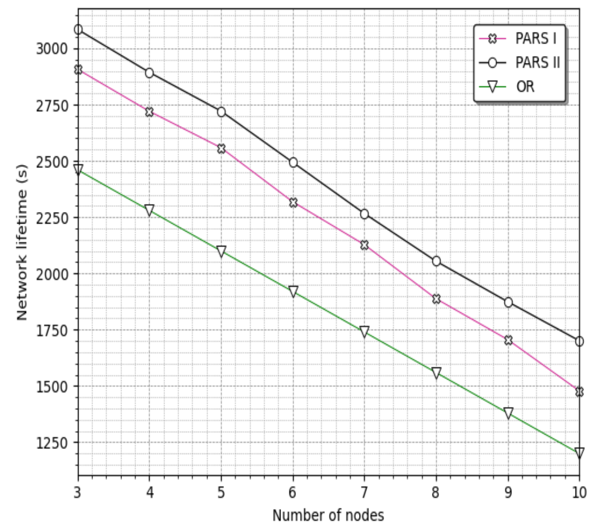

Fig. 6: Network lifetime against the number of nodes under Decode-and-forward cooperation

6.4 Performance evaluation of Decode-and-forward cooperation using PARS criterion I, PARS criterion II and OR criterion against the number of nodes

Figure 6 shows the result obtained for the network lifetime against the number of nodes for DF cooperation using PARS relay selection criteria and the OR selection criterion. From the graph, it was observed that by increasing the number of nodes in the network, the network lifetime also decreases which was due to an increase in power consumption during the Channel state information (CSI) estimation.

The result also shows that under DF mode, PARS criterion II is more energy-efficient than PARS criterion I at an average of 16.3% which is due to the consideration of the residual power level of each node while the PARS strategies maintained the network lifetime at an average of 62.1% over the OR strategy which indicates that the network lifetime is maximized to a larger extent in Decode-and-forward (DF) than in Amplify-and-forward cooperation scheme due to the stricter channel conditions required for cooperation in DF scheme than AF scheme. At the target number of nodes of 6, the value obtained from network lifetime for PARS criterion I, PARS criterion II and OR criteria were 2318.658s, 2494.068s, and 1920s respectively.

7 Conclusion

The evaluation of the Power-aware relay selection scheme (PARS) under both amplify-and-forward and decode-and-forward relaying strategies over the Rayleigh fading channel has

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been performed. The system model was developed and simulated using the Python programming language. It was clearly shown that the developed Power-aware relay selection scheme (PARS) maximizes the network lifetime of nodes more than the existing Opportunistic relaying (OR) model and that PARS criteria are more power-efficient in DF mode than in AF cooperation mode. With the developed strategy, PARS criterion I greatly extend the network lifetime than PARS criterion II.

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