Lifetime Enhancement of Cooperative Wireless Ad-Hoc Networks using Optimal Power Allocation and Relay Selection Scheme

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ORIGINAL RESEARCH

Abstract- Cooperative Communication (CC) has greatly reduced the effect of multipath fading, thereby improving the quality of transmitted signals in wireless ad-hoc networks. However, existing works on CC suffers from degradation of network lifetime due to inaccurate selection of the optimal relay terminal. This results in frequent battery recharging due to high energy consumed and battery depletion. Hence, in this paper, lifetime enhancement of cooperative wireless ad-hoc networks is carried out using allocated optimal power and relay selection scheme to ensure an optimal selection of the best relay by balancing and conserving the energy consumption of the nodes. Transmit power optimization problems were formulated for Amplify-and-Forward (AF) and Decode-and-Forward (DF) relaying strategies to obtain the optimal power allocations required to transmit the information. The proposed scheme named Energy-Aware Relay Selection (EARS) was simulated in MATLAB software environment and average network lifetime performance evaluation was performed. The result obtained shows that the proposed EARS improves the network performance by 10.06% and 3.56% for AF and DF relaying strategies, respectively over the existing Power-Aware Relay Selection (PARS) schemes.

Keywords- Amplify-and-Forward, Decode-and-Forward, Optimal power allocation, Optimization, Relay selection,

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1 INTRODUCTION

Wireless communication is an expedient means of information dissemination for seamless and adequate connectivity of wireless devices. However, this is influenced by environmental hindrances which includes; multipath fading, pathloss and scattering (Goldsmith, 2005; Akande et al., 2022). One of the techniques used to address these problems is cooperative communication. This involves utilization of virtual antennas via potential relay terminals to enhance signal strength between source and destination. This helps to broaden the coverage area, offer good quality-of-services (QoS) and reduce energy consumption of wireless network users (Laneman, et al., 2004; Ojo et al., 2022).

Besides these advantages, the inadequate selection of optimal relay terminal results in high energy consumption which rapidly reduces the network lifetime (Chen, et al., 2006). The deployment of relaying strategy in cooperative communication is majorly classified into two namely; amplify-and-forward (AF) and decode-and-forward (DF) relaying (Laneman et al., 2004, Sendonaris, et al., 2003). In the AF relaying, the selected relay terminal amplifies noise alongside successfully received signal. The merit of this protocol is that in the worst and unfavourable wireless environment, the relay can still forward overheard signal to intended destination even with less complex circuitry due to it analogue nature. Unlike the DF protocol which is based on digital transmission, the selected relay must correctly decode the signal received from the source. Such signal is characterized with minimal noise effect and better quality in favourable channel condition. However, in an unfavourable channel condition, the DF strategy may prematurely result in several retransmission attempts and results in low network lifetime.

In the aforementioned protocols discussed, resource allocation is imperative in ensuring the efficient management of scarce and underutilized network resources (Goldsmith, 2005). Some of the major and essential resources includes spectrum and transmit power management. Since cooperation provide spectrum efficiency enhancement at the expense of high energy consumption in transmitting this information. This further resulting in early expiration of the network lifespan since network devices are operated on limited powered batteries which requires frequent charging and replacement (Engmann, et al., 2018). To address this problem, power control allocation becomes necessary for network performance improvement.

Power control is also categorized as fixed and adaptive transmit power (Xiaoying, et al., 2017). Fixed transmit power is used in network where little or no emphasis is required on the time varying manner of the wireless network environment. This however, leads to wider interference, low spectrum reuse and reduced network lifetime due to transmitting at the maximum power (Rappaport, 2002). Nevertheless, adaptive transmit power provides an adapt amount of power required in transmitting a signal utilizing the instantaneous network conditions. This allows the conservation of energy and limits the interference coverage of the network.

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Section B- ELECTRICAL/ COMPUTER ENGINEERING & RELATED SCIENCES
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Selecting the best optimal relay with adaptive transmitting power now becomes a difficult task to be surmounted (Akande, et al., 2018). Several relay selection strategies were proposed over the years and can be employed either in central or distributed model. In infrastructural based networks such as in cellular with central control systems, the relays are selected in a central manner. Conversely, distributed relay selection is mostly applicable to wireless ad-hoc networks due to its constrained energy capacity and selection complexities (Abdulhadi, et al., 2012).

The distributed type relay selection is further subdivided into single user and multiple users which rely on the utilization of relays employed. For a single user, only the best relay is elected while more than one best relay is chosen for the multiple users. The multiple users improve the signal quality through diversity and multiplexing gain but consumes more energy and hardware complexities (Nosratinia, et al., 2004). Besides, the single user relies solely on selecting the optimal relay using the instantaneous network requirement to minimize the energy expended and provide better signal quality. Therefore, the major contributions this paper present are:

a. to elongate the network lifetime of wireless ad-hoc network by formulating optimization problem with the objective of minimizing the transmission power of the energy constrained devices in AF and DF proactive relaying.
b. to propose an efficient energy-aware relay selection scheme that will assist in retransmitting the successfully received information to the destination and then compare with existing relay selection schemes.

The remaining parts of the paper are organized as follows. Section 2 present the related works, while section 3 gives the details of the method. Section 4 present the simulation and numerical results obtained and conclusion in section 5.

2 RELATED WORKS

Cooperative wireless ad-hoc networks have witnessed enormous consideration over the last decade due to its importance in enhancing the capacity of wireless network by ensuring high data transmission, reduced energy consumption, prolonged network lifetime and better QoS delivery. However, all these characteristics features cannot be attained simultaneously in a network of this nature. This is because of the availability of an optimal relay selection scheme which may provide certain network performance based on instantaneous network capability and requirement (Akande, et al., 2018). Some of the works of researchers that have paid attention to this area of study are discussed as follows.

Akande, & Salleh, (2019) proposed a network lifetime extension-aware cooperative medium access control protocol to improve the performance of mobile ad-hoc networks. Network lifetime optimization problem was formulated for DF with the goal of achieving a multi-objective target orientation in both symmetric and asymmetric power policies. The result showed that the lifetime and other important network performances can be accomplished through optimal selection of an efficient relay terminal.

In the work of Bletsas, et al. (2006), a network path selection for simple cooperative diversity was analysed. The work focused on the selection of the best relay terminal in an opportunistic and distributed manner. This was accomplished by considering the local instantaneous channel condition measurement for different fading environments using ready-to-send (RTS) and clear-to-send signalling handshake of the IEEE802.11b PHY. However, the topological information of the relay terminal was not considered. The results obtained revealed that the scheme achieves diversity-multiplexing trade-off similar to an existing complex scheme.

In addition, Chen, et al. (2006) proposed a power-aware cooperative relay selection (PARS) scheme in wireless ad-hoc devices to elongate the network lifetime. Optimal power allocation and three criteria was developed to select the best relay terminal. The results showed that the PARS scheme performed better in network lifetime and energy saving. Nonetheless, the relay selection scheme suffers selection inefficiency due to its long-time consuming selection process. Alsharoa, et al., (2018) investigated the challenges of multiple relays to support energy efficient uplink transmissions of Internet of Things (IoT) devices. In the work, an optimal relay location aware protocol was proposed to reduce the network's total energy consumption using mixed integer linear programming problem. The result revealed that the work outperformed other protocols.

Saghezchi, et al., (2016) proposed an energy-aware relay selection scheme in cooperative wireless network. In the work, an assignment game optimization problem was formulated for heterogeneous network to reduce the energy consumed by energy constrained wireless devices. The formulated assignment game problem was divided into two stages namely, a linear programming problem was formulated for the optimal relay selection stage while the second stage, the fair allotment of the payoff of the players (relay) was considered to ensure discouragement from quitting the coalition. The simulation result showed that the scheme performed better in energy saving with prolonged battery life. Based on the related works discussed, the energy consumption of wireless ad-hoc network devices still requires great attention as wireless energy constrained devices with energy harvesting are expensive to deploy and it is difficult to upgrade existing wireless devices to possess harvesting modules.

3 METHODOLOGY

3.1 SYSTEM MODEL

The cooperative wireless ad-hoc network depicted in Fig. 1, is a proactive relaying scheme which comprises of a source terminal (S), N number of relay terminals distributed uniformly and the destination terminal (D). The successful transmission of the information using this scheme can be divided into two time slots. In the first slot, the source broadcast its information to the relay terminal and the destination while in the second slot, the selected

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relay retransmits it received information to the destination. All the terminals deployed are half duplexed and capable of acting as a relay terminal.

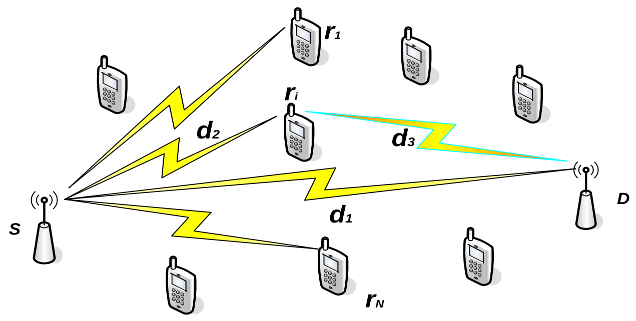

Fig. 1: System model

In addition, the relays were equipped with omnidirectional antennas and can perform AF or DF relaying operations. The source terminal usually has information to send to the destination terminal and relay terminal is ready to assist provided it is able to correctly decode this information and acts as a relaying terminal to the ongoing transmission. To choose the optimal relay terminal, each relay estimates its channel gains between itself and the source denoted as $\left(g = \left|h_{S,r_i}\right|^2\right)$ and the destination denoted as $\left(h = \left|h_{r_i,D}\right|^2\right)$ while that of the source to destination is denoted as $\left(k = \left|h_{S,D}\right|^2\right)$ which are further used in measurement of their Signal-to-Noise Ratio (SNR) and energy required in transmitting the decoded information. Also, the distance between the source-destination, source-relay and relay-destination locations denoted as d_1, d_2 and d_3, respectively, are required in this paper, therefore, applying the RTS-CTS handshake signalling becomes a necessity for instantaneous Channel State Information (CSI). The candidate relay that meets the relay selection criteria then compete to be chosen the optimal relay terminal. At the destination terminal, the information from the selected optimal relay terminal and the direct link are combined using the Maximum Ratio Combiner (MRC). Similarly, all the channels are modelled as independently and identically distributed with block Rayleigh fading distribution and experiences path loss effect. More importantly, a relay terminal selected as the optimal relay must possess the best optimal transmit power allocation.

3.2 COOPERATIVE WIRELESS AD-HOC NETWORK WITH AF RELAYING

The cooperative wireless ad-hoc network been considered in this paper comprises of both the direct link between the source-destination, the source-relay and the relay-destination. The achievable transmission rate for the direct link with the source-relay link R_{AF} after MRC operation given as;

$$R_{AF} = \log_2\left(1 + \gamma_{S,D} + \gamma_{e2e}\right) \quad (1)$$

where $\gamma_{S,D}$ is the destination's received SNR via the direct link and γ_{e2e} is the end-to-end received SNR via the source-relay and the relay-destination links which are expressed, respectively in (2) and (3) as;

$$\gamma_{S,D} = \frac{Pkd_1^{-\alpha}}{\sigma^2} \quad (2)$$

$$\gamma_{e2e} = \frac{\gamma_{S,r_i}\gamma_{r_i,D}}{\gamma_{S,r_i}+\gamma_{r_i,D}+1} \quad (3)$$

where P is the source transmit power, α is the path loss exponent, σ^2 is circularly complex additive while Gaussian random variable, γ_{S,r_i} is the relay terminal's received SNR and $\gamma_{r_i,D}$ is the destination terminal's received SNR which are expressed in (4) and (5), respectively as;

$$\gamma_{S,r_i} = \frac{P_S g d_2^{-\alpha}}{\sigma^2} \quad (4)$$

$$\gamma_{r_i,D} = \frac{P_{r_i} h d_3^{-\alpha}}{\sigma^2} \quad (5)$$

3.3 COOPERATIVE WIRELESS AD-HOC NETWORK WITH DF RELAYING

For the DF relaying, the achievable transmission rate at the destination terminal after performing MRC operation is expressed as;

$$R_{DF} = \frac{1}{2}\log_2\left(1 + \gamma_{S,D} + \min\left(\gamma_{S,r_i}, \gamma_{r_i,D}\right)\right) \quad (6)$$

3.4 OPTIMAL POWER ALLOCATION PROBLEM FORMULATION AND SOLUTION

Optimal power allocation plays a curial role in wireless communication networks by ensuring adequate control of power and other network resources with guaranteed better QoS delivery. The power allocation for the protocol is further discussed as follows.

3.4.1 Direct Transmission

The transmit power required to send the information from the source to the destination is expressed as (Chen, et al., 2006);

$$P_D = \frac{\left(2^R - 1\right)\sigma^2 d_1^{\alpha}}{k} \quad (7)$$

where R is the rate of transmission.

3.4.2 Optimal Power Allocation with AF Cooperative Transmission

The power allocation for the AF cooperative transmission is formulated by minimizing the total transmit power of the information transmitted subject to network constraint such as minimum total transmit power must be less than the maximum transmit power in $c1$, the achievable transmission rate is higher than the transmission rate threshold in $c2$ and the transmit power at both the transmitter and selected relay is greater than zero in $c3$. The formulated optimization is expressed as;

$$\begin{aligned} &\min_{P_S, P_{r_i}^{AF} \geq 0} P_S + P_{r_i}^{AF} \\ &s.t\ c1: P_S + P_{r_i}^{AF} \leq P_{max}, \forall\, i \in N \\ &\quad c2: R_{th} \leq R_{AF}, \forall\, i \in N \\ &\quad c3: P_S, P_{r_i}^{AF} \geq 0, \forall\, i \in N \end{aligned} \quad (8)$$

By applying the Lagrange multiplier technique and the Karush Kuhn-Tucker (KKT) optimality condition (Boyd, & Vandenberghe, 2004), the optimal solution is derived. Without loss of generality, the optimal relay power is assumed to be twice the transmit power at the relay terminal i.e., $P_S = 2P_{r_i}^{AF}$. This will result in obtaining the near optimal solution of the transmit power at the source

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and best AF relay terminals which are derived in (9) and (10), respectively due to space restriction as;

$$P_S{}^* = \begin{cases} \left[\frac{\lambda_2\left(DA+\frac{1}{4}EZ\right)}{2ln2(1-\lambda_1)\left(A+\frac{1}{2}Z\right)\left(D+\frac{1}{2}Z\right)} - \frac{D+\frac{1}{2}E}{A+\frac{1}{2}Z}\right]^+, k < h \\ P_D, \quad k \geq h \end{cases} \tag{9}$$

$$P_{r_i}^{AF*} = \begin{cases} \frac{1}{2}P_S{}^*, k < h \\ 0, \quad k \geq h \end{cases} \tag{10}$$

where $\lambda_1, \lambda_2 \geq 0$ are the Langrange multipliers, $A = kgd_1^{-\alpha}d_2^{-\alpha}$, $B = khd_1^{-\alpha}d_3^{-\alpha}$, $C = ghd_2^{-\alpha}d_3^{-\alpha}\sigma^2$, $D = gd_2^{-\alpha}\sigma^2$, $E = hd_3^{-\alpha}\sigma^2$, $Z = B + C$.

3.4.3 Optimal Power Allocation with DF Cooperative Transmission

In a similar manner, the power allocation for the DF cooperative transmission is formulated by minimizing the total transmit power subject to network constraints $c1$, $c2$ and $c3$ is expressed as;

$$\min_{P_S, P_{r_i}^{DF} \geq 0} \; P_S + P_{r_i}^{DF}$$

$$\begin{aligned} s.t\; c1&: P_S + P_{r_i}^{DF} \leq P_{max}, \forall\, i \in N \\ c2&: R_{th} \leq R_{DF}, \forall\, i \in N \\ c3&: P_S, P_{r_i}^{DF} \geq 0, \forall\, i \in N \end{aligned} \tag{11}$$

Using the Lagrange multiplier technique and the KKT optimality condition, due to space restriction the optimal solutions are derived as;

$$P_S{}^* = \begin{cases} \left[\frac{\lambda_2}{2ln2(1-\lambda_1)} - \frac{1}{\xi}\right]^+, k < h \\ P_D, \quad k \geq h \end{cases} \tag{12}$$

$$P_{r_i}^{DF*} = \begin{cases} \left[\frac{\lambda_2}{2ln2(1-\lambda_1)} - \frac{1}{\mu}\right]^+, k < h \\ 0, \quad k \geq h \end{cases} \tag{13}$$

where $\xi = \frac{kd_2^{\alpha}+gd_1^{\alpha}}{d_1^{\alpha}d_2^{\alpha}\sigma^2}$ and $\mu = \frac{ghd_1^{\alpha}}{\sigma^2 d_3^{\alpha}[(2^{2R}-1)d_2^{\alpha}+gd_1^{\alpha}]}$.

3.5 ENERGY-AWARE RELAY SELECTION

Energy-aware relay selection (EARS) scheme is employed to choose the optimal relay terminal which will assist in retransmitting an ongoing information between the source and destination terminals. In this paper, the relay selection modifies the one in Chen, et al., (2006). The reason for this is to improve the lifetime of the network by balancing the residual energy of all the terminals and also ensure the optimal allocation of transmit power at both the source and relay terminals. The criterion for the selection is the unification of the three criteria. The criterion for electing the relay with minimum total power has its timer counter β_{r_i} which expires earlier is expressed as:

$$\beta_{r_i} = \tau \cdot min\left\{\frac{P_S+P_{r_i}^X}{\left(\left\{E_{rS}+P_ST\prime E_{rr_i}+P_{r_i}^XT\right\} \times \left\{\frac{P_ST}{E_{rS}}, \frac{P_{r_i}^XT}{E_{rr_i}}\right\}\right)}\right\} \tag{14}$$

where τ is a dimensionless factor to hasten the election of the relay and $X \in \{AF, DF\}$.

4 SIMULATION AND NUMERICAL RESULTS

In this section, the simulation of the proposed lifetime enhancement of cooperative wireless ad-hoc network using AF and DF relaying strategies were performed in MATLAB R2018b software environment. The topology of the wireless ad-hoc network provides that the source and destination terminals are separated by distance with the relay terminals spread around the two terminals. The proposed strategies were evaluated over 10^3 runs in terms of average network lifetime performance and then compared with existing strategies in Chen, et al., (2006). The average network lifetime in this paper is the time it takes the first node to completely drain out its battery power. The simulation parameters used is as presented in Table I.

Table 1. Simulation Parameters

Parameters	Type
N	1:1:10
Fading Channel	Rayleigh
σ^2	1
R_X	2 bit/s/Hz
P_{max}	1 mW
α	3
E_o	1 J
τ	0.01
T	1 sec

Fig. 2 presents the plot of average network lifetime against the initial total power of each node with AF relaying. The result obtained depicts that as the initial total power of each node increases, the average network lifetime increases for all the strategies considered. The proposed strategy demonstrated a slight improvement over the PARS strategies. This is because both the optimal power allocation in (9) and (10) as well as the energy-aware relay selection scheme play a crucial role in enhancing the average lifetime of the network. In addition, the result revealed that at initial total power of each node at $1.5 \times 10^4\, W$, the average network lifetime of $11.23\, sec$, $11.17\, sec$, $10.52\, sec$ and $9.40\, sec$ were recorded for proposed EARS, PARS III, PARS II and PARS I, respectively.

In Fig. 3, the plot of average network lifetime against the initial total power of each node with DF relaying was depicted. The result obtained is similar to AF relaying except that the DF relaying strategy showed better performance for all the scheme. This is because the selected relay decodes correctly the overheard information at a reduced total transmission power as a result of the optimal power allocation in (12) and (13) while ensuring an improved residual energy. From the plot, at $1.5 \times 10^4\, W$, the average network lifetime of $11.64\, sec$, $11.51\, sec$, $10.93\, sec$ and $9.65\, sec$ were recorded for proposed EARS, PARS III, PARS II and PARS I, respectively using AF strategy. Comparison between the AF and DF strategies revealed that the DF strategy exhibited significant elongation of the average network lifetime as against the AF strategy which is due to correct decoding thereby reducing the energy consumption cost of transmitting the information.

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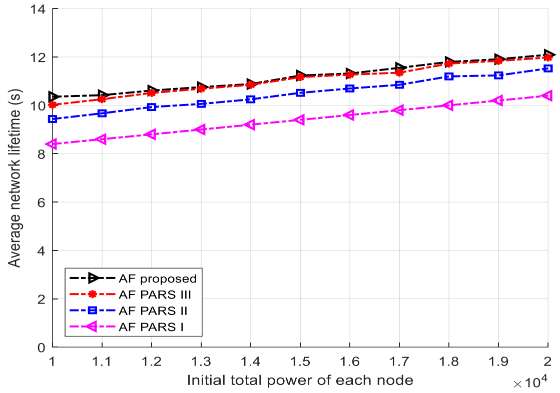

Fig. 2: Average network lifetime against initial total power of each node with AF relaying cooperative strategy.

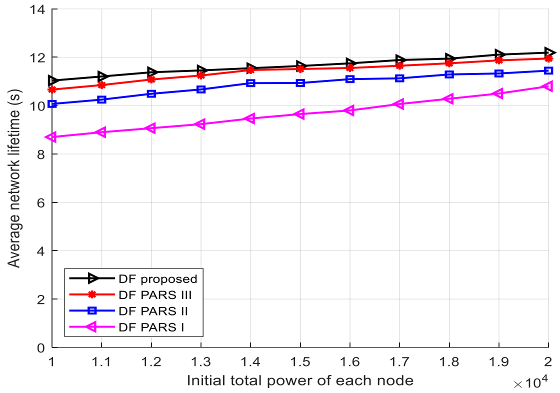

Fig. 3: Average network lifetime against initial total power of each node with DF relaying cooperative strategy.

Fig. 4 shows the plot of the average network lifetime against the number of nodes with AF cooperative strategy. In the result, the average network lifetime elongation is dependent on the number of nodes increment. This is as a result of sufficient potential relays available to help in retransmitting the overheard information. Due to the EARS employed in this work, the performance of the proposed strategy improved significantly as compared to the existing PARS criterion. At number of nodes set at 5, the network lifetime recorded for the proposed EARS with AF strategy was extended by 8.77%, 13.13% and 33.14% over PARS III, PARS II and PARS I, respectively while 10.06%, 12.90% and 30.62%, were improvement observed for EARS over the PARS III, PARS II and PARS I, respectively, at number of nodes equals 10.

Furthermore, Fig. 5 presents the plot of the average network lifetime against the number of nodes with DF cooperative strategy. In the result, the average network lifetime also improves as the number of nodes deployed increases. From the plot, at number of nodes set to 5, the average network lifetime improved by 5.4 %, 11.79% and 26.13% were recorded for proposed EARS over PARS III, PARS II and PARS I, respectively. Also, at number of nodes set to 10, the average network lifetime improved by 3.56 %, 8.96% and 20.98% were recorded for proposed EARS over PARS III, PARS II and PARS I, respectively, using DF strategy. Comparing the result obtained in the number of nodes mentioned earlier, the result implies that more energy is been consumed at higher node valves. Comparison between the AF and DF in the proposed strategies in Fig. 4 and Fig. 5 showed that the DF strategy exhibited significant extension in the average network lifetime by 14 %, over the AF strategy.

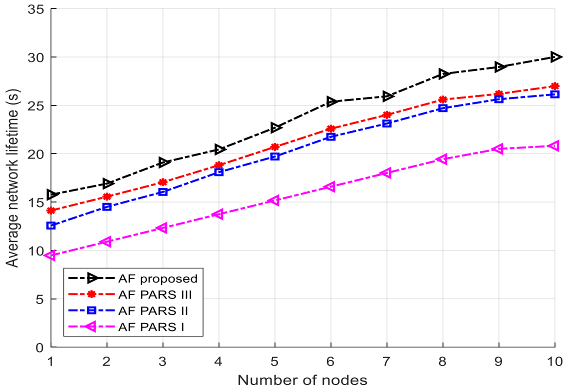

Fig. 4: Average network lifetime against number of nodes with AF cooperative strategy.

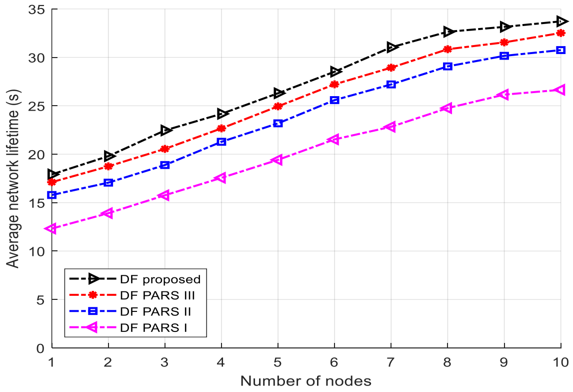

Fig. 5: Average network lifetime against number of nodes with DF strategy.

5 CONCLUSION

In this paper, lifetime enhancement of cooperative wireless ad-hoc networks known as EARS for AF and DF relaying strategies over the Rayleigh fading channel has been carried out. Optimization problem formulation for the proposed strategies were presented. The Lagrange multiplier technique and KKT conditions were employed in obtaining the solutions of the optimal power allocated. The simulation of the proposed strategies was performed on MATLAB software. The result revealed that the proposed EARS and optimal power allocation maximizes the average network lifetime of nodes better than the existing PARS criteria in both AF and DF cooperative strategies.

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