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# Effectiveness of SWIPT in Cooperative Device-to-Device Communication Based AF Relaying Protocol

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## Abstract
One of the major problems of wireless devices involved in cooperative device -to-device (D2D) communication is their energy constrained nature which has an effect on the performance on the system model. Though in cooperative communication, in order to sustain information transmission through the energy constrained relay node. The relay node takes advantage of the radio frequency (RF) energy harvesting (EH) to sustain its effectiveness in transmission of information from the source to destination. Existing studies on EH protocol rely on traditional linear EH model, which is impractical in nature. The EH protocol implemented in this paper is the power splitting (PS) protocol using the amplify and forward (AF) relaying protocol as it shows better performance. Therefore, the need to model the realistic behaviour of EH circuits using the non-linear EH model. Simulation results displayed the behaviour of the proposed non-linear EH model in terms of power harvested and throughput which outperforms the conventional non-linear EH model and traditional linear EH model based on the effectiveness of Simultaneous wireless information and power transfer (SWIPT) in information transmission as the proposed non-linear EH model ensures more active time for the energy constrained relay node.

## Keywords
Energy Harvesting, Power splitting, Throughput, Cooperative communication

## 1. Introduction

One of the futures of 5G network is cooperative communication which helps to solve the problem of multipath fading and enhances throughput performance of the network [1],[2]. Traditional cellular users (CUs) are no longer satisfied with network performance due to enormous usage of smart devices, which is growing every day, therefore the need to reduce network traffic. Device-to-Device communication (D2D) which involves communication between smart devices without using the core network, ensures minimal delay and enhanced throughput performance of the network [3],[4]. Cooperative D2D plays crucial role in numerous network paradigms, due to the fact that it enhances high data rate and an amount of energy efficiency (EE) that is acceptable [5], [6]. Cooperative D2D sustainability is threatened due to energy constrained nature of dedicated relay [7]. Replacing batteries of the dedicated relay is not realistic in a large-scale communication network due to its accessibility [8]. Therefore, the need to replenish energy used during information transmission to the end user. This limitation can be addressed using Simultaneous wireless information and power transfer (SWIPT), which is a radio frequency (RF) Energy Harvesting (EH) technique to alleviate this limitation at the dedicated relay [9]. Existing literature described two EH namely Time switching (TS) and power splitting (PS) strategies [10], [11], [12]. The PS strategy will be implemented in this research due its better performance [12].

Many work existed on the design of EH schemes for relay based D2D network using either amplify and forward (AF) or decode and forward relaying protocols [13], [14]. Though amplify and forward is preferred in some cases were minimal computational complexity and low latency are required [15]. Existing literature takes cognizance of the effectiveness of linear EH model in cooperative D2D communication and cellular network for its sustainability, which is not practical in nature. Therefore, the need for the non-linear behaviour of the EH circuits which portrays the actual characteristics of EH circuit for its sustainability in relay based D2D network.

[16] investigated the throughput performance of traditional linear EH model and logistic non-linear model in concurrent cellular and D2D communication. The TS and PS-EH schemes were employed at the relay nodes for the cellular link, while the D2D nodes employed these same schemes to harvest power from the base station (BS). Though the PS scheme out performs the TS scheme for each both the D2D link and the cellular link. Though the logistic non-linear EH model shows a close behaviour of the EH circuits but not actually fits to the real measurement data [17].

[18] investigated the combination of RF-EH and cooperative D2D networks using a linear EH model with PS scheme. The paper examined how the data-rate improves using the PS technique based on genetic algorithm as compared to exiting resource allocation algorithm. However, gives a misrepresentation of the data rate relative to network parameters leading to resource allocation mismatching.

The effectiveness of RF-EH in D2D communication was investigated by [19] studied EH in cooperative D2D networks using a linear EH model with PS. The paper examined how the distance between the D2D transmitter and receiver affects both the network data rate and the energy harvested at the relay node. However, the linear model overestimated the harvested energy and misrepresent the data rate relative to network parameters leading to inefficient resource allocation.

In the work of [20], the effectiveness of linear EH model was based on the through and EE performances of cooperative communication. This was considered in a mix Racian and Rayleigh fading channels. The combination of relay selection and RF-EH at the relay enhances the performance metrics considered. Though the linear EH model which was considered in this work, still leads to resource allocation mismatch.

[21] investigated the combination of SWIPT and cooperative Non-orthogonal Multiple Access (CNOMA) to improve communication of cell-edge users and solve complex energy supply problems. The PS and TS schemes were proposed as the EH protocol for the CNOMA network to solve the complex energy supply problems at the selected relay node. The closed form expression for outage probabilities of each user were obtained. A one-dimensional Markov chain with the energy state was used to vary the harvested energy by the relay. The work failed to consider the non-linear behavior of the energy harvester circuit at the selected relay node.

It is evident that most of the reviewed paper considered linear EH model at the relay node. These works suffers from the realistic behaviour of the energy harvesting circuit, which misinterpret the resources needed to be allocated. Only few considered conventional non-linear EH model which suffers from analytical complexity. The contributions of this work are as follows:

- A piecewise linear EH model is implemented which is realistic non-linear EH model was proposed
- The closed form expression for throughput was derived
- The proposed model was evaluated and compared with logistic non-linear EH model and traditional linear EH model based on the effectiveness of the energy harvested with respect to transmit power and distance between nodes.

The remaining part of the paper is structured as follows. Section 2 represent the system model and SWIPT architecture. In Section 3, System Model Equation is provided and Section 4 presents the results and discussion while Section 5 concludes the work.

## 2. System Model and SWIPT Architecture

A simple D2D network with dedicated relay is shown in Fig. 1, with the relay node R, harvesting energy from the D2D source node S and also from the interference signal from the cellular uplink. The relay node receives signal from the node

S, and uses the PS scheme to harvest energy and re-transmit the information to the intended destination node D, using the AF relaying protocol.

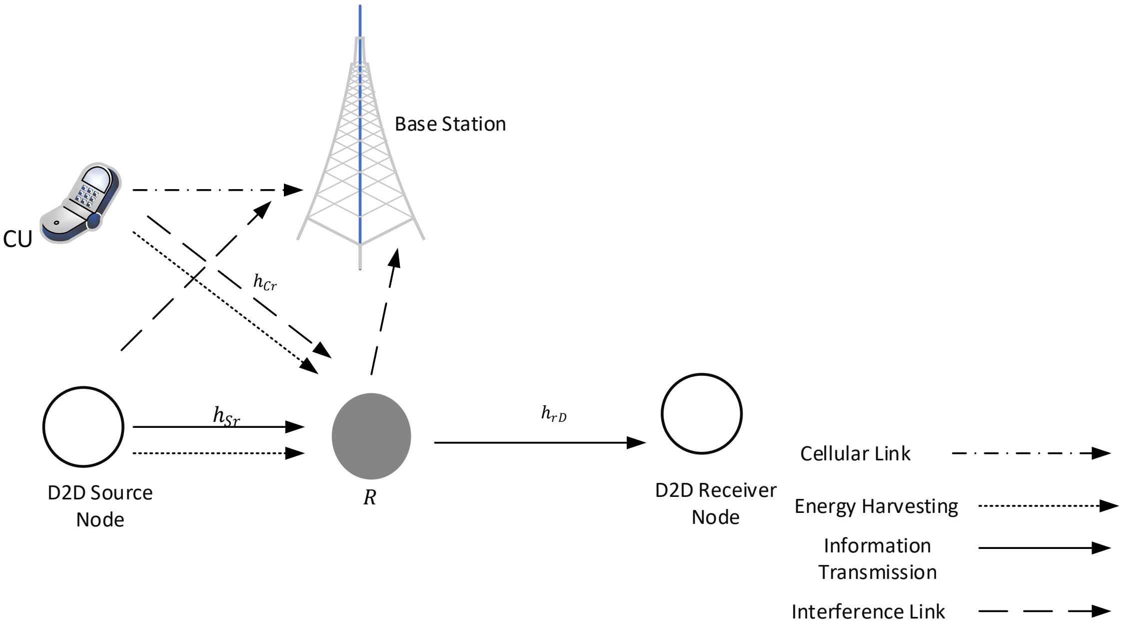


**Fig. 1** System model for Dedicated Relay-based D2D communication

The communication link between nodes is assumed to be modelled as Rayleigh fading channels with perfect channel state information (CSI) assumed. The PS architecture is displayed in Fig. 2, in the PS scheme the energy of the signal is splits into two, where the fraction $\varepsilon$, of the received signal at node R, is used for EH, while the remaining fraction $(1-\varepsilon)$, is used for information processing. The relay harvest energy while receiving the signal simultaneously based on PS protocol. The architecture shows that half of the block time T/2 is used for information transmission from node S to R, while the remaining T/2 is used for information transmission from node R, to node D. The relay node in this work is assumed to use the harvest-use transmission management, where the harvested energy is been used without further storing it.

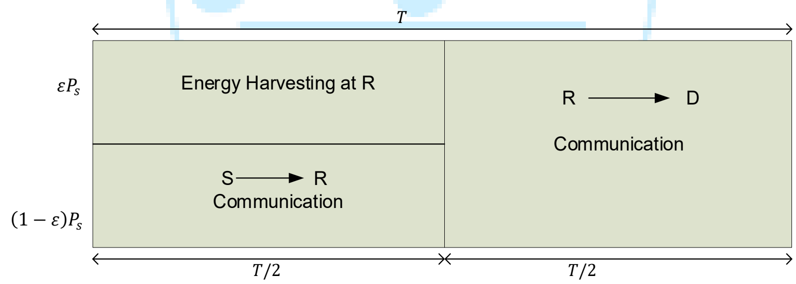


**Fig. 2** PS Architecture for RF-EH

## 3. System Model Equation

The received signal equation at the relay node is given as:

$$u_r = \sqrt{1-\varepsilon}\left(\sqrt{P_s}\, h_{Sr} x_s + \sqrt{P_C}\, h_{Cr} + n_r\right) + n_p \tag{1}$$

where $P_s$ represents the transmit power of node S, $P_c$ represents the transmit power of the interference signal from cellular link, $h_{Sr}$ and $h_{Cr}$ represent the attenuation coefficients of the D2D link and Cellular link respectively. The attenuation coefficients are modeled as $h_{Sr} = g_{Sr} d_{Sr}^{-\rho}$ and $h_{Cr_i} = g_{Sr} d_{Cr_i}^{-\rho}$ where $g_{Sr}$ and $g_{Cr}$ are the respective channel coefficientswith regards to Rayleigh fading, $d_{Sr}$ is the distance between the node S, and node R, $d_{Cr}$ is the distance between the CU and the node R, $\rho$ is the path loss exponent. $n_r \sim CN(0, \sigma_r^2)$ represent the additive white gaussian noise due to the receiving antenna and $n_p$ represent the noise due to conversion from RF band to baseband signal. $x_s$ is the source node signal such that $\mathbb{E}\{|x_s(t)|^2\} = 1$. The relay harvest energy based on the piecewise linear EH model using the PS scheme, where the power of the relay is obtained as [12]:

$$P_r = \begin{cases} 0, & P'_{RF} < P_{th}^1 \\ (a_k P'_{RF} + b_k), & P'_{RF} \in \left[P_{th}^k,\ P_{th}^{k+1}\right] \\ & k = 1, \dots, N-1\,. \\ P_m, & P'_{RF} > P_{th}^N \end{cases} \tag{2}$$

where $P_r$ is the power of the relay node R, $a_k$ and $b_k$, stands for the coefficient and intercept for the linear function of the *k-th* segment respectively. The portion used for EH from the received signal is given as:

$$P'_{RF} = \sqrt{\varepsilon}\left(\sqrt{P_S}\, h_{Sr} + \sqrt{P_C}\, h_{Cr} + n_r\right) \tag{3}$$

The signal received at the destination node is given as:

$$y_d = h_{rD}\mu\, u_r + n_d \tag{4}$$

where $h_{r_iD} = g_{rD}\, d_{rD}^{-\rho}$ is the channel response between the node R and node D, $g_{rD}$ is the complex channel coefficient between the node R and node D, $d_{rD}$ is the distance between the R and D, $n_d \sim$ CN $(0, \sigma_d^2)$ is the AWGN at node D, where $\mu$ which is the amplification factor of node R using AF, which is given as:

$$\mu = \sqrt{\frac{P_r}{(1-\varepsilon)(P_S|h_{Sr}|^2+P_C|h_{Cr}|^2+\sigma_r^2)+\sigma_P^2}} \tag{5}$$

Substituting equations (1) and (5) into equation (4) result in the signal to interference plus noise ratio (SINR) obtained as:

$$\gamma_1 = \frac{(1-\varepsilon)P_rP_S|h_{rD}|^2|h_{Sr}|^2}{(1-\varepsilon)(P_rP_C|h_{rD}|^2|h_{Cr}|^2+\sigma_r^2P_r|h_{rD}|^2+f\sigma_d^2)+\sigma_P^2(P_r|h_{rD}|^2+\sigma_d^2)} \tag{6}$$

where $f = P_S|h_{Sr}|^2 + P_C|h_{Cr}|^2 + \sigma_r^2$

The throughput is obtained as:

$$\tau_1 = \frac{T}{2}\log_2(1+\gamma_1) \tag{7}$$

where T is the unit block time for information transmission, without loss of generality, the unit block time is assumed to be 1s. The throughput is considered under the piecewise linear EH model, where the block time takes cognisance of three cases:

*Case 1:* when $P_{RF} < P_{th}^1$, the power of the node R, $P_r = 0$. This results in signal transmission outage between relay node and D2D receiver node, therefore $\tau_1 = 0$.

*Case 2:* This considers when the node R harvests energy in the $(N-1)$ linear regions, such that: $P_r = (a_kP'_{RF} + b_k) = a_k\,\rho_i\left(P_S|h_{Sr}|^2 + P_C|h_{Cr_i}|^2 + \sigma_r^2\right) + b_k$ for the *k-th* linear region, $\forall\, k \in \{1,\ldots\ldots, N-1\}$, where $P_{RF}^{PS} \in [P_{th}^k, P_{th}^{k+1}]$ and $P_S|h_{Sr}|^2 + P_C|h_{Cr}|^2 + \sigma_r^2 > P_{th}^k$ must be satisfied based on the fact that $0 < \rho_i < 1$. Substituting the expression for $P_r$ into the numerator and denominator of Equation (6), noting that $f = P_S|h_{Sr}|^2 + P_t^C|h_{Cr}|^2 + \sigma_r^2$, then the end-to-end SINR is obtained as:

$$\gamma'_1 = \frac{-\varepsilon^2a_k\,fP_S+\varepsilon(a_kP_Sf-b_kP_S)+b_kP_S}{-m'\varepsilon^2+n\varepsilon+l}|h_{rD}|^2|h_{Sr}|^2 \tag{8}$$

where $m' = a_k\, f(P_C|h_{Cr}|^2 + \sigma_r^2)|h_{rD}|^2$

$n = a_k\, f(\sigma_r^2 + \sigma_P^2 + P_c|h_{Cr}|^2)|h_{rD}|^2 - b_k(P_c|h_{Cr}|^2 + \sigma_r^2)|h_{rD}|^2 - \sigma_d^2 f$

$l = b_k(\sigma_r^2 + \sigma_P^2 + P_c|h_{Cr}|^2)|h_{rD}|^2 + (f + \sigma_P^2)\,\sigma_d^2$

The throughput is obtained as:

$$\tau'_1 = \frac{1}{2}\log_2(1+\gamma'_1) \tag{9}$$

*Case 3*: If $P'_{RF} > P_{th}^N$, then $\varepsilon(P_S|h_{Sr}|^2 + P_C|h_{Cr}|^2 + \sigma_r^2) > P_{th}^N$, therefore $P_r = P_m$, substituting for $P_r$ into Equation (6), then end-to-end SINR is expressed as:

$$\gamma_1^N = \frac{(1-\varepsilon)P_mP_S|h_{rD}|^2|h_{Sr}|^2}{(1-\varepsilon)(P_mP_C|h_{rD}|^2|h_{Cr}|^2+\sigma_r^2P_m|h_{rD}|^2+f\sigma_d^2)+\sigma_P^2(P_m|h_{rD}|^2+\sigma_d^2)} \tag{10}$$

The throughput in this case is obtained as:

$$\tau'_1 = \frac{1}{2}\log_2(1+\gamma_1^N) \tag{11}$$

Though, the *Case 3* is for the saturation region, which is taken into account by the linear segments region, which is *Case 2.*

## 4. Results and Discussion

This section compares the designed piecewise linear EH model scheme with linear EH model and logistic linear EH model using the PS scheme. The piecewise linear EH model employed in this work was based on 3-segment ($N = 3$) and

4-segment ($N = 4$) piecewise linear EH model with coefficients $[a_o, a_{1,} a_2, a_3] =$ [0.34, 0.3527, 0.4497, 0.019], intercept [ $b_o, b_{1,} b_2, b_3, b_4$] = [0.34, -6.8, 1.11, 7.003, 23.90] mW, with fixed PS ratio $\varepsilon = 0.5$, source to destination distance $d_{SD}$ = 1 ~ 100m, source to relay distance was considered to be 0.4 of $d_{SD}$ . All noise powers are assumed to be equal to -100 dBm, path loss exponent $\rho = 3$. Maximum transmit power of source and celluar user, $P_S$ and $P_C$ were set to 30 dbm.

Fig. 3, displays the harvested power result with different input RF power. The linear EH model produces an overestimation of the power harvested, due to the fact that it did not capture the realistic behaviour of the energy harvester. The piecewise linear EH model with 4-segment shows better accuracy than the 3-segment piecewise linear EH model as it shows a close reality to measurement data than 3-segment piecewise linear EH model. The piecewise linear EH model is more accurate than the conventional non-linear EH model as the number of segments increases and it is analytically tractable.

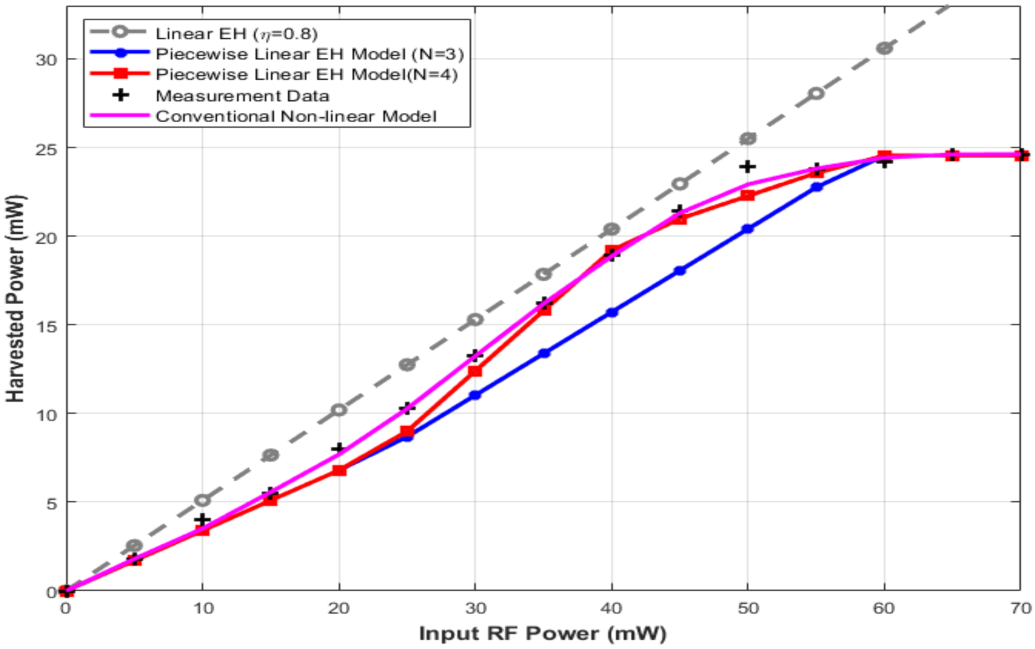


**Fig. 3** Comparison of different EH Models using PS Strategy

Fig. 4, represent the harvested power relationship with source to destination distance with relay node at 0.4 of the source to destination distance. The piecewise linear EH model with N=4 and N = 3 the value of the harvested power at R, for the source to destination distance from 0 m to 22.22 m was 28.04 mW, which shows that the value of the energy harvested was constant at this range, showing the actual behaviour of the energy harvester circuit. While that of the conventional non-linear EH model decreases from 13 mW to 6.21 mW for source to destination distance from 0 m to 22.22 m in exponential manner. It was observed that values of energy harvested by R, within this range for linear EH model was overestimated compared to that of conventional non-linear EH and piecewise linear EH models due to its inaccuracy which result to resource allocation mismatching.

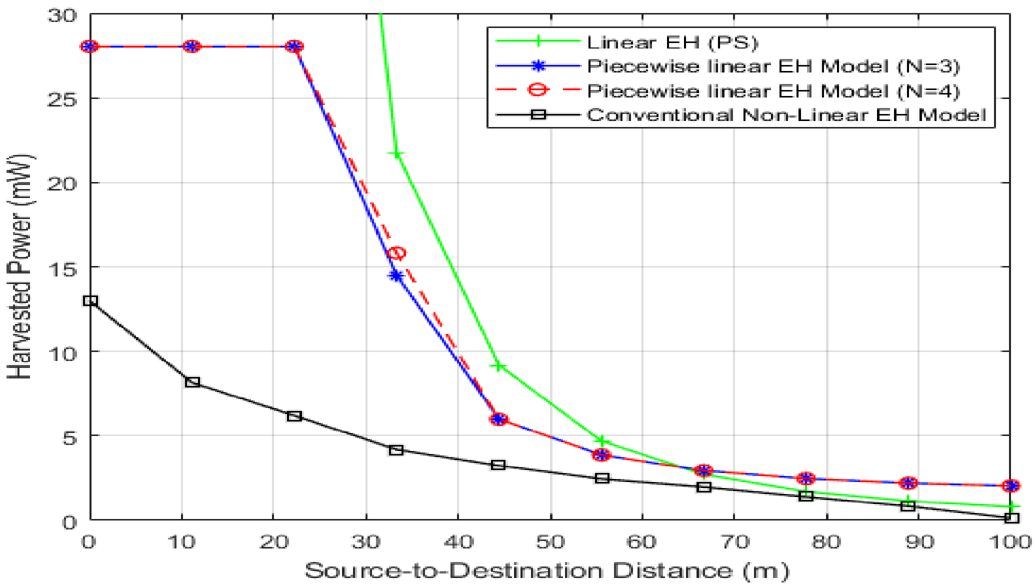


**Fig. 4** Harvested power at Relay node versus distance between D2D Source and Destination at $d_{Sr}$= $0.4 \times d_{Sd}$ using PS scheme

Fig. 5, presents the average throughput achieved by the PS scheme under the designs of the piecewise linear, linear EH and logistic non-linear EH models with varying source to destination distance.

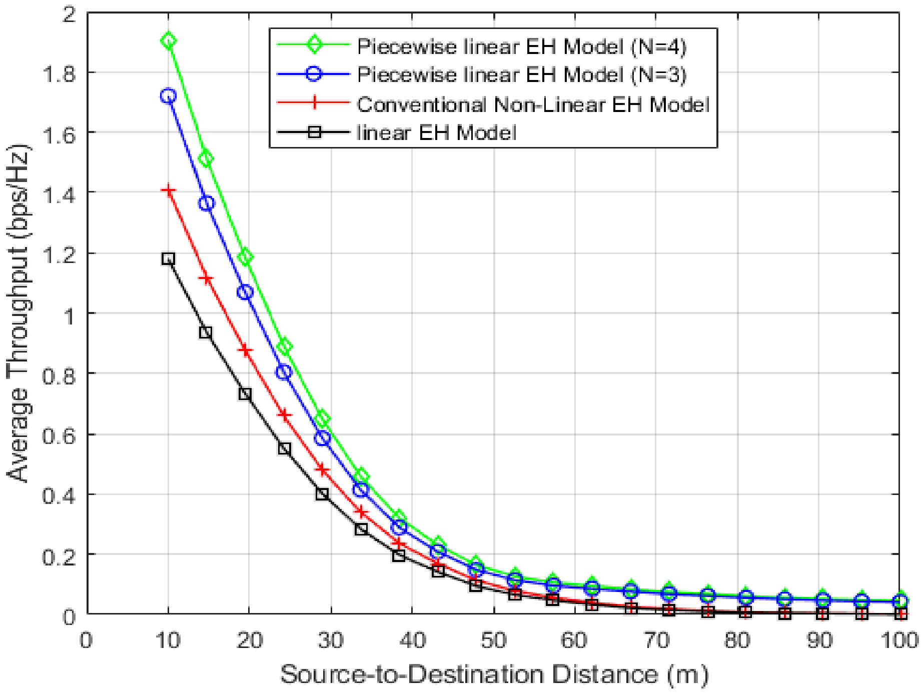


**Fig. 5** Average throughput versus distance between D2D Source and Destination at $d_{Sr}= 0.4d_{Sd}$ using PS scheme

It is obvious that these models like the piecewise linear EH model has a higher average throughput at varying, S node to D node distances, both for 3-segment and 4-segment piecewise linear EH model. The average throughput at source to destination distance of 10m for 3-segment and 4-segment piecewise linear EH model are 1.720 bps/Hz and 1.906 bps/Hz respectively. While the corresponding values of the average throughput for linear EH and logistic non-linear EH models are 1.18 bps/Hz and 1.41 bps/Hz respectively. The average throughput at source to destination distance of 24.21 m for 3-segment and 4-segment piecewise linear EH model are 0.8044 bps/Hz and 0.89126 bps/Hz respectively. While the corresponding values of the average throughput for linear EH and logistic non-linear EH models are 0.5517 bps/Hz and 0.6599 bps/Hz respectively. This shows that the average throughput linear EH model and conventional non-linear EH model which is the logistic non-linear EH model drops drastically as compared to the piecewise linear EH model.

## 5. Conclusion

This paper has presented the effectiveness piecewise linear EH model using the PS scheme under the AF relaying protocol in cooperative D2D network. The investigation of harvested RF energy harvested by the node R using this piecewise linear model shows the realistic behaviour of the piecewise linear model and its effectiveness in maintaining the required Quality of Service (QoS) of the cooperative D2D link. It is found that the piecewise linear EH model shows better performance for varying distance than the logistic non-linear EH and linear EH models due its ability to perform acceptable resource allocation matching and simple analytical tractability. This piecewise linear EH model can be applied to ultra-dense network due to its improve performance. As part of future work, this work allows choosing appropriate valuable EH technique in improving system performance metrics.


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## Author's Contributions

Gbenga A. Gbotoso and Zachaeus K. Adeyemo wrote the original draft preparation. Damilare O. Akande, Gbenga A. Gbotoso and Ayoade B. Ogundare did the first review and editing. Oluwatobi O. Oyedokun, Olusegun B. Adesina and Sobowale O. Soneye did the Conceptualization and Validation. All authors reviewed and approved the final version of the manuscript.


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## Conflicts of Interest

The authors declare no conflict of interest.

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