Performance Analysis of Energy Harvesting Scheme using Dual-hop Wireless Link

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ABSTRACT

In recent years most researchers in different sectors of wireless communication are analysing to find out maximum channel capacity with the optimal solutions of signal energy at the receiving end of the wireless communication system. In our thesis paper, we have tried to solve the major difficulty of obtaining an optimal solution for the "power splitting ratio" of an energy harvesting scheme that utilized a dual-hop wireless link. However, in order to figure out the solution that is most effective for overcoming that difficulty, we will be required to consider the optimal condition of "power supply at source terminal" and "relay gain."

INTRODUCTION

- Dual-hop energy harvesting (EH) offers various complex challenges, one of which is adjusting link parameters to get the maximum achievable signal-to-noise ratio (SNR) at the receiving end.
- This paper describes three ways to optimize "power supply at source terminal," "power splitting ratio," and "relay gain."
- In the first and second approaches of this paper, try to optimize analytically from the profile of normalized channel capacity and bit error rate (BER) among the mentioned parameters. The corresponding graphs show maxima and minima at the same point, which indicates that this is the optimal point for the parameters.
- In the third approaches, try to locate the point at which the gap between the 'normalized channel capacity' profiles of EH and non-EH is at its narrowest and most optimal.

INTRODUCTION (cont.)

- None of the previous studies that we carried out in preparation for authoring this paper found anything significant about the two parameters: (a) the space diversity of wireless links; (b) the impact of the 'energy splitting ratio' of energy harvesting schemes. Again, the previous studies made no reference of optimizing a dual-hop EH network.
- When a network is operating at its optimal condition in terms of the link parameters, the SNR at the destination is at its highest level, the BER is at its lowest level, the channel capacity or throughput is at its highest level, and the channel capacity gap between EH and non-EH is at its smallest level.
- In this paper, try to complete the job by taking into consideration the aforementioned four instances.

LITERATURE REVIEW

The purpose of this study is to determine whether or not the addition of a third node, in the form of a wireless relay (R), located between the source node (S) and the destination node (D), can result in an increase in the system's overall energy efficiency. A comparison of the amount of energy used for each successful bit transmission in a collinear arrangement reveals that it is only possible to save energy when R is placed at a certain distance from S (or D), and that there exists an optimal location where energy saving is maximized. This is the case only when R is placed at the optimal distance. However, the amount of energy that may be saved when dealing with non-linear situations is dependent on the two-dimensional co-ordinates of R. In this case, they have found spots on the S–R–D plane that meet a minimum standard for saving energy [1].

[1] Chandra, A., Ghosh, B., Biswas, N., Brante, G. and Souza, R.D., "Energy efficient relay placement for dual hop wireless transmission," International Journal of Electronics Letters, 1(4), pp.198-209, 2013.

The study proposes a relay node iterative scheduling approach for dual-hop wireless networks that maximizes channel capacity. The suggested technique, which is based on the amplify-and-forward relay protocol, picks relay nodes iteratively according to the criterion that maximizes the instantaneous capacity when the destination node executes joint decoding. The selection procedure continues until the number of chosen relays equals the number of source transmitting antennas or until the channel's capacity no longer increases. The simulation results show that under different conditions, such as the total number of relay nodes, the number of source transmitting antennas, and the signal-to-noise ratios of the forward and backward channels, the algorithm can achieve greater capacity gains and multi-relay diversity gains than traditional algorithms and can get closer to the information-theoretic capacity upper bound [2].

[2] Zhang-Yu, L.U.O. and Xiao-Lin, Z.H.O.U.,"A Relay Scheduling Algorithm in Dual-Hop Wireless Networks," Journal of Shanghai Jiaotong University, 45(03), pp.331, 2011.

SYSTEM MODEL

- To improve the quality of the received signal, a dual-hop wireless link should be utilized efficiently.
- In this link, the signal that is being broadcast is first relayed by a suitable repeater that has some gain. The figure below provides a visual representation of the dual-hop wireless link along with its link parameters.

Fig. 1 Dual-hop wireless link

SYSTEM MODEL (cont.)

- The received signal at the relay is represented as:

$$Y_R(t) = \sqrt{P_S} * h_{S\text{-}R}(t) * x(t) + n(t)$$

  - P_S is the power that is transferred from the source.
  - $h_{S\text{-}R}(t)$ represents the channel response from the source to the relay link.
  - x(t) is the signal that is being transmitted.
  - n(t) is the additive white Gaussian noise (AWGN) of the channel.

- In the end, the signal that has been received will be:

$$Y_D(t) = G\sqrt{P_R} * h_{R\text{-}D}(t) * Y_R(t) + n(t)$$

  - P_R is the power that is transferred by the relay.
  - $h_{R\text{-}D}(t)$ is the channel response of relay to the destination link.
  - *G* is the gain of the relay.

- If the SNR of the first-hop link is $\gamma_{S\text{-}R}$ and that of the second-hop link is $\gamma_{R\text{-}D}$, then equivalent SNR becomes:

$$\gamma_{R\text{-}D} = (\gamma_{S\text{-}R} * \gamma_{R\text{-}D}) / ((\gamma_{S\text{-}R} + \gamma_{R\text{-}D}) + c)$$

SYSTEM MODEL (cont.)

- In the energy harvesting model of the dual-hop connection, the relay station gets power from the RF signal.
- The harvested energy is split as the ratio of ρ and (1- ρ), where portion ρ is used for transmitting the signal and that of (1- ρ) for signal processing like the figure below:

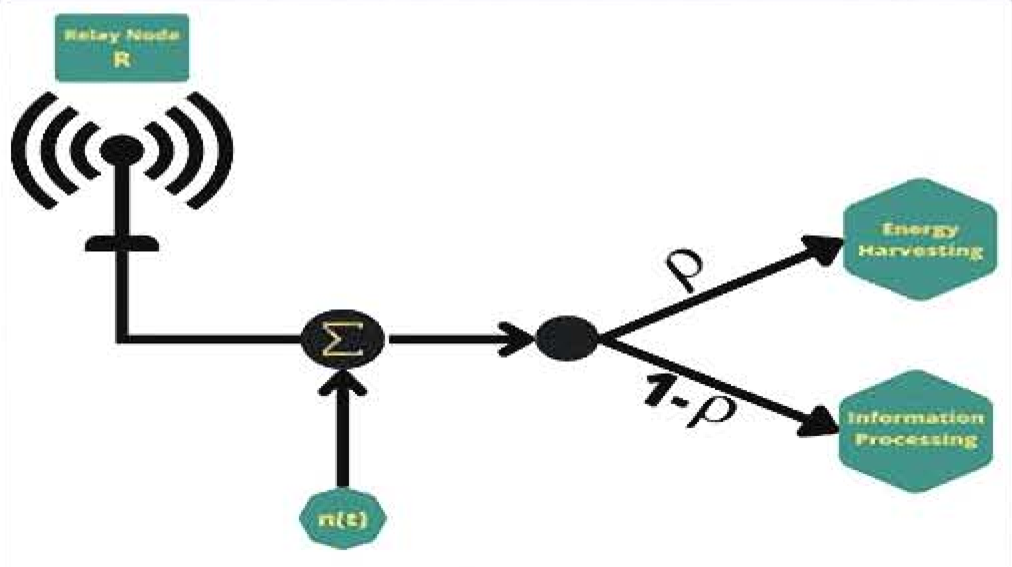


Fig. 2 Energy splitting at the relay

SYSTEM MODEL (cont.)

- The signal that was received by the relay is:

$$Y_R = \sqrt{P}_S * h_{S\text{-}R} * x + n$$

- The SNR from source to relay node is:

$$\gamma_{S\text{-}R} = ((1-\rho)*P_S*h^2_{S\text{-}R}) / ((1-\rho)*\sigma^2_n + \sigma^2_{n'})$$

where σ^2_n and $\sigma^2_{n'}$ are the variance of n and n′ . Again, n′ denotes the AWGN due to RF-to-baseband conversion.

- The SNR at the destination node can be written as:

$$\gamma_{R\text{-}D} = (\eta*G^2*h^2_{S\text{-}R}*h^2_{R\text{-}D}*\rho*P_S) / \sigma^2_D$$

where σ^2_D is the variance of n″. Again, n″ is the AWGN at the destination .

- In contrast to a normal dual-hop AF system, the energy harvesting technique has two separate SNRs that are denoted by the notations $\gamma_{S\text{-}R}$ and $\gamma_{R\text{-}D}$. The normalized channel capacity of the dual-hop relayed connection (where the unit for the capacity is bits/Hz) under energy harvesting is stated as:

$$C = \log_2\{1 + \min(\gamma_{S\text{-}R}, \gamma_{R\text{-}D})\}$$

RESULTS

Table I

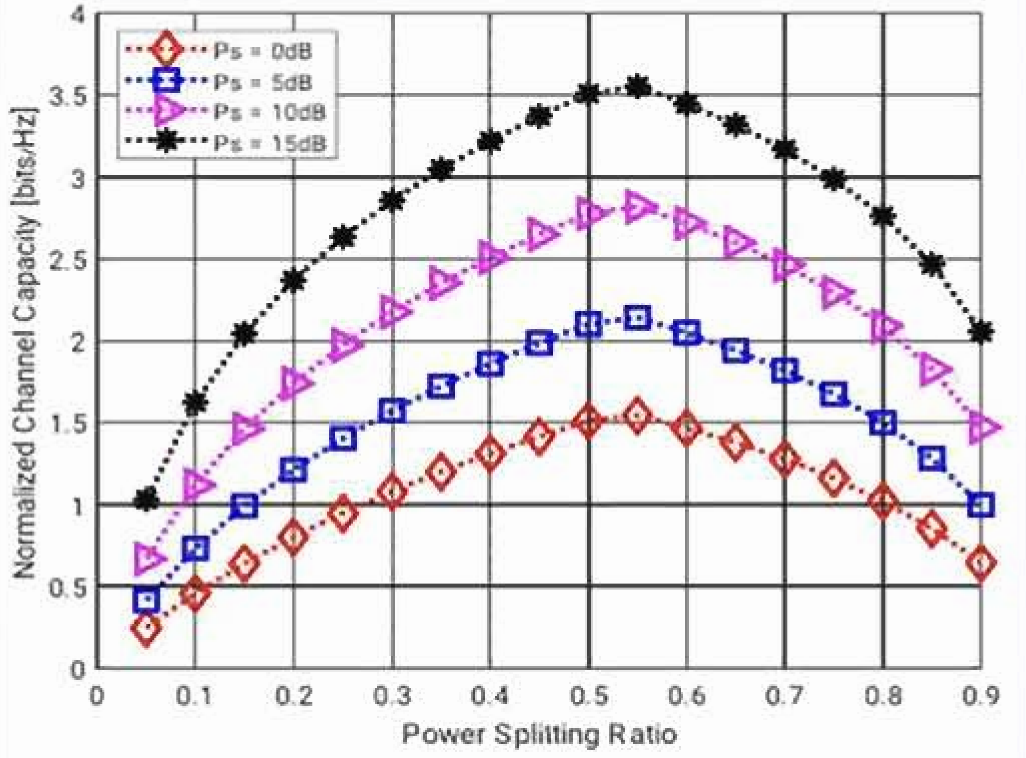
Parameters of 4 cases

P_S in dB	0	5	10	15
Gain of Relay (G)	6 dB	8 dB	10 dB	12 dB
Maximum SNR at receiving end in dB	1.8056	5.3143	8.6361	11.5423
Optimum ρ	0.66	0.55	0.4	0.3
BER QPSK	0.0838	0.0523	0.0153	9.331×10^{-04}
BER 16-QAM	0.1712	0.1356	0.0730	0.0119

Based on the data in Table I, we might conclude that, when P_S is assigned a higher value, the total SNR will likewise be found to be greater .

RESULTS (cont.)

- According to the figure, the channel capacity is at its lowest point when P_S = 0dB throughout all four curves.
- In conclusion, the point where P_S = 15dB is the point at which the channel capacity is the highest across all four curves.
- So, there is also an increase in the channel's capacity, when P_S is assigned a higher value, as illustrated in the figure.
- In this scenario, the pick signal to noise ratio (PSNR) reaches an equilibrium point at a power splitting ratio of $\rho = 0.55$ across all four curves.

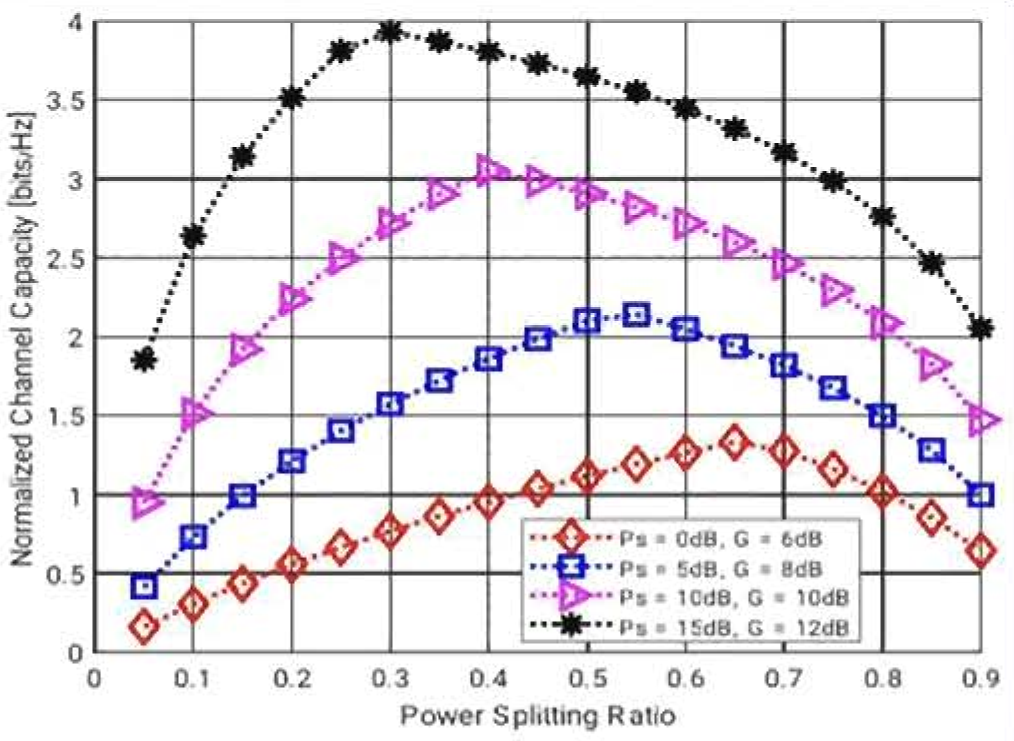


(a) Impact of Ps (Ω = 8dB)

Fig. 3 Variation of normalized channel capacity against power splitting ratio

RESULTS (cont.)

- The high relay gain is capable of transmitting information in a short amount of time, which results in the relay using a lower amount of energy.
- The optimal power splitting ratio ρ_{opt} will be achieved at a lower value of ρ with an increment of relay gain G, as shown in the figure.
- From the graph, the value of ρ is at its maximum when G = 6dB across all four curves ($\rho = 0.66$ at $G = 6$dB).
- Lastly, the value of ρ is at its lowest point across all four curves when G = 12dB ($\rho = 0.3$ at $G = 12$dB).
- The effect of P_S and G working together on C is seen in the figure.

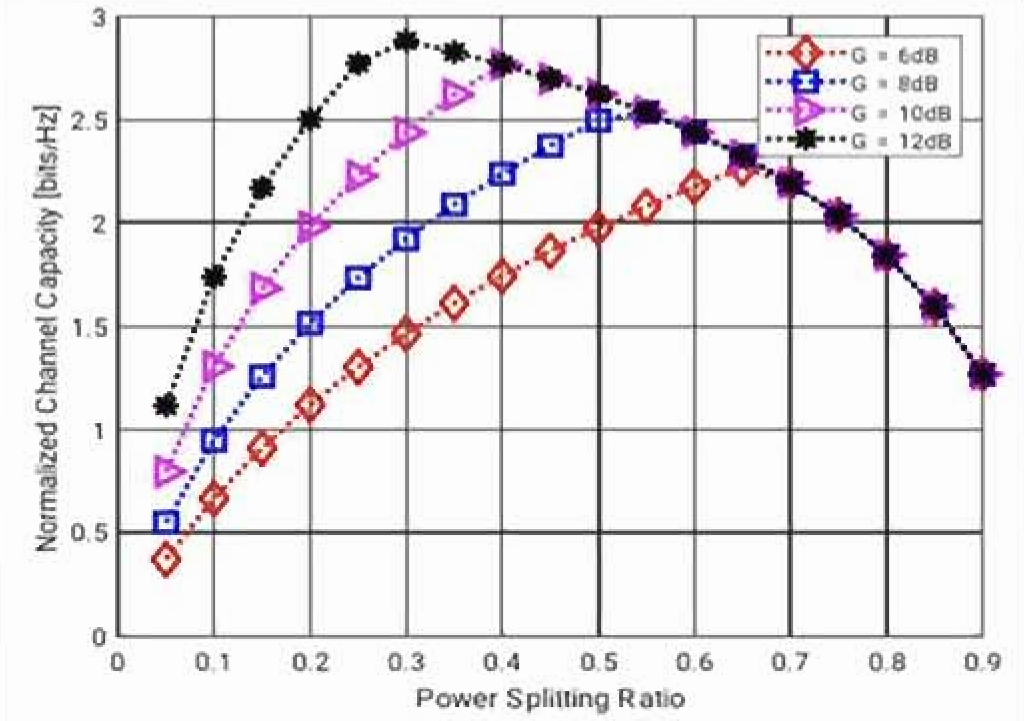


(b) Impact of both Ps and G

Fig. 3 Variation of normalized channel capacity against power splitting ratio

RESULTS (cont.)

- The figure shows that, how G changes in the outcome if P_S is constant while increasing the G by a certain amount.
- As illustrated in the graph, this graph demonstrates the impact of relay gain G only, while the PSNR or peak channel capacity, has a minimal effect compared to the combined effect of P_S and G.
- The shifting of ρ does not change from what it was previously.

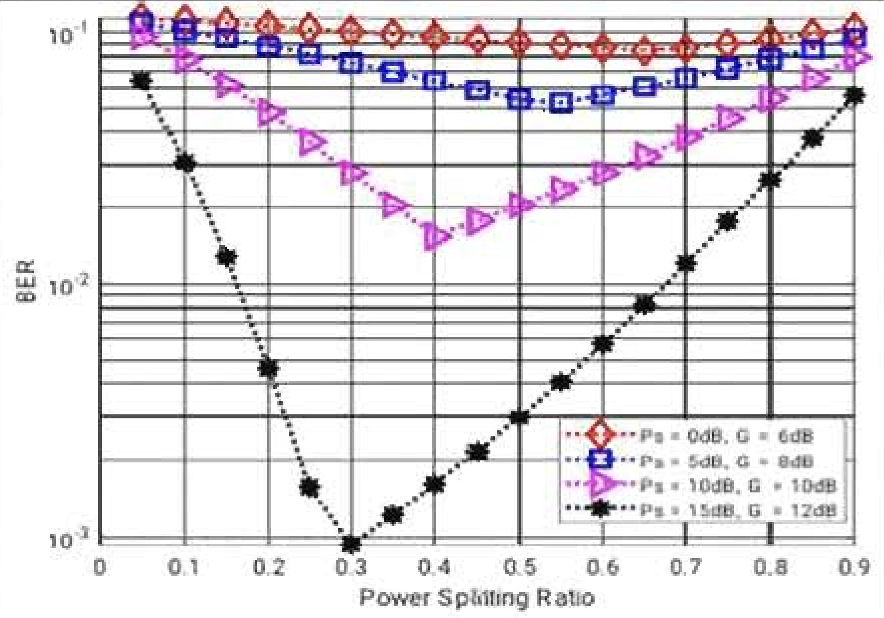


(c) Impact of G (P_S = 8dB)

Fig. 3 Variation of normalized channel capacity against power splitting ratio

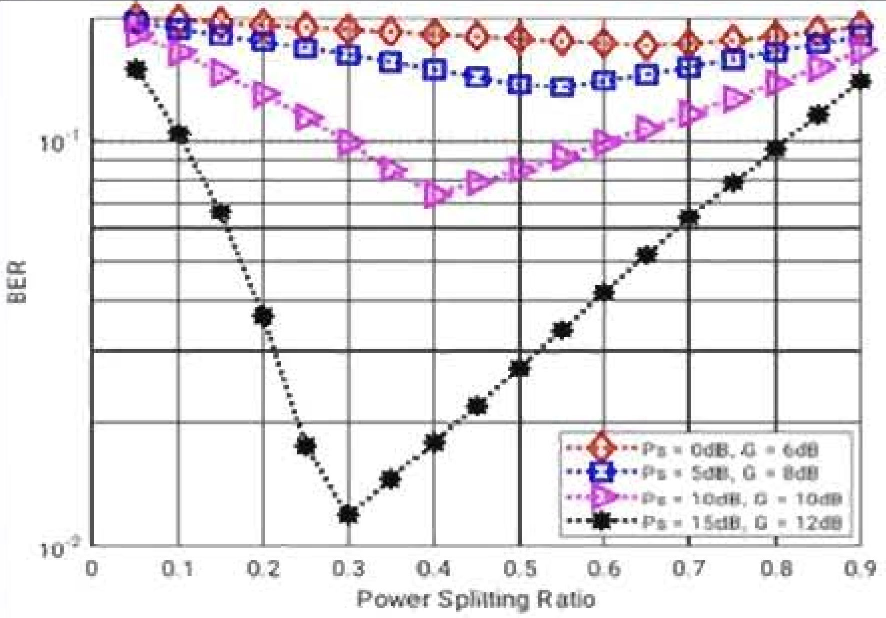
RESULTS (cont.)

- The next thing is to make a graph of BER vs ρ using P_S and G as the parameters for both QPSK and 16-QAM.
- The figures below show that, the minimum value of BER can be seen to exist at the same optimal value of ρ.



(a) QPSK

Fig. 4 Variation of BER against power splitting ratio

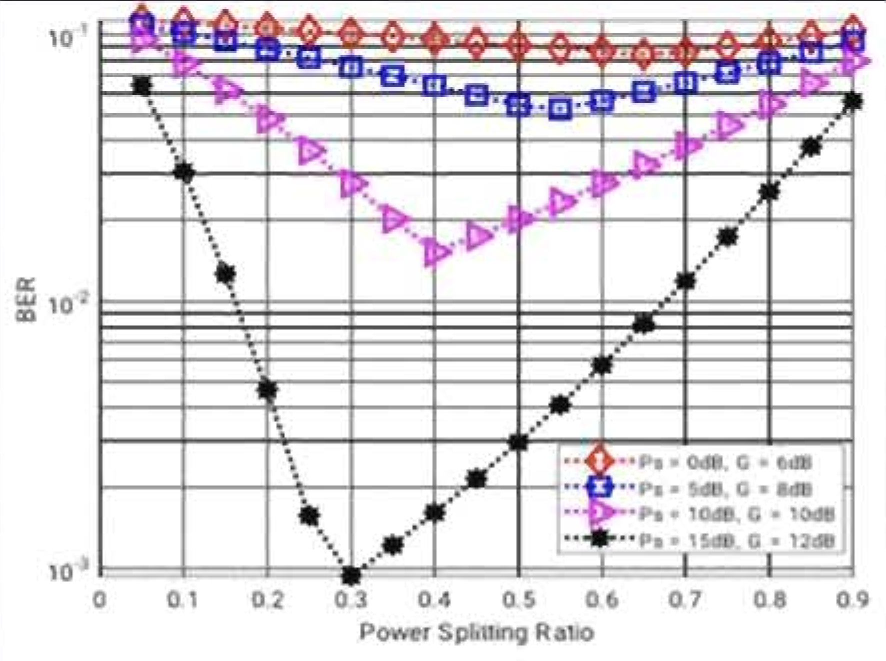


(b) 16-QAM

Fig. 4 Variation of BER against power splitting ratio

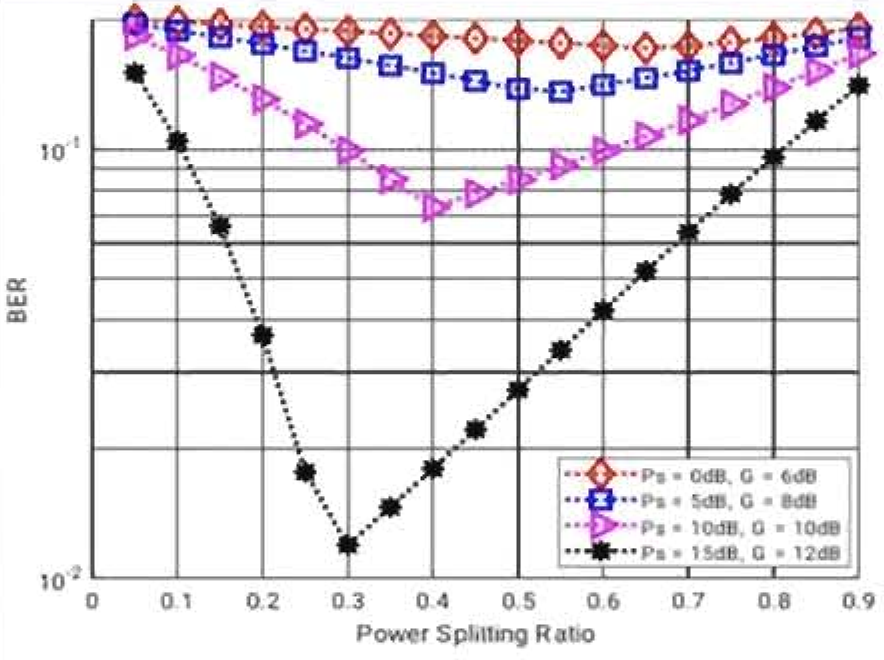
RESULTS (cont.)

- The optimal state of the EH link is achieved when the normalized channel capacity is at its highest and the bit error rate is at its lowest.
- The bit error rate in QPSK is lower than that in 16-QAM.



(a) QPSK

Fig. 4 Variation of BER against power splitting ratio



(b) 16-QAM

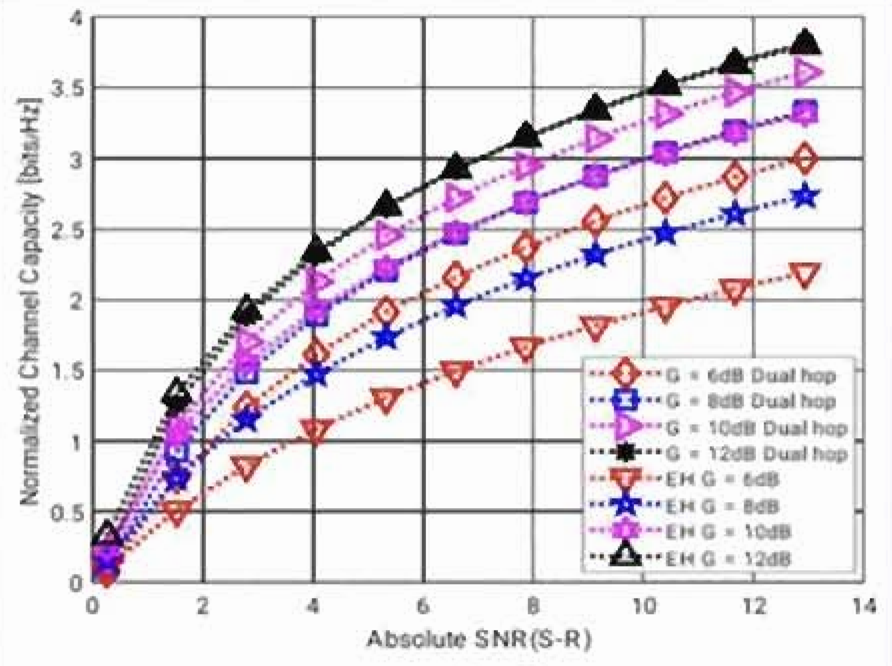
Fig. 4 Variation of BER against power splitting ratio

RESULTS (cont.)

1. In the non-EH model, the relay can use as much energy as is necessary to keep the desired SNR at the receiving end.
2. In the EH model, the amount of energy that can be used is restricted; as a result, the desired SNR at the destination cannot always be guaranteed if the R-D link has a low gain.
3. The channel capacity of the non-EH model is greater than that of the EH model.
4. The gap between the two models is capable of being narrowed by selecting an appropriate value for ρ.
5. Based on the difference in channel capacity between non-EH models and EH models, try to verify that the EH link has been optimized to its fullest capacity.
6. If the relay has a low gain, the EH model is equivalent to the non-EH model when ρ is given a large value.
7. If the gain of the relay is large, then two models will approach one another at a smaller value of the parameter ρ.

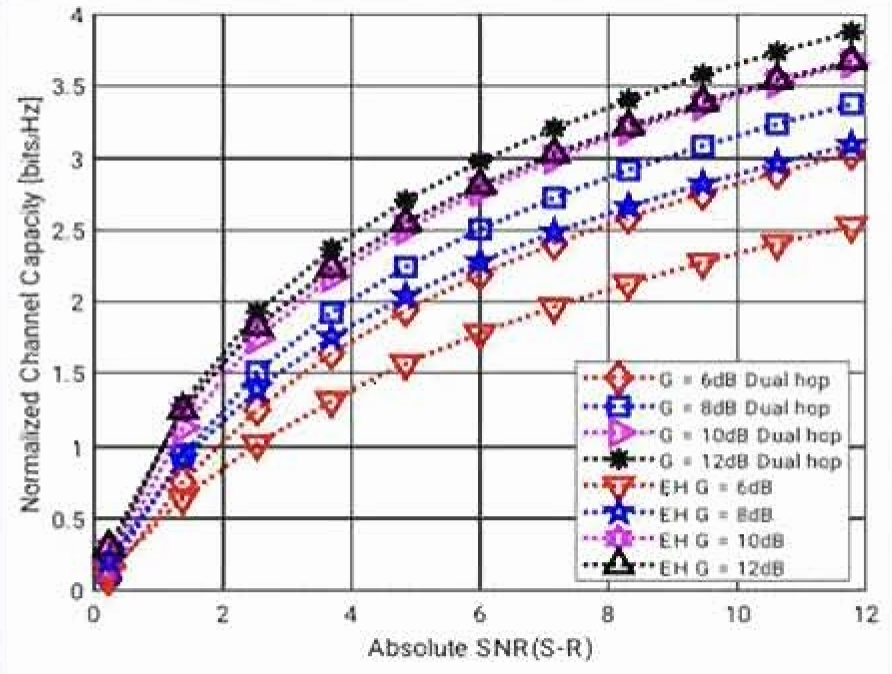
RESULTS (cont.)

- The parameters $\rho = 0.3$, $P_S = 15$ dB, and G = 12 dB are found to be near for one curve of EH and one curve from non-EH in the figure 5(a).
- This can be seen in the figure 5(b), where the EH and non-EH curves merge together to form a closed shape when the following criteria are met: $\rho = 0.4$, $P_S = 10$dB, and G = 10dB.



(a) $\rho = 0.3$

Fig. 5 Comparison of channel capacity of conventional dual-hop and EH scheme

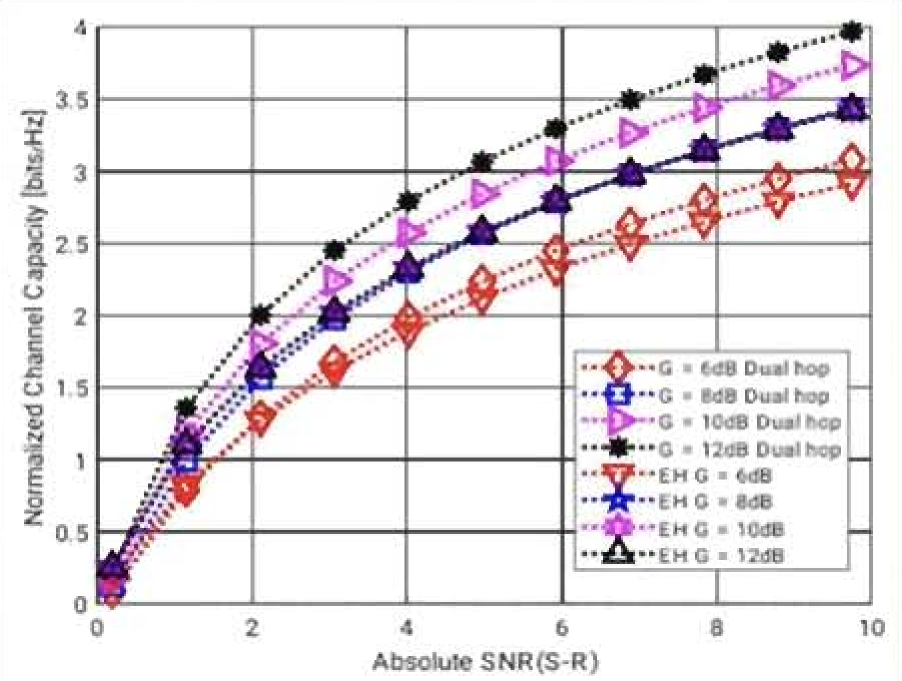


(b) $\rho = 0.4$

Fig. 5 Comparison of channel capacity of conventional dual-hop and EH scheme

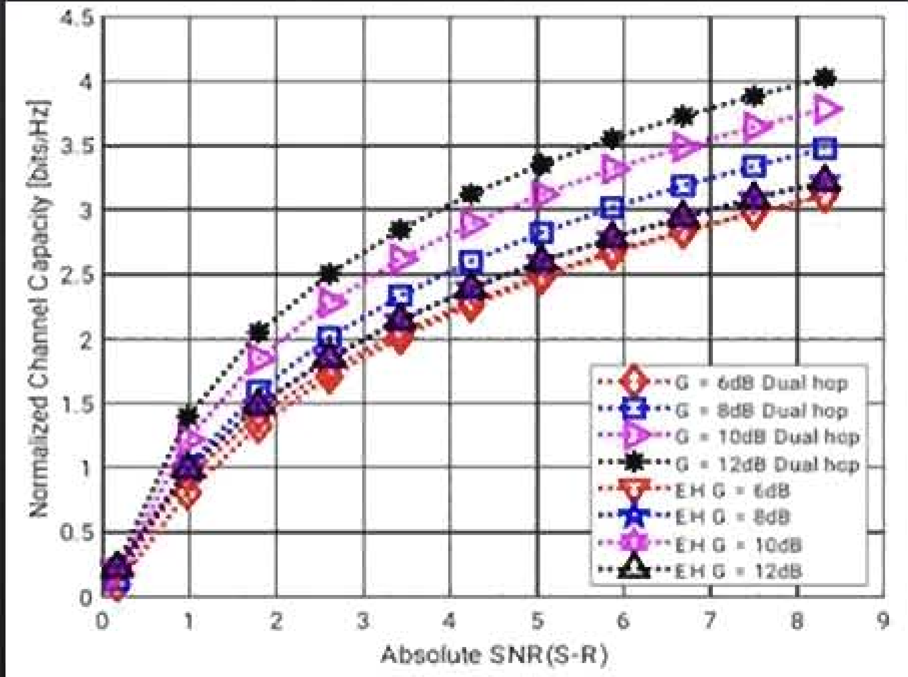
RESULTS (cont.)

- In a similar manner, the near result for ideal parameters in the figure 5(c) and 5(d), which are respectively (ρ = 0.55, P_S = 5dB, G = 8dB) and (ρ = 0.66, P_S = 0dB, G = 6dB).
- In this case, found that there is an inversing relationship between the optimum value of ρ and relay gain G.



(c) ρ = 0.55

Fig. 5 Comparison of channel capacity of conventional deal-hop and EH scheme



(d) ρ = 0.66

Fig. 5 Comparison of channel capacity of conventional dual-hop and EH scheme

CONCLUSION

- In this paper, verified the optimal condition of the dual-hop wireless connection under EH in four distinct approaches.
- Additionally, identified the condition of maxima, minima, and peak SNR all at the same place.
- Under the same conditions, even the difference in distance between EH and non-EH individuals are shown to be minimal.

Thank you!