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Power Allocation for Link Adaptive Relaying System with Energy Harvesting Nodes

J. Raja, R. Anitha

Abstract— In this paper, we consider optimal power allocation for link adaptive relaying systems with energy harvesting(EH) node. EH means source communicates with destination via EH Decode-and-Forward relay over the fading channels. We propose two types of relaying system. The first one is conventional relaying system, the source and relay transmit the signal in consecutive time slot and another one is buffer-aided link adaptive relaying system, the source-relay and relay-destination channels as well as amount of energy available at source and relay finding whether the source or relay is selected for transmission. Our main aim is to maximize the system throughput and to reduce the delay by using the technique is RSS. In both type of relaying system having offline and online power allocation method. Based upon this to analyses the performance gain and give the simulation result.

Index Terms—Buffer- aided link adaptive relaying, conventional relaying, energy harvesting, power allocation, RSS.

I. INTRODUCTION

A source and number of relay expend their energy for processing and transmitting data in cooperative communication systems. For some application , power grid is connected to source and relay but this is not possible for all the condition. So we will go for Pre-charged battery some of the problem overcome by this method. In practice, the limited storage capacity of battery and high transmit power may result in quick drain the battery. As the result replaced/recharged the battery periodically which can be sometime impractical. An alternative solution is deployment of energy harvesting(EH) nodes. EH node harvest the energy from their surrounding environment to carry out their function. Energy can be harvest from solar, thermal, wind etc. EH nodes no need to replace the battery periodically. It will give the long lifetime of the network.EH source and EH relay during the data transmission at random tine and random amount of energy harvest independently. Eh nodes expend the energy from their storage and only the unused energy remains in the battery during the data transmission and other signal processing in the network.

In a source and relay act as a energy harvesting nodes, the type relay used here is Decode and Forward relaying system. We propose two types of relaying mechanism. They are Conventional and Buffer-Aided link adaptive relaying system. To compare their performance for both relaying techniques. In conventional relaying, for offline power allocation we formulate the convex optimization and online case we propose dynamic programming. To eliminate the complexity of dynamic programming, we also propose sub optimal power allocation online scheme. In buffer aided link adaptive relaying, for offline optimization link selection result in a mixed integer non-linear program which solve optimally using spatial branch-and-bound method. In [2] a single source-destination non-cooperative link with an EH source was considered and an optimal offline along with an optimal and several sub-optimal online transmission policies were provided for allocation transmit power to source according to random variation of the channel and energy storage condition. In this paper, we consider the point to point data transmission with an energy harvesting transmitters, but it have a limited amount of battery capacity. In this we consider the two main objectives: 1)maximizing the throughput by the deadline, and 2)minimizing the transmission completion time sequence of the communication session. Then we introduce a *directional water-filling* algorithm, it will gives a simple and short interpretation of necessary optimality condition. We also propose offline and online optimal policies under the various configuration.

In [3], the same system model was considered, where the dynamic programming to allocate the source transmit the power for the case when causal channel state information(CSI) was available. Two type of side information(SI) on the channel condition and harvested energy are assumed to be available: 1) Casual SI is consist the past and present slots of channel condition, in terms of SNR, and amount of energy harvest in the past slots 2)Full SI is consist also the past and present slot, in addition to that future slots of the channel condition and amount of energy harvested

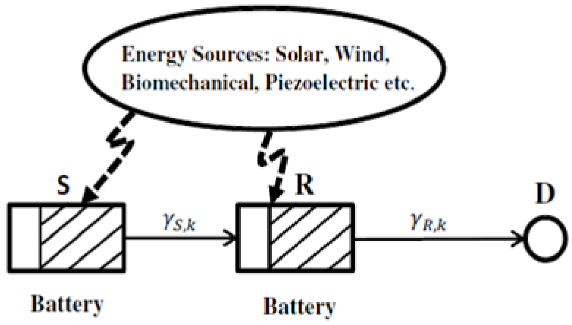

Fig. 1. System model for single link S-R-D

The use of EH relays in cooperative communication was introduced in [4], where the performance analysis was performed for relay selection in cooperative network employing EH relay. We introduce the concept of energy constrained and energy unconstrained relay and analytically characterize the symbol error rate of the system. Further gained by asymptotic analysis that consider the case where signal to noise ratio or number of relays

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Dr. J. Raja, Professor, Department of ECE, Adhiparasakthi Engineering College, Melmaruvathur, Kanchipuram, India.

Miss. R. Anitha, M.E Applied Electronics, Department of ECE, Adhiparasakthi Engineering College, Melmaruvathur, Kanchipuram, India.

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are large. Our analysis based on the EH relays used and its availability for relaying. It does not depends only a relay energy harvesting process , but also on its transmit power setting and other relay in the system. A deterministic EH model for the Gaussian relay channel was consider [5], here delay and no-delay constrained traffics were studied. 1) Delay-Constrained(DC) traffic: The destination is required to decode the i-th source data, i=1,...,N, immediately after it receives the signal from the source in the i-th block and from relay in the (i+1)-th block and then forwarded to destination. 2)No-delay Constrained(NDC): Decoding delays provided that all source messages are decoded at the end of each N-block transmission.

In [6] we consider the power splitting receiver which dynamically splits the received power into two power streams for information decoding and energy harvesting. We design the power allocation algorithms maximizing the spectral efficiency(bits/s/Hz) of the data transmission. In this the constraint on the minimum power delivered to the receiver. The suboptimal algorithm will produce the excellent performance. In summary the contribution of this paper are follows:

I. We propose optimal offline, online and sub optimal online power allocation scheme for EH nodes employing the conventional relaying protocol in the fading channel. The optimal offline and online power allocation is formulated as a convex optimization problem and DP problem respectively. To reduce the complexity of optimal online scheme, several sub optimal, low complexity online scheme are proposed.

II. We propose optimal offline, online and sub optimal online power allocation scheme for EH nodes employing the buffer-aided relaying protocols in the fading channel. The optimal offline joint power allocation and link selection scheme is formulated as an MINLP problem, which is solved optimally by the sBB method. The two sub optimal, low complexity online power allocation scheme are proposed,

II. System Model

We consider an EH relay system, where the source, S communicates with destination, D via a cooperative relay R(Decode-and-Forward) relaying system as shown in Fig. 1. Both S and R are the EH device and are equipped with battery, which have limited storage capacity and store the harvest the energy for the future uses. The S and R in the signal transmission and processing depends on the amount of harvested energy stored in their battery. The harvested energy can be in any form for example solar, wind, thermal. We assume that S has perfect knowledge of the channel SNR and energy harvested at R.

A. Conventional Relaying

Signal Model: In conventional relaying system, during the first time slot, S transmit the R receive, and during the second time slot, R transmit and D receive. This sequential process continue for K time slot, where K is assumed to be an even number . The received packets at R in the (2k-1) th time slot is modeled as

$$y_{R,2k-1}= h_{S,2k-1}x_{2k-1}+ n_{R,2k-1},\ k\ \varepsilon \{1, 2, ... k/2\} \quad (1)$$

where $h_{S,2k-1}$ is the fading gain of the S-R link and $n_{R,2k-1}$ is the noise sample at R. The transmitted packets x_{2k-1} contain Gaussian-distributed symbol. Assume DF relay, the detected packet, $\hat{x}_{2k}$ is transmitted from R during time slot 2k. Thus the received packets at D is given by

$$y_{D,2k}= h_{R,2k}\ \hat{x}_{2k}+ n_{D,2k} \quad (2)$$

where $h_{R,2k}$ and $n_{R,2k}$ is the fading gain of the R-D link and the noise sample at D respectively. $h_{S,2k-1}$ and $h_{R,2k}$ can follow any fading distribution, eg Rayleigh, Rician fading . $n_{R,2k-1}$ and $n_{D,2k}$ are the Additive White Gaussian Noise(AWGN) samples having zero mean and unit variance. We assume the channels are quasi-static within each time slot and channel SNRs of the S-R and the R-D link denoted by $\gamma_{S,2k-1}$ and $\gamma_{R,2k-1}$ respectively. For future reference, we introduce the average SNRs of the S-R and R-D links as $\overline{\gamma_S}$ and $\overline{\gamma_R}$ respectively.

System Throughput: If x_{2k-1} is transmitted from S with transmit power $P_{S,2k-1}$ during the time slot 2k-1,

$$\xi_{S,2k-1} = \log_2 (1+ \gamma_{S,2k-1}\ P_{S,2k-1}) \quad (3)$$

bits of data can be received error-free at R. Similarly , if $\hat{x}_{2k}$ is transmitted form R with transmit power $P_{R,2k}$

$$\xi_{R,2k} = \log_2 (1+ \gamma_{R,2k}\ P_{R,2k}) \quad (4)$$

bits of data can be received error-free at D. During the 2kth and (2k-1) th time slots, S and R , respectively, do not transmit any data, i.e $P_{S,2k}=0$ and $P_{R,2k-1}=0$. We assume that R ensures error-free detection by employing an approximate error correction coding scheme and hence $\hat{x}_{2k}= x_{2k-1}$. Therefore , the end-to-end (S-R) system throughput is given by $\frac{1}{2}\min\{ \xi_{S,2k-1}, \xi_{R,2k} \}$bits/s/Hz where the factor $\frac{1}{2}$ is due to half- duplex constraint.

B. Buffer-Aided Adaptive Link Selection

Signal Model: For buffer -aided link adaptive relaying, relay R is equipped with a buffer in which it can temporarily store the packets received from S. In this case, S decides whether S or R should transmit in a given time slot, k ε {1, 2, ... k }, based on the CSI of the S-R and the R-D links. Therefore , unlike conventional relaying , in any time slot k, S or R can transmit packets. Lets d_k ε {0,1} denote a binary link selection variable, where d_k = 0 (d_k = 1) if the S-R(R-D) link selected for transmission. When d_k = 0, the received packets at R is given by

$$y_{R,k} = h_{S,k}\, x_k + n_{R,k}. \quad (5)$$

On the other hand , when d_k = 1, the received packets at D is given by

$$y_{D,k}= h_{R,k}\ \hat{x}_k+ n_{D,k}. \quad (6)$$

System Throughput: When d_k = 0, S is selected for transmission and $\xi_{S,k}$ bits of data can be transmitted error-free via the S-R link. Hence, R receives $\xi_{S,k}$ data bits from the S and appends them to the queue in its buffer. Therefore, the number of bits in the buffer at R at end of the *k*th time slot is denoted as Q_k and given by $Q_k= Q_{k-1}+ \xi_{S,k}$. However, when d_k = 1, R transmits and the number of bits transmitted via the R-D link is given by min{ $\xi_{R,k}$, Q_{k-1}}, i.e the maximal number of bits that can be by R is limited by the number of bits in the buffer and the instantaneous capacity of the R-D link. The number of bits remaining in the buffer at the end of the *k*th time slot is given by $Q_k= Q_{k-1}-\min\{ \xi_{R,k}, Q_{k-1}\}$. We assume that S has always data transmit and the buffer at R has very large capacity to store them. Therefore, a total of $\sum_{k=1}^{K}\min\{dk\, \xi R, k, Qk-1\}$ bits are transmitted from S to D during the entire transmission time.

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III. POWER ALLOCATION AND LINK SELECTION FOR BUFFER-AIDED RELAYING

In this section, we propose offline and online joint link selection and power allocation schemes for EH system employing buffer-aided relaying. Buffer-aided relaying is preferable over conventional relaying for purpose which can stand delays but require high throughput.

A. Offline Power Allocation

Our goal is to maximizing the total number of transmitted bits (from S to D) delivered by a target of K time slots for the link adaptive transmission protocol. The offline information about the full CSI and the energy arrivals at S and R in each time slot are assumed to be identified in proceed. The consequential maximization problem is subject to a causality control on the harvest energy and the storage control for the battery at both S and R. The major problem is non-convex MINLP due to binary variable d_k and non-convex and non-linear constraint. Then, we propose two optimal method to solve the buffer-aided link adaptive offline optimization problem.

1) Exhaustive Search: This method of searching the cost function is maximizes. This approach cannot be adopted for large value of K.

2)Spatial Branch-and-Bound(sBB): The feasible lower bounds are chosen to be local minimizes of the problem whereas the upper bounds are obtained from convex relaxation .

B. Online Power Allocation

In practice, only fundamental information about channels and harvested energy is available for power allocation. Therefore, the offline power allocation scheme is not eagerly related as, at a given time slot, the future CSI and upcoming harvested energy are not know in proceed. To this end, we could formulate an optimal online method using stochastic DP. Unfortunately, this approach leads to a very high computational complexity because of the adaptive link choice in every time slot and may not be implementable in practice. Therefore, we propose two efficient suboptimal online schemes which have low complexity.

1) Suboptimal Harvesting Rate (HR) Assisted Online Power Allocation: We propose an efficient online power allocation scheme referred to as "HR Assisted". To this end, we create an optimization problem which is based on the average data rate, the average energy causality constraints at S and R, and the average buffering constraint.

2) Suboptimal Online Power Allocation: In the suboptimal power allocation scheme for link adaptive relaying, at every time slot, K,S and R consider the total of energy stored in their batteries as their transmit power. Based on the transmit power, S and R calculate their capacity. The buffer status should be taken into account in the computation of the capacity of R. The S-R (R-D) link is selected if the capacity of S is greater (smaller) than that of R.

IV. POWER ALLOCATION FOR CONVENTIONAL RELAYING

In this section, we propose an offline and several online power allocation scheme for the considered EH system with conventional relaying. We note that conventional relaying is preferable over buffer-aided relaying if small end-to end delays are required.

A. Offline Power Allocation

Like for buffer-aided relaying, for conventional relaying, our goal is to maximize the total number of transmitted bits delivered by a deadline of K time slots. We assume offline information of full CSI and the energy arrivals at S and R in each time slot. The offline optimization problem for maximization of the throughput of the considered system of K time slot.

B. Online Power Allocation by DP

Unlike buffer-aided link adaptive relaying, the link selection policy is pre-defined for the conventional relaying, i.e., $d_{2k-1} = 0$ and $d_k = 1$, K ε {1,2,..... k}. This feature of the conventional relaying reduce the complexity of stochastic DP compared to link adaptive relaying. Therefore, for conventional relaying, we consider a stochastic DP approach for optimum online power allocation

C. Received Signal Strength (RSS) for offline and Online Power Allocation

We propose the technique is called as RSS. In the wireless network many number relays will be there. Based on RSS value to select the relay and then find the route between the S and D. Compared to the previous one using the RSS to give the maximize the throughput.

V. SIMULATION RESULTS

In this section, we evaluate the performance of the proposed offline and online power allocation for conventional, buffer-aided link adaptive without RSS and buffer-aided link adaptive with RSS relaying protocols.

A. Packets Received

In this subsection, we show the performance of the proposed power allocation scheme for conventional and buffer-aided adaptive relaying.

In Fig. 2 show number of packets received for various relaying system. Based upon this to analysis the performance.

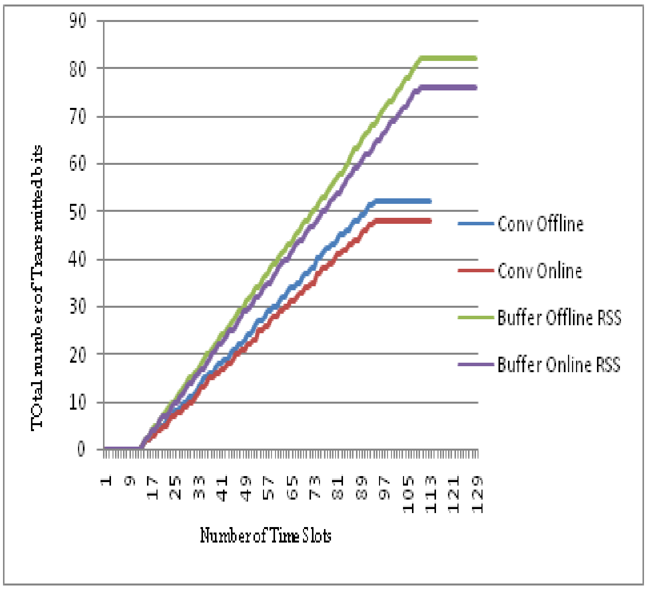

Fig. 2 Number of Time Slots vs. Total number of Transmitted bits

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B. Throughput

In this subsection, we show the performance of the proposed power allocation scheme for conventional and buffer-aided adaptive relaying

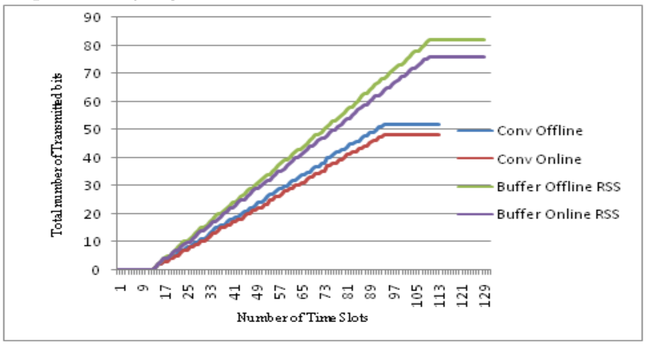

Fig. 3 Number of Time Slots vs. Total number of Transmitted bits

In Fig. 3 show number of packets received efficiently for various relaying system. Based upon this to analysis their performance.

C. Harvesting Energy

In this subsection, we show we propose power allocation scheme for conventional and buffer-aided adaptive relaying.

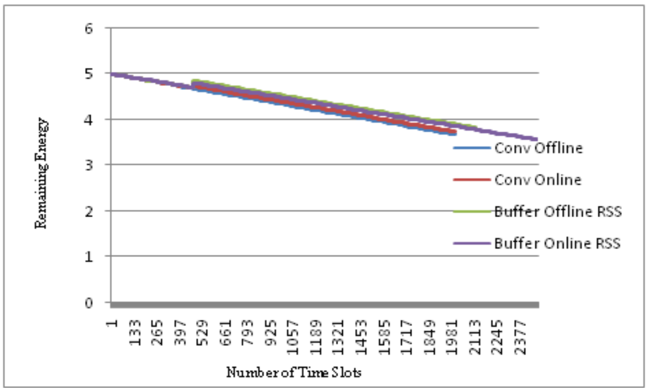

Fig. 4. Number of Time Slots vs. Remaining Energy

In Fig 4 show that after the data transmission and processing remaining energy contain the particular node having.

D. Performance of Offline

In this subsection, we show the throughput analysis of offline power allocation for the buffer-aided link adaptive relaying system with RSS and without RSS. In Fig. 5 show, to compare the both relaying system with RSS show that the best performance results. Hence the more number of packets will be received by the short number of time slots period.

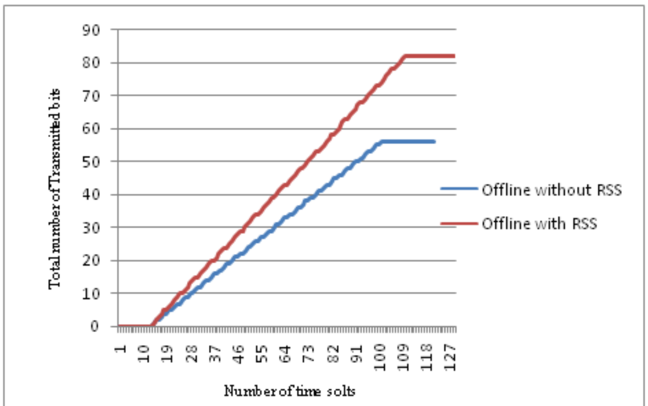

Fig. 5 Number of Time Slots vs. Total number of Transmitted bits

E. Performance of Online

In this subsection, we show the throughput analysis of online power allocation for the buffer-aided link adaptive relaying system with RSS and without RSS. In Fig. 6 show, to compare the both relaying system with RSS show that the best performance results. Hence the more number of packets will be received by the short number of time slots period

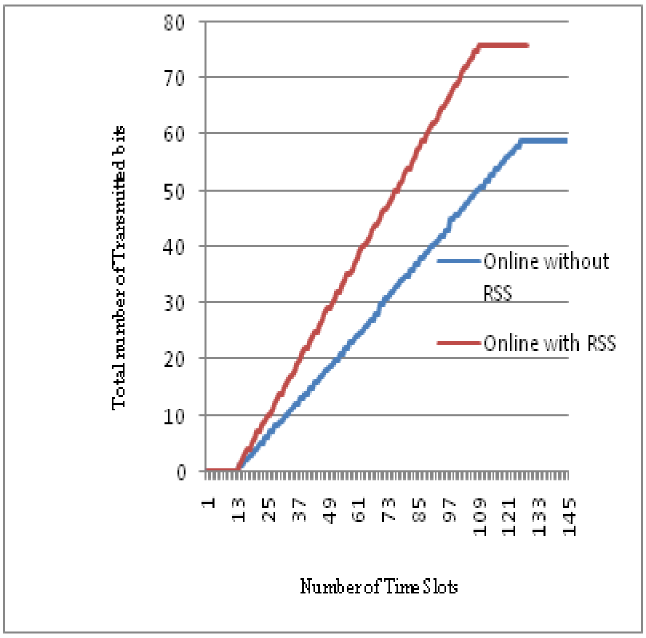

Fig. 6 Number of Time Slots vs. Total number of Transmitted bits

In Table 1 and Table 2 show the compare the offline and online power allocation for the buffer-aided link adaptive relaying system with RSS and without RSS calculation of different number of time slots. Hence show that for both with RSS values give the best performance. Among that offline power allocation for buffer-aided link adaptive with RSS gives the best performance result.

Table 1. Comparison table for Offline power allocation buffer-aided link adaptive relaying system with and without RSS value of the different number of time slots

Number of Time Slots	Number of Transmitted Bits	
	Without RSS	With RSS
10	0	0
25	8	10
40	17	20
50	25	30
65	30	40
75	40	50
90	50	60
100	55	69
115	56	82

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Table 2. Comparison table for Online power allocation buffer-aided link adaptive relaying system with and without RSS value of the different number of time slots

Number of Time Slots	Number of Transmitted Bits	
	Without RSS	With RSS
10	2	3
25	8	10
40	15	20
50	25	30
65	30	40
80	40	60
105	50	76
129	59	76

VI. CONCLUSION

In this paper, we have considered the problem of transmit power allocation for multi relay networks, where harvest the energy needed for transmission from the surrounding atmosphere is Source and Relay. Two different relaying mechanism, namely conventional relaying and buffer-aided link adaptive relaying. have been measured. We proposed several optimal and suboptimal offline and online power allocation schemes maximizing the system throughput of the measured EH systems. Simulation result showed that the proposed suboptimal online scheme have a good complexity-performance. Moreover, we showed that, for both offline and online optimization, adopting the link adaptive protocol radically improves the throughput compared to conventional relaying, specially for asymmetric link qualities, and buffer-aided link adaptive relaying is more robust to changes in the EH profile than conventional relaying. Finally, using RSS in buffer-aided link adaptive offline simulation result will give the best performance compare to all other relaying system.

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Dr. J. Raja, received his B.E (Electronics and Communication Engineering) from Anna University Guindy, M.E (Power Electronics) from Anna University Guindy and Ph.d from MIT Chennai. Currently, he is working in Adhiparasakthi Engineering College, Melmaruvathur as Professor.

R. Anitha, received her B.E (Electronics and Communication Engineering) from Saveetha Engineering College, Chennai and pursuing M.E (Applied Electronics) in Adhiparasakthi Engineering College, Melmaruvathur.

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