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An Instantaneous Transmission Mode Analysis in Energy Harvesting for Half-Duplex and Full-Duplex Relaying Network

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Abstract

Energy harvesting (EH) based on surrounding radio frequency (RF) has lastly become advanced approach to prolong the lifetime of the wireless networks. This paper deals with energy harvesting architecture of the half duplex and the full duplex relaying networks. By applying time switching based relaying (TSR) protocol and Amplify-and-Forward (AF) scheme, we derive the closed-form expression of the instantaneous throughput and then compare instantaneous throughput of two networks. An important result can be seen clearly that the time fraction, the position of relay, noise at relay, energy conversion factor as well as target rate in TSR impact on their throughput. Finally, numerical results show an efficient relaying strategy in half-duplex and full duplex cooperative networks.

***Keywords**: Energy harvesting (EH), full duplex (FD), half duplex (HD), instantaneous throughput, Amplify-and-Forward (AF)*

1. Introduction

Maintain the lifetime of a wireless network by energy harvesting has drawn huge concern of many researchers in recent time. The simultaneous wireless power and information transfer (SWIPT) for system-cyphered duplex relay transmittance from a communication theory opinion, in that two resources reciprocate communication over a power collecting relay is studied. By examining the time switching (TS) relay receiving structure, the TS-based two-way relaying (TS-TWR) protocol as well as a secret information model for half-duplex amplify-forward relay systems in the available several wiretaps are introduced. Not the same popular relay system, knowing that the relay is "green", *i.e.*, it is energized by the power collected from the relay supervisions [1-4].

An amplify-and-forward (AF) relaying system is examined, in that a power constrained relay node collects power from the receiving RF signal and utilizes that collected power to transmit the resource communication to the target. Relied on the time switching and power splitting receiving structures, two relaying protocols i) time switching-based relaying (TSR) protocol and ii) power splitting-based relaying (PSR) protocol are suggested to offer power collecting and communication solving at the relay [5-9].

A knowledge scenario in that a power collecting secondary user (SU) divides the channel with a primary user (PU) is considered. The SU is set up with two antennas. It maintains a fix size power waiting line and two free size information waiting lines, in that one for saving its very information batches and another for saving the first undistributed information packets [10-15]. The advantage of this solution lies in the fact that RF signals

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can carry energy and information at the same time. Thus, energy constrained nodes can scavenge energy and process the information simultaneously [16-21].

Therefore, in this paper, we analyze the instantaneous throughput of half-duplex and full-duplex relaying with novel ability of energy harvesting and information transfer. Based on the analytical expressions, their throughput and performances are studied, by that we can compare and draw which one is better than to use.

The remainder of this paper is organized as follows. Next section describes the system model of the EH enabled and HD and FD one-way relaying network. Third section is the instantaneous throughput analysis. Simulation results are presented in forth section. Finally, conclusion is proposed in this paper.

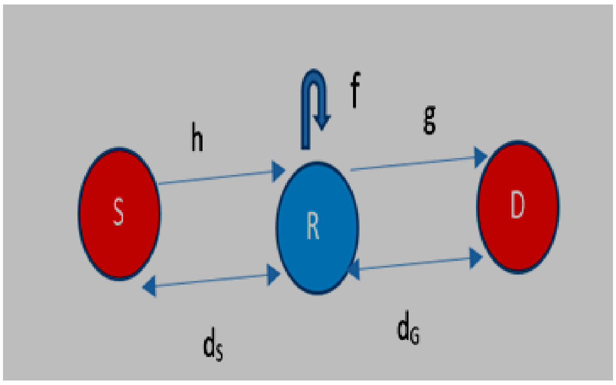


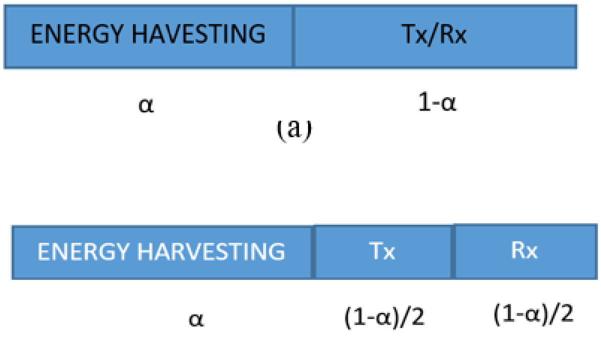
Figure 1. System Model of One Way Half Duplex and Full Duplex Relaying

2. System Model

We suppose a three-node network consisting of one resource S, one relay node R and one destination D. Figure. 1 depicts the network model. There is no direct link between source-destination and communication can be exchanged through the relay node. Every nodes are set up with one antenna (the relay operates in FD mode is equipped with two antennas, one for transmission and other for reception). The source node has always data to transmit. The relay node has no energy supply and harvests energy from the environment in order to forward the source's signal. It adapts an energy harvesting architecture and so it directly converts the harvested energy to electric energy for operating its circuits. Due to hardware/circuit constraints the relay node cannot simultaneously receive/transmit data and harvest energy. Communication is organized in time-frames of duration one time unit T.

Based on the TSR protocol proposed in Figure 2, the communication process is divided into two phases. In the first phase, the energy transfer from the source to the relay with a duration of $\alpha T, (0 < \alpha < 1)$ and the second phase, the remaining time, $(1-\alpha)T$ is used to transmit information (in case full-duplex) and $(1-\alpha)T/2$ for information receiving, another $(1-\alpha)T/2$ for information transfer(in case half-duplex protocol), in which α is time switching coefficient and T is time for the considered signal frame.

We assume that all the harvested energy can be used for transmission. The relay node employs an Amplify-and Forward (AF) relaying strategy and can operate either in HD or in FD mode. All wireless links exhibit fading and additive white Gaussian noise (AWGN). The fading is assumed to be frequency nonselective Rayleigh block fading. h, g and f denotes the exponential channel power gains for the link S → R, R → D and R → R (loop interference from the relay output to the relay input for the case of FD operation).



(b)

(a) Full-Duplex, (b) Half-Duplex

Figure 2. Illustration of the Parameters of TSR Protocol

2.1. Full-Duplex Relaying

Through the energy harvesting period, the receiving signal at the relay as

$$y_R = \sqrt{\frac{P_S}{d_S^m}} h x_S + n_R \tag{1}$$

In which P_S is the resource transmittance energy, n_R is the additive white Gaussian noise at R with zero-mean and variance of σ_n^2.

Dealing with radio receiving power, the collected power at the relay is taken by [2]

$$E_h = \eta \alpha T \frac{P_S |h|^2}{d_S^m} \tag{2}$$

where m is the exponential path loss, η is the power conversion factor, h_s, h_d are the channel gain factors between resource-relay line and relay-destination line, in turn.

In the communication transmittance phase, suppose that the resource node transfers signal x_S to R and R re-transfers signal x_r to the destination node x_j, $j = S, R$, in turn. They have unit energy and zero–mean, i.e., $E\left[|x_j|^2\right] = 1$ and $E\left[x_j\right] = 0$. So, the received signal at the relay under self-noise resource is given as

$$y_R = \sqrt{\frac{P_S}{d_S^m}} x_S h + f x_R + n_R \tag{3}$$

where f is the residual self-noise co-efficiency at R.

We assume R collects y_R and in the one after timeslot, R utilize the collected power to magnify y_R. So the amplification of the priority receiving signal, x_R, is

$$x_R = H y_R \tag{4}$$

In which H is the magnification factor of R.

Relied on AF relaying model at R, the magnification factor is given by

$$H = \sqrt{\frac{P_R}{\frac{P_S}{d_S^m}\left|h\right|^2 + P_R\left|f\right|^2 + \sigma_n^2}} \tag{2}$$

It is worth writing that harvested energy then assist operation for the next stage transmittance, P_R is taken by

$$P_R = \frac{E_h}{(1-\alpha)T} = \mu P_S \frac{\left|h\right|^2}{d_S^m} \tag{6}$$

In which μ is denoted as $\mu = \alpha\eta(1-\alpha)^{-1}$

Then, we get the receiving signal at destination as

$$y_D = \frac{h_R}{\sqrt{d_R^m}} x_R + n_D \tag{7}$$

In which n_D is additive white Gaussian noise at destination node with a zero-mean and variance of $\sigma_d^2 = \sigma_n^2 = \sigma^2$.

Replacing (4), (5), (6) into (7), we compute the receiving signal as

$$y_D(\kappa) = \underbrace{\frac{g}{\sqrt{d_2^m}} H \frac{h\sqrt{P_S}}{\sqrt{d_S^m}} x_S}_{signal} + \underbrace{\frac{g}{\sqrt{d_R^m}} H f x_R}_{RSI} + \underbrace{\frac{g}{\sqrt{d_R^m}} H n_R + n_D}_{noise} \tag{8}$$

Through rudimentary substitute, we get new formula as

$$\gamma_{FD} = \frac{\dfrac{P_S\left|h\right|^2 P_R\left|g\right|^2}{d_S^m d_R^m P_R\left|f\right|^2}}{\dfrac{\sigma^2 P_S\left|h\right|^2}{P_R\,|\,f\,|^2\, d_S^m} + \dfrac{P_R\left|g\right|^2}{d_R^m} + \sigma^2} \tag{9}$$

We suppose that the channel gains $\left|h\right|^2, \left|g\right|^2$ are independent and identically distributed exponential.

2.2. Half- Duplex Relaying

The same full-duplex system, in half duplex network, we obtain

$$y_{RHD} = \sqrt{\frac{P_S}{d_S^m}} h x_S + n_R \tag{10}$$

and the relay magnifies the input signal by a factor which is taken by

$$H_{HD} = \sqrt{\frac{P_R}{\frac{P_S}{d_S^m}\left|h\right|^2 + \sigma^2}} \tag{11}$$

where $P_{RHD} = 2\mu P_S \frac{|h|^2}{d_S^m}$

Then, we get the receiving signal at destination as

$$y_{DHD} = \frac{g}{\sqrt{d_R^m}} x_R + n_D \tag{12}$$

The same as above calculate, we get

$$\gamma_{HD} = \frac{\frac{P_S |h|^2 P_R |g|^2}{d_S^m d_R^m \sigma^2}}{\frac{P_S |h|^2}{\sigma^2 d_S^m} + \frac{P_R |g|^2}{d_R^m \sigma^2} + 1} \tag{13}$$

2.3 Throughput Analysis

In this section, we analyze the instantaneous throughput of half-duplex and full-duplex one-way relaying with energy harvesting and information transfer. Based on those analytical expressions, the throughput of schemes is derived and we can evaluate their performance.

The instantaneous throughput at the scheme, when the relay harvests energy from the source signal and uses that power to amplify and forward the source signal to the destination is a function of the energy harvesting time α. In the delay-limited transmission protocol, the transmitter is communicating at a fix transmission rate R bits/sec/Hz and $(1-\alpha)T$ is the effective communication time. So, the throughput of systems are obtained as:

for FD relaying network

$$\tau_{FD} = (1-\alpha)\log_2(1+\gamma_{FD}) \tag{14}$$

for HD relaying network

$$\tau_{HD} = \frac{(1-\alpha)}{2}\log_2(1+\gamma_{HD}) \tag{15}$$

Unfortunately, it is difficult to derive instantaneous throughput mathematically but we can obtain their performances by simulation as presented in the next section.

3. Results and Discussion

In this section, we use the derived analytical results to compare instantaneous of two systems. We set the source transmission rate $R = 3\,(bps/Hz)$ (except Figure.8), and then the outage SINR threshold is given by $Z = 2^R - 1$. The energy harvesting efficiency is set to be $\eta = 1$ (except in Figure.5), the path loss exponent is set to be $m = 3$. For simplicity, we set the distance $d_S = d_R = 1$ (except Figure.4). Also, we set $\lambda_s = \lambda_d = 1; \lambda_r = 0.1$, $\sigma^2 = 0.1$ (except Figure.3) and $\alpha = 0.3$ (except Figure.6 and Figure.7).

It can be seen from Figure. 3, when σ increases, throughput of full-duplex system increases, throughput of half-duplex are on the contrary. This is because σ is as high as influence on performance of two systems. We can find that when $\sigma < 0.2$ throughput of half-duplex system is better full-duplex a little.

As your observation, Figure 4 examines the impact of position of relay on the instantaneous throughput of systems. The throughput of HD is as higher when relay is as closer resource node, and as far S node, throughput of HD as small than FD mode. The throughput of FD system increases as d_S increases from 0.15 to optimal value 1, however it starts decreasing as d_S increases over its value. This is because for the values of d_S higher than, it means d_R decrease, and this factor impacts on their performance.

In Figure 5, we can see clearly that effect of energy conversion factor on performances of two systems. When $\eta < 0.65$ throughput of FD is better than HD. Just only having a little contrary when η is greater than this value.

Figure 6 and Figure 7 show that α factor impacts on throughput of two systems, α as high throughput as small. This is easy to understand because there are much information than transferred to destination when α decreasing.

In Figure 8, we can see clearly that effect of target rate on performances of two systems. R is as big, throughput is as high.

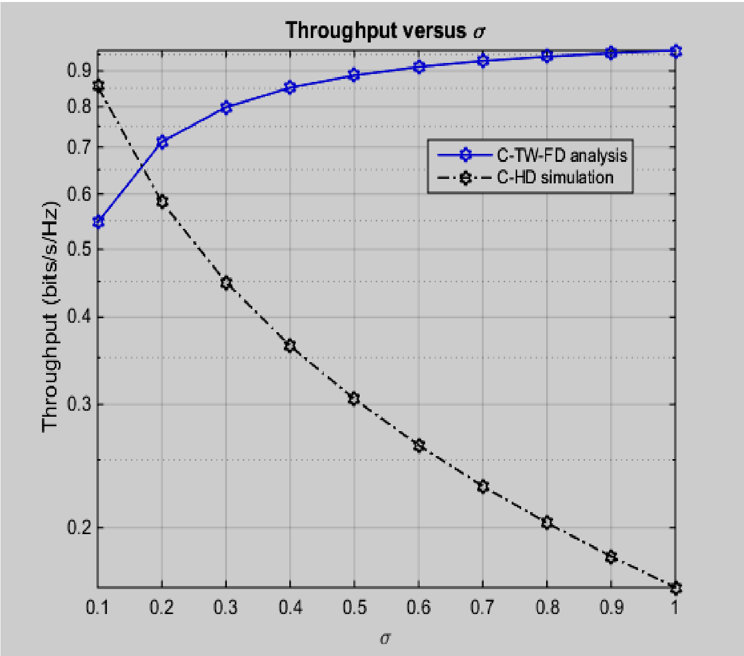


Figure 3. Instantaneous Throughput of HD and FD Energy-Aware Relaying Network Versus σ

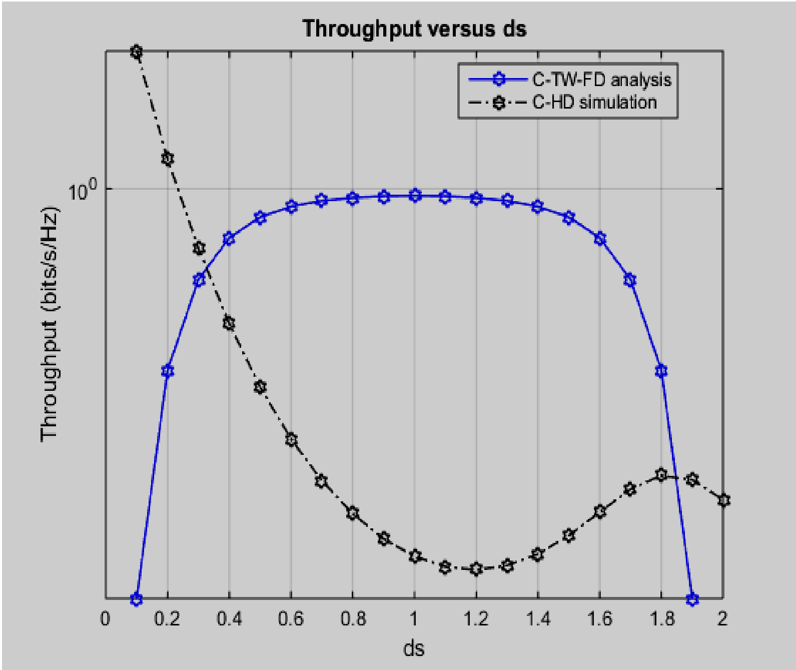


Figure 4. Instantaneous Throughput of HD and FD Energy-Aware Relaying Network Versus dS

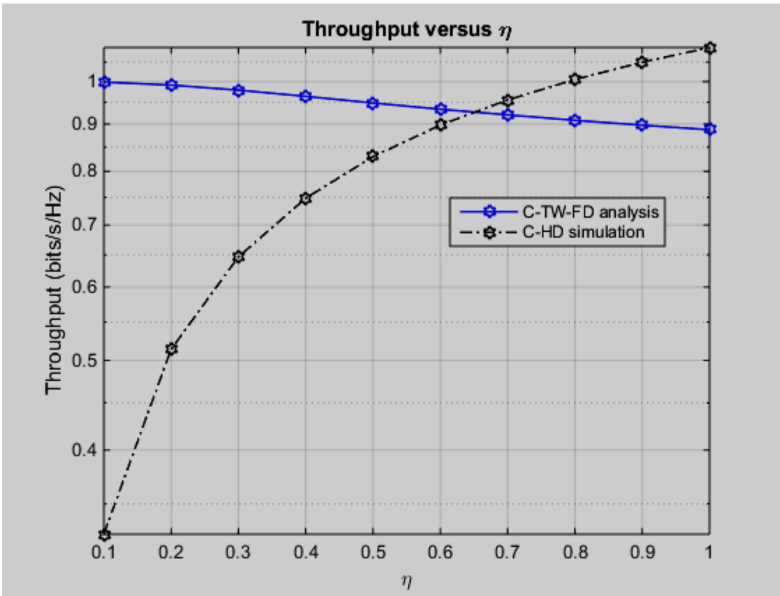


Figure 5. Instantaneous throughput of HD and FD Energy-aware Relaying Network versus η

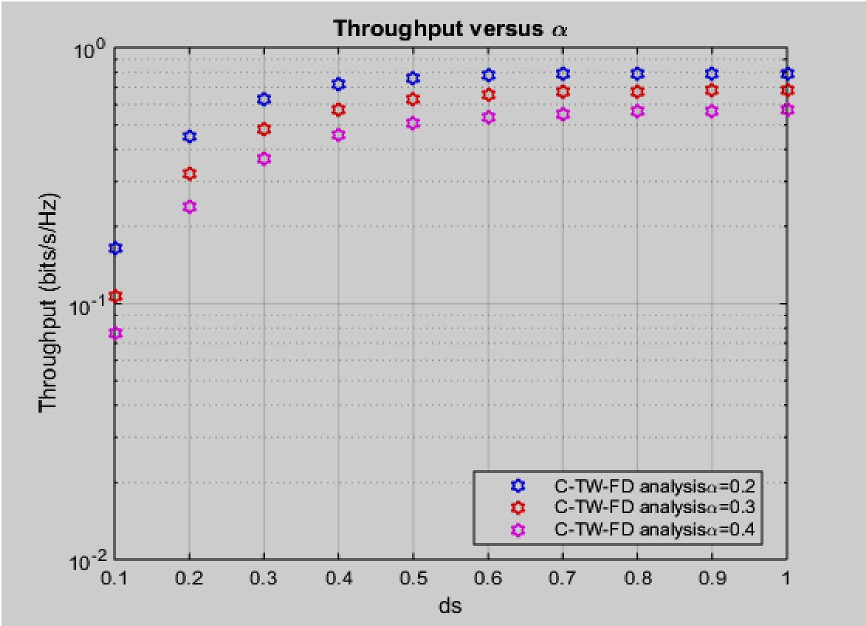


Figure 6. Instantaneous Throughput of FD Energy-Aware Relaying Network Versus α

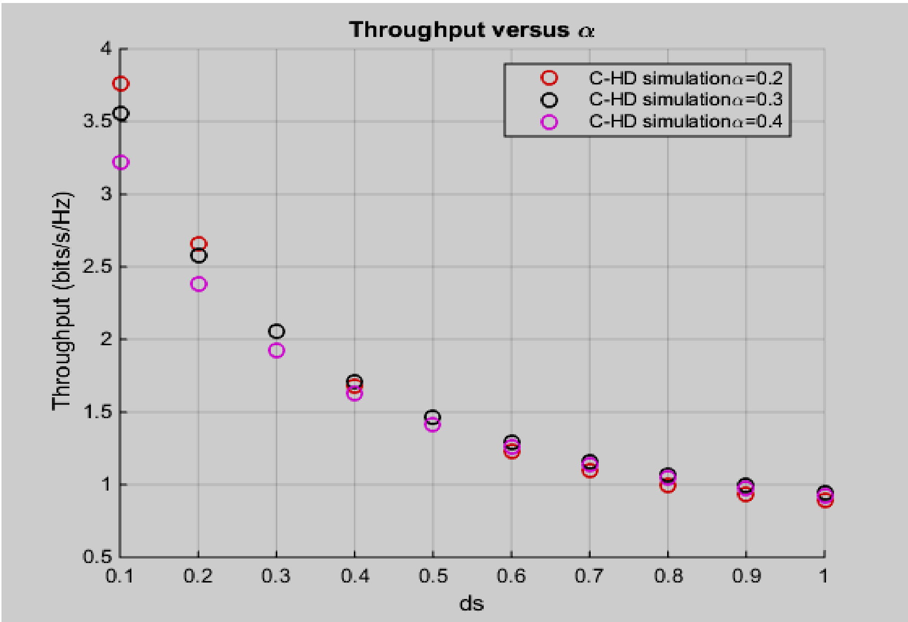


Figure 7. Instantaneous Throughput of HD Energy-Aware Relaying Network Versus α

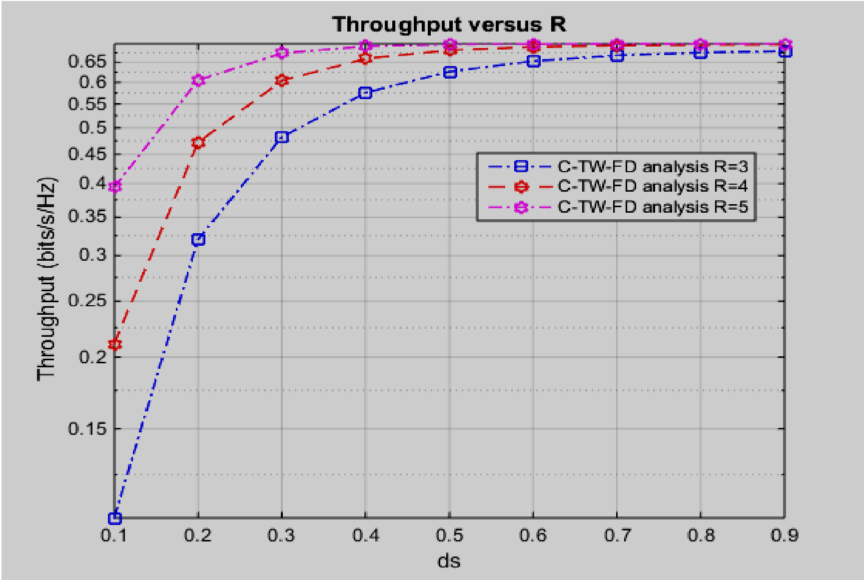


Figure 8. Instantaneous Throughput of FD Energy-Aware Relaying Network Versus R

5. Conclusion

In this paper, we have proposed a half-duplex and full duplex relaying network with wireless energy harvesting and information transfer protocol, where an energy constrained relay node harvests energy from the received RF signal and uses that harvested energy to forward the source signal to the other sources. In order to determine the instantaneous throughput, analytical expressions for the instantaneous throughput of two systems in TSR protocol can be found by simulation. Through that, it is obviously seen full-duplex mode outperforms half-duplex system in instantaneous throughput of AF mode in TSR protocol.

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