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# Performance Analysis of The Energy Harvesting Techniques in Cooperative Communication Systems of NBIoT Devices Using Amplify and Forward (AF) Relaying Protocol

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## ABSTRACT

This study examines the system's performance with implementation of the energy harvesting (EH) techniques at source node, S and relay node, R. The RF signals which are used to energy harvesting proccess are broadcasted by destination node, D. The information signals from S are sent to D via a R in a cooperative communication framework. The R uses the amplify and forward (AF) protocol to forward the received signal from S to D. We propose a network system which contain of three femto cells, and an access point of each femto cells work as a relay (R), in a macro cell with a base station or eNB as a destination (D). To find the best R for forwarding the information signal from S to D, we choose the partial relai selection strategy. From the simulation results can be shown that the throughput system and the outage probability system are affected by the location of S or the distance of between S-R and S-D. Also affected by the access point power of femto cell that is connected to electric source, and time swithing factor, $\rho$ which is used to harvest energy at S and R nodes. The shorter distance of between S-R and S-D results a better value of throughput system and the outage probability system, since the gain channel value will be high and increases the SNR value at D. More bigger the power from battery of access point femto cell that is used together with the harvested power by R to forward the signal will result a better value of throughput system and the outage probability system. More smaller time swithing factor, $\rho$ results more time period for transmitting signal by S and forwarding sinyal by R, therefore increases the transmit power at S and R. Increasing the transmit powers result the increasin SNR value at D, and result a better value of throughput system and the outage probability system.

**Keywords**: energy harvesting, time-switching, cooperative comunication, relay selection, throughput, outage probability.

## INTRODUCTION

Internet of Things (IoT) technology has grown rapidly by offering a global connection that is interconnected, such as forming a smart world. Many studies on the topic of IoT have been published, such as in papers [1]-[3]. With the global internet every time various kinds of objects such as consumer goods, moving goods such as cars, motorcycles, sensors or other necessities can be connected to IoT so that it can increase efficiency or productivity. Several terms for the application of IoT are well known, such as smart transportation, smart home, smart healthcare, smart grid, etc. [4]. But the weakness of IoT devices is that the battery capacity is limited so that the operating time is not long. Recharging the battery (battery recharging) or replacing a new battery also takes time and is expensive, especially if you are in a difficult environment.

Fortunately, the energy harvesting (EH) technique was emerged to solve this problem [5]. One of the energy harvesting (EH) technique is radio frequency energy harvesting (RF-EH) which is independent of solar heat [6], wind [7] and easy to be controled [8]-[10]. The other advantage of RF-EH technology are able to encourage the growth of Internet of Things (IOT) application because it can increase the life time of IoT devices without charging and replacing batteries. Varshney introduced the technique of energy harvesting and sending signal information simultaneously, known as simultaneous wireless information and power transfer (SWIPT) [11]. Natsir et al [12], introduces the time switching relaying (TSR) and power splitting-based relaying (PSR) protocols that perform EH processing and relay data transmission on a cooperative communication network. In [12] the TSR protocol was applied to the AF and DF relay protocols and an evaluation of the throughput efficiency was carried out. The performance of SWIPT on a cooperative communication system by implementation of the Partial Relay Selection scheme on Decode-and-Forward (DF) relay protocol is reported in the paper [13]. In [13] two SWIPT schemes are applied, static power splitting based relaying (SPSR) and optimal dynamic power splitting based relaying (ODPSR), and system performance is displayed in outage probability values with parameters of SNR value, number of relays and harvesting efficiency value. In paper [13] the EH process is carried out on the relay terminal of the RF signal sent by S, and the relay forwards the information signal to D only by utilizing the power obtained from EH. Also the relay protocol used is the decoding and forward (DF) protocol.

In contrast to paper [13], this study will evaluate the throughput of a cooperative communication system using the amplify and forward (AF) relaying protocol. The system scenario is a network of three areas as femto cells with diameter about 30 meters in a macro cells area. Each femto cell has an access point as a relay node, and the best of these relay nodes will be selected to forward the information signal from S to the main access point of macro cells area as D. Also the TSR protocol of the energy harvesting (EH) technique is used at S and R to produce the electric energy from the RF signal which is transmitted by D. Assume S and each of R are equipped by the circuit to process the radio frequency energy harvesting (RF-EH) and the EH power will be used together with the battery power of R to forward the signal to D.

Compared with previous papers, the contribution of this paper, since R is an access point which has a fixed battery power from the electric source. This power can be used together with the harvested energy to forward the information signal from S to D, and when the electric power source is shutdown, the battery power is off, R node still can forward the signal using the its harvested energy.

## METHODS

### *A. Energy Harvesting and Signal Transmission*

The proposed system model is equipped with energy harvesting techniques using Amplify and Forward (AF) relay protocol and Time Switching Based Relaying (TSR) protocol applied to S and R nodes, as shown in Fig. 1. It is a cooperative communication system. In this system, there is a user (UE) as source S. The three femtocell access points across the EU, $R_k, k \in (1, 2, 3)$ as relays, and the main access point of the macrocell as destination, D, form an uplink transmission mode.

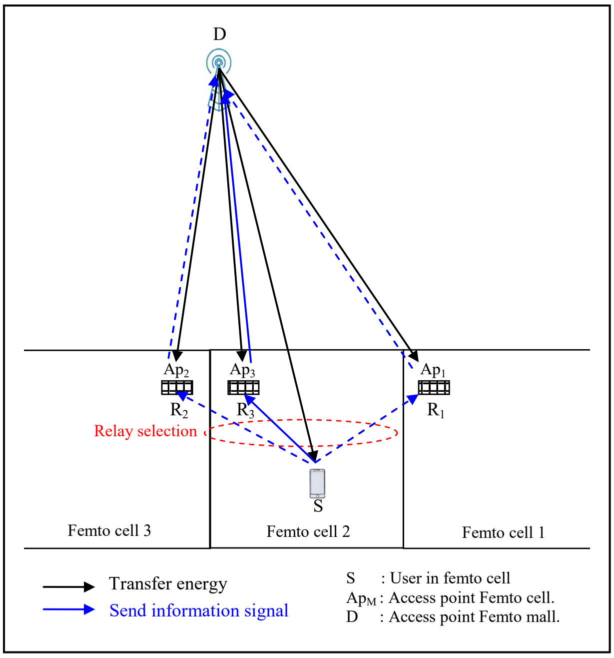


Figure 1. System model, three femto cells with uplink transmission.

It is assumed the fading of the S – D link is large enough and the transmit power of S, is limited, so the signal transmission from S to D is considered non-existent, or the information signal which is received by D is only from a selected R. And to send the information signal from S to D, we use a relay selection strategy to find an access point as a selected R. Then by the selected R the signal is forwarded to D by applying AF protocol relaying. Each R, S, and D device has an antenna and operates in half-duplex mode. S and each R have circuitry for the energy harvesting process.. Each R and S processes energy harvesting from the RF signal which is transmitted by D.

The time division according to TSR protocol of the energy harvesting technique is shown as Figure 2.

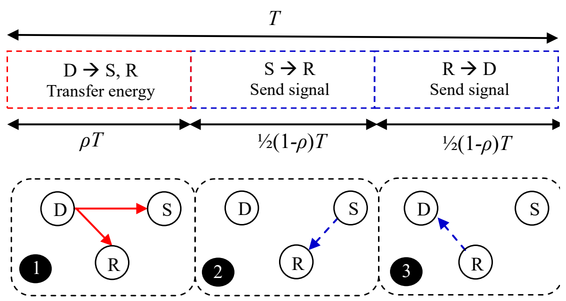


Figure 2. Time division according to the TSR protocol.

The amount of energy obtained in S and $R_k$ considering distance and path loss exponent m is written as,

$$E_s = \eta\rho T P_{BS}(|h_{SD}|^2/d_{SD}^m) \quad (1)$$

$$E_{R_k} = \eta\rho T P_{BS}\left(\left|h_{R_kD}\right|^2/d_{R_kD}^m\right), k = 1,2,3 \quad (2)$$

where $P_{BS}, \eta$ is the transmit power of the macrocell or D's main access point, and the energy conversion efficiency, $0 \le \eta \le 1$. $h_{SD}, h_{R_kD}$ is the coefficient channel of S - D connection, $R_k$ – D connection. $d_{SD}, d_{R_kD}, m$ are the distance S - D, the distance $R_k$ – D, and the path attenuation exponent, respectively. And the transmit power at S and the kth access point ($R_k$) can be written as,

$$\begin{aligned} P_S &= E_S/[(1-\rho)T/2] \\ &= 2\eta P_{BS}(|h_{SD}|^2/d_{SD}^m)\,\rho/(1-\rho) \end{aligned} \quad (3)$$

$$\begin{aligned} P_{R_k} &= E_{R_k}/[(1-\rho)T/2] \\ &= 2\eta P_{BS}\left(\left|h_{R_kD}\right|^2/d_{R_kD}^m\right)\rho/(1-\rho) \end{aligned} \quad (4)$$

The received information signal at the k-th R from S can be written as,

$$y_{SR_k} = \sqrt{P_S d_{SR_k}^{-m}}\, h_{SR_k}\, x + n_{SR_k} \quad (5)$$

where $h_{SR_k}, n_{SR_k}$ is the coefficient channel of the (S – $R_k$) connection, the AWGN noise at the kth R. $d_{SR_k}$ is the distance between S – $R_k$. At R, the received signal is amplified by a fixed gain factor $G$, so the transmitted signal from $R_k$ is

$$\begin{aligned} x_{R_k} &= G_k y_{SR_k} \\ &= G_k\left(\sqrt{P_S d_{SR_k}^{-m}}\, h_{SR_k}\, x + n_{SR}\right) \end{aligned} \quad (6)$$

where

$$G_k = \frac{\sqrt{P_{R_k}}}{\sqrt{\frac{\left|h_{SR_k}\right|^2 P_S}{d_{SR_k}^m} + N_0}} \quad (7)$$

$P_{R_k}$ is the transmitted power at $R_k$ due to the RF-EH process and $n_{SR_k}$is the AWGN noise at $R_k$ with zero mean and variance $N_0$..

$$\sqrt{\frac{\left|h_{SR_k}\right|^2 P_S}{d_{SR_k}^m} + N_0} = \sqrt{\left|h_{SR_k}\right|^2 P_S d_{SR_k}^{-m} + N_0}$$

called the power constraint factor.

The received signal at D can be written as,

$$y_D = \frac{h_{R_kD}}{\sqrt{d_{R_kD}^m}} x_{R_k} + n_{RD}$$

$$= \frac{h_{R_kD}}{\sqrt{d^m_{R_kD}}} G_k\left(\sqrt{P_S d^{-m}_{SR_k}}\, h_{SR_k}\, x + n_{SR}\right) + n_{R_kD}$$

$$= \frac{h_{R_kD}}{\sqrt{d^m_{R_kD}}} G_k\left(\sqrt{P_S d^{-m}_{SR_k}}\, h_{SR_k}\, x\right) +$$

$$\frac{h_{R_kD}}{\sqrt{d^m_{R_kD}}} G_k(n_{SR}) + n_{R_kD}$$

$$= \underbrace{h_{R_kD}\sqrt{d^{-m}_{R_kD}}\, G_k\left(\sqrt{P_S d^{-m}_{SR_k}}\, h_{SR_k}\, x\right) +}_{\text{Power section}}$$

$$\underbrace{h_{R_kD}\sqrt{d^{-m}_{R_kD}}\, G_k(n_{SR}) + n_{R_kD}}_{\text{Noise section}} \qquad (8)$$

where $h_{R_kD}, n_{R_kD}$ are the channel coefficients of the $R_k$ - D connection and the AWGN noise in D, each with zero mean and $N_0$ variance.

### *B. Relay Selection Strategy*

In this research, a partial relay selection (PRS) strategy was applied to obtain the best R that will used to forward information signals from S to D. PRS strategy chooses the best relay based on the maximum value of the SNR at S based on S – $R_k$ distance and conversion efficiency ($\eta$) of each R.

$$\gamma_{RS_{best}}: R_{best} = \max_{k=1,2,..,K} \gamma_{R_kS} \qquad (9)$$

$$\gamma_{RS_{best}} \approx \frac{P_{R_{best}} d^{-m}_{SR_{best}} \left|h_{SR_{best}}\right|^2}{\sigma^2_{SR_{best}}} \qquad (10)$$

with

$$P_{R_{best}} = 2\eta_{best} P_{BS}\left(\left|h_{R_kD}\right|^2 / d^m_{R_kD}\right)\rho/(1-\rho)$$

By having the best R, the signal received at the D be written like,

$$\begin{aligned} y_D &= h_{R_{best}D}\sqrt{d^{-m}_{R_{best}D}}\, G_k\left(\sqrt{P_S d^{-m}_{SR_{best}}}\, h_{SR_{best}}\, x\right) \\ &+ h_{R_{best}D}\sqrt{d^{-m}_{R_{best}D}}\, G_k\left(n_{SR_{best}}\right) + n_{R_{best}D} \end{aligned} \qquad (11)$$

where $h_{R_{best}D}$ is the channel coefficient of $R_{best}$ – D. For simplification of writing the word $h_{R_{best}D}best$ is omitted so eq. (10) can be written as follows,

$$\begin{aligned} y_D &= h_{RD}\sqrt{d^{-m}_{RD}}\, G\left(\sqrt{P_S d^{-m}_{SR}}\, h_{SR}\, x\right) \\ &+ h_{RD}\sqrt{d^{-m}_{RD}}\, G(n_{SR}) + n_{RD} \end{aligned} \qquad (12)$$

Using eq. the SNR value at, D is written as,

$$\gamma_D = \frac{|h_{RD}|^2\, d^{-m}_{RD}\, G P_S\, d_{SR}^{-m}\, |h_{SR}|^2}{|h_{RD}|^2 d^{-m}_{RD}\ \ G_k^2\, N_0 + N_0} \qquad (13)$$

If the transmit power in R used to pass the signal to D is the sum of RF-EH power and battery power, then the gain factor $G_k$ can be written as,

$$G = \frac{\sqrt{P_R + P_{AP}}}{\sqrt{|h_{SR}|^2 P_S d^{-m}_{SR} + \sigma^2_{SR}}} \qquad (14)$$

$P_{AP}$ represens the battery power of R.

### *C. Throughput and Outage Probability*

Throughput system at D can be determined when the SNR value at D is known, such as equation (13), for the delay-limited transmission type. Throughput is determined by evaluating the outage probability, $p_{out}$, with a fixed transmission rate from R to D, $R$ bits/sec/Hz.

The data transmission rate or data rate is expressed as,

$$R \triangleq \log_2(1 + \gamma_{th}) \qquad (15)$$

and $\gamma_{th}$ = represents the threshold value of SNR at D. Or, $\gamma_{th} = \gamma_D$ can be wrtten as,

$$R\gamma_{th} = 2^R - 1 \quad (16)$$

Outage probability is defined as the SNR probability of end-to-end point below the SNR threshold value. is expressed as, $p_{out}$

$$p_{out} = Pr(\gamma_D < \gamma_{th}) = F_{RD}(\gamma_{th}) \quad (17)$$

where $F_{RD}$ is the CDF of $\gamma_{th}$.

Since the $\gamma_D$ value contains the parameters of the energy harvesting period $\rho$, the probability outage is also a function of $\rho$. If the $\rho$ value is large, the transmission power at R is also large and decreases the outage value.

If S transmits signal with the transmission rate of *R* bits/sec/Hz and the effective period of signal transmission from the S to D through R is $(1-\rho)T$, then the throughput at D, $\tau$ can be expressed as,

$$\begin{aligned} \tau &= (1-p_{out})R\frac{(1-\rho)T}{T} \\ &= (1-p_{out})R(1-\rho) \end{aligned} \quad (18)$$

*D. Transmission Optimization Scenario*

The transmission of a symbol signal is divided into three periods. In the first period, $\rho T$. D broadcast the RF signal which is harvested by S and R. At the beginning of the second period $(1-\rho)/2T$, small portion of this period is used by each R to send a few pilot bits to S, using a small portion of power or its harvested energy. A best R is selected by S based on signal-to-noise ratio of those pilot bit signal. And the relay selection process can be done by evaluating the distance of S-R and energy conversion efficiency, $\eta$ of each R that influence the SNR value at S. After a best R is selected, S then sends the information signal to this selected R at the remaining portion of second period $(1-\rho)/2T$.

The information signal received from S is relayed through the selected relay for a third period of time $(1-\rho)/2T$, where $0 \le \rho \le 1$ is the time switching factor of the TSR protocol. In the AF relaying protocol, R amplifies the received signal by the fixed gain factor (eq. 14) before forwarding it to D. Finally, we evaluate the system's performance by using the SNR value of the received signal at D. Since the access points as R are connected to electric power source so forwarding the signal from R to D would use the summing of harvested energy and energy from electric power source.

**RESULT AND DISCUSION**

The parameters of our simulation are listed below**.**

- Path loss exponent = 1.7
- Distance between S and R = 4 - 10 meters.
- Distance between S and D = 30 – 40 meters.
- Distance between R and D = 35 meters.
- The harvesting efficiency, η = 0.6 - 0.9.
- The time swithing factor, ρ = 0.3 - 0.6.
- Transmit power of macro cell = max 30 dBm.
- The number of R (access points ) = 3.
- Data transmission rate, R = 1, 2, 3 and 4. where: UE, the access point of macro cell, and access point of femto cell are as S, D and R.

*A. Performance for Different Distances*

The data transmission rate, R = 2, the throughput and outage probability system with different distance of S-R and S-D are shown in Figure 3 and 4.

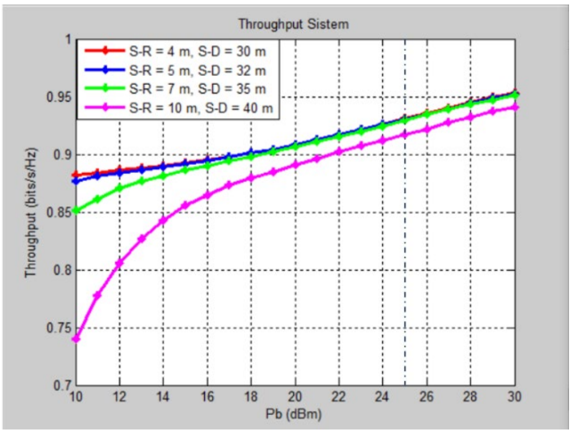

Figure 3. The throughput system

From Figure 3, it can be seen when the transmitted power of RF signal from D to S and

R for harvesting energy is 25 dBm, the system throughput at a distance of S-R = 4 meters and S-D = 30 meters, the distance of S-R = 5 meters and S-D = 32 meters, as well as the distance of S-R = 7 meters and S-D = 35 meters, as 0.93 bits/s/Hz. When the distance S-R = 10 meters and S-D = 40 meters, the throughput system reaches a value of 0.92 bits/s/Hz. From these results it can be concluded that the throughput system will be high when the distance between S-D and R-D are low.

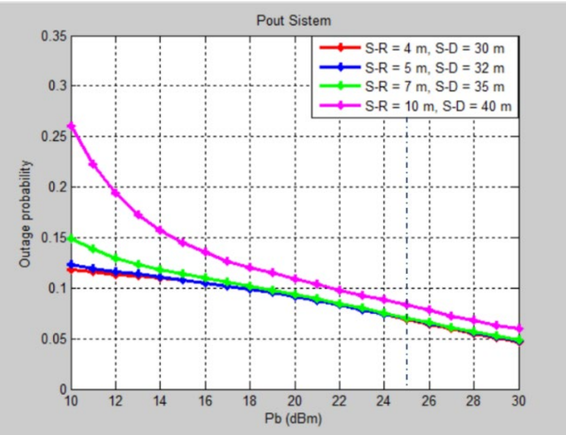


Figure 4. The outage probability system.

From Figure 4 the outage probability system value for a distance of S-R = 4 meters and S-D = 30 meters, a distance of S-R = 5 meters and S-D = 32 meters, as well as a distance of S-R = 7 meters and S-D = 35 meters, are same as 0.07 . When the distance S-R = 10 meters and S-D = 40 meters, the outage probability system value is 0.08. From these results, it can be concluded that the outage probability system is affected by the distance between S-D and R-D and the value will be high when the distance between are high.

*B. Performance of Difference Battery Power of Femto Cell Access Point (R), Pap.*

The throughput and outage probability system with different battery power of femto cell access point, Pap are shown in Figure 5 and 6.

From figure 5, it can be seen when the transmit power of RF signal from D is 25 dBm, the throughput system for Pap = 0.1 watts, 0.09 watts, 0.07 watts and 0.05 watts, the throughput system are 0.92 bits/sec/Hz, 0.915 bits/sec/Hz, 0.910 bits/sec/Hz, and 0.905 bits/sec/Hz, respectivey. And without using battery power Pap, or using harvested energy only the throughput system is only 0.89 bits/s/Hz. From these results it can be concluded that the throughput system will be better when the battery power of the femto cell access point, Pap is getting bigger.

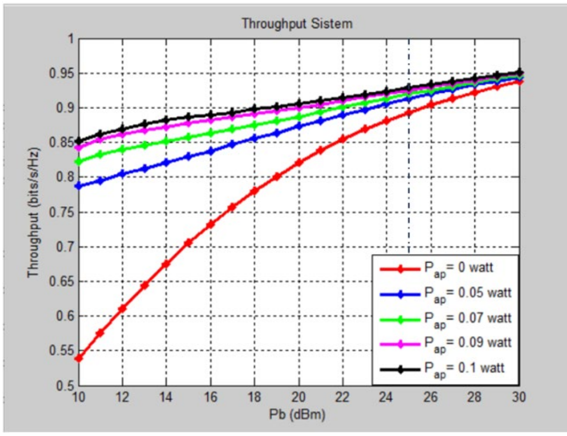


Figure 5. The throughput system with different battery power access point, Pap.

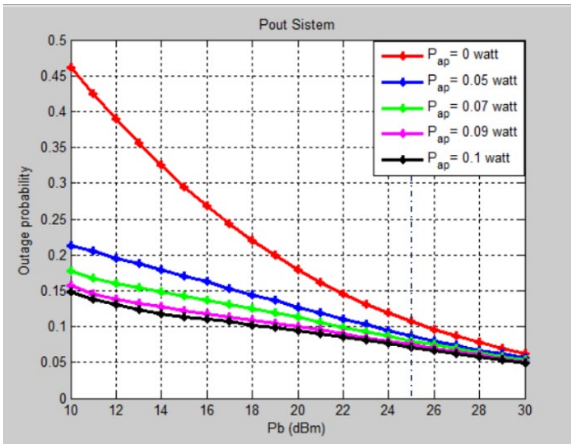


Figure 6. Th outage probability system with different battery power access point, Pap.

The transmit power of RF signal from D is 25 dBm, for Pap = 0.1 watts, 0.09 watts, 0.07 watts and 0.05 watts the outage probability system value is 0.07, 0.072, 0.08, and 0.09 respectively. Without Pap power the outage probability system is 0.11. From these results, it can be concluded that the outage probability system is affected by the amount of power are given by the femto cell access point, Pap.

*C. Performance of Different Time Switching Factors (ρ)*

The *Time Switching* Factors ($\rho$) is the factor that determine how long the harvesting energy time period or transmitting sinyal time period are used. The curves in Figure 7 and 8 shows this factor affects the system performances.

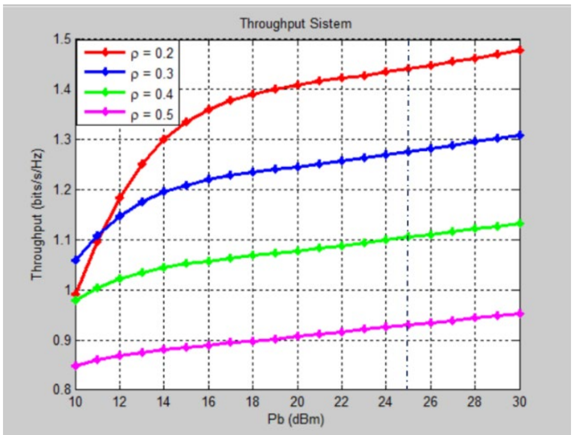


Figure 7. System throughput with *Different ρ*

Figure 7 shows the throughput system values when transmit power form D is 25 dBm. For $\rho$ = 0.2, 0.3, 0.4 and 0.5 the throughput system values are 1.42 bits/sec/Hz, 1.29 bits/sec/Hz, 1.11 bits/sec/Hz and 0.92 bits/sec/Hz respectively. From these results it can be concluded that the throughput system will be better when $\rho$ is small.

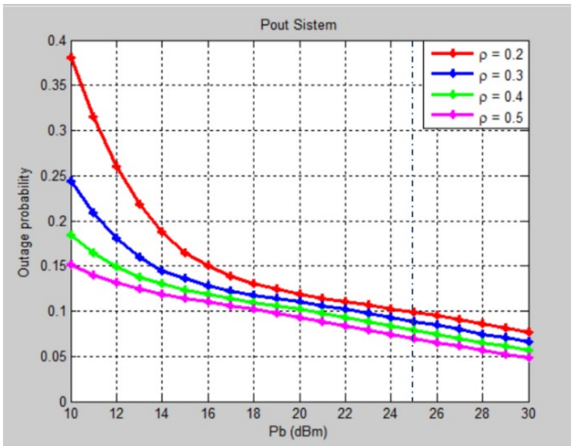


Figure 8. The outage probability system with *Different ρ*

Figure 8 shows the outage probability system values when transmit power form D is 25 dBm. For $\rho$ = 0.2, 0.3, 0.4 and 0.5 the the outage probability system are 0.1, 0.09, 0.08 and 0.07. From these results, it can be shown that the outage probability will be better when the $\rho$ is high.

## CONCLUSION

We have conclusion that the throughput system and the outage probability system are affected by the location of S or the distance of between S-R and S-D. Also affected by the access point power of femto cell as R, and the time swithing factor, $\rho$ which is used to harvest energy at S and R. The shorter distance of between S-R and S-D results a better value of throughput system and the outage probability system, that is 0.93 bits/s/Hz and 0.08. More bigger the power of access point femto cell is used together with the harvested power by R to forward signal will result a better value of throughput system and the outage probability system, that is 0.92 bits/s/Hz, and 0.07. More smaller time swithing factor, $\rho$ results more time period of the transmitting signal by S and forwarding sinyal by R, and results the throughput and the outage probability values of 1.42 bits/s/Hz and 0.1.

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