Error Performance of Information Decoder for SWIPT With Integrated Receiver

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Abbreviations

- SWIPT - Simultaneous Wireless Information and Power Transfer
- EH - Energy Harvester
- ID - Information Decoder
- QD - Quadratic Detector
- ED - Envelope Detector
- RX - Separated Receiver
- IoT - Internet of Things
- IIE-RX - Integrated Information and Energy Receiver
- SISO - Single-Input Single-Output
- ASK - Amplitude Shift Keying
- BER - Bit Error Rate
- ADC - Analog to Digital Converter

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Abstract

- SWIPT can be realized by means of Integrated Receiver, where both the EH and ID operate on rectified received signal.
- Researchers investigate the effect of the non-linearity of rectifier on the error performance of the information decoder when transmitting over a Nakagami-m fading channel.
- Demonstrated through analysis and simulation, that, the low-noise error performance strongly depends on the small-signal behaviour of the rectifier.
- Approximating the rectifier by a quadratic detector yields accurate bit error rate results, whereas an over-optimistic error performance is obtained when applying the envelope detector approximation.

Introduction

- SWIPT is a promising technique for powering energy-limited information-processing devices, which are commonly used in the IoT.
- Recently, a new type of RX was proposed, namely IIE-RX, which rectifies the incoming signal, and subsequently splits the rectifier output current between the EH and ID circuits.
- Authors investigate the error performance of the ID in the IIE-RX, using biased ASK on a SISO Nakagami-m block-fading channel, with the receiver knowing the distorted ASK constellation at the rectifier output.
- The main contribution is the derivation of an analytical expression for the BER of the Maximum Likelihood(ML) detector in the low-noise regime.

SWIPT with Integrated ID and EH Receiver

- Considering a single-antenna TX sending symbols $a(k)$ from a normalized constellation(i.e, $E[|a(k)|^2] = 1$) over a flat Nakagami-m block-fading channel to a single-antenna IIE-RX.
- As discussed, the IIE-RX rectifies the input signal and then splits up the output current between ID and EH.

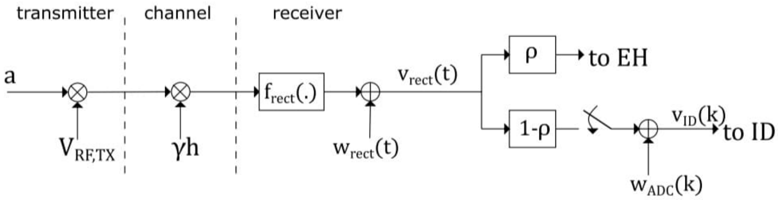

Figure: Block diagram of the Model for the IIE-RX

Symbols used in the above figure are as described,

TABLE I

SYMBOL DESCRIPTION TABLE

$V_{\mathrm{RF,TX}}$	TX rms voltage	ρ	current splitting factor
V_{RF}	RX rms voltage	f_{rect}	rectifier characteristic
v_{ID}	voltage at ID	w_{rect}	rectifier noise
P_{EH}	harvested power	w_{ADC}	quantization noise
v_{rect}	rectifier output	w_{ID}	total noise at ID
γh	channel gain	$\mathcal{A}_M$	M-ASK constellation

- During the kth symbol interval $(kT, kT+T)$, an RF voltage $v_{RF,TX}(t)$ is applied to the TX antenna, with,

$$v_{RF,TX}(t) = \sqrt{2}|a(k)|V_{RF,TX}cos(2\pi f_c t + \angle a(k)) \tag{1}$$

  where $|a(k)|$ and $\angle a(k)$ denote the magnitude and phase of $a(k)$; the rms value of $v_{RF,TX}(t)$ in this interval equals $|a(k)|V_{RF,TX}$, making $V_{RF,TX}$ the long-term rms value.
- γh is the channel gain, such that $-20log(\gamma)$ denotes pathloss(in dB) and h is normalized fading gain.
- Assuming, $h = |h|e^{j\angle h}$ is constant over a block of K symbol intervals; $|h|$ has a Nakagami-m distribution with $E|h^2| = 1$ and $\angle h \in [0, 2\pi)$, (1) can be written as,

$$v_{RF,TX}(t) = \sqrt{2}V_{RF}|h||a(k)|cos(2\pi f_c t + \theta(k)) \tag{2}$$

  where, $V_{RF} = \gamma V_{RF,TX}$ and $\theta(k) = \angle a(k) + \angle h$.

- The corresponding rectifier output signal $v_rect(t)$ is decomposed as ,

$$v_{rect}(t) = f_{rect}(|h||a(k)|V_{RF}) + w_{rect}(t) \tag{3}$$

- The function $f_{rect}(A)$ is referred to as the rectifier characteristic, which expresses the rms value A of a sinusoidal input signal.
- Considering the simple rectifier circuit from Fig.,

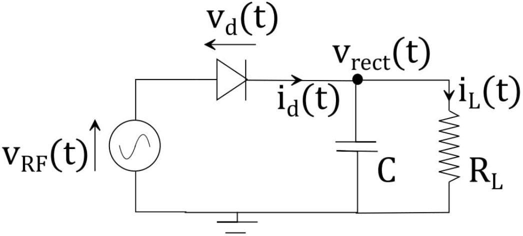

Figure: Simple Rectifier Circuit

- Here,resistive load R_L in Fig. 2 represents the parallel connection of the EH part (load $\frac{R_L}{\rho}$) and the ID part (load $\frac{R_L}{1-\rho}$) of the receiver, which draw currents $\rho\frac{v_{rect}}{R_L}$ and $(1-\rho)\frac{v_{rect}}{R_L}$, respectively.
- The current drawn by the ID part is fed to a sampler and ADC, which results in the voltage $v_{ID}(k)$,

$$v_{ID}(k) = (1-\rho)f_{rect}(|h||a(k)|V_{RF}) + w_{ID}(k) \tag{4}$$

where, $w_{ID}(k) = (1-\rho)w_{rect}(kT) + w_{ADC}(k)$, (4) suggests that $v_{ID(k)}$ doesn't depend on the phase of data symbol $a(k)$.

Rectifier Characteristic

- We determine the characteristic $f_{rect}(A)$ of the rectifier from above fig. by solving the differential equation,

$$C\frac{dv_{rect}}{dt}+\frac{v_{rect}}{R_L}=I_s.(e^{\frac{1}{nv_{th}}}-1) \tag{5}$$

where V_{th} is thermal voltage and the diode is characterized by the reverse saturation current I_s and ideality factor n.

- On solving using proper assumptions, we get,

$$f_{rect}(A)=\frac{1}{2}\left(\frac{1}{R_L I_s}+\frac{1}{nV_{th}}\right)^{-1}\cdot\left(\frac{A}{nV_{th}}\right)^2 \tag{6}$$

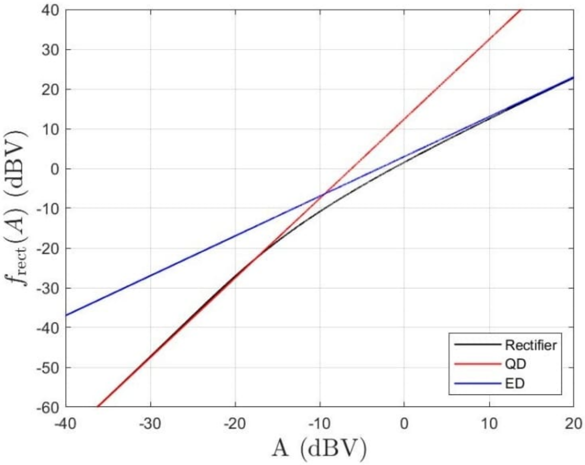

Figure: Rectifier Characteristics showing DC output voltage versus rms input voltage.

BER Analysis

- Considering the transmission of uncoded symbols from biased M-ASK constellation A_M .
- This constellation gets distorted by the rectifier: the signal component in $v_{ID}(k)$ corresponding to $a(k) = \alpha_\ell$ is denoted as,

$$S_\ell = (1-\rho) f_{rect}(|h| \alpha_\ell VRF) \tag{7}$$

- For given $|h|$, the BER is given by,

$$BER = \frac{1}{M log_2 M} \sum_{i,j=0}^{M-1} n_{i,j} P_{i,j} \tag{8}$$

where $n_{i,j}$ is the number of bits in which α_i and α_j differ and $P_{i,j}$ is the probability that α_i is detected when α_j is transmitted.

- After performing extensive calculation, it is obtained that,

$$BER_{avg} = C_{A_M}(m, \beta). \left(\frac{\sigma_{ID}^{2/\beta}}{V_{RF}^2} \right)^m \tag{9}$$

where m is the Nakagami parameter, β is the variable which tells whether the detector is ED($\beta = 1$) or QD($\beta = 2$) and,

$$C_{A_M}(m, \beta) = \frac{1}{Mlog_2 M} . \sum_{i,j=0}^{M-1} n_{i,j} D(m, \beta, i, j) \tag{10}$$

- From (9), we can say, for small σ_{ID},

$$BER_{avg} \propto \left(\frac{\sigma_{ID}^{2/\beta}}{V_{RF}^2} \right)^m \tag{11}$$

this indicates a performance advantage of ED over the rectifier for small σ_{ID}.

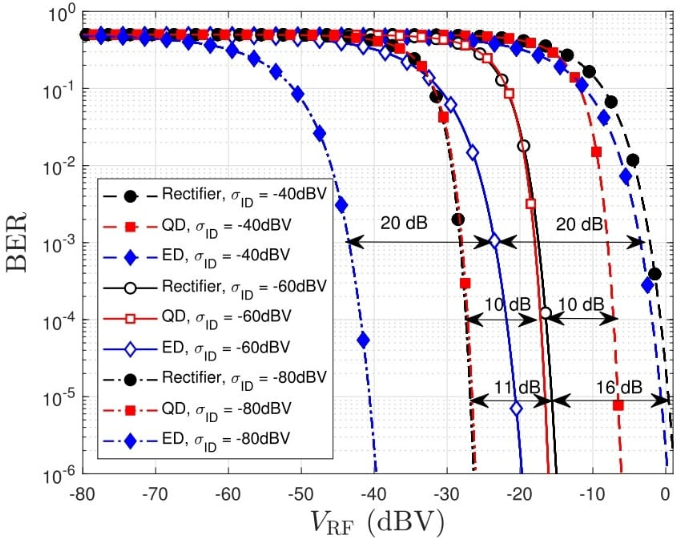

Figure: Conditional BER ($|h| = 1$) versus VRF (2-ASK).

Conclusion

- It is investigated the BER of the ID for SWIPT with an IIE-RX, for the uncoded transmission of biased ASK on a Nakagami-m fading channel, and presented an analytical expression for the resulting BER in the small-noise regime.
- The characteristics of the rectifier and the QD differ considerably for larger input signals, but their small-noise BER curves nearly coincide, even when the average operating point of the rectifier is outside the quadratic region.
- This behavior does not occur for a fixed channel gain, where the BER of the rectifier is closer to the BER of the ED when the rectifier operating point is outside the quadratic region.

Thank You