Blind Spectrum Sensing Using Stochastic Resonance

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Outline

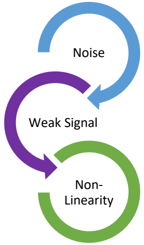
- Spectrum Sensing Challenges/Requirements
- SR Signature
- SR-based sensing in literature
- Proposed Approach
- Performance Evaluations
- Summary

Challenges/Requirements

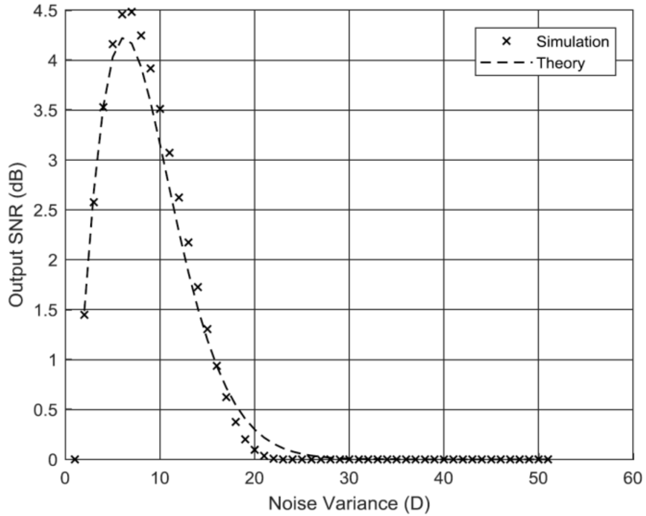
- Blind operation
- Reliable at low SNR
- Resilience to channel noise uncertainty
- Robust performance under frequency selectivity & other channel impairments (fading / time dispersion)
- High Accuracy (low P_{fa})
- Short sensing duration (sensing speed *vs* sensing reliability)
- Low complexity

SR Signature

- Counter-intuitive
- **Stochastic Resonance (SR)** is a phenomenon in which **addition of an optimal amount of noise** can help Improve signal **detectability**, in the spectrum-sensing context,
- SR can be considered as a **noise-induced enhancement** of the response of a *nonlinear system* to a weak input signal.



SR signature



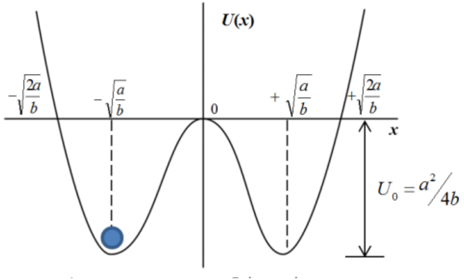
A multi-freq. signal of the form :

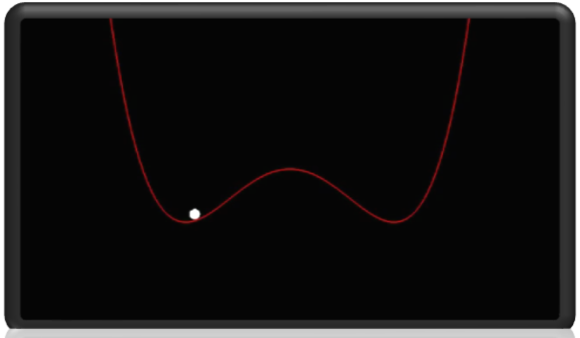
$$s(t) = \sum_{n=1}^{N} A_n \cos(\omega_n t)$$

With N=8 and frequencies generated randomly between 0.1-1 Hz.

SR Background/Signature

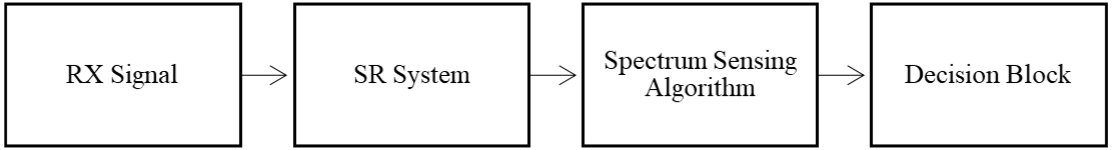
- **Stochastic Resonance (SR)** can be explained in terms of motion dynamics of a particle oscillating in a bistable double-well system, in the presence of a weak (driving/input) signal + noise.
- Stochastic **resonance** occurs when period of inter-well transitions (**Kramer's rate**) matches the period of the driving signal (resonance @ particular noise intensity).
- In the presence of a weak periodic signal, and noise of intensity "D", the double-well gets tilted back and forth, asymmetrically.
- **Performance metrics**: SNR, Mutual Information, Fisher Information, Correlation, PSD, Discrimination Index …
- SR Comes in **different flavours** : Suprathreshold, Chaotic SR, aperiodic SR, cascaded/sequential …
- **"Well" types** : Single / double (bi-stable)/Tri-stable, …





Main Challenge: dynamic tuning of SR system "control" parameters i.e. a, b, .., D.

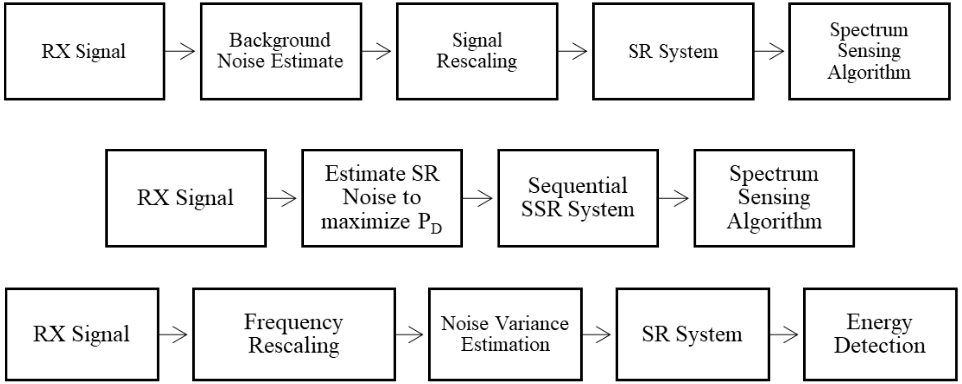
SR-based Sensing in Literature



General approach to SR-enhanced Spectrum Sensing

The **related works in the literature** :

- Are mostly limited to **single/multi-frequency sinusoids and single carrier modulated signals** ,
- Use **SNR or PSD** as an objective function (with few exceptions), whilst metric such as **P_d @ given CFAR**, is a more suitable, in the sensing context,
- Rely on the **knowledge or estimation of channel noise**,
- Ignore (or not report) observed/measured P_{fa},
- Rely on **pre-conditioning techniques** e.g. freq. re-scaling, which is dependent on knowledge of background channel noise,
- Use **empirically derived, off-line calculations** or crude mechanisms for estimation of SR system parameters.

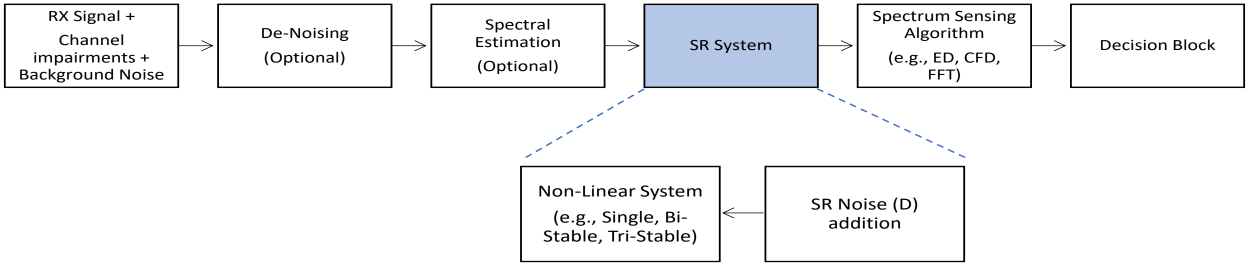


Approaches to SR-enhanced Spectrum Sensing

BUT, gains* of 2-10 dB (over classical techniques) have been reported.

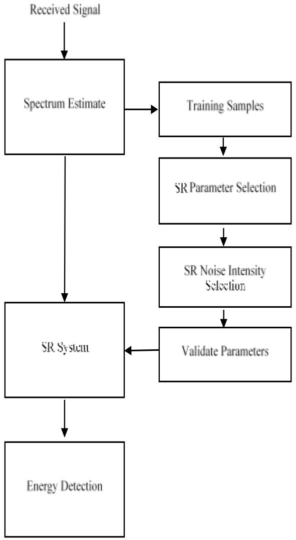
* "gains" refer to e.g. achieving Pd of e.g., 90% at 2-10dB less SNR than classical detection methods

Proposed Stochastic Resonance Aided Sensing (SR-ED)



Aim: **Improve detectability** of multi-carrier modulated signals **using an optimally tuned nonlinear system** (i.e. to achieve maximum P_d while keeping P_{fa} under the constraint), followed by a classic sensing system.

- *"tuning" refers to identification of optimal SR system parameters*



- The received signal is OFDM modulated (incl. channel impairments + noise)
- Using small # test/training samples, SR system parameters e.g. a, b, ..D, are identified/tuned (during a two-step process) & validated,
- All received samples passed through SR system and then onto the ED module for final detection/output.
- Method NOT reliant on noise power estimation/knowledge;
- No re-scaling/pre-conditioning of input signal required

Performance Evaluations

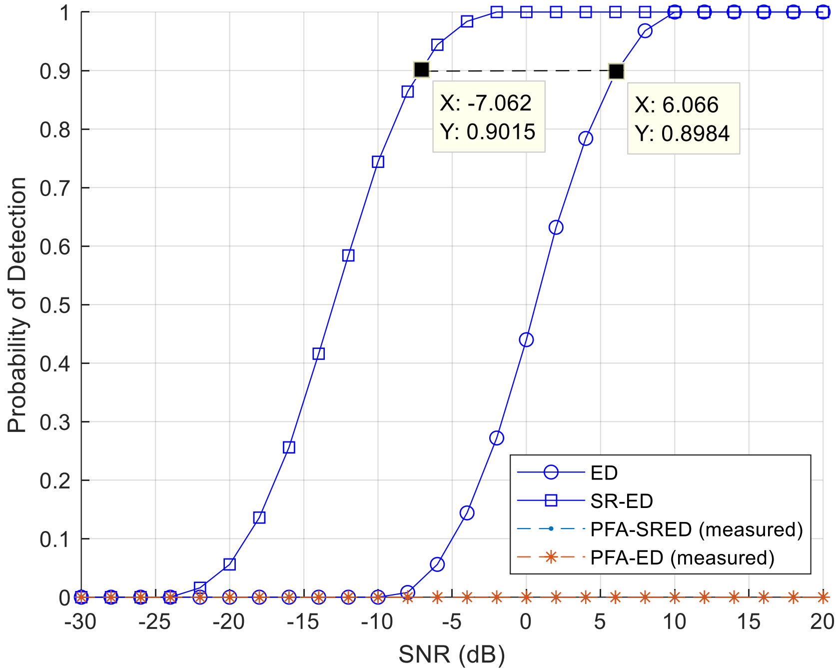
Proposed Stochastic Resonance Aided Sensing

Performance in Frequency Selective Fading Channel with AWGN

Simulation Settings:
Number of OFDM Symbols: 1
Equivalent Samples: 2192
Sub-Carriers: 512
Modulation Type: OFDM-QPSK
Channel: Frequency Selective Fading + AWGN
Noise Uncertainty (NU) : 0dB Noise Variance Uncertainty

Observations - @ Pd = 90% & Pfa (CFAR) @ 1%

SR-ED : SNR = -7 dB with Pfa 1%
Classical ED : SNR = 6 dB with Pfa 1%



90% probability of detection achieved at 13 dB less SNR, using SR-ED.

Proposed Stochastic Resonance Aided Sensing

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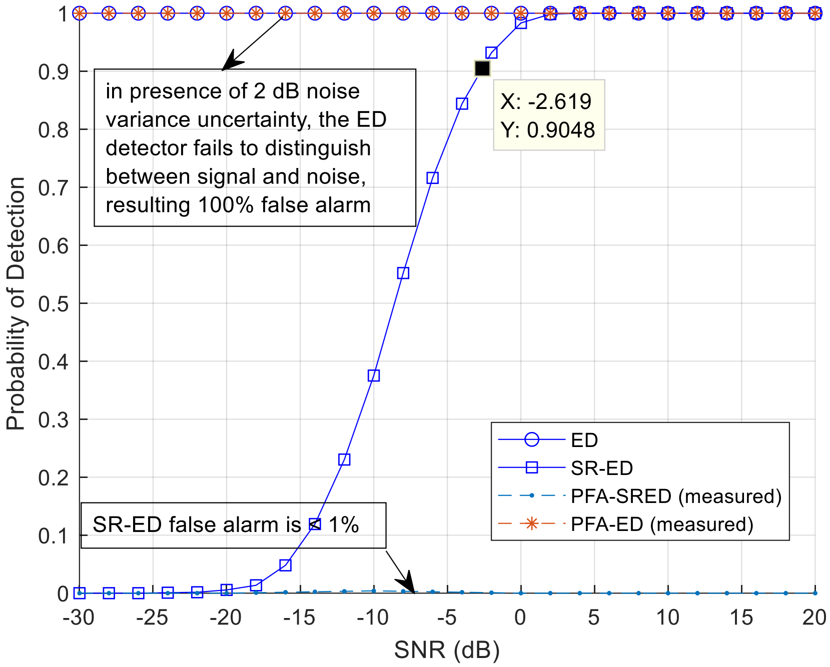
Performance in Frequency Selective Fading Channel with AWGN and noise uncertainty (NU)

Simulation Settings:
Number of OFDM Symbols: 1
Equivalent Samples: 2192
Sub-Carriers: 512
Modulation Type: OFDM-QPSK
Channel: Frequency Selective Fading + AWGN
Noise Uncertainty (NU) : 2dB Noise Variance Uncertainty

Observations - @ Pd = 90% & Pfa (CFAR) @ 1%

SR-ED : SNR = -2.6 dB with Pfa 1%
Classical ED : Fails to distinguish between signal and noise.



Classical ED fails under Noise Uncertainty.

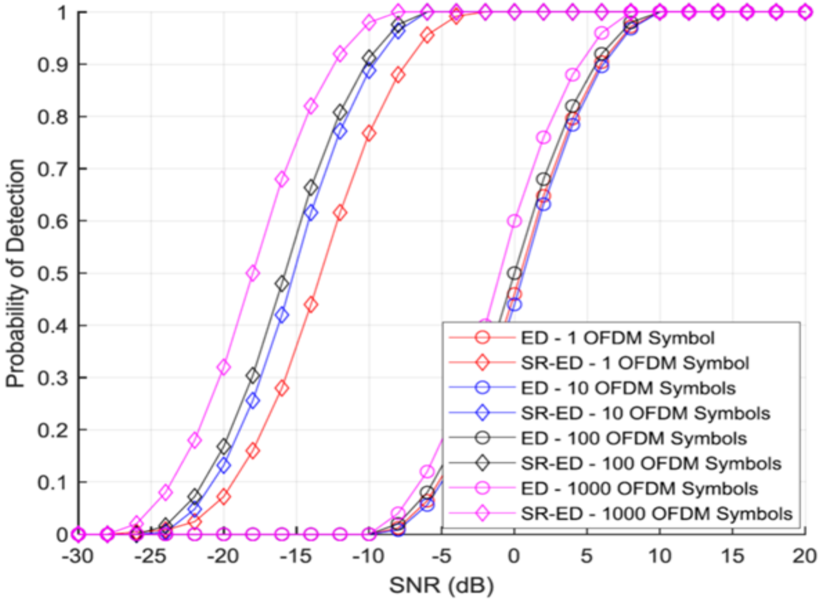
Proposed Stochastic Resonance Aided Sensing

SNR Wall, Increasing number of samples/sensing time

Simulation Settings:
Number of OFDM Symbols: 10, 100,1000
Sensing duration: 0.6ms, 6ms, 60ms
Equivalent #Samples: 22k, 219k, 2M
Sub-Carriers: 512
Modulation Type: OFDM-QPSK
Channel: Frequency Selective Fading + AWGN
Noise Uncertainty (NU) : 0dB Noise Variance Uncertainty

Observations - @ Pd = 90% & Pfa (CFAR) @ 1%

100 OFDM Symbols:
SR-ED : SNR = -10 dB
Classical ED : SNR = 5.5 dB
1000 OFDM Symbols:
SR-ED : SNR = -12 dB
Classical ED : SNR = 5 dB

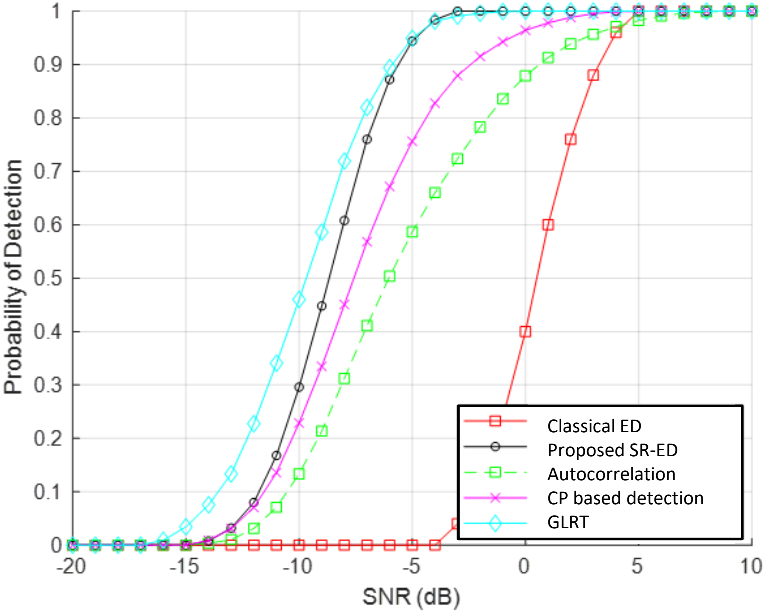


Unlike ED, SR-ED performance can be improved with increasing # samples

Proposed Stochastic Resonance Aided Sensing

SR-ED comparison with SoTA techniques

- Performance of proposed SR-ED on-par with GLRT
- The LRT based detection is known to be the optimal scheme, but highly susceptible to channel uncertainty/state changes



Proposed Stochastic Resonance Aided Sensing

SR-ED comparison with SoTA techniques

	Best Performing SR-based sensing algorithm *	Best Performing non-SR based sensing algorithm **	Proposed SR-ED		
SNR @ Pd = 90%	-24 dB	-33.2 dB	-18 dB	-25 dB	-34 dB
target Pfa (@Pd = 90%)	-	-	≤ 10%	≤ 10%	≤ 10%
Sensing duration	250µsec	1sec	10µsec	100µsec	25ms
# Samples	5,000	20,000,000	200	2,000	500,000

Single Carrier QPSK signal , NU = 0 dB, AWGN-only.

	Pilot-based detection	CP-based detection	AC-based detection	Proposed SR-ED
SNR @ Pd = 90%	-35 dB	-13 dB	-15 dB	-20 dB
target Pfa (@Pd = 90%)	≤ 10%			
# Samples	2000			

OFDM-QPSK signal , NU = 0 dB, AWGN-only.

* Jun Wang, et. al., "Adaptive Bistable Stochastic Resonance Aided Spectrum Sensing" IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS, VOL. 13, NO. 7, JULY 2014.
** A.M. Ghaleb, et. al., "A New Dynamic Max-to-Mean Ratio Energy Spectrum Sensing Model for 5G Cognitive Radio Systems", ICMSCE 2015, Jan 13, 2015.

Summary

- Classical (non-SR based) sensing schemes have a number of known short-comings,
- SR-based (SR-aided) schemes aim to address the shortcomings, and can provide substantial gains over classical blind schemes (improved resilience to NU; SNR-wall improvement, performance under channel impairments (fading/CFO/TO) …),
- A Blind spectrum-sensing technique relying on SR as pre-processing stage, has been developed,
- Proposed SR-ED approach provides a reliable mechanism to identify/tune SR-system parameters, NOT relying on knowledge or estimation of noise power, nor signal re-conditioning,
- Comparisons between proposed SR-ED & classical schemes has been provided and analytical SNR expression derived,
- Proposed approach enables fast spectrum sensing & makes dynamic/opportunistic spectrum access possible; SR-ED provides min. 13-14 dB improvement over classical ED,
- The computation complexity of SR-ED is higher than classical ED; however the computation time of SR-ED remains lower,
- More research on this topic currently ongoing …

Thank You.