

Outline:

## 1 Motivation

## 2 Limits of Existence-Based Detection

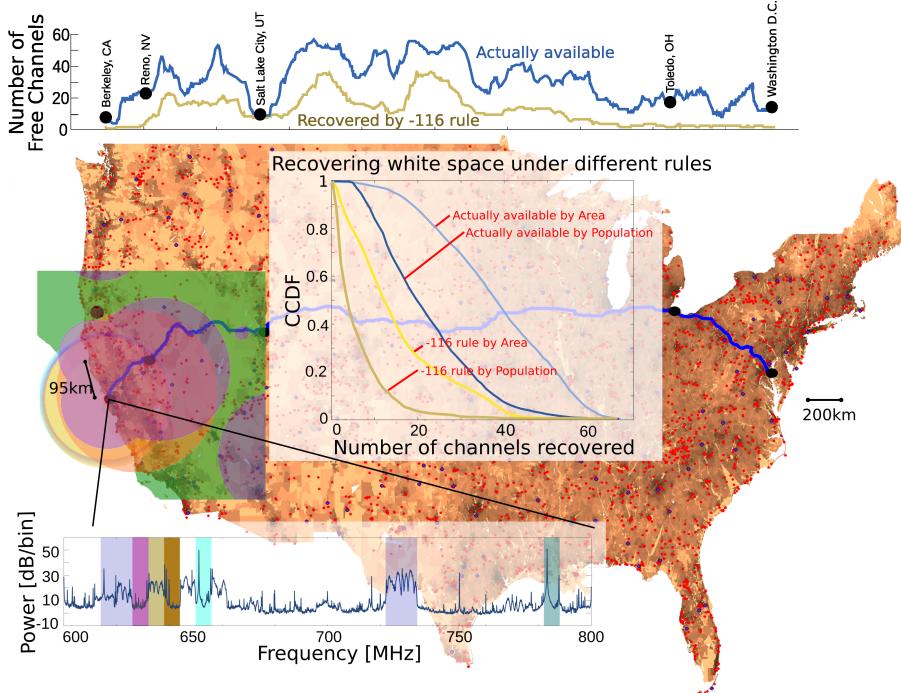
## 3 Cooperative Event-Based Detection

## 4 Limits of Event-Based Detection

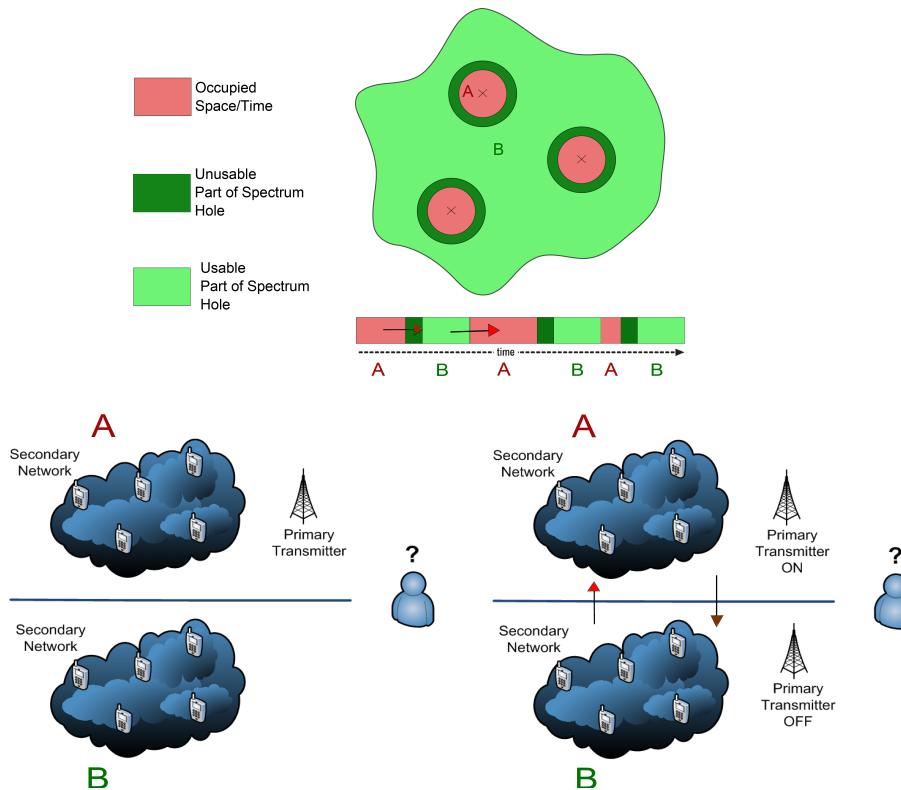
Arash Parsa, Amin Aminzadeh Gohari, and Anant Sahai,  
 "Exploiting Interference Diversity for Event-Based Spectrum Sensing,"  
*IEEE DySpAN* in Chicago, IL Oct. 2008.

Paper available: [www.eecs.berkeley.edu/~sahai/Papers/EventSensingDySpAN08.pdf](http://www.eecs.berkeley.edu/~sahai/Papers/EventSensingDySpAN08.pdf)  
 Slides available: [.../~sahai/Presentations/EventSensingDySpAN08.pdf](http://.../~sahai/Presentations/EventSensingDySpAN08.pdf)  
 This Handout: [.../~sahai/Presentations/EventSensingDySpAN08.H.pdf](http://.../~sahai/Presentations/EventSensingDySpAN08.H.pdf)  
 Further discussion, related work, and references can be found in the paper.

# 1 Motivation

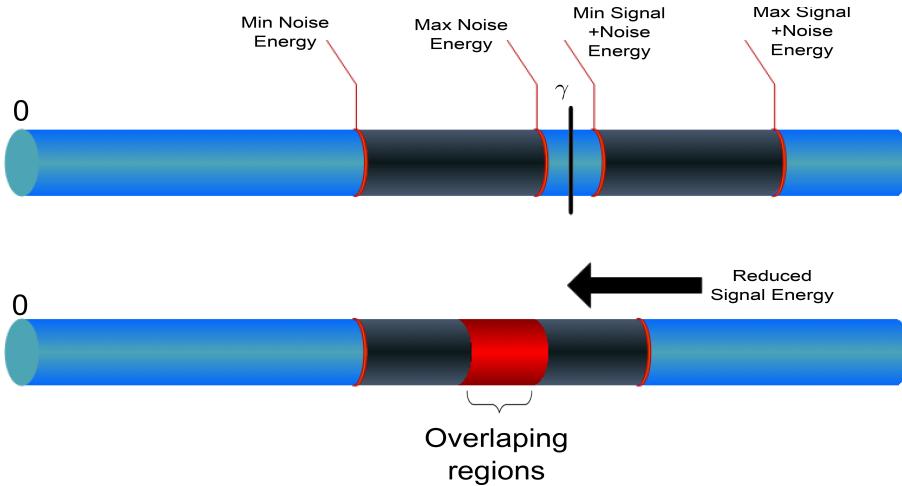


Starting from the San Francisco Bay Area on this map of the U.S. shaded by population density, we see that TV towers have footprints that do not cover everything. The uncovered spaces are “holes” in spectrum usage that can be reclaimed by cognitive radios. As we take a virtual trip along Interstate 80, we see from the plot at the top that there are lots of channels not being used throughout the U.S. However, the central figure shows that there are somewhat fewer opportunities where most people live. This figure was created by Mubaraq Mishra and is borrowed from A. Sahai, S.M. Mishra, R. Tandra, and K. Woyach, “Cognitive Radios for Spectrum Sharing,” to appear in the *DSP Applications* column in the *IEEE Signal Processing Magazine* for January 2009.



An existence-based detector is a detector that chooses to test for the existence/absence of the primary signal. Many currently studied algorithms fall in this category. These implicitly assume that the focus is on the spatial-dimension of a spectrum hole. The ‘x’ indicates the position of primaries and the secondary needs to verify that it is not close enough to pose a threat. However, for any given secondary user, it is a time-centered perspective that frames the question in steady state: is it safe to keep using this channel or should we start using that channel? An event-based detector is a detector that chooses to test for the entrance/exit of the primary signal.

## 2 The Limits of Existence-Based Detection

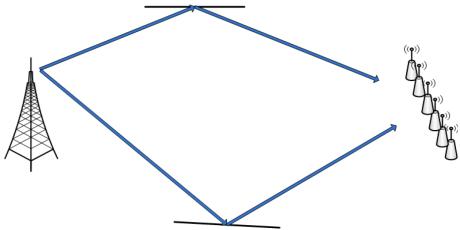


The noise uncertainty models that *the noise distribution is known only up to a set*. For example, an interval for the noise variance imposes a fundamental limit on the performance of the radiometer. The length of this interval can never be less than the **maximum** number of significant interferers that might co-exist in an environment times the average power of a typical significant interferer. Therefore interference is a fundamental cause of sensing limitations.

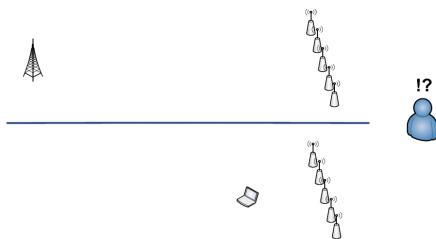
$$H_0 : \text{Covariance Matrix} \rightarrow \sigma_w^2 I$$



$$H_1 : \text{Covariance Matrix} \not\rightarrow \sigma_w^2 I$$

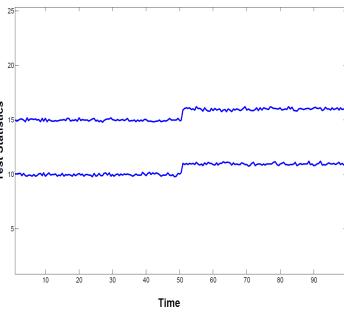
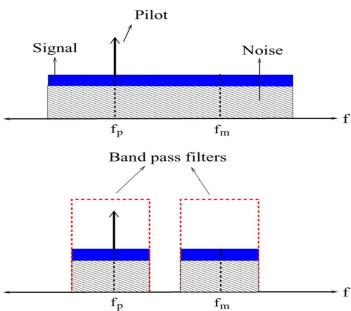


Multiple-antenna approaches like the max-min eigenvalue detector assume that noise is *white and uniform (in terms of power) over different antennas*. If the primary signal is absent, the correlation between samples at different antennas and/or different times will be zero and thus the covariance matrix of the observations would be the identity. If the primary signal is present, some of these correlations will not be zero. Therefore the detector tries to distinguish between these two scenarios by computing the covariance matrix.



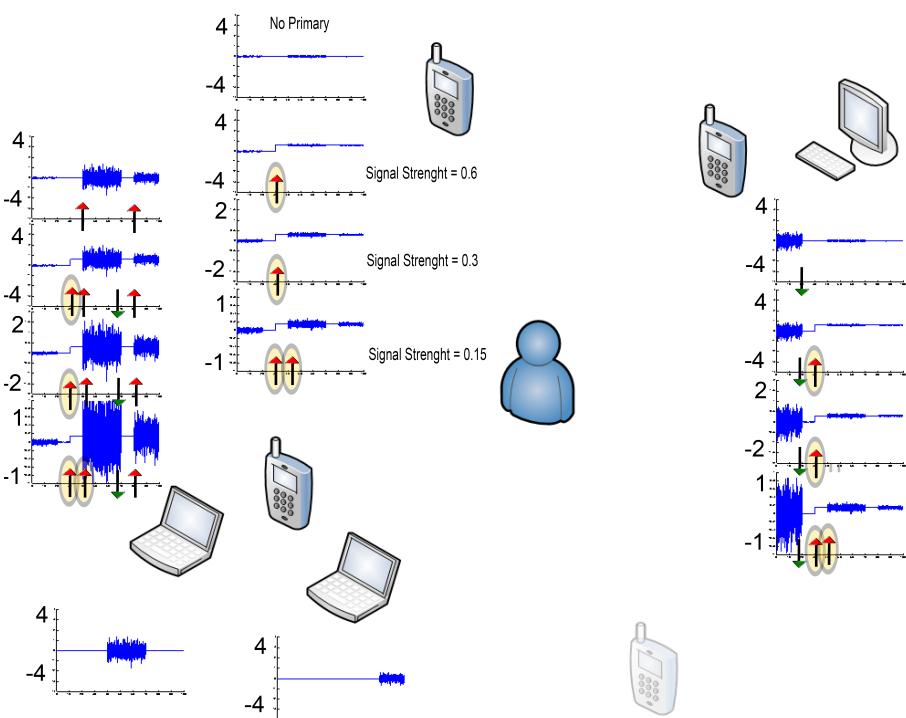
Unfortunately, from the perspective of the max-min eigenvalue detector, there is no difference between a very weak primary and a local emitter. Interference in general is some combination of "unintentional emitters" (e.g. *a laptop leaking power or a microwave oven cooking food*) and "intentional emitters" (other secondary networks using the band when the primary is absent).

## 3 Event-Based Detection



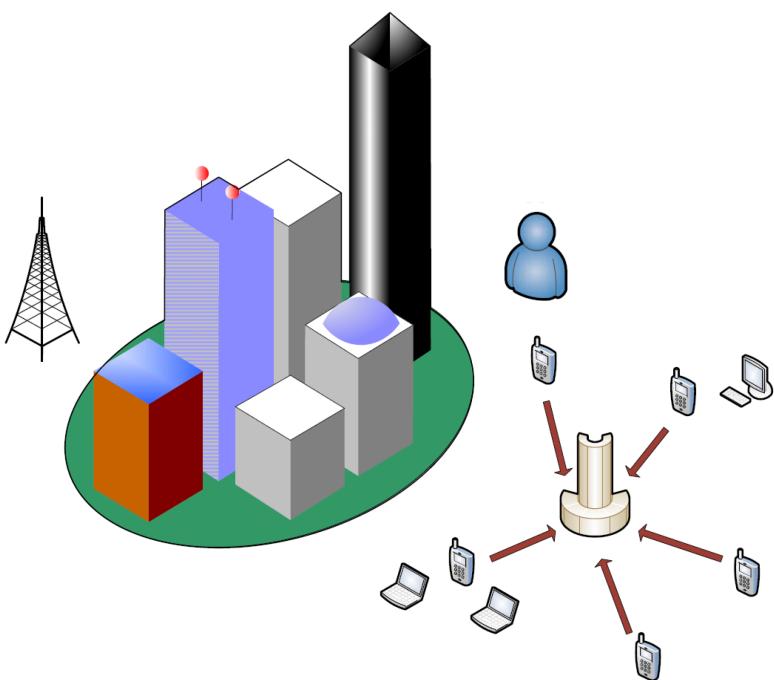
In existence-based sensing, the idea of noise-calibration is used to *estimate the noise variance by looking in nearby frequencies where the desired signal feature is not present*. The residual uncertainty is just the potential color of the noise. Similarly, event-based sensing is insensitive to the steady background level of the noise because it gets implicit calibration. For event-based sensing, the residual uncertainty comes from the on-off pattern of interferers.

<i>Detector:</i>	<b>Traditional existence-based</b>	<b>Event-based</b>
<i>Hypotheses:</i>	High-power vs low-power $\begin{cases} \mathbf{H}_0[n] : \text{primary on at time } n; \\ \mathbf{H}_1[n] : \text{primary off at time } n; \end{cases}$	Increased vs decreased vs unchanged power $\begin{cases} \mathbf{H}_-[n] : \text{negative edge at time } n; \\ \mathbf{H}_+[n] : \text{positive edge at time } n; \\ \mathbf{H}_I[n] : \text{otherwise.} \end{cases}$
<i>Detector statistic:</i>	Received power-level	Change in received power-level
<i>False alarms:</i>	Noise higher than expected	“Noise” increases suddenly 
<i>Missed detections:</i>	Noise lower than expected	“Noise” drops suddenly 
<i>Dominant uncertainty:</i>	Number of active interferers	Activity pattern of interferers

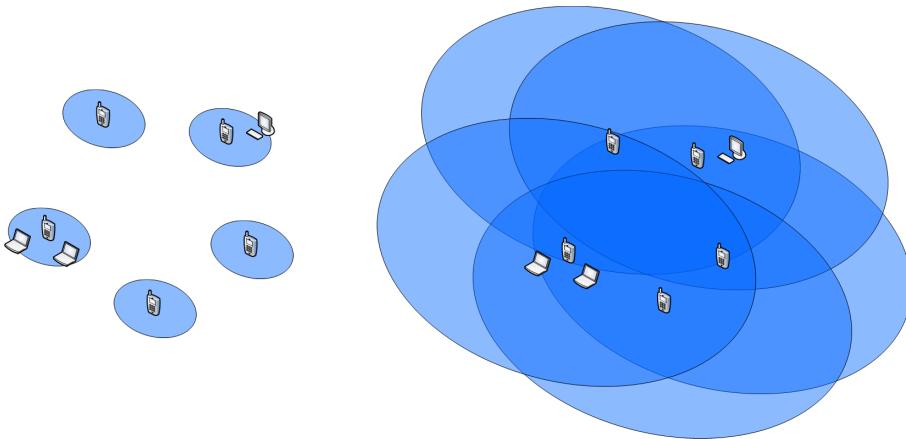


Unintentional interference has low power and is thus local in the sense that *the arrival or departure of one such interferer can only cause a few nearby sensors to trigger false alarms*. In contrast, when a primary signal enters or exits, it does so with a global footprint causing *many sensors to fire alarms simultaneously*. The physical effect is that of interference diversity. However, it does not hold forever. When the desired signal is very weak, the interference is no longer local.

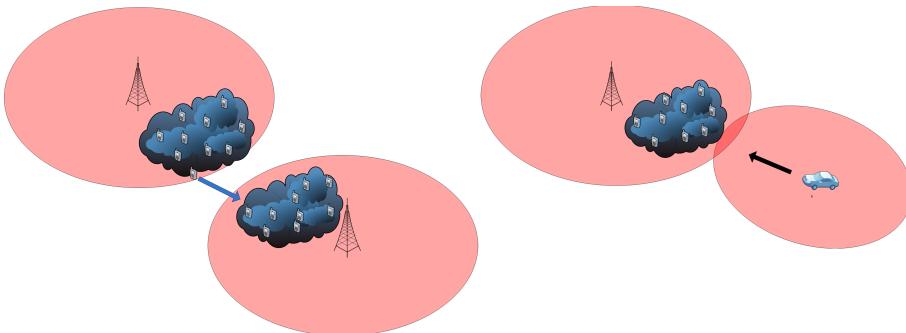
Cooperative multi-sensor event-based detection can exploit this interference diversity to reliably distinguish between the two events by gathering information from geographically separated sensors. Each sensor sends a positive/negative alarm to the fusion center when it senses an increase/decrease in the power-level of its received signal. When the primary does not change its status, the fusion center expects to see approximately equal number of (false) positive and (false) negative alarms. When the primary enters, it expects to see more positive alarms than negative alarms and vice-versa when the primary exits.



## 4 The Limits of Event-Based Sensing



As long as the interferers are local, cooperative event-based sensing is able to correctly detect weak primary signals given enough cooperating nodes. However, as we search for ever weaker primary signals, the unintentional emitters will eventually cease to be local to any one user. Neighboring users might hear the same unintentional emitter.



On the flip side, the assumption of global behavior by the primary will become invalid if some nodes move far enough away from each other that they are in different spectrum holes. **Interference diversity is no substitute for the basic requirement of all cooperative algorithms: that all the nodes cooperating to sense are indeed trying to sense the same spectral hole!**

Another similar, but distinct, problem arises when an active primary user moves toward the secondary network or the network moves toward an area with generally more unintentional emitters (like from early-morning to mid-morning as devices get turned on). This case is like the story of the frog in slowly boiling water — the secondaries may miss this very slow transition. This suggests that in practice, a compound existence/event-based approach must be taken to cooperative sensing.

This talk is intended to bring out the following ideas:

- Even with multiple-antenna processing, single-user detection of a very weak primary user faces SNR Walls from the real-world uncertainty of local interference.
- If our perspective is to identify whether we are now within a time-domain spectral hole, it makes sense to use event-based sensing rather than traditional existence-based sensing.
- Event-based sensing looks for transitions in the usage of spectrum and hence benefits from a natural kind of noise calibration.
- Multiuser event-based sensing can exploit cooperative interference diversity since unintentional emitters are likely to be local to only a few users while the primary user has a more global footprint. This means that very weak signals can be reliably discovered using this approach as long as the control-channel bandwidth is high enough.
- However, the potential mobility of both primary and secondary users suggests that a combination of cooperative event-based and cooperative existence-based sensing is required.