Covariance-based spectrum sensing methods in practice

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Introduction

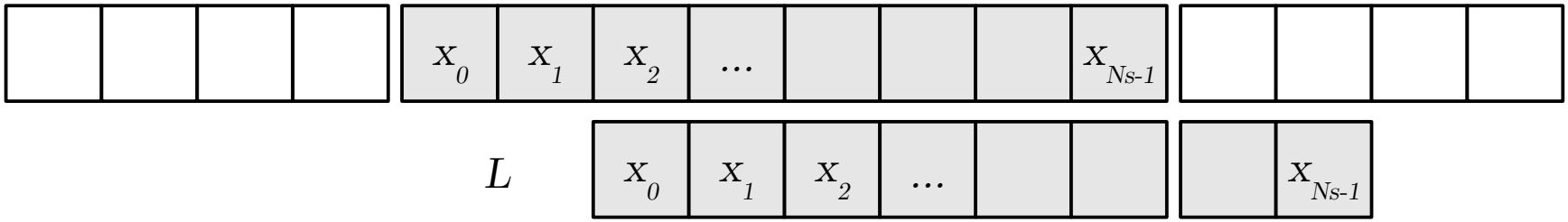
- A compact, low-cost spectrum sensor is desired.
  - Provides channel occupancy table to an agile radio.
  - Secondary usage of TVWS with consumer devices.
- Sample covariance-based methods (CBM)
  - Identified as a good compromise between implementation complexity, generality and sensing performance.
  - Simulations show good detection of typical transmissions in UHF band (e.g. legacy wireless microphones).
- Impact of realistic signal impairments is hard to predict theoretically.

Goals

- Compare CBM with energy detection (ED).
  - USRP, SNE-ESHTER as digital frontends for CBM and ED.
  - SNE-ISMTV-UHF as analog ED.
- Compare effect of different digital frontends.
  - USRP vs. SNE-ESHTER using same configuration
  - what are good design goals for a spectrum sensor?
- Assess feasibility of using constrained devices.
  - how well do CBM perform with low sample rates, low number of samples?

Covariance-based methods (CBM)

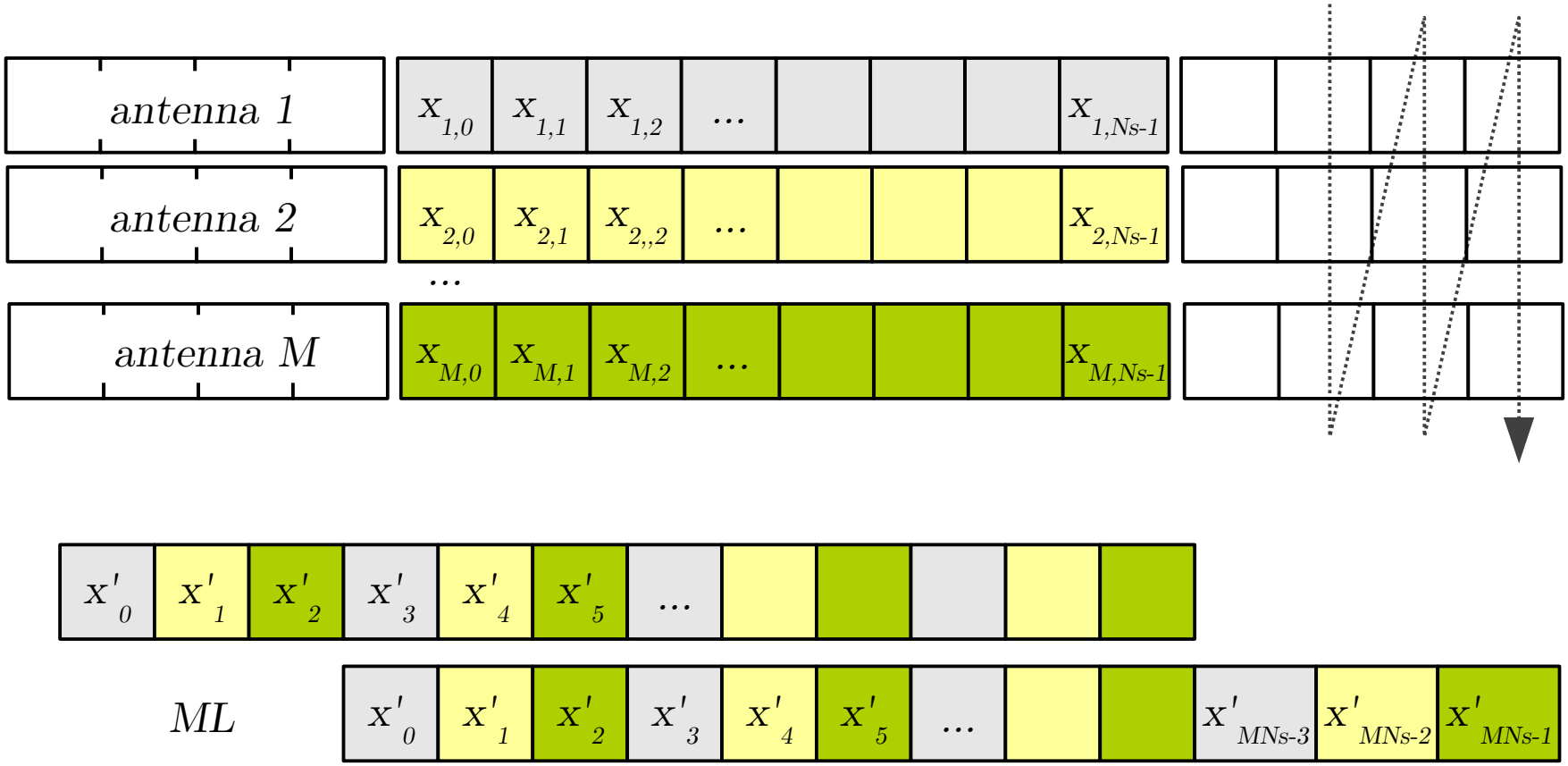
$$\sigma_l = \frac{1}{N_s} \sum_{n=0}^{N_s-1} x_n \cdot x_{n-l} \qquad l \in [0, L-1]$$



$$\mathbf{R} = [r_{ij}] = \begin{bmatrix} \sigma_0 & \sigma_1 & \dots & \sigma_{L-1} \\ \sigma_1 & \sigma_0 & \dots & \sigma_{L-2} \\ \vdots & \vdots & \ddots & \vdots \\ \sigma_{L-1} & \sigma_{L-2} & \dots & \sigma_0 \end{bmatrix}$$

ZENG , Y., AND LIANG , Y. C. Spectrum-Sensing Algorithms for Cognitive Radio Based on Statistical Covariances. In *IEEE Transactions on Vehicular Technology* (2009), vol. 58, pp. 1804–1815.

Extension to M antennas



$$\sigma_l = \frac{1}{MN_s} \sum_{n=0}^{MN_s-1} x'_n \cdot x'_{n-l} \qquad l \in [0, ML-1]$$

(not tested in this experiment)

Simple CBM

$$\gamma = \frac{T_1}{T_2}$$

CAV $\quad T_1 = \frac{1}{L}\sum_{i=1}^{L}\sum_{j=1}^{L}|r_{ij}| \qquad T_2 = \frac{1}{L}\sum_{i=1}^{L}|r_{ii}|$

CFN $\quad T_1 = \frac{1}{L}\sum_{i=1}^{L}\sum_{j=1}^{L}|r_{ij}|^2 \qquad T_2 = \frac{1}{L}\sum_{i=1}^{L}|r_{ii}|^2$

MAC $\quad T_1 = \max_{i\neq j}|r_{ij}| \qquad T_2 = \frac{1}{L}\sum_{i=1}^{L}|r_{ii}|$

ZENG , Y., AND LIANG , Y. C. Robust spectrum sensing in cognitive radio.
In *IEEE International Symposium on Personal, Indoor and Mobile Radio Communications Workshops* (2010), IEEE, pp. 1–8.

Eigenvalue-based CBM

$$|\lambda_0| \geq |\lambda_1| \geq \ldots \geq |\lambda_{L-1}|$$

MME $$\gamma = \frac{|\lambda_0|}{|\lambda_{L-1}|}$$

AGM $$\gamma = \frac{\frac{1}{L}\sum_{l=0}^{L-1} |\lambda_l|}{\sqrt[L]{\prod_{l=0}^{L-1} |\lambda_l|}}$$

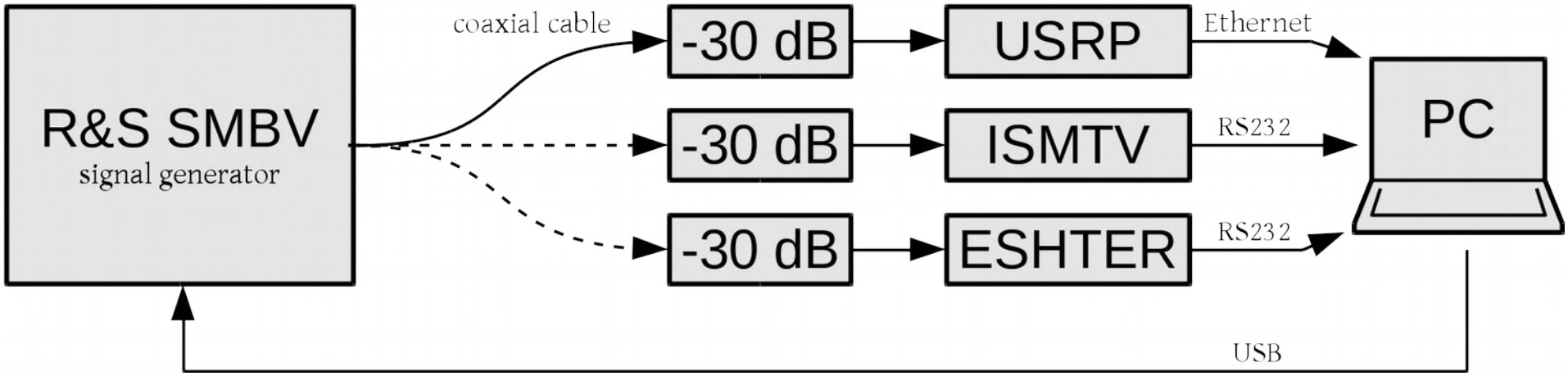
EME $$\gamma = \frac{\sum_{n=0}^{N_s-1} x_n^2}{\lambda_{L-1}}$$

MET $$\gamma = \frac{|\lambda_0|}{\sum_{l=1}^{L} \lambda_l}$$

ZENG , Y., AND LIANG , Y. C. Eigenvalue-Based Spectrum Sensing Algorithms for Cognitive Radio. *IEEE Transactions on Communications* 57, 6 (2009), 1784–1793.

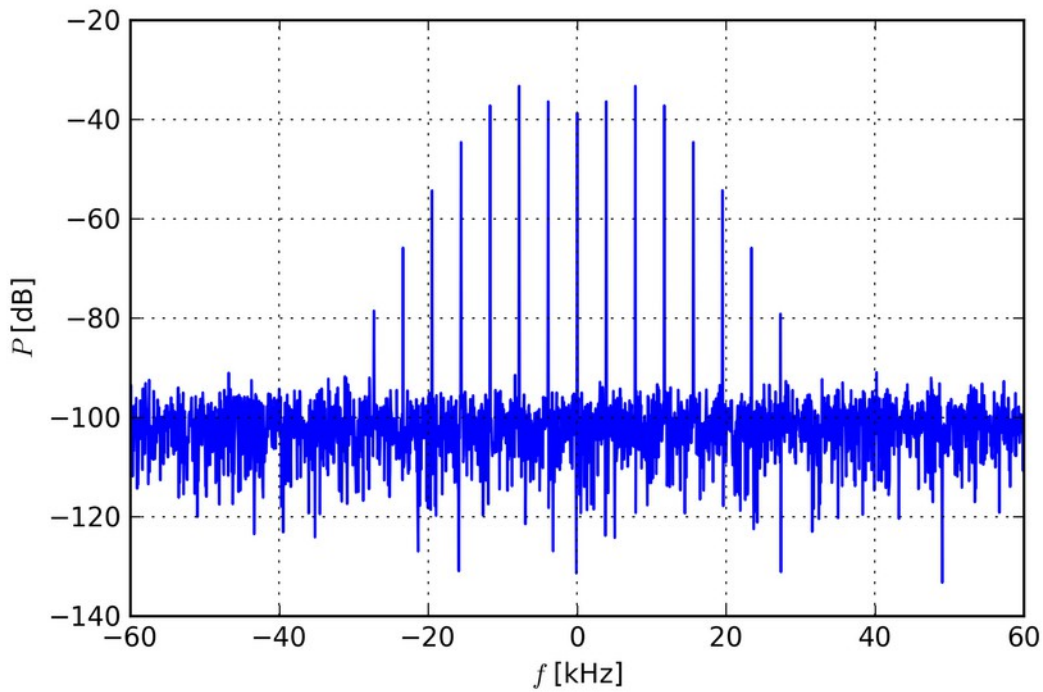
Experimental setup

- Rohde & Scharz SMBV100A vector signal generator
  - -30 dB attenuator (to protect against accidental overloads)
  - remotely controlled through USB
- Device under test
  - USRP N200 (SBX daughterboard)
  - VESNA sensor node (SNE-ISMTV and SNE-ESHTER radios)



Test signal

- tone-modulated FM carrier
  - “soft speaker” IEEE wireless microphone signal test vector



$$f_m = 3.9\text{kHz} \qquad \Delta f = 15.0\text{kHz}$$

C LANTON , C., K ENKEL , M., AND TANG , Y. Wireless Microphone Signal Simulation Method. IEEE 802.22-07/0124r0, 2007.

Test configurations

A) embedded profile

- e.g. ARM Cortex M3, single 1 Msample/s ADC, 96 kB RAM

B) embedded profile

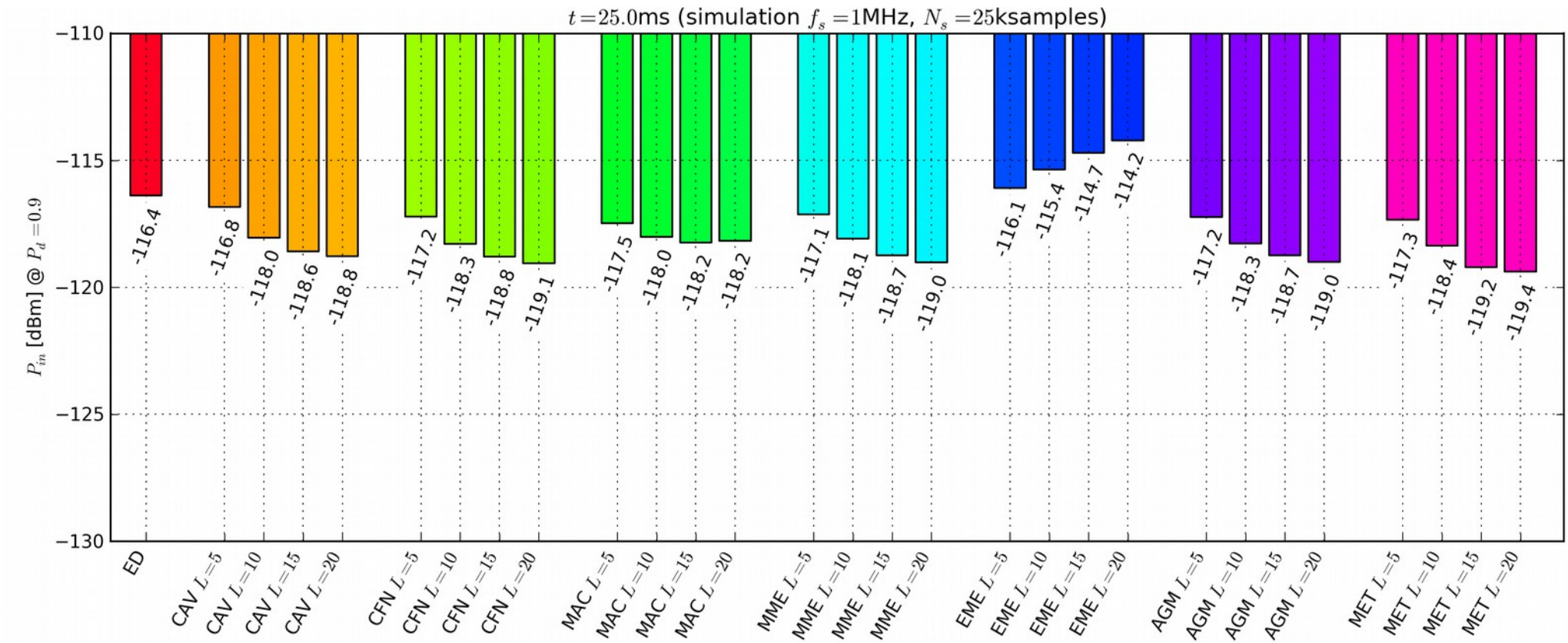
- e.g. ARM Cortex M3, dual 1 Msample/s ADCs, 96 kB RAM

C) high-end profile

		USRP		SNE-ISMTV-UHF	
	t_s [ms]	f_s [kHz]	N_s [samples]	f_s [kHz]	N_s [samples]
A	25.0	1,000	25,000	147	3,676
B	12.5	2,000	25,000	147	1,838
C	10.0	10,000	100,000	147	1,471

Simulation results

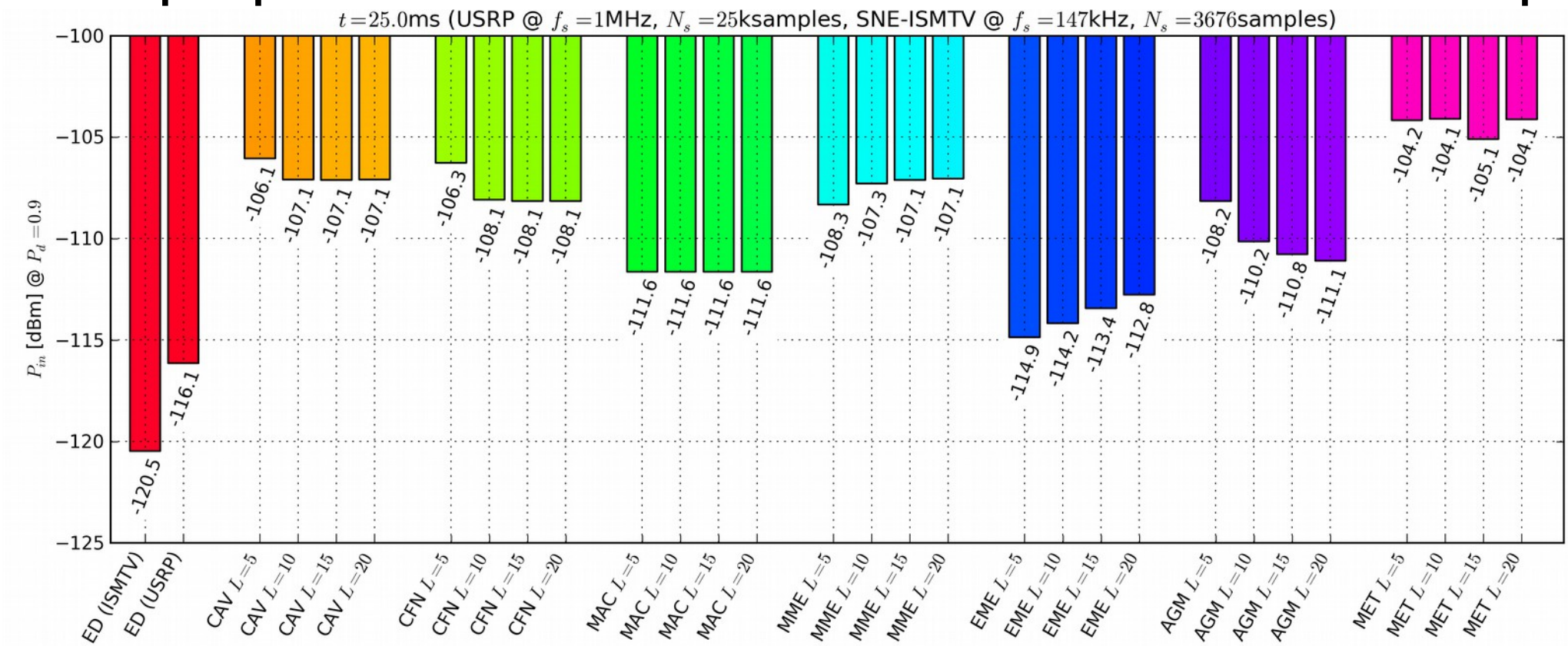
- Ideal signal waveform with AWGN.
- Ideal sampling, channel filtering, etc.



USRP & SNE-ISMTV-UHF

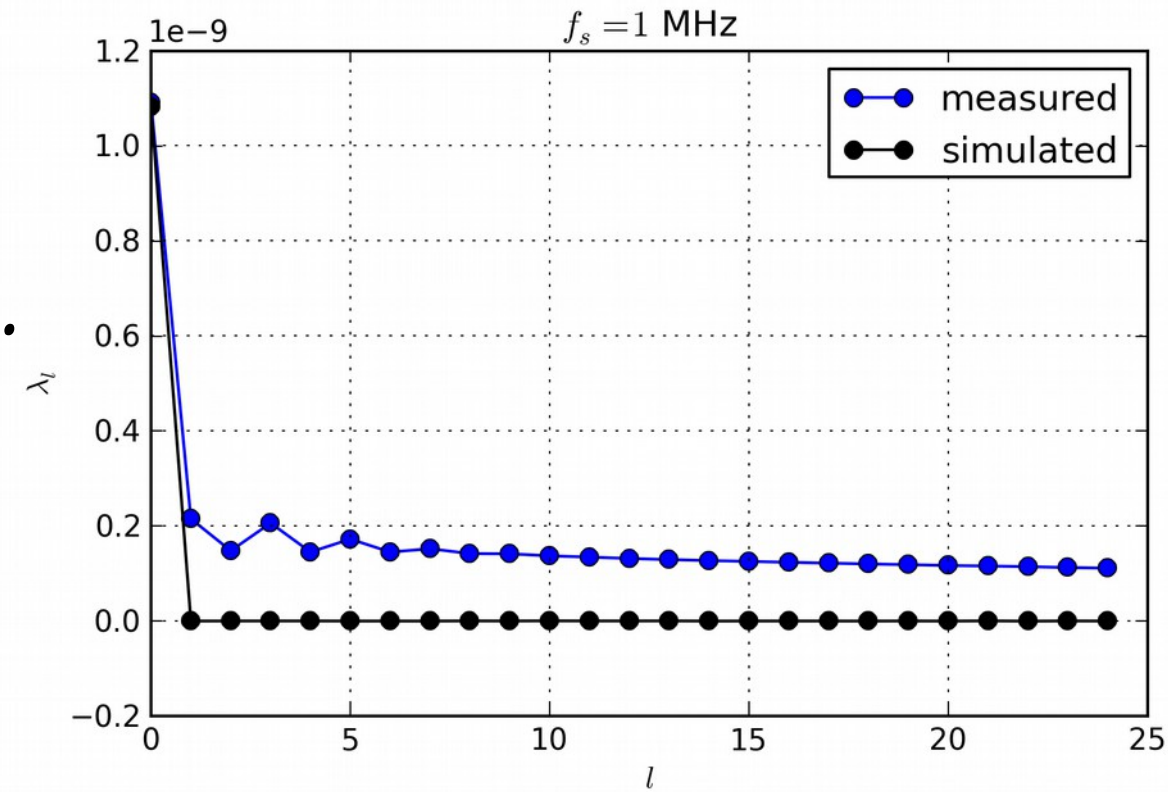
ED with SNE-ISMTV-UHF (analog), USRP (digital)

CBM with USRP



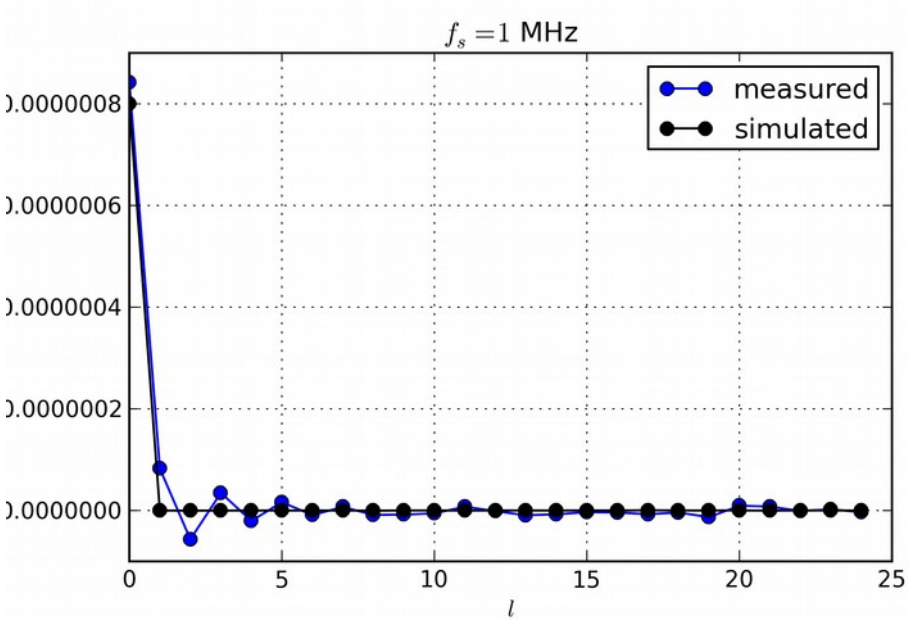
Explaining bad CBM performance

- USRP noise samples are already correlated.
- Compensation with Cholesky decomposition was not used.
- **Theory**: part of noise not Gaussian. (e.g. not due to linear filtering)



Immunity to noise level changes

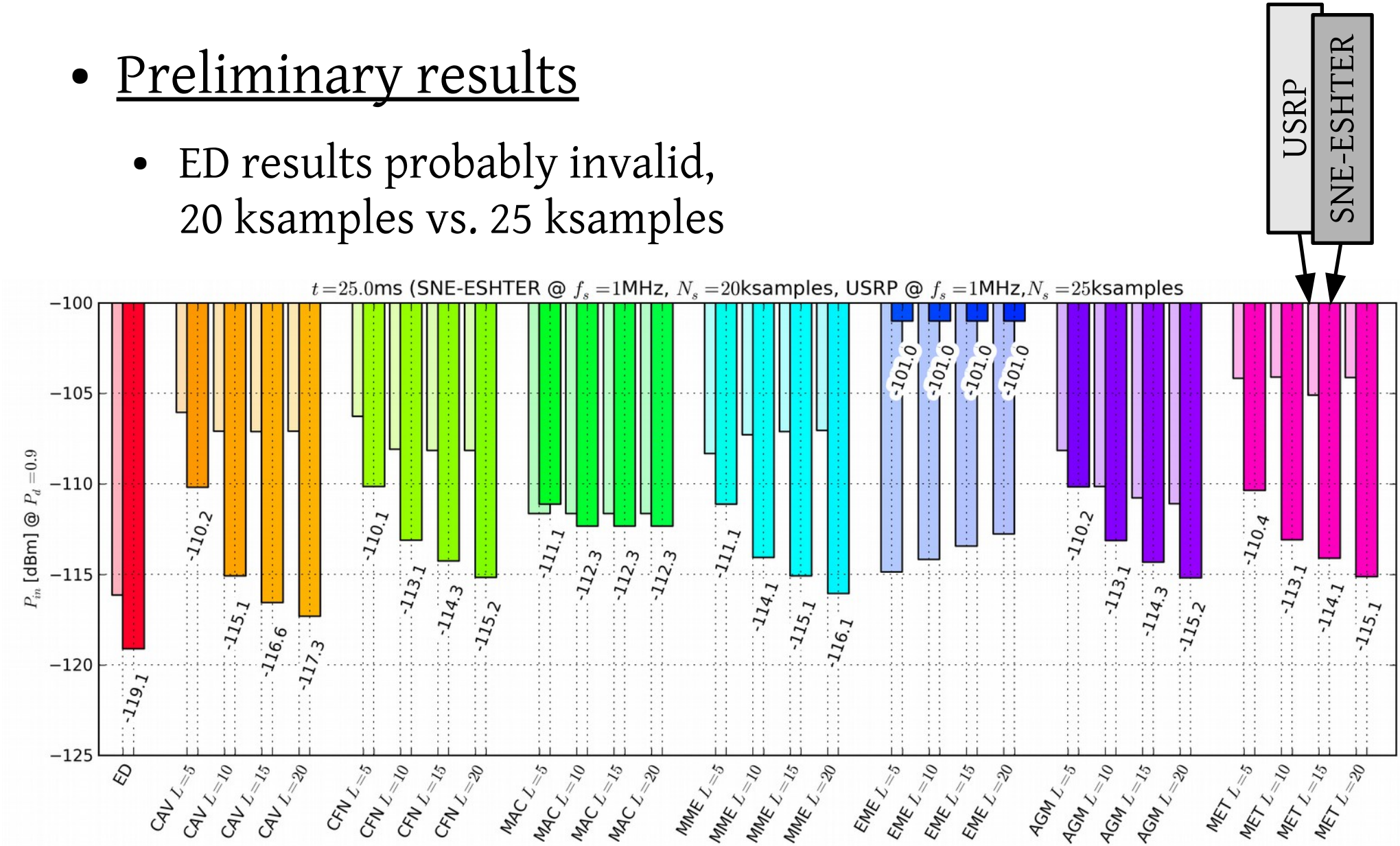
- Theory predicts that CBM should be immune to noise level changes
- Inject noise using the signal generator.



f_s N_s	1MHz 25ksamples	2MHz 25ksamples	10MHz 100ksamples
Method	ΔP_{noise}[dB] @ $P_{fa} = 0.2$		
ED (USRP)	**0.3**	**0.4**	**0.5**
CAV $L = 5$	> 40.0	> 40.0	> 40.0
CAV $L = 10$	> 40.0	> 40.0	> 40.0
CAV $L = 15$	> 40.0	> 40.0	> 40.0
CAV $L = 20$	> 40.0	> 40.0	> 40.0
CFN $L = 5$	> 40.0	> 40.0	> 40.0
CFN $L = 10$	> 40.0	> 40.0	> 40.0
CFN $L = 15$	> 40.0	> 40.0	> 40.0
CFN $L = 20$	> 40.0	> 40.0	> 40.0
MAC $L = 5$	> 40.0	> 40.0	> 40.0
MAC $L = 10$	> 40.0	> 40.0	> 40.0
MAC $L = 15$	> 40.0	> 40.0	> 40.0
MAC $L = 20$	> 40.0	> 40.0	> 40.0
MME $L = 5$	> 40.0	> 40.0	> 40.0
MME $L = 10$	> 40.0	> 40.0	> 40.0
MME $L = 15$	> 40.0	> 40.0	> 40.0
MME $L = 20$	> 40.0	> 40.0	> 40.0
EME $L = 5$	> 40.0	**2.2**	> 40.0
EME $L = 10$	**0.5**	**0.4**	**1.2**
EME $L = 15$	**0.4**	**0.4**	**0.9**
EME $L = 20$	**0.4**	**0.4**	**0.8**
AGM $L = 5$	> 40.0	> 40.0	> 40.0
AGM $L = 10$	> 40.0	> 40.0	> 40.0
AGM $L = 15$	> 40.0	> 40.0	> 40.0
AGM $L = 20$	> 40.0	> 40.0	> 40.0
MET $L = 5$	> 40.0	> 40.0	> 40.0
MET $L = 10$	> 40.0	> 40.0	> 40.0
MET $L = 15$	> 40.0	> 40.0	> 40.0
MET $L = 20$	> 40.0	> 40.0	> 40.0

SNE-ESHTER compared to USRP

- <u>Preliminary results</u>
  - ED results probably invalid, 20 ksamples vs. 25 ksamples



Conclusions

- CBM detection threshold is worse than expected.
  - Assumption about uncorrelated noise samples is false.
  - Further work needed to find cause of noise correlation.
- Best performance for constrained device with MAC.
  - No noticeable benefits with Eigenvalue-based methods.
  - Higher smoothing factor does not always mean better performance.
- CBM are robust against changes in noise floor.
  - Simple energy detector outperforms CBM in practice if noise floor variance is not a factor.

Questions?

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