Fusion Strategies for Collaborative Spectrum Sensing

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Outline

- Objective
- Motivation
- Spectrum Sensing
- Collaborative Spectrum Sensing
  - Hard decision based fusion optimisation
  - Genetic Algorithms based soft decision fusion optimisation
- Conclusions

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Objective

"To optimise performance of collaborative spectrum sensing."

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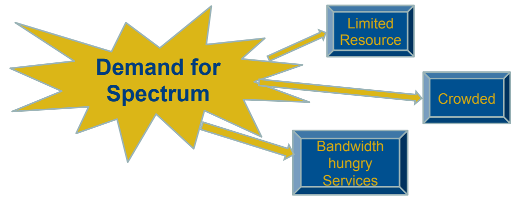
Motivation for this research…



- People/users do not need spectrum, they need **capacity** and **adequate quality communication** means!
- **Technology** converts the limited spectrum into capacity

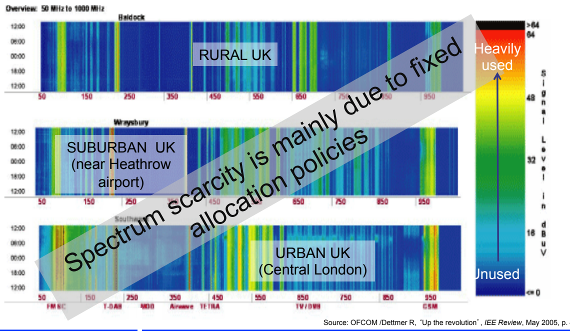
Motivation – ctd.

- Possible solutions
  - Use higher spectrum (higher frequency bands)
    - Do fundamental physical limits allows us to do so?
  - Increase modulation efficiency or spectrum efficiency
    - Can we go beyond Shannon capacity?
  - MIMO techniques
    - How much spectrum can be squeezed through more efficient antenna techniques?
  - Cognitive Radio exploiting White Spaces?

Motivation – ctd.

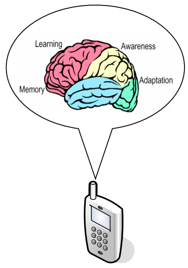
- What is a White Space (WS)?
  - Unoccupied spectrum bands at a particular location and time
  - Exists even in urban areas (depending on location and time)
- Where does WS come from?
  - Fixed and rigid spectrum allocations
  - Terrain signal blockage
  - Uneven demand for spectrum
  - TVWS emerge due to the digital switchover in Britain (Europe, USA and some other countries as well)
- How to utilise them?
  - Cognitive Radio by performing spectrum sensing

Motivations - ctd



Cognitive Radio as "enabler"

- Many definitions exist
- In simple words:
  - An intelligent radio that makes decision for its operating frequency, modulation scheme, transmitting power etc based on factors like:
    - Current location
    - Policies at that particular location
    - Time of the day and available white spaces
    - Negotiations with other opportunistic devices



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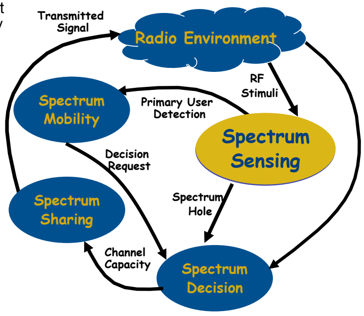
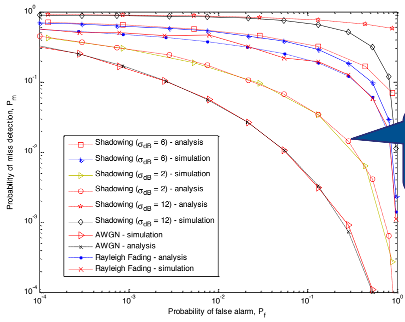
Spectrum Sensing

- Goal is to reliably detect the presence of Primary (Licensed) User
- Three main approaches:
  - Match Filter detection
  - Energy Detection
  - Cyclostationary Feature Detection

Energy Detection
- "Optimal" detector
- Simple architecture
- Easy to implement
- Less complexity



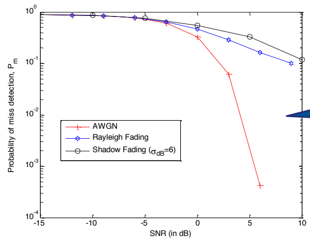
Local Spectrum Sensing - Results



Simulation Parameters

Nodes	= 1
SNR	= 5dB
BT product	= 5
Channel(s)	= AWGN, Rayleigh, Shadowing

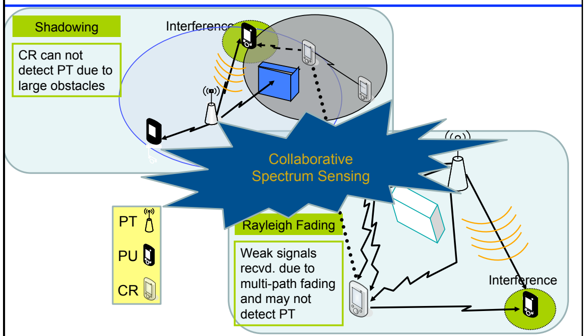
Local Spectrum Sensing – Results (Ctd)



Simulation Parameters

Nodes	= 1
SNR	= 5dB
BT product	= 5
P_{fa}	= 10^{-1}
Channel(s)	= AWGN, Rayleigh, Shadowing

Limitations of Local Spectrum Sensing



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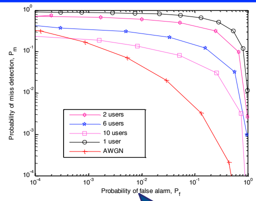
Collaborative Spectrum Sensing (CSS)

- A central unit (fusion centre) collects sensing information, identifies the available spectrum, and broadcasts this information to other cognitive radios
- Use of control channels to share spectrum sensing result
- Nodes may send 1-bit decision (Hard decision - HDC) or observation (Soft decision - SDC) to fusion centre
- Why collaboration?
  - Significantly decreases the probabilities of mis-detection and false alarm
  - Helps solving hidden primary user problem
  - More effective when collaborating users observe independent fading or shadowing

Performance of CSS - HDC



Nodes = 5
SNR = 5 dB
BT product = 5
Fusion rule = OR
Channel(s) = AWGN, Shadowing

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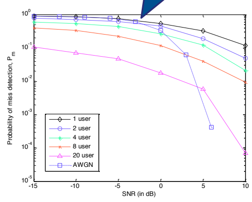

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Optimum Fusion for HDC

- Is the "OR" fusion rule superior in all cases?
- Three different scenarios are considered:
  - Case 1
    - All users have similar mean SNR
  - Case 2
    - Half of the users have higher mean SNR than other half
  - Case 3
    - When only one user has high mean SNR
- Decision Fusion Rule
  - Voting, OR, AND, 1-user rule
- Analytical formulation and Monte-carlo simulations were carried out to find optimal fusion in HDC

Analytical Formulation - HDC

$$y_c = \begin{cases} \sum_{i=1}^{M} D_i \geq K, & ;\mathcal{H}_1 \\ \sum_{i=1}^{M} D_i \leq K, & ;\mathcal{H}_0 \end{cases}$$

M = Total number of users
D_i = 1-bit decision of i^{th} user

Global probability of detection and false alarm is given as,

$$Q_d = R(\mathbf{D}) \prod_{S_0} (1 - P_d^i) \prod_{S_1} P_d^i$$
$$Q_f = R(\mathbf{D}) \prod_{S_0} (1 - P_f^i) \prod_{S_1} P_f^i$$

P_d and P_f are local probabilities
S_0 = group of users decided signal is absent
S_1 = group of users decided signal is present

R(D) is decision fusion rule at fusion centre and defined as,

$$R(\mathbf{D}) = \begin{cases} 1 \quad \text{(PU present)} & \text{if} \quad \sum_{i=1}^{M} D_i \geq K \\ 0 \quad \text{(PU absent)} & \text{if} \quad \sum_{i=1}^{M} D_i < K \end{cases}$$

$$K = \begin{cases} 1 & \text{OR} \\ M & \text{AND} \\ \lceil \frac{M}{2} \rceil & \text{Voting} \end{cases}$$

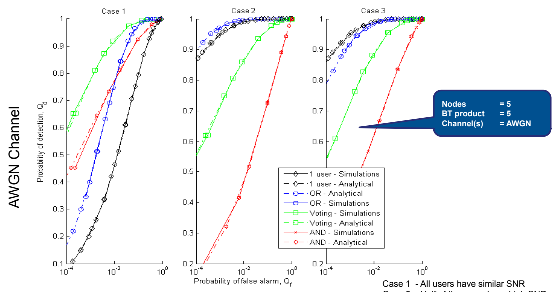
For 1-user rule

$$R(\mathbf{D}) = \begin{cases} 1 & \text{if} \quad D_i = 1 \\ 0 & \text{otherwise} \end{cases}$$

Where i^{th} user is chosen as,

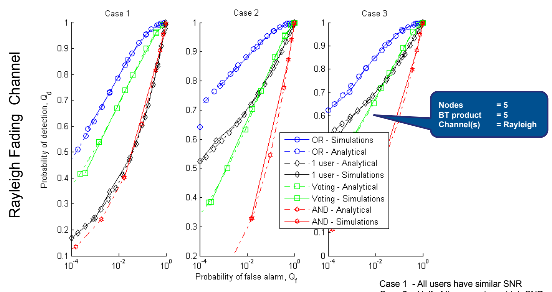
$$i = \arg\max_j \{\gamma_j\}$$

Results - HDC



Case 1 - All users have similar SNR
Case 2 – Half of the users have high SNR
Case 3 – Only one user have high SNR

Results - HDC



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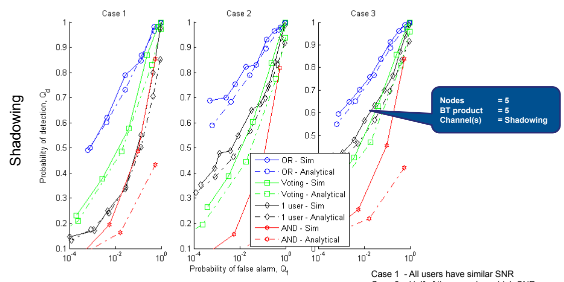
Results - HDC



Case 1 - All users have similar SNR
Case 2 – Half of the users have high SNR
Case 3 – Only one user have high SNR

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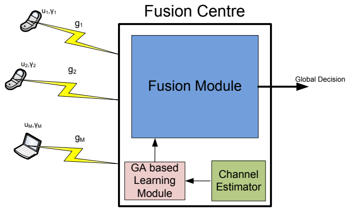
Soft Decision Combining (SDC) Framework

Problem

How to fuse local observations of cognitive radios at fusion centre to decide globally the existence of licensed user?

Solution Approach

For a given channel conditions and targeted probability of false alarm, weights are assigned to the secondary user observations in such a way that it maximises global probability of detection. Optimum weights are calculated using genetic algorithms.



Problem definition - SDC

- Maximise global probability of detection at the fusion centre, considering
  - Two scenarios (users with same mean SNR and with different mean SNR values)
  - Noisy reporting channels with channel gains
- Global probability of detection can be defined as Qd = Q(f(w)), where f(w) is given by

$$f(\mathbf{w}) = \frac{\sqrt{\mathrm{Var}[y_c/\mathcal{H}_0]}Q^{-1}(Q_f) + \mathrm{E}[y_c/\mathcal{H}_0] - \mathrm{E}[y_c/\mathcal{H}_1]}{\sqrt{\mathrm{Var}[y_c/\mathcal{H}_1]}}$$
$$= \frac{Q^{-1}(Q_f)\sqrt{\mathbf{w}^T\mathbf{A}\mathbf{w}} - \mathbf{w}^T[\mathrm{diag}(\mathrm{g})\mathrm{diag}(\boldsymbol{\sigma})'}{\sqrt{\mathbf{w}^T\mathbf{B}\mathbf{w}}}$$

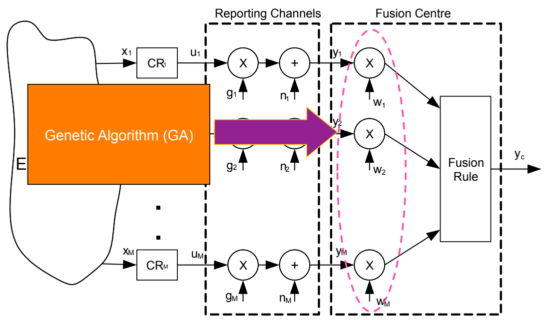
where matrices $\mathbf{A}$ and $\mathbf{B}$ are defined as,

$$\mathbf{A} = 2N\mathrm{diag}^2(\mathrm{g})\mathrm{diag}^2(\boldsymbol{\sigma}) + \mathrm{diag}(\delta)$$
$$\mathbf{B} = 2(NI_M + 2\mathrm{diag}(\overline{\gamma}))\mathrm{diag}^2(\mathrm{g})\mathrm{diag}^2(\boldsymbol{\sigma}) + \mathrm{diag}($$

Problem

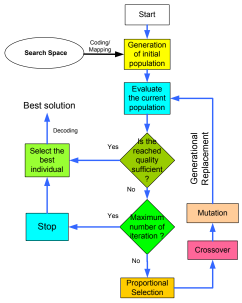
$$\text{minimise} \quad f(\mathrm{w})$$
$$\text{st.} \quad ||\mathrm{w}||_2^2 = 1 \quad \text{and} \quad w_i > 0 \ \forall i \in \{1,2,3,...,M\}$$

Proposed weighted framework

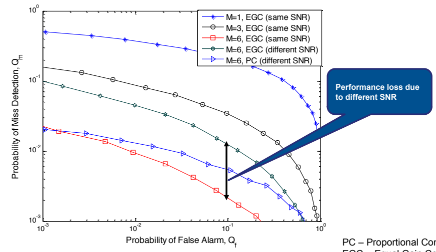


Why genetic algorithm?

- Very useful for complex and loosely defined problems.
- Quickly can scan a vast solution set.
- Global optimisation technique.
- Does not have to know any rules of the problem.
  - **It works by its own internal rules.**
- Supports parallel processing.
  - Multiple solution capability

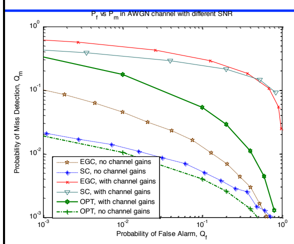


Simulation results - SDC

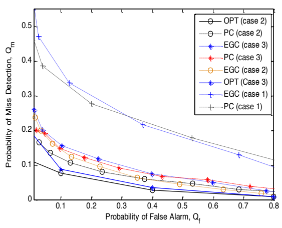


PC – Proportional Combining
EGC - Equal Gain Combining

Simulation results - SDC



AWGN



Rayleigh

OPT = GA based optimal combining
PC = Proportional Combining
EGC = Equal Gain Combining

Case 1 - All users have good reporting channels
Case 2 – All users have bad reporting channels
Case 3 – Only two users have good reporting channels

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- Collaborative spectrum sensing improves sensing performance significantly
- Different position (mean SNR) of users have significant effect on the performance of collaborative spectrum sensing
- Optimum fusion rule must consider mean SNR values of users in both cases i.e. HDC and SDC
- Proposed Genetic Algorithm based weighted collaborative spectrum sensing improves sensing performance
- Proposed scheme requires knowledge about SNR of each user as well as channel conditions
  - Larger reporting channel bandwidths are required
  - Topic of our current research

Acknowledgments

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Questions ???