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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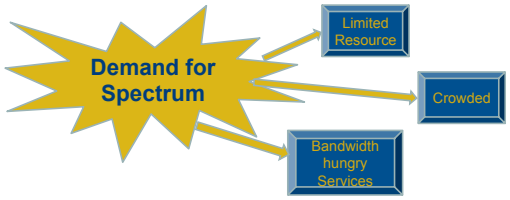
Motivation for this research...



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

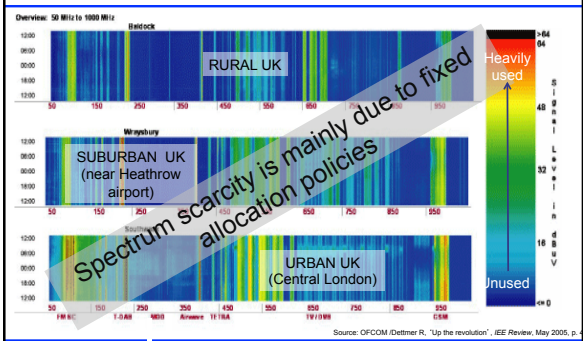
Motivation – ctd.

- 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

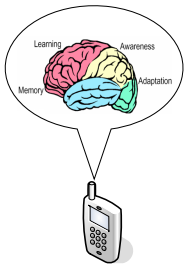
Motivations - ctd



Source: OFCOM /Dettmer R, "Up the revolution", *IEE Review*, May 2005, p. 4

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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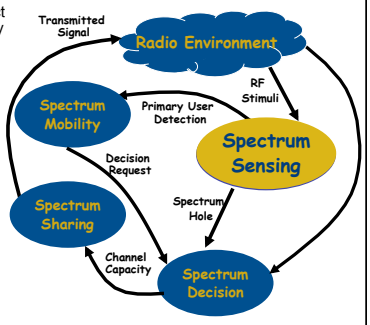
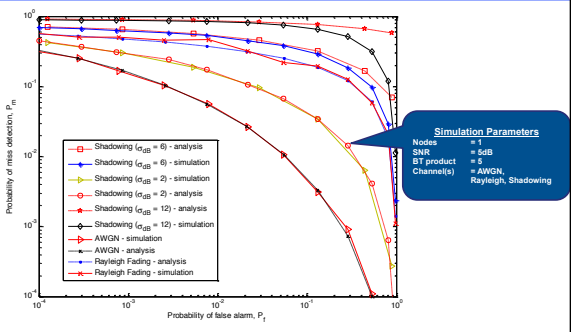
Spectrum Sensing

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

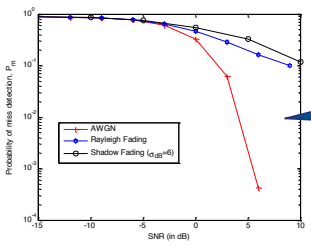
Energy Detection
- "Optimal" detector
- Simple architecture
- Easy to implement
- Less complexity



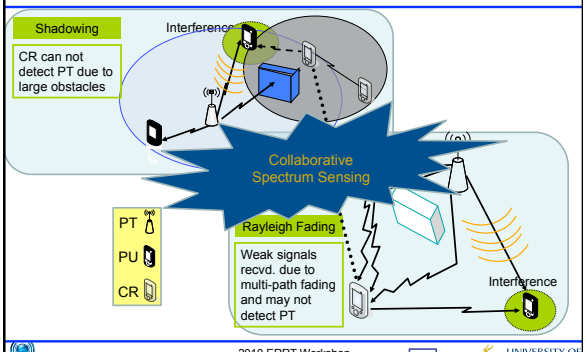
Local Spectrum Sensing - Results



Local Spectrum Sensing – Results (Ctd)



Limitations of Local Spectrum Sensing



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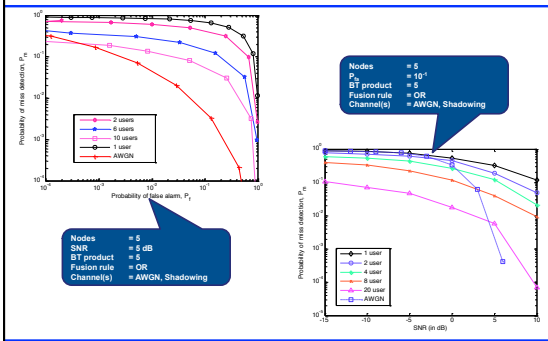
Collaborative Spectrum Sensing (CSS)

- 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



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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,

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

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,

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

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

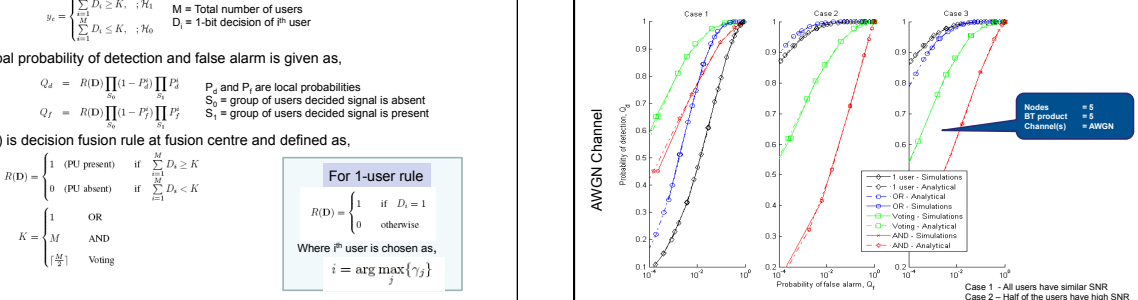
For 1-user rule

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

Where i^{th} user is chosen as,

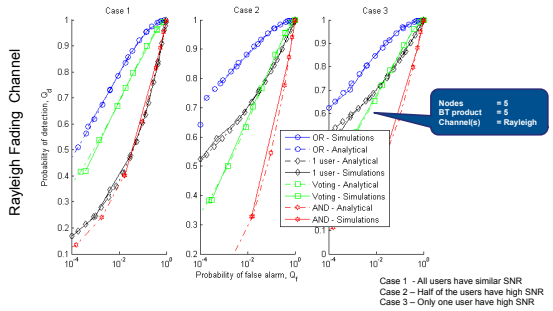
$$i = \arg\max_j \{\gamma_j\}$$

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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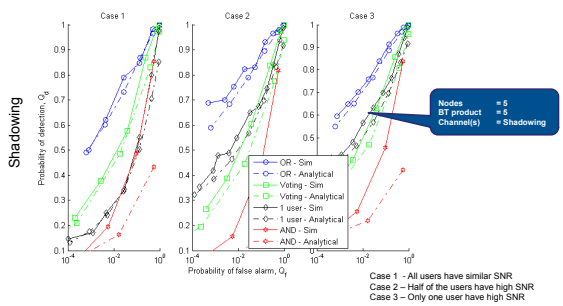
Results - HDC



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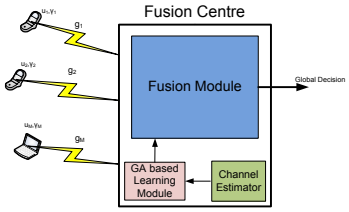
Soft Decision Combining (SDC) Framework

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

$$f(\mathrm{w}) = \frac{\sqrt{\mathrm{Var}[y_c/\mathcal{H}_0]}Q^{-1}(Q_f) + \mathrm{E}[y_c/\mathcal{H}_0] - \mathrm{E}[y_c/\mathcal{H}_1]}{\sqrt{\mathrm{Var}[y_c/\mathcal{H}_1]}}$$

$$= \frac{Q^{-1}(Q_f)\sqrt{\mathrm{w}^T\mathbf{A}\mathrm{w}} - \mathrm{w}^T[\mathrm{diag}(\mathrm{g})\mathrm{diag}(\boldsymbol{\sigma})]'}{\sqrt{\mathrm{w}^T\mathbf{B}\mathrm{w}}}$$

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

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

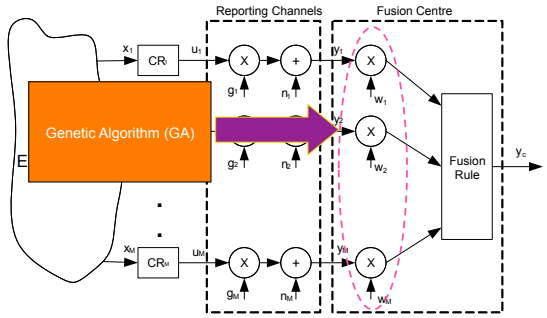
$\mathbf{B} = 2(NI_M + 2\mathrm{diag}(\overline{\gamma}))\mathrm{diag}^2(\mathrm{g})\mathrm{diag}^2(\boldsymbol{\sigma}) + \mathrm{diag}($

Problem

$$\text{minimise} \quad f(\mathrm{w})$$

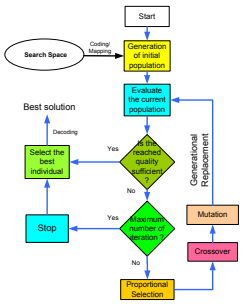
$$\text{st.} \quad ||\mathrm{w}||_2^2 = 1 \quad \text{and} \quad w_i > 0 \ \forall i \in \{1,2,3,...,M\}$$

Proposed weighted framework

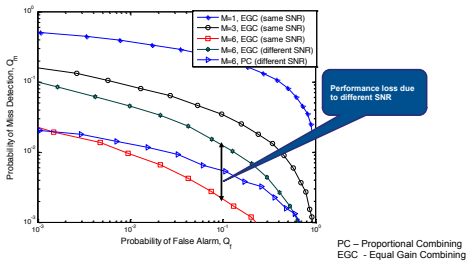


Why genetic algorithm?

- 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

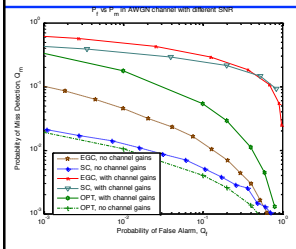


Simulation results - SDC

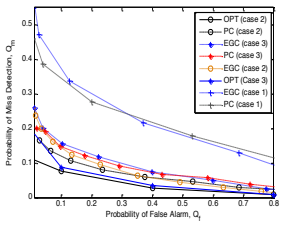


PC – Proportional Combining
EGC - Equal Gain Combining

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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Conclusions

- 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

This work was performed in project E3 and QoSMOS which have received research funding from the Community's Seventh Framework programme. This paper reflects only the author's views and Community is not liable for any use that may be made of the information contained therein. The contributions of colleagues from E3 and QoSMOS consortium are hereby acknowledged.

Questions ???