Improved coexistence between multiple cognitive tactical radio networks by an expert rule based on sub-channel selection

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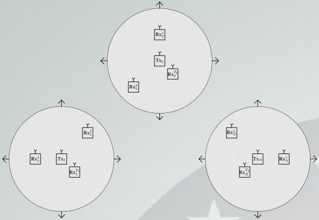
Outline

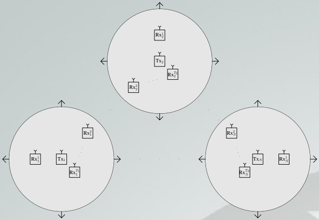
Introduction

Convergence behavior of various versions of the iterative waterfilling algorithm (IWFA) for the coexistence of multiple cognitive tactical radio networks



- For wireline systems (DSL), IWFA solves the distributed power control problem in a frequency selective interference channel [Yu02] (Uniqueness of the Nash equilibrium).
- For wireless systems, robust versions of the IWFA have been introduced in [Wang08][Scutari08][Setoodeh09][Gohary09][Hong11] (multiple Nash equilibria).
- The IWFA has been extended to parallel Gaussian broadcast channels with only common information [LeNir10] (closed form solution).
- We present and improved convergence behaviour of the IWFA by introducing an expert rule based on sub-channel selection.

IWFA in BC with only common information



- For the theoretical analysis, we assume that the links between the transmitters and the receivers exhibit quasi-static fading, i.e. in which the coherence times of the fading channels are larger than the time necessary to compute the algorithm.
- The received signal $y_{j,it}$ in network j, sub-channel i and receiver t can be modeled as

$$y_{j,it} = h_{jj,it}x_{ij} + \sum_{k \neq j}^{N} h_{jk,it}x_{ik} + n_{j,it}$$

where N_c is the number of sub-channels, N the number of networks, $n_{j,it}$ the complex noise with variance $\sigma^2_{j,it}$ for the receiver t of network j on sub-channel i, x_{ij} the transmitted signal for network j on sub-channel i, and $h_{jk,it}$ the channel from network k to the receiver t of network j on sub-channel i.

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IWFA in BC with only common information

We consider the maximization of the aggregate common rate subject to a total power constraint per network

$$\max_{\underline{\underline{\phi}}} \sum_{j=1}^{N} R_{0j}(\underline{\underline{\phi}})$$
$$\text{subject to} \sum_{i=1}^{N_c} \phi_{ij} = P_j^{tot} \; \forall j$$

with

$$R_{0j}(\underline{\underline{\phi}}) = \min_{1 \dots T_j} R_{0jt}(\underline{\underline{\phi}})$$

with

$$R_{0jt}(\underline{\underline{\phi}}) = \Delta f \sum_{i=1}^{N_c} \log_2 (1 + \frac{|h_{jj,it}|^2 \phi_{ij}}{\Gamma(\sigma_{j,it}^2 + \sum_{k \neq j} |h_{jk,it}|^2 \phi_{ik})})$$

and $\underline{\underline{\phi}}$ the power allocation among all sub-channels and networks, $\phi_{ij} = E[|x_i|^2]$ the variance of the input signal on sub-channel i for network j, P_j^{tot} the total power constraint for network j, Δf the sub-channel bandwidth, and Γ the SNR gap which measures the loss with respect to theoretically optimum performance [Cioffi91].

IWFA in BC with only common information

The distributed algorithm called IWFA iteratively updates the power allocation of each network while considering the interference of all other neworks as noise.

- For $T_j = 1$, the power allocation for interference channels [Yu02] is given by

$$\phi_{ij}^{opt} = \left[\frac{1}{\tilde{\lambda}_j} - \frac{\Gamma\tilde{\sigma}^2_{j,i1}}{|h_{jj,i1}|^2}\right]^+$$

- For $T_j = 2$, the power allocation for parallel Gaussian broadcast channels with only common information [LeNir10] is given by

Find $\underline{\phi}_j^{(w_{j1},w_{j2})^{opt}}$ $\forall j$ given by

$$\phi_{ij}^{(w_{j1},w_{j2})} = \left[\frac{1}{2\tilde{\lambda}} + \sqrt{\frac{1}{4\tilde{\lambda}^2} - \frac{(a_{ij}-b_{ij})(w_{j1}-w_{j2})}{2\tilde{\lambda}} + \frac{(a_{ij}-b_{ij})^2}{4}} - \frac{a_{ij}+b_{ij}}{2}\right]^+$$

with

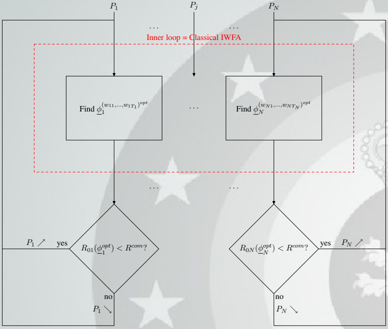
$$(w_{j1}, w_{j2})^{opt} = \min_{w_{j1},w_{j2}} \frac{\sqrt{\frac{1}{T_j}\sum_{t=1}^{T_j}[(R_{0jt}(\underline{\phi}_j^{(w_{j1},w_{j2})}) - \frac{1}{T_j}\sum_{t=1}^{T_j} R_{0jt}(\underline{\phi}_j^{(w_{j1},w_{j2})}))^2]}}{\frac{1}{T_j}\sum_{t=1}^{T_j} R_{0jt}(\underline{\phi}_j^{(w_{j1},w_{j2})})} \quad \forall j$$

in which $\underline{\phi}_j$ the power allocation among all sub-channels for network j,

$a_{ij} = \dfrac{\Gamma\tilde{\sigma}^2_{j,i1}}{|h_{jj,i1}|^2}$ and $b_{ij} = \dfrac{\Gamma\tilde{\sigma}^2_{j,i2}}{|h_{jj,i2}|^2}$.

IWFA in BC with only common information

The results from the previous optimization problem are also valid in case of the minimization of the aggregate toal power subject to a common rate constraint per network (distributed power control). An inner loop determines iteratively for each network the power allocation maximizing the common rate and satisfying its total power constraint. Then, an outer loop minimizes the total powers of the different networks individually such that a common rate constraint R^{com} is achieved.



Expert rule based on sub-channel selection

Additioning an expert rule based on sub-channel selection gives three advantages

- Lower the complexity of the algorithm by allocating power only over a subset of the available sub-channels
- Lower the complexity of the physical layer in the case of a multi-carrier waveform with non-overlapping sub-channels
- Improve the convergence of the algorithm by giving more facility to the networks to avoid each other

At each iteration of the inner loop in the IWFA in parallel Gaussian broadcast channels with only common information, a network can only use L contiguous sub-channels, with $L \in \{1, N_c\}$. In fact, the network j chooses the subset of contiguous sub-channels exhibiting the maximum common rate

$$l_j^{opt} = \max_{l_j} \min_{t=1\ldots T_j} \Delta f \sum_{i=l_j}^{l_j+L-1} \log_2\left(1 + \frac{|h_{i,jj}|^2 P_j^{tot}}{L\Gamma \tilde{\sigma}_{j,it}^2}\right)$$

The optimal subset of sub-channels to be used for the network j is therefore determined by

$$\mathcal{A}_j = \{l_j^{opt}, l_j^{opt} + L - 1\}$$

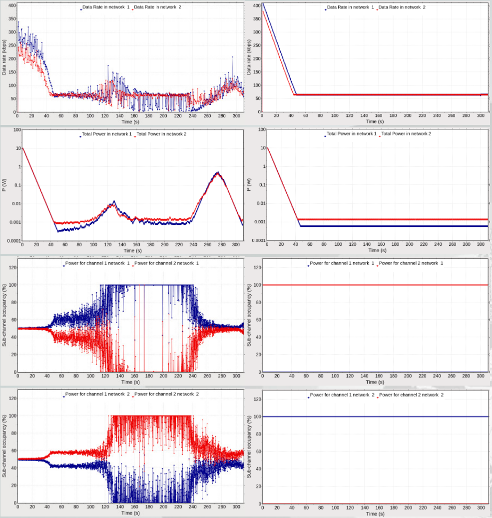
Simulation results

The convergence behavior of the algorithm is studied by an implementation in the event-driven simulator OMNeT++/MiXiM. The first network is mobile and follows a pre-defined trajectory with a constant velocity v (about 90 km/h). The sub-channel gains of the direct channels follow a Rayleigh distribution and do not change during the simulation as the relative doppler is zero. The sub-channel gains of the interference channels vary at each inner loop since their coherence time is approximately $t_c = 0.05$s.

Carrier frequency f_c	80 MHz	Number of networks N	2
SNR gap Γ	9.8 dB	Time between inner loops	0.1s
Sub-channel bandwidth	25 kHz	Time between outer loops	0.5s
Path loss exponent n	4	Power updates (outer loop)	0.46 dB
Common rate constraint R^{com}	64 kbps		

Simulation results

Comparison between classical IWFA (left) and IWFA with sub-channel selection of a single sub-channel (right) ($N_c = 2$ sub-channels)



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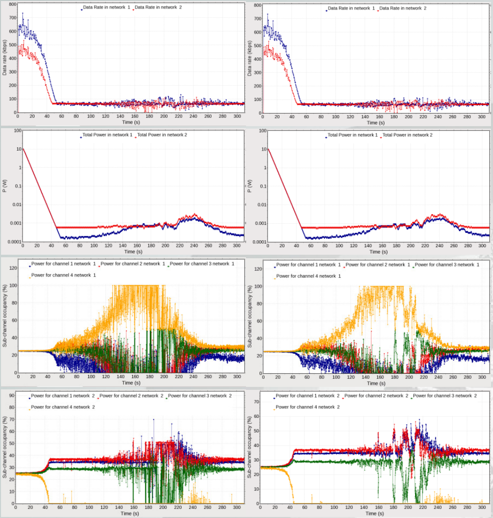
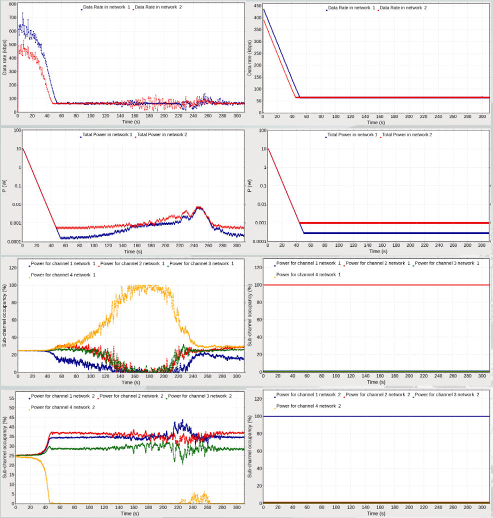
Simulation results

Comparison between classical IWFA (left) and IWFA with averaging [Hong11] (right) ($N_c = 4$ sub-channels)



Simulation results

Comparison between IWFA with circular averaging (left) and IWFA with sub-channel selection of a single sub-channel (right) ($N_c = 4$ sub-channels)



Conclusion

- Expert rule based on sub-channel selection
  - Lowers the complexity of the algorithm by allocating power only over a subset of the available sub-channels
  - Lowers the complexity of the physical layer in the case of a multi-carrier waveform with non-overlapping sub-channels
  - Improves the convergence of the algorithm by giving more facility to the networks to avoid each other
- IWFA with sub-channel selection of a single sub-channel shows no errors of convergence, which could be seen as an enhanced version of a simple "detect and avoid" strategy.
- Future work
  - Non-continuous transmission for voice and data
  - Develop a multi-channel contention-based MAC layer adapted to IWFA with sub-channel selection of a single sub-channel
  - Implementation on USRPs

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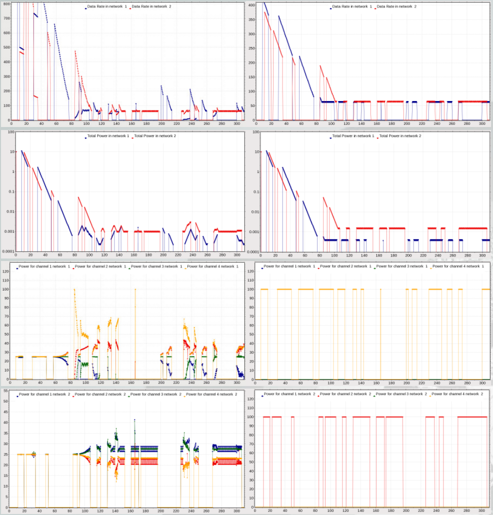
Extended Results

Non-continuous transmission for voice (exponential distributions with 10s mean service time and 10s mean idle time)



Extended Results

Non-continuous transmission for data (exponential distributions with 0.1s mean service time and 0.1s mean idle time)