Firefly Algorithm based Power Control in Wireless TV White Space Network

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Introduction

- Studies show that spectrum assigned to primary (licensed) users is underutlilized.
- More and more devices and applications want spectrum and yet the usable spectrum is limited.
- Dynamic spectrum access (DSA) is currently being embraced as a solution of spectrum underutilization and spectrum scarcity.
- Dynamic spectrum access – Spectrum allocated to primary users and any other idle bands can be made use of by secondary users as long as they do not cause harmful interference to primary users.

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Definition of terms

- Primary user – primary receiver e.g TV receiver
- TV white spaces (TVWS):
  - VHF and UHF spectrum band (470-790 MHz) not being utilized by TV transmitters.
  - Good for wireless communication because it has good propagation characteristics
- Secondary user – Device with cognitive radio that makes use of TVWS spectrum
- White space device (WSD) – Same as secondary user
- GLDB – Geo-location database

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Introduction: Incumbent Protection

- There are three main methods for incumbent (PU) protection: geo-location database, spectrum sensing and use of beacons.
  - **Use of beacons**:
    - WSD will only transmit if it receives a beacon granting it permission to transmit in specific channels.
    - The downside of this technique is development of beacon infrastructure.
  - **Spectrum sensing**:
    - WSD senses whether a channel is not being utilized by a primary user.
    - Spectrum sensing suffers from hidden node problem
  - **Geolocation database**: Computes and stores channels available for secondary use in a particular area.

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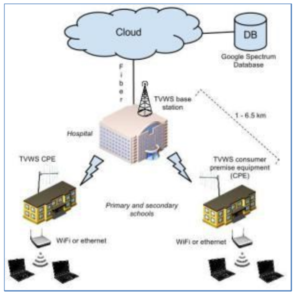
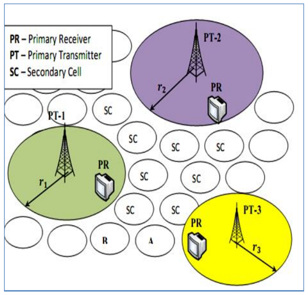
Introduction: Geo-location Database

- Contains estimated power levels of all TV transmitters in a particular region of interest.
- If the received power for a TV tower falls below a certain threshold (-114 dBm) at a particular location point, then the channel used by that tower is available for secondary use.
- A white space device (WSD) will query the central database to find out idle channels which can be used on a secondary basis at a particular point or area.
- Popular GLDB service providers are Google and Microsoft.

TVWS Network Architecture



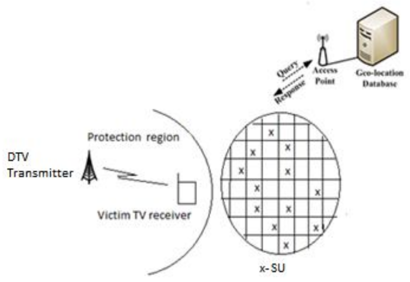


Introduction: Interference in GLDB based TVWS network

- It is expected there will be continued demand for dynamic spectrum access (DSA) – vehicle to vehicle communications, internet of things
- Problem of interference will arise a TVWS network if there is a high number of secondary users.
- There are two types:
  - Co-channel interference
  - Adjacent channel interference
- Adjacent channel interference cannot be ignored when there is a high density of users.
  - It is as harmful as co-channel interference.

Introduction: Interference in GLDB based TVWS network

- Protection ratio at PU
- QoS/SINR constraints at at SUs



Power Control Based on Firefly Algorithm

- There is need for power control in a TVWS network when there is a high density of devices that considers both both co-channel and adjacent channel interference.
- Existing algorithms ignore adjacent channel interference, use heuristic algorithms, or consider a device-to-device network.
- Firefly algorithm chosen because it has been proven to perform better than genetic algorithm and particle swarm optimization in terms of solution quality and convergence time.
- Firefly algorithm compared with fixed power allocation algorithm

Algorithm 1: Pseudocode for Firefly Algorithm[13]

Step 1: Initialize the control parameter values for the FA: light absorption coefficient γ, attractiveness β, randomization parameter α, maximum number of iterations t_{max}, number of fireflies NP, domain space D.

Step 2: Define objective function $f \underset{x}{\rightarrow}, \underset{x}{\rightarrow} = x_1, x_2, x_3, \ldots, x_n$. Generate the initial location of fireflies x_i $(i = 1,2, \ldots, NP)$ and set the iteration number $t = 0$.

Step 3:

while $t \leq t_{max}$ **do**
  for $i = 1$ to NP (do for each individual sequentially) **do**
    for $i = 1$ to NP (do for each individual sequentially) **do**
      compute light intensity β_i as x_i is determined by $f(x_i)$
      if $\beta_i < \beta_j$, **then**
        Move firefly i towards j as described in Equation 9
      Endif
      Attractiveness varies with distance r via $e^{-\gamma r}$
      Evaluate new solutions and update light intensity
      Check updated solutions are within limits
    end for
  end for
  Step 3.1
  Rank the fireflies and find the current best;
  Increase the iteration count
end while

Objective function $f(\mathbf{x})$, $\mathbf{x} = (x_1, \ldots, x_d)^T$
Generate initial population of fireflies $\mathbf{x}_i$ $(i = 1, 2, \ldots, n)$
Light intensity I_i *at* $\mathbf{x}_i$ *is determined by* $f(\mathbf{x}_i)$
Define light absorption coefficient γ
while *(t <MaxGeneration)*
for $i = 1 : n$ *all n fireflies*
  for $j = 1 : i$ *all n fireflies*
    if $(I_j > I_i)$, *Move firefly i towards j in d-dimension;* end if
    Attractiveness varies with distance r via $\exp[-\gamma r]$
    Evaluate new solutions and update light intensity
  end for j
end for i
Rank the fireflies and find the current best
end while
Postprocess results and visualization

Algorithm 2: Power control using firefly algorithm

Step 1:
- Specify the number of SUs
- Set the dimension of fireflies D

Step 2:
- Initialize the control parameters of the algorithm α, β, γ firefly number NP and maximum number of iterations t_{max}.
- Generate initial position of fireflies randomly $x_i = [x_{1,i}, x_{2,i}, \ldots x_{d,i} \ldots\ldots, x_{D,i}]$ where $P_{min} \leq x_{d,i} \leq P_{max}$ and $i \in (1 \ldots\ldots NP)$

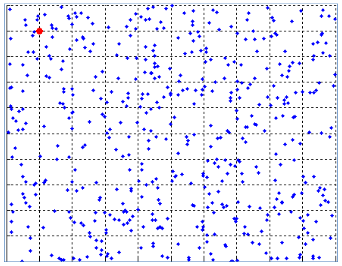
Step 3:
- Check firefly x_i to see if the power values in the power vector are within range. If any values are out of range then create random values that are within range to replace them.

Step 4
- Calculate the fitness value of each firefly using equation (14) and rank the fireflies according to their fitness values
- Find the current best solution

Step 5
- For every firefly, move it to the better solution according to equation (12)

Step 6
- If it reaches the predefined maximum number of iterations then derive the power vector of the current best solution mentioned in step 4 and stop the progress else go to step 3 and continue.

Simulation Set Up



- SUs distributed over 1sq. km
- Red dot – Primary user
- Blue dots – secondary users
- No. of SUs varied from 100, 500, 1000
- Free space path loss model used

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Simulation Parameters

Table 1: Simulation parameters

Parameter	*Value*	*Comment*
B	6 MHz	Bandwidth of TV channel
f_a	650 MHz	Centre frequency of DTV signal
P_{DTV}	-70.6 dBm	Power of DTV signal at victim TV receiver
δ_n^2	-102 dBm	Noise power
ω_o	23 dB	TV receiver SINR threshold
ρ_o	7 dB	SU SINR threshold
P^{BS}	36 dBm (4W)	Transmit power of base station
p_{max}	30 dBm	Maximum SU transmit power
$\mu(x_i, a)$	0, -28 dB	Adjacent channel interference co-efficient
G_{SU}	10 dB	SU antenna gain
G_{PU}	10 dB	PU antenna gain
G_{BS}	10 dB	Access point antenna gain

Simulation Results

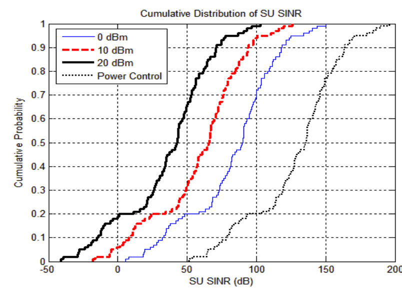

Figure 4: SU SINR distribution for network with 100 SUs

Simulation Results

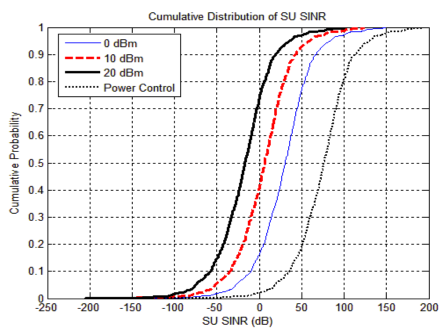

Figure 4: SU SINR distribution for network with 500 SUs

Simulation Results

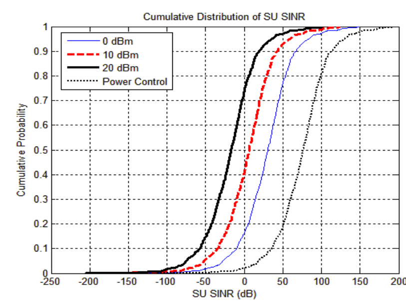

Figure 4: SU SINR distribution for network with 1000 SUs

Simulation Results

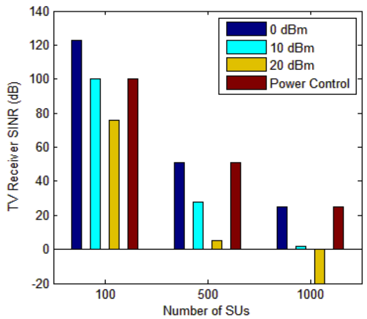

Figure 6: PU SINR for network with different number of SUs

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Conclusion

- Firefly algorithm performs better than fixed power allocation method of power allocation.
- The algorithm is able to protect the PU and SUs against harmful interference.
- Future work: Firefly algorithm will be compared to genetic algorithm and particle swarm optimization.

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Thank you

Asante Sana

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