Impact of Secondary Users' Field Size on Spectrum Sharing Opportunities

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Outline

Spectrum Sharing

- Radio spectrum: scarce resource but under-utilized.
- Spectrum sharing: a new spectrum management paradigm.
- Sharing schemes: overlay & underlay.

Harmful Interference

- Interference event vs. harmful interference.
- Different metrics to gauge harmful interference.
- These metrics $\equiv f$(system & channel parameters).

Motivation

- Field size receives least attention.
- Usually infinite field size is assumed, e.g., in [Menon05], [Menon06], [Ghassemi08] and [Win09].
- Impact of field size on spectrum sharing?

Interference Characterization in Large Wireless Networks (1/2)

Literature Overview

- Many papers investigate interference in large wireless networks using Poisson Point Process, e.g., [Sousa90], [Sousa92], [Ilow98], [Chan01], [Yang03], [Haenggi05], [Menon05], [Menon06], [Weber07], [Hasan07], [Ghasemi08], [Salbaroli09] and [Win09].
- Using a singular distance-dependent attenuation model leads to having an alpha-stable distribution of the aggregate interference power. This distribution has a closed form expression for the characteristic function but not for the CDF/PDF except for one special case [Sousa90].

Interference Characterization in Large Wireless Networks (2/2)

Literature Overview

- More realistic performance results are obtained by using non-singular distance-dependent attenuation models [Inaltekin09].
- If an exclusion region is imposed around the victim receiver or a non-singular distance-dependent attenuation model is used, the distribution of the aggregate interference power has a characteristic function in a closed form expression.
- However, no closed form expression is known for the distribution function. A numerical inversion of the characteristic function is an option.
- Alternatively, approximating the distribution of the aggregate interference using a finite set of moments (or cumulants) is a viable option.

Our Approach and Contributions

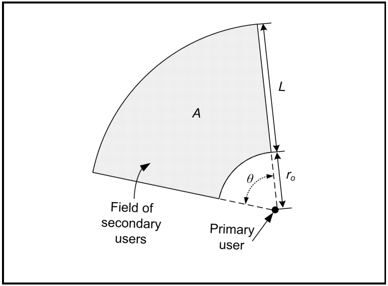
- We consider a finite field with an exclusion region (an infinite field is a special case of our results).
- First, we investigate the effect of field size on spectrum sharing by deriving an upper bound on the interference probability using the first two cumulants, i.e., mean and variance.
- Then, we extend cumulants formulations provided in [Menon06], and approximate the distribution of the aggregate interference based on a finite set of these cumulants.
- Finally, we repeat the investigation of the effect of the field size on spectrum sharing opportunities utilizing the approximation of the distribution of the aggregate interference.

System Model

- Field of secondary users sharing a spectrum with a primary user.
- Aggregate interference power:

$$I_A = \sum_{i \in N} I_i = \sum_{i \in N} r_i^{-n} W_i$$

- Analysis objective:
  Investigate effect of L on I_A and spectrum sharing.



Interference Probability

A harmful interference metric [Ghasemi08] and [Win09]

- Non-harmful interference:

$$P(I_A \geq I_{th}) \leq \beta$$

$\Rightarrow$ spectrum sharing allowed

- Harmful interference:

$$P(I_A \geq I_{th}) > \beta$$

$\Rightarrow$ spectrum sharing NOT allowed

Mean of the Aggregate Interference

Formulation

- Mean of I_A (i.e., $\sum_{i \in N} r_i^{-n} W_i$):

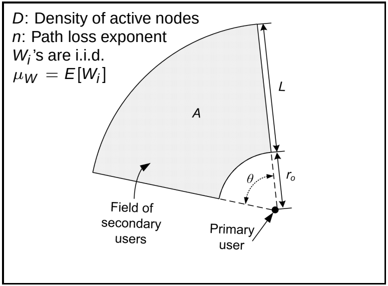
$$\mu_A = \frac{1}{n-2} D\theta r_o^{2-n} \mu_W \times \left[1 - \left(\frac{r_o}{r_o + L}\right)^{n-2}\right]$$

- For $L << r_o$:

$$\mu_A \simeq D\theta {r_o}^{1-n} L \, \mu_W$$

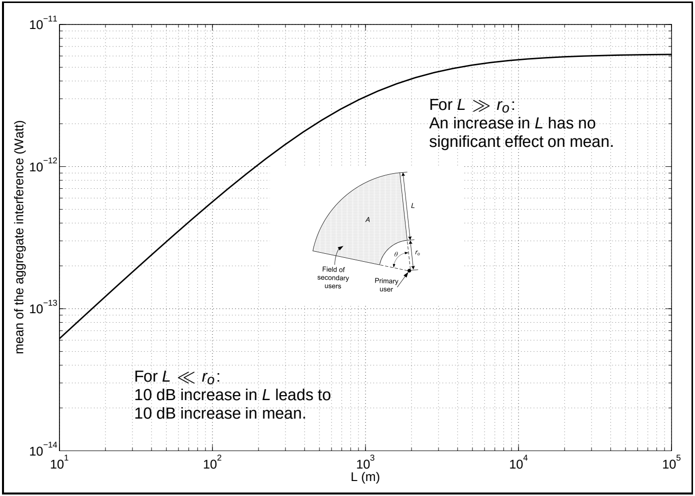
- For $L >> r_o$:

$$\mu_A \simeq \frac{1}{n-2} D\theta r_o^{2-n} \mu_W$$



Mean of the Aggregate Interference

Effect of Field Size



Variance of the Aggregate Interference

Formulation

- Variance of I_A (i.e., $\sum_{i \in N} r_i^{-n} W_i$):

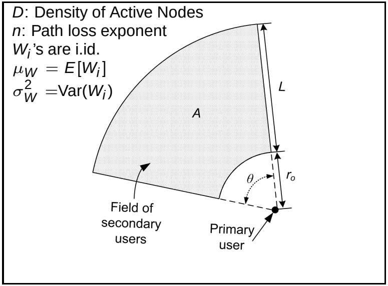
$$\sigma_A^2 = \frac{1}{2n-2} D\theta r_o^{2-2n} \, \mu_W^2 (1 + \frac{\sigma_W^2}{\mu_W^2}) \times \left[1 - \left(\frac{r_o}{r_o + L} \right)^{2n-2} \right]$$

- For $L << r_o$:

$$\sigma_A^2 \simeq D\theta r_o^{1-2n} L \, \mu_W^2 (1 + \frac{\sigma_W^2}{\mu_W^2})$$

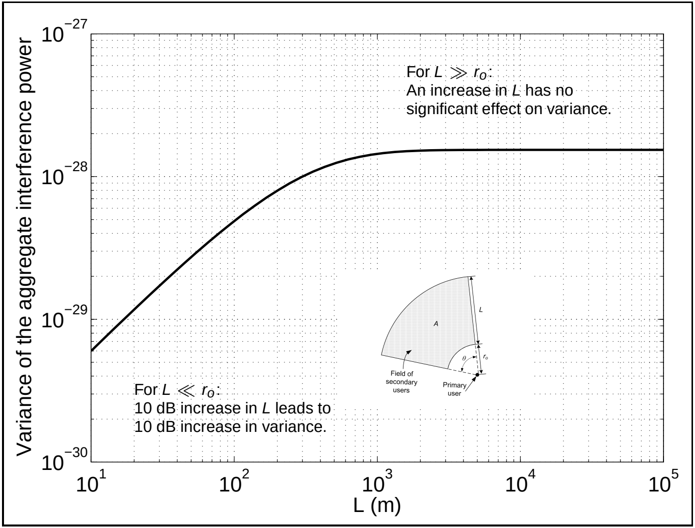
- For $L >> r_o$:

$$\sigma_A^2 \simeq \frac{1}{2n-2} D\theta r_o^{2-2n} \, \mu_W^2 (1 + \frac{\sigma_W^2}{\mu_W^2})$$



Variance of the Aggregate Interference

Effect of Field Size



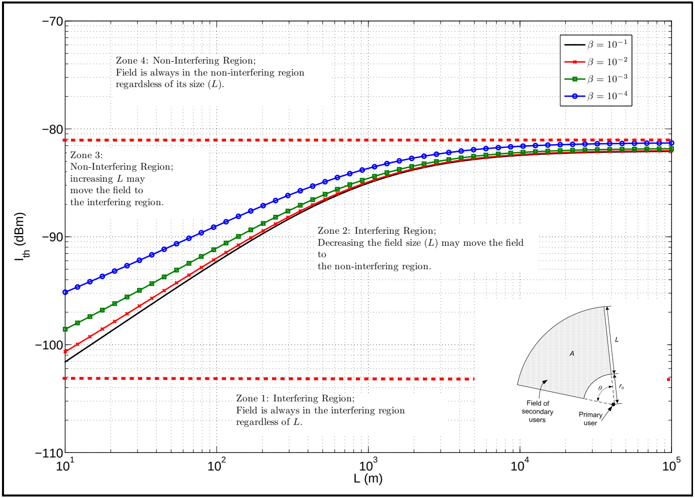
Upper Bound on the Interference Probability

Formulation

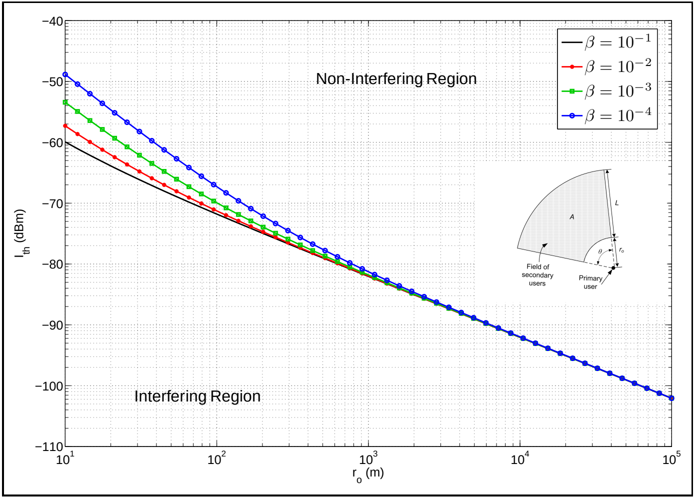
- Based on Chebyshev inequality, interference probability is bounded by:

$$P(I_A \geq I_{th}) \leq \frac{\sigma_A^2}{(I_{th} - \mu_A)^2}$$

Effect of Field Expansion



Effect of Exclusion Region



Cumulants of I_A

- Cumulants of I_A (i.e., $\sum_{i \in N} r_i^{-n} W_i$):

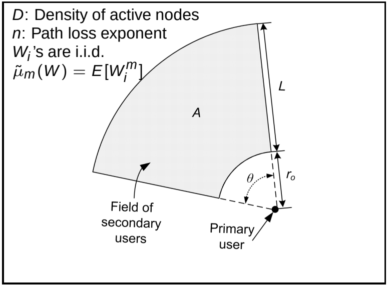
$$\kappa_m(I_A) = \frac{1}{nm-2} D\theta \tilde{\mu}_m(W) r_o^{2-mn} \times \left[1 - \left(\frac{r_o}{r_o + L}\right)^{mn-2}\right]$$

- For $L << r_o$:

$$\kappa_m(I_A) \simeq D\theta {r_o}^{1-mn} L \, \tilde{\mu}_m(W)$$

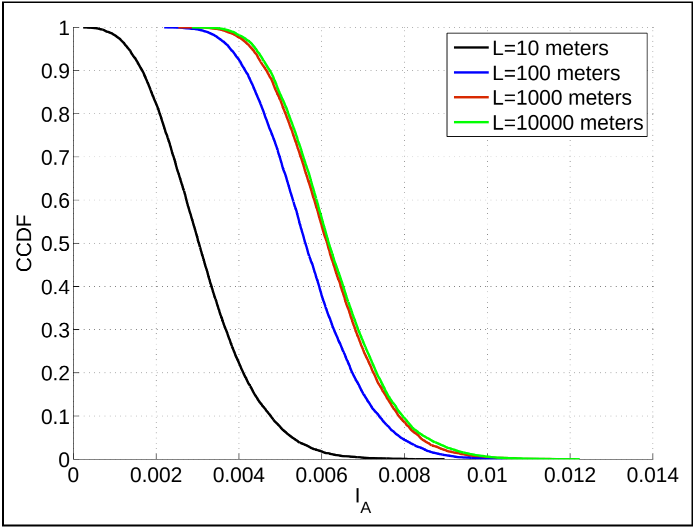
- For $L >> r_o$:

$$\kappa_m(I_A) \simeq \frac{1}{nm-2} D\theta \tilde{\mu}_m(W) r_o^{2-mn}$$

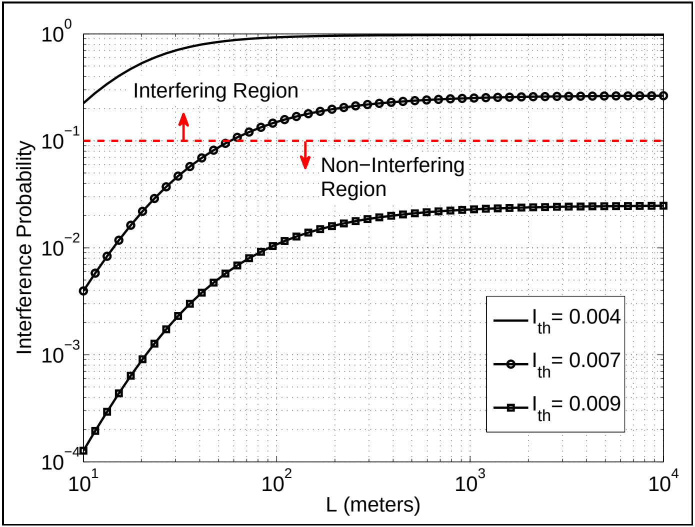


Effect of Field Size on the CCDF of I_A

Simulation



Effect of Field Size on Spectrum Sharing (2)



Summary

- Asymptotic results for infinite fields:
  - Applicable for finite but relatively large fields.
  - Too conservative otherwise.
- Spectrum sharing vs. field size:
  - In some cases, small reduction in size may create spectrum sharing opportunities.
  - In some other cases, huge increase in size may not eliminate spectrum sharing opportunities.
- In certain cases, concurrent and continuous spectrum sharing is possible without the need for cognitive radio functionalities.

Thank you