TESSO: An Analytical Tool for Characterizing Aggregate Interference and Enabling Spatial Spectrum Sharing

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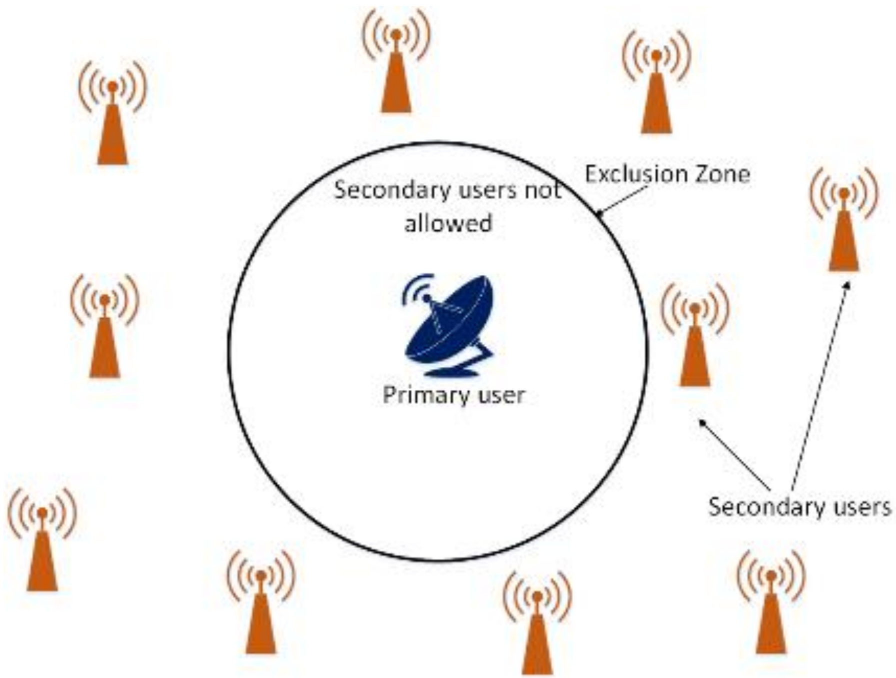
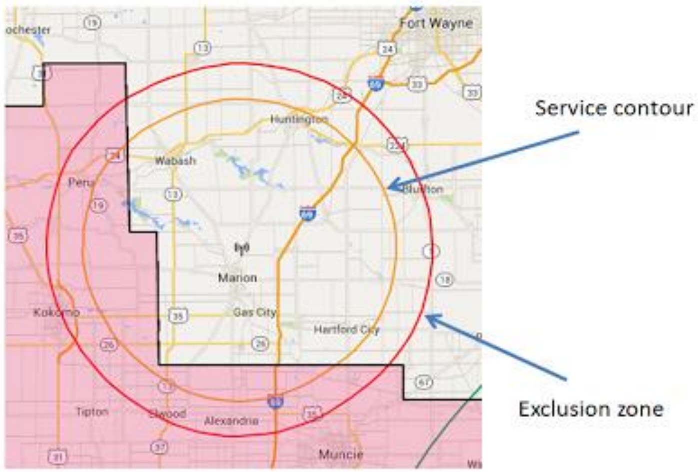
Spatial Spectrum Sharing



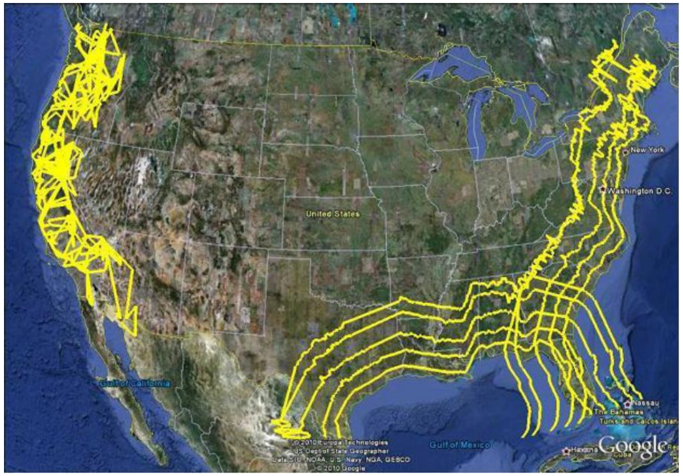
- Spatial spectrum sharing relies on sufficient geographical separation between primary and secondary users of the spectrum.
- Often, an *exclusion zone (EZ)*—i.e., a spatial separation region defined around the primary user where co-channel SUs are prohibited—facilitates spatial spectrum sharing.
- Regulators often use radio propagation models to define an EZ.

Exclusion Zones (EZs)

- An exclusion zone is a **spatial separation region** defined around a primary user where co-channel secondary users (SUs) are not allowed to operate.
- It is the **primary** ex-ante (a.k.a. preventive) enforcement scheme employed by the FCC and the NTIA to protect primary users (PUs) from SU-induced interference.
- Defining an EZ is **challenging** because of the following conflicting requirements:
  - ✓ It should be sufficiently large to protect the PU from SU-induced interference.
  - ✓ It should not be overly large to unnecessarily limit SUs' spectrum access opportunities.



Example of an EZ in TV band



EZs of ship-borne radars in the 3.5 GHz band

Irregular Terrain Model (ITM)

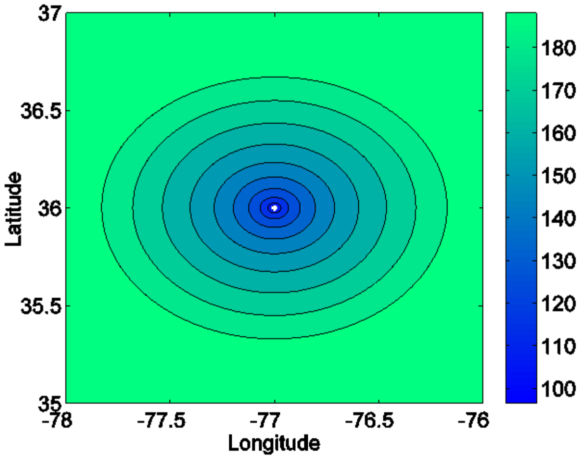
- The effectiveness of an EZ depends on the effectiveness of the radio propagation model used for estimating the path loss from SUs to the PU.
  - A propagation model that overestimates or underestimates the path loss either poses risk to the primary user's interference protection requirement or reduces SUs' spectrum utilization opportunities.

- The ITM is a popular radio propagation model which predicts tropospheric radio transmission loss over irregular terrain for a radio link.

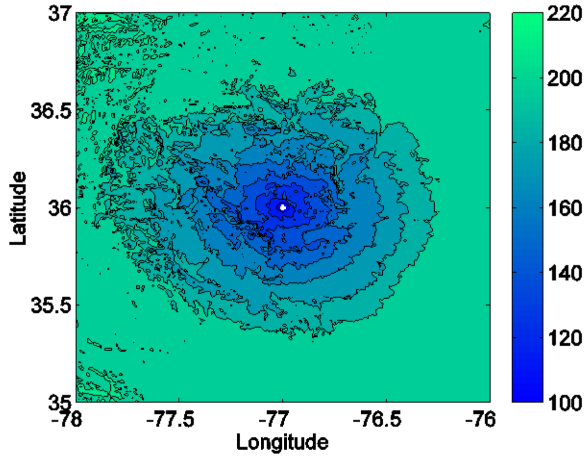
- There are two modes of operation of ITM:

Area prediction (AP) mode	Point to point (PTP) mode
• Predicts path loss based on the average terrain around the Tx.	• Predicts path loss based on the actual obstructions in the link.
• Path loss values are often smaller and less accurate than the ITM-PTP mode.	• Path loss values are highly accurate; they agree closely with the measured data.
• Results in conservative (large) EZs around the IU.	• Results in realistic (and often smaller) EZs around the IU.
• Requires less computations.	• Computationally intensive.

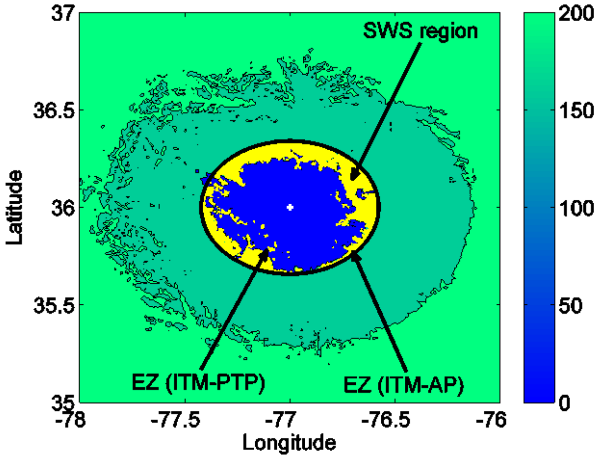
ITM-PTP Mode and Spatial White Spaces



Path loss map (in dB) using ITM-AP mode



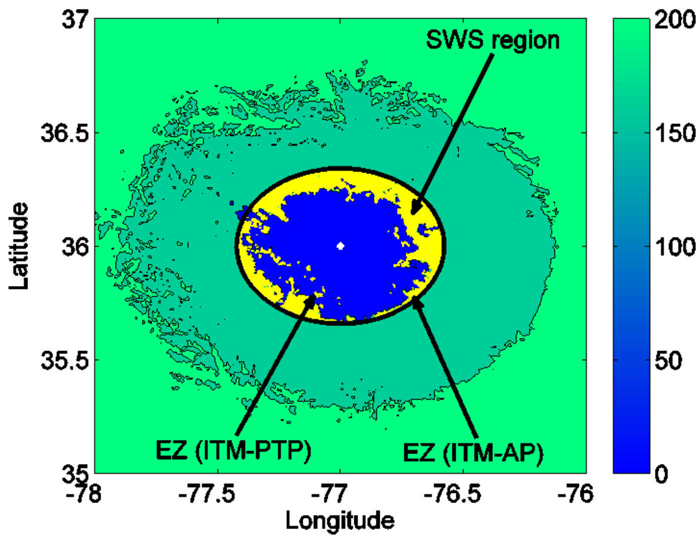
Path loss map (in dB) using ITM-PTP mode



SWS opportunities discovered by ITM-PTP mode

ITM-PTP mode's ability to produce accurate path loss estimates can be utilized to identify spatial white space opportunities, albeit such an approach would incur a high computational cost.

Number of Permissible SUs in the SWS region



Let us define the IU's interference protection criteria as follows,

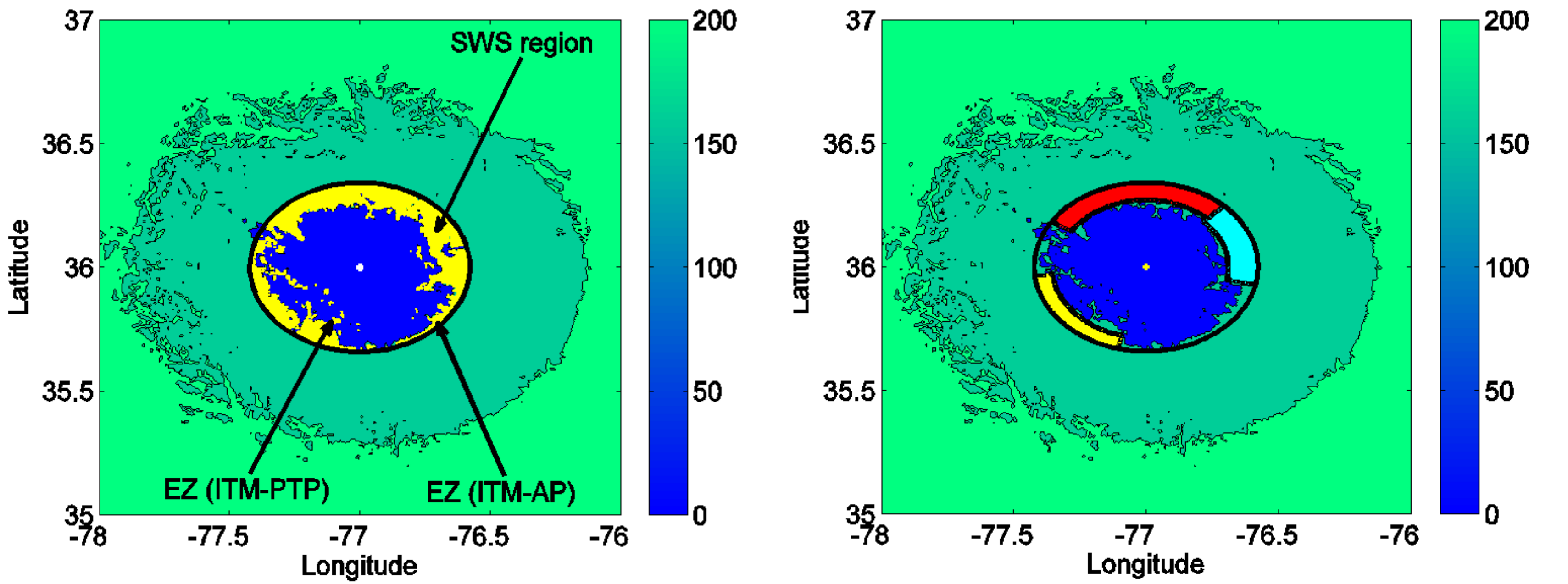
$$P(I_{agg} \leq I_{th}) \geq 1 - \epsilon$$

<u>A straight forward (but computationally intensive) approach</u>

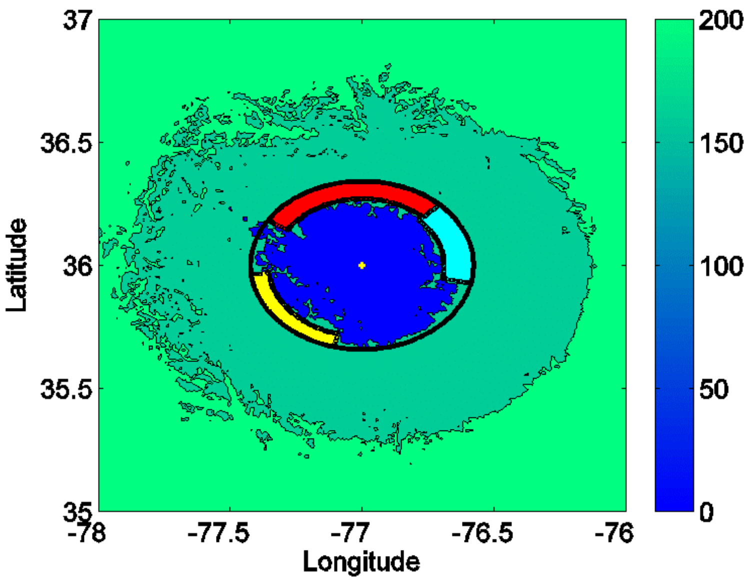
- For each SU requesting access from the SWS region, the estimated interference to the IU can be computed by using ITM-PTP path loss value.
- The requesting SU is allowed to access the co-channel only if the above inequality is satisfied. The maximum number of SUs allowed to access the channel is computed.
- The above steps can be repeated for different set of SU locations and the expected number of SUs that can be safely allowed to operate in the SWS region can be computed.

TESSO

- The approach defined in the previous slide is challenging to implement in real-time systems because:
  - It is based on ITM-PTP mode, which is computationally intensive.
  - It requires precise geolocations of SUs which might not be always available.
- We propose *TESSO—A Tool for Enabling Spatial Sharing Opportunities*—that addresses these limitations by analytically modeling the distribution of aggregate interference, I_{agg}, caused by SUs.



TESSO



Step 1:

- Start with the simplified path loss model with exponential path loss and log-normal shadowing

$$P_L = a + 10\gamma \log(d) + \Psi$$

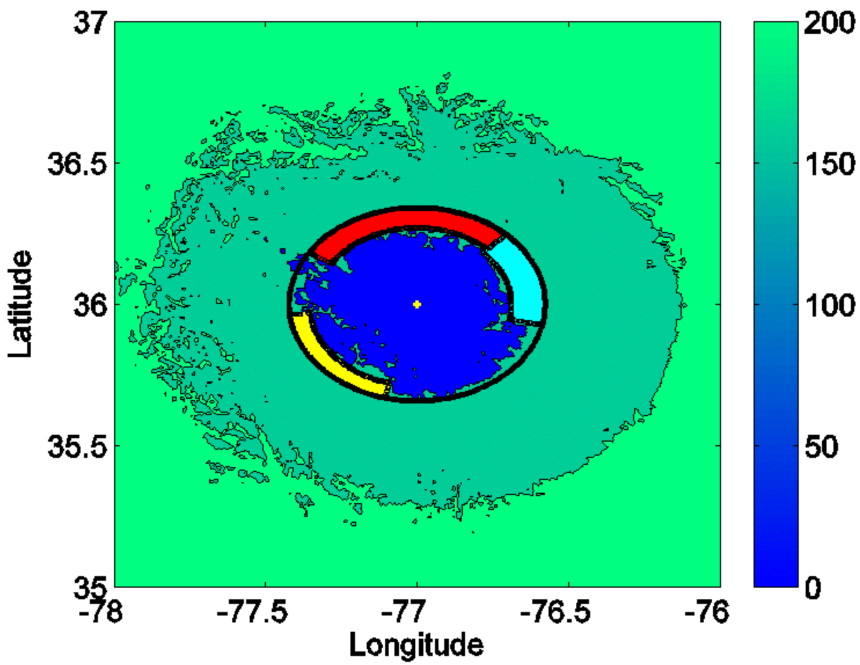
- Characterize the distribution of interference caused by a single randomly chosen SU inside a SWS sector.
- We have shown that when SUs are uniformly distributed in a SWS sector, the distribution of individual SU-induced interference can be approximated as a LN distribution.

Step 2:

Use results from step 1 to characterize the distribution of aggregate interference.

- The aggregate interference is the sum of log normally distributed random variables.
- It has been shown that the summation of log-normally distributed random variables can be approximated as another log-normal.
- Hence, the aggregate interference is also log-normally distributed whose closed form expressions have been derived in the literature.

TESSO



Step 3:
Solve the optimization problem to compute the maximum number of SUs that can be safely allowed to operate in each SWS sector.

- Objective: maximize the total number of SUs in the SWS sectors
- Constraints:
  - Interference protection requirement of the incumbent user
  - SU-SU coexistence

$$\text{Maximize}: \; N = \sum_{j=1}^{\mathcal{S}} N^{(j)}$$

Total # of SUs in the SWS sectors

$$\text{subject to}: \; P\left(\sum_{j=1}^{\mathcal{S}} \sum_{i=1}^{N^{(j)}} I_{SU_{i,j}} \le I_{th}\right) \ge 1 - \epsilon$$

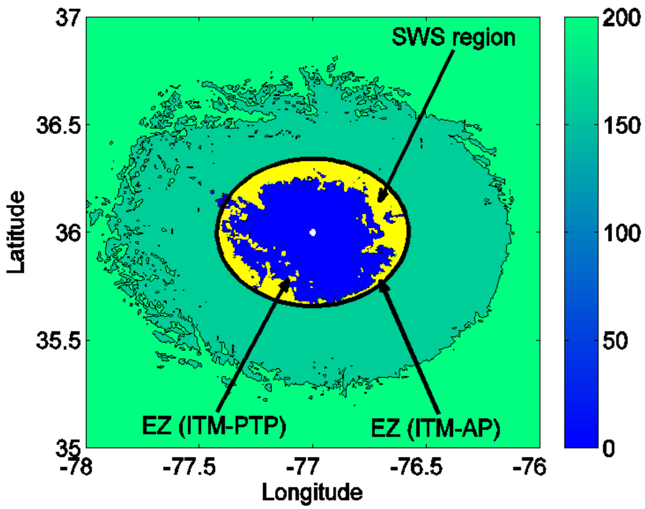
Interference protection requirement of the IU

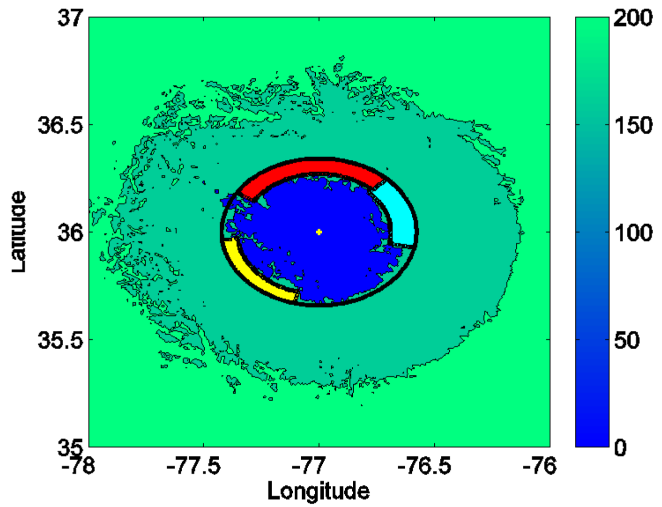
$$0 \le N^{(j)} \le N_{\max}^{(j)}, \qquad j = 1 \ldots \mathcal{S}$$

SU-SU coexistence

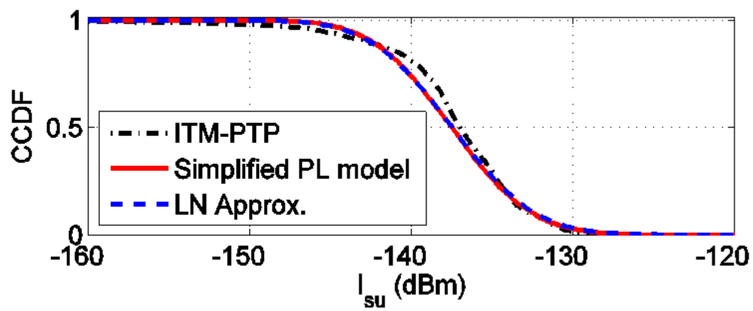
Case Study 1: Norfolk Region

Defining SWS Sectors

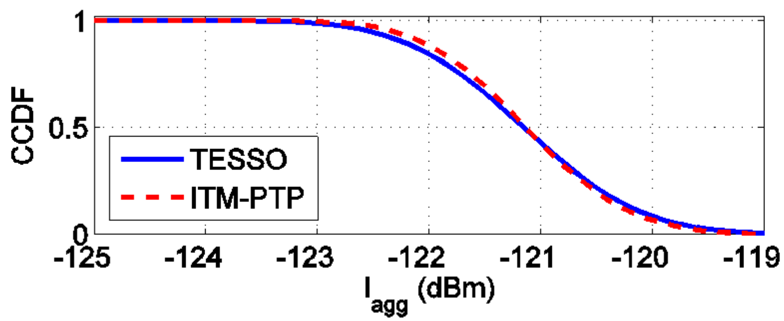




Distribution of Interference



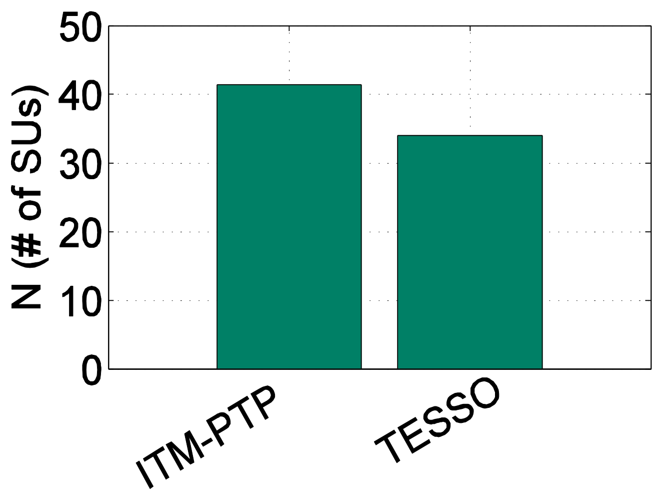
Interference from a single SU operating in one of the SWS sectors

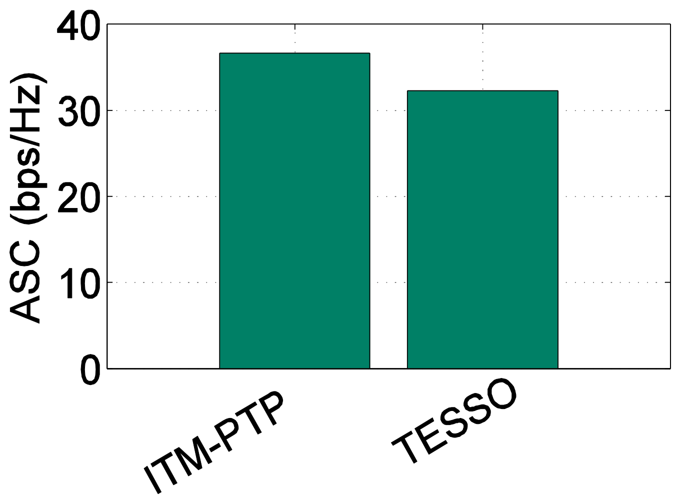


Aggregate interference from all SUs

Case Study 1: Norfolk Region

ITM-PTP versus TESSO





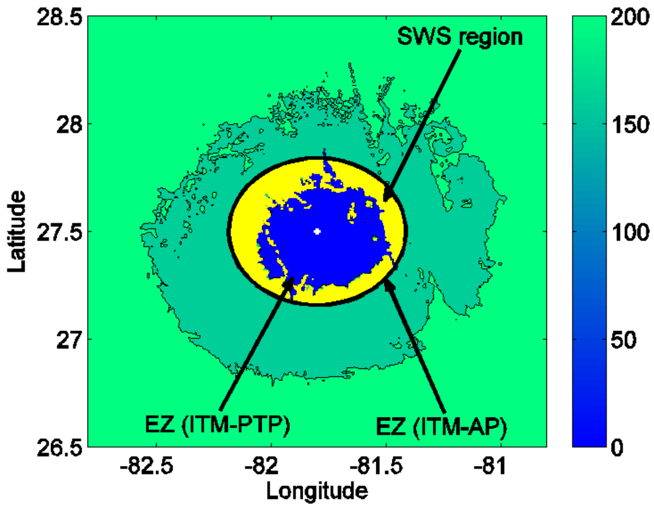
The performance of TESSO, in terms of spectrum utilization and incumbent protection, is comparable to that of the ITM-PTP mode.

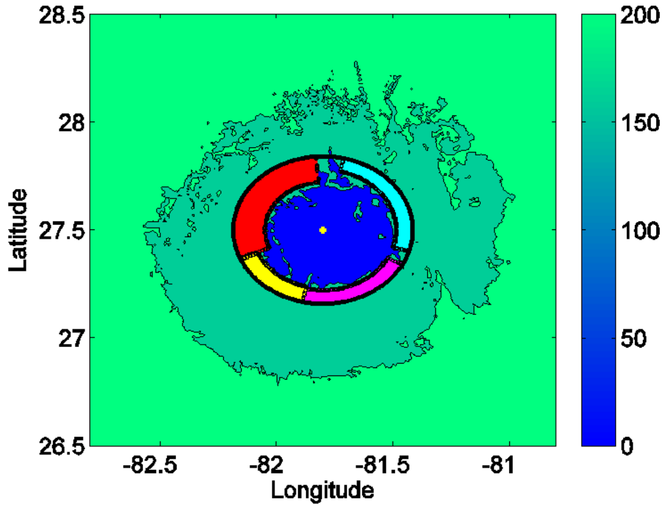
Method	Time Taken
ITM-PTP	~4.1 sec
TESSO	~1 sec

TESSO is 4.1 times more efficient than ITM-PTP in terms of computational complexity.

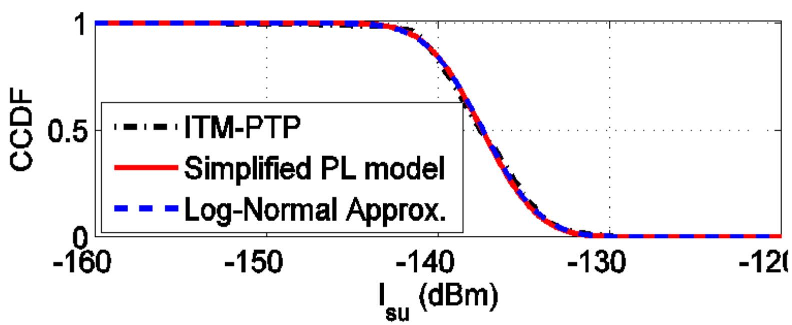
Case Study 2: Fort-Green Region

Defining SWS Sectors

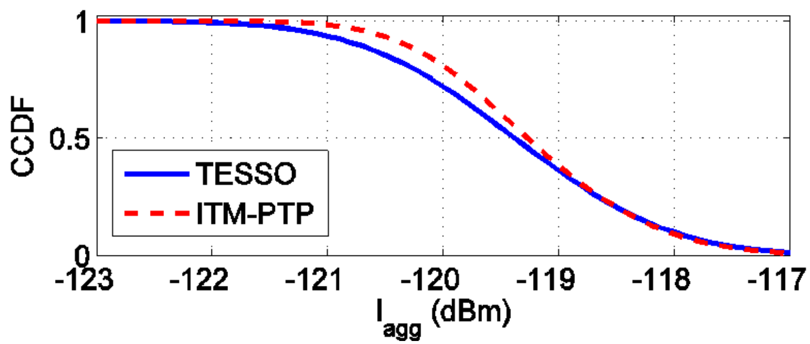




Distribution of Interference



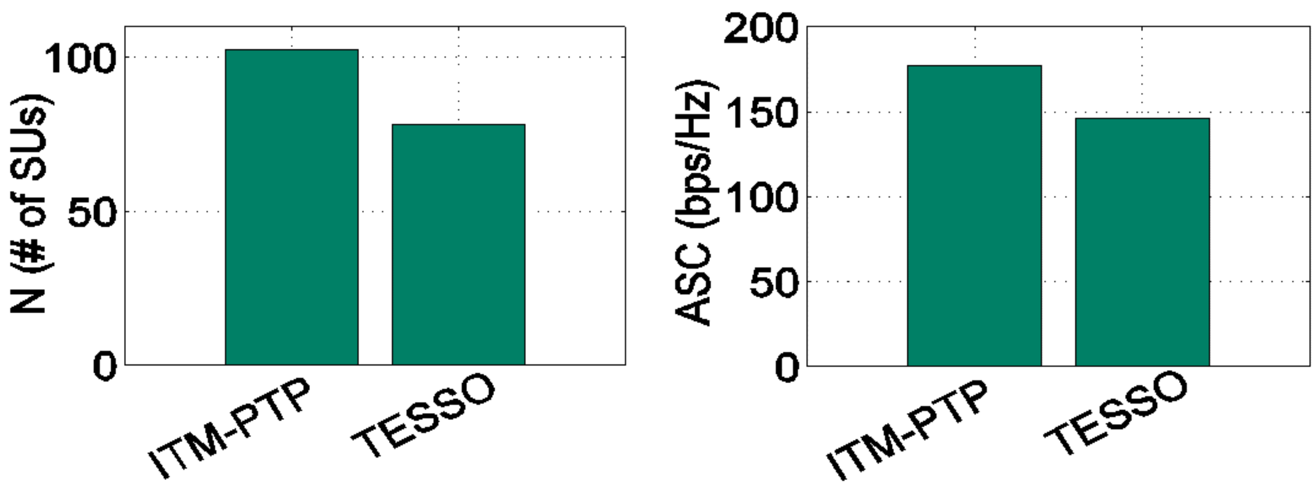
Interference from a single SU operating in one of the SWS sectors



Aggregate interference from all SUs

Case Study 2: Fort-Green Region

ITM-PTP versus TESSO



The performance of TESSO, in terms of spectrum utilization and incumbent protection, is comparable to that of the ITM-PTP mode.

Method	Time Taken
ITM-PTP	~10.2 sec
TESSO	~1 sec

TESSO is 10.2 times more efficient than ITM-PTP in terms of computational complexity.

Summary

- The characterization of aggregate interference plays a pivotal role in spectrum sharing. But often times, accurate propagation models may not be feasible because they are computationally intensive and require the precise geolocations of SUs.

- We proposed a computationally efficient tool, namely TESSO, and showed that it can be used to characterize aggregate interference in dynamic spectrum sharing. TESSO, if used appropriately, provides almost as effective results as existing techniques, such as the ITM-PTP.

- TESSO is scalable because its computation time is a constant, unlike ITM-PTP whose computation complexity grows proportionally with the number of SUs. Furthermore, TESSO does not require precise geolocations of SUs.

Thank you!