Framework for Mapping of Receiver Interference Tolerance Masks to Tolerable Effective Isotropic Radiated Power Levels

GPS ABC Workshop V

RTCA Washington, DC

October 14, 2016

Hadi Wassaf, PhD　　*George Dimos*

Volpe The National Transportation Systems Center

Advancing transportation innovation for the public good

U.S. Department of Transportation
Office of Research and Technology
John A. Volpe National Transportation Systems Center

Outline

- Interference Tolerance Mask (ITM) to Effective Isotropic Radiated Power ($EIRP$) for the particular case of a single transmitter

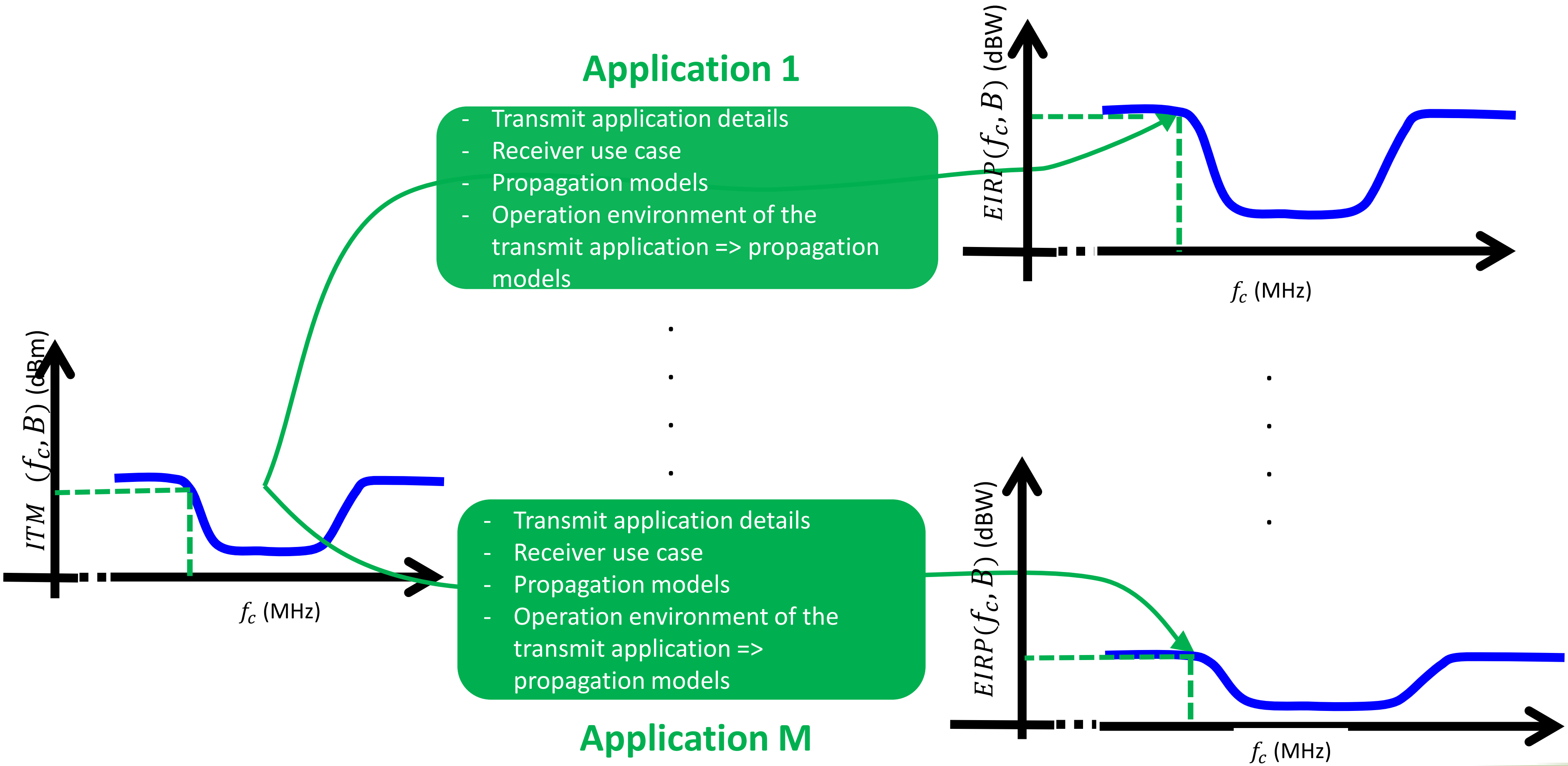
- $ITM(f_c)$ to $EIRP(f_c)$ for the general case of multiple transmitters

- Input parameters needed to solve for $EIRP(f_c)$
  - Proposed transmit application parameters (derived from transmit application use case)
  - GNSS receiver related parameters (derived from receiver use case)
  - Environmental parameters => Propagation model(s)

- Example Analysis for downlink (DL)
  - Case 1: Single transmitter
  - Case 2: Multiple transmitters

Note: This presentation provides preliminary views with recognition that more work is needed to improve the framework, especially for the uplink (UL) use case.

ITM to $EIRP_{Tol}$ Mapping



Analysis Framework Assumptions

- The Transmit environment is quasi-stationary: The location and orientations of the transmit antennas are fixed for a minimum time comparable to the time τ needed for a receiver to update its CNR estimate and perform a solution update (few seconds).

- For the case of multiple transmitters all transmitters of the same type (i.e. all uplink or all downlink transmitters) have:
  - $EIRP_k(f_c)$ constant over a duration τ
  - Similar gain patterns $G_T(\theta, f_c)$

- Receiver is spatially stationary for the same relevant time scale τ

- Transmitter signals are uncorrelated (incoherent) and therefore receive power is additive.

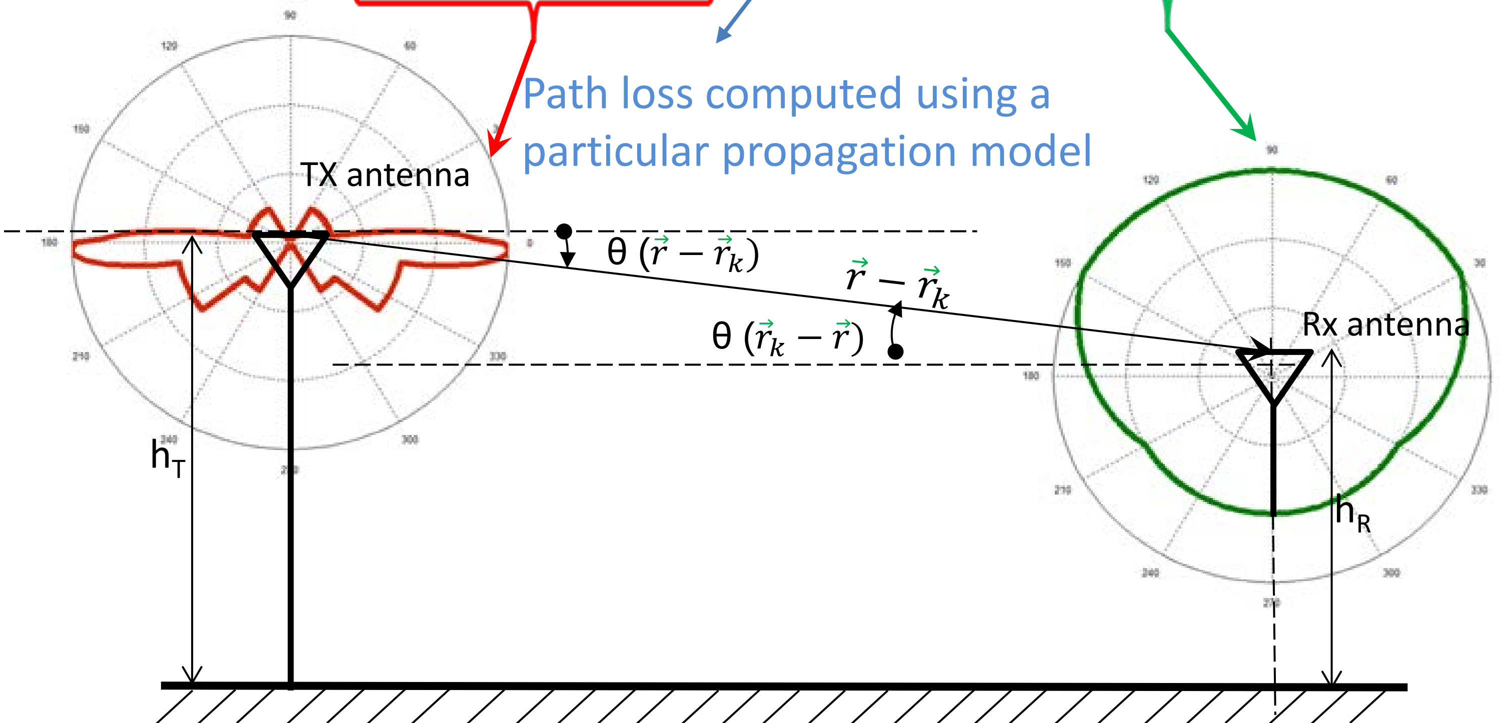
- All received electromagnetic (EM) waves are linearly polarized and the same receiver antenna gain pattern can be applied to EM waves received from any of the transmitters.

Transmitter-Receiver Geometry and Link Budget

- The power out of the passive element of the GNSS receiver antenna at location $\vec{r}$ due to a single transmitter at location $\vec{r}_k$ is:

$$P_k(\vec{r}) = \mathrm{G_T}(\theta(\vec{r}-\vec{r}_k), f_c) . \frac{P_{in}}{PL(\vec{r}_k,\vec{r})} . G_R(\theta(\vec{r}_k-\vec{r}), f_c) =$$

$$= \underbrace{\boldsymbol{g_T}(\boldsymbol{\theta}(\vec{\boldsymbol{r}}-\vec{\boldsymbol{r}}_k), \boldsymbol{f_c})} . \frac{EIRP}{PL(\vec{r}_k,\vec{r})} . \underbrace{\boldsymbol{G_{R,Max}}\, \boldsymbol{g_R}(\boldsymbol{\theta}(\vec{\boldsymbol{r}}_k-\vec{\boldsymbol{r}}), \boldsymbol{f_c})}$$



$PL(\vec{r}_k,\vec{r}) = \left(\frac{4\pi|\vec{r}-\vec{r}_k|}{\lambda}\right)^2$ for the case of free space path loss.

Single Transmitter Case: Tolerable EIRP From ITM at a Particular Interference Center Frequency

$$P_{k,Tol}(\vec{r}) = g_T(\theta(\vec{r}-\vec{r}_k), f_c).\frac{EIRP_{Tol}(f_c,\vec{r})}{PL(\vec{r}_k,\vec{r})}.\cancel{\boldsymbol{G}_{R,Max}}.\, g_R(\theta(\vec{r}_k-\vec{r}), f) = \cancel{\boldsymbol{G}_{R,Max}}.\, ITM(f_c)$$

$$\boxed{EIRP_{Tol}(f_c,\vec{r}) = \frac{PL(\vec{r}_k,\vec{r})}{g_T(\theta(\vec{r}-\vec{r}_k), f_c).\, g_R\,(\theta(\vec{r}_k-\vec{r}), f_c)}.ITM(f_c)}$$

$$EIRP_{Tol}(f_c) = Min_{\vec{r}}\{EIRP_{Tol}(f_c,\vec{r})\}$$

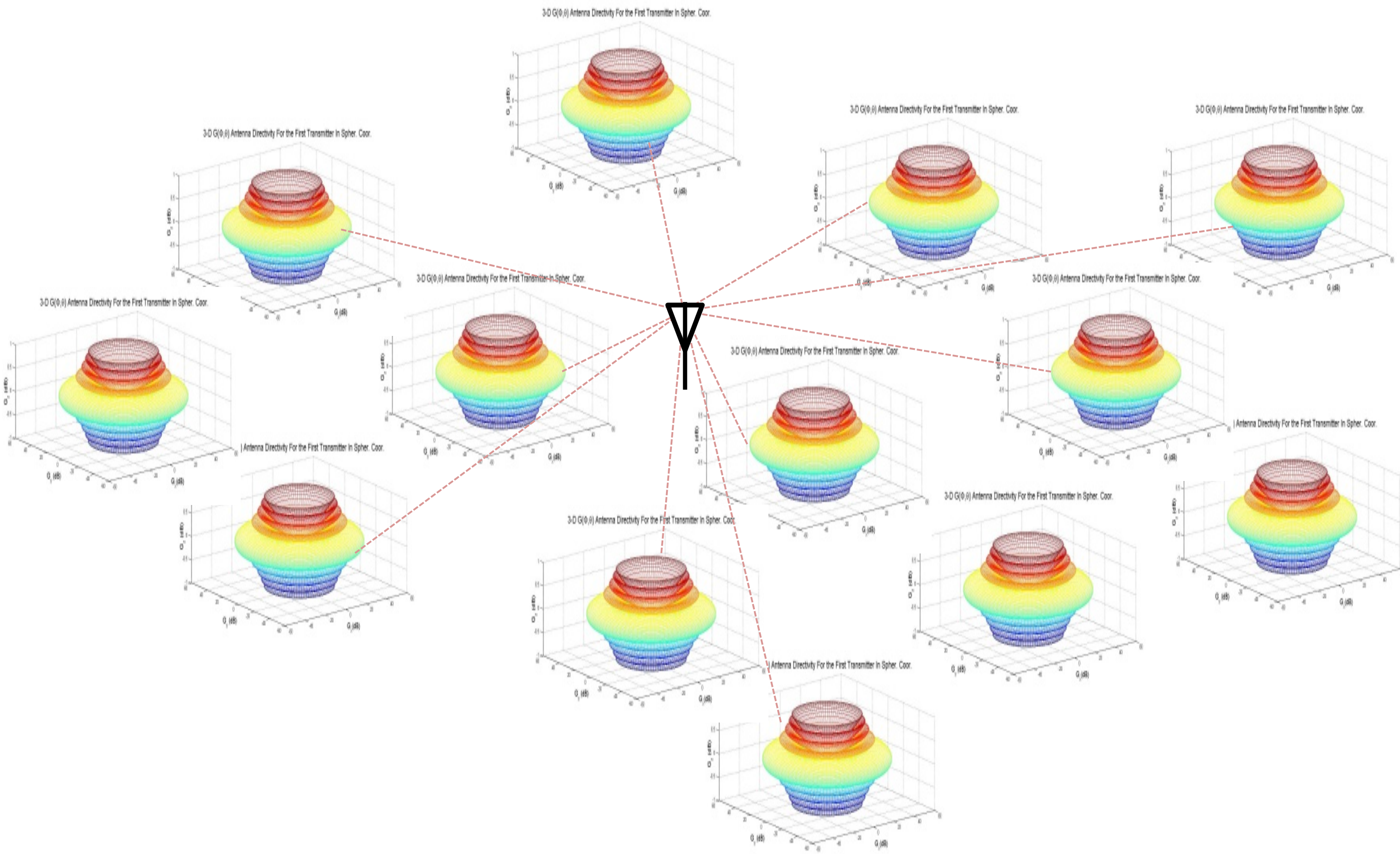
The tolerable EIRP is the minimum EIRP found by searching all possible receiver locations $\vec{r}$. The search domain limit is dictated by the receiver use-case

Note That:

1- Only normalized receiver antenna patterns for linear polarization are needed.

2- Because the 1-dB CNR degradation level is a relative criteria. The actual GNSS signal powers are not relevant for these calculations.

Multiple Transmitter Case



Multiple Transmitter Case: $EIRP_{Tol}(f_c)$ (on a per Transmitter Basis) Given $ITM(f_c)$

For the General case of transmitters with different power settings, We define $EIRP_{Tol}$ as the EIRP corresponding to the transmitter with largest output power settings. Therefore, the individual transmitters EIRPs is given by:

$$EIRP_{k,Tol}(f_c) = \alpha_k \,.\, EIRP_{Tol}(f_c) \; with \; 0 \leq \alpha_k \leq 1$$

$$\sum_{k=1}^{N_T} P_{k,Tol}(\vec{r}) = \sum_{k=1}^{N_T} g_T(\theta(\vec{r} - \vec{r}_k), f_c).\frac{EIRP_{k,Tol}(f_c)}{PL(\vec{r}_k, \vec{r})}.g_R(\theta(\vec{r}_k - \vec{r}), f) \quad = ITM(f_c)$$

$$EIRP_{Tol}(f_c, \vec{r}) = ITM(f_c).\left[\frac{1}{\sum_{k=1}^{N_T} \frac{\alpha_k.\, g_T(\theta(\vec{r} - \vec{r}_k), f_c).\, g_R(\theta(\vec{r}_k - \vec{r}), f_c)}{PL(\vec{r}_k, \vec{r})}}\right]$$

$$EIRP_{Tol}(f_c) = Min_{\vec{r}}\{EIRP_{Tol}(f_c, \vec{r})\}$$

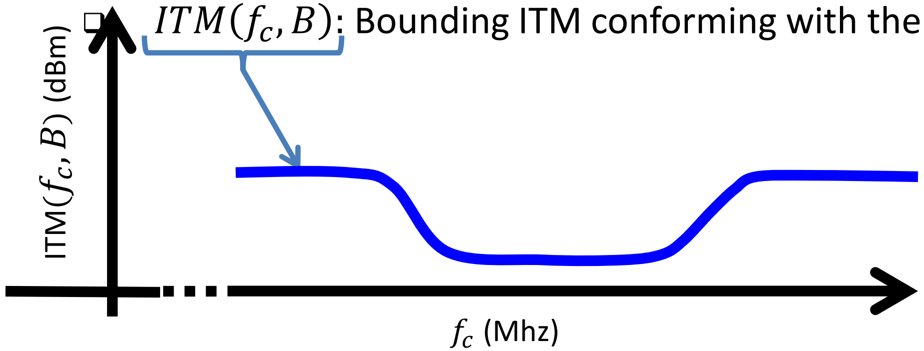
Similar to the single transmitter case, the spatial search for the minimum over receiver location $\vec{r}$ Is governed by the receiver use case.

Transmit Application Parameters

- Define transmit application to be evaluated:
  - Signal Type: Narrowband, Broadband, LTE
  - Polarization: linear, RHCP or something else
  - Transmit network topology:
    - N_T: Number of transmitters
    - $\overrightarrow{r_k} =< \mathrm{x_k}, \mathrm{y_k}, \mathrm{z_k} > \ \{\mathrm{k} = 1..\mathrm{N_T}\}$: Transmitter locations
    - $g_T(\theta, f)$: Normalized antenna gain pattern (or normalized directivity pattern) assumed to have azimuthal symmetry.

Receiver Characteristics

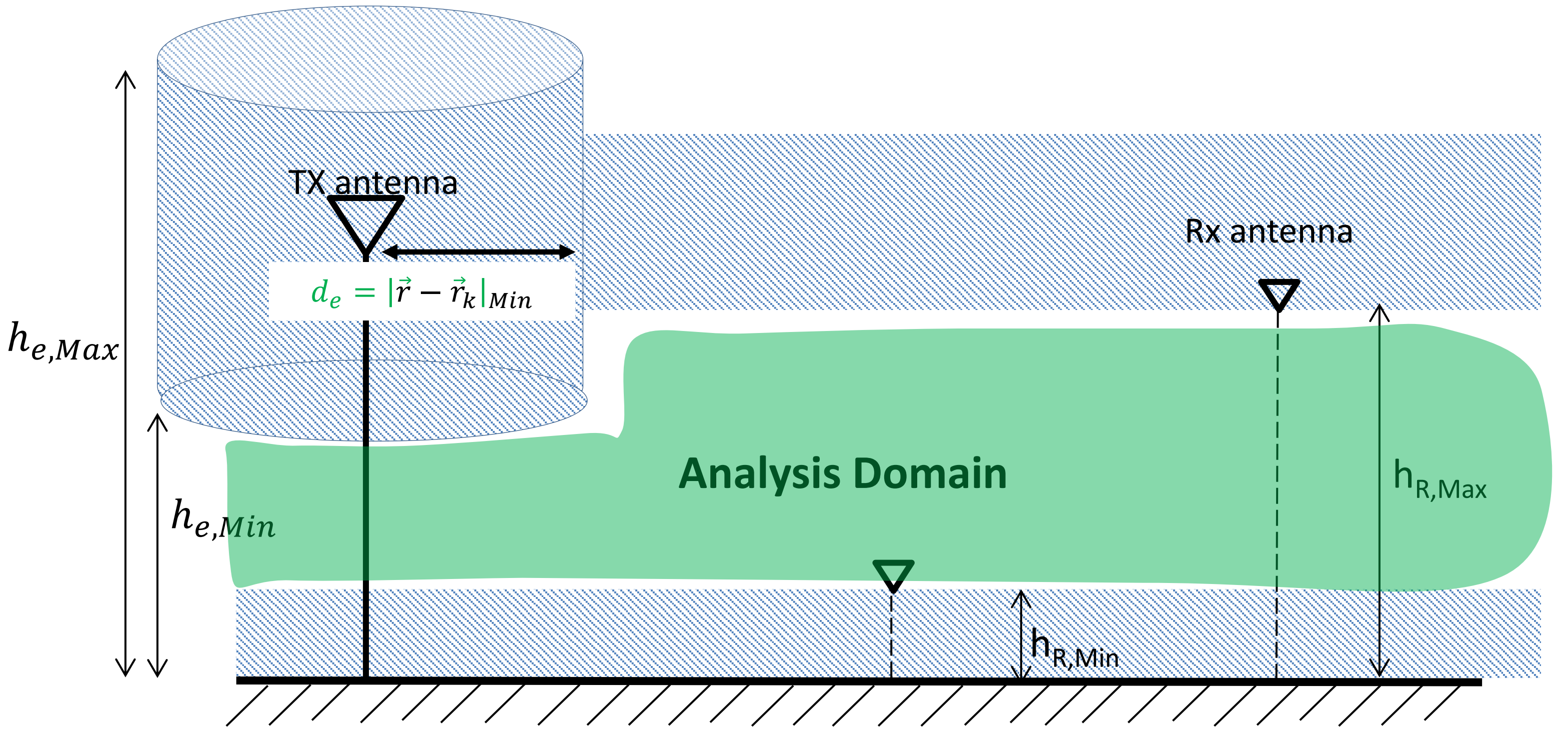
- GNSS service (or set of GNSS services) considered for current iteration of the analysis
- Receiver category considered for this iteration of the analysis
- $ITM(f_c, B)$: Bounding ITM conforming with the first two bullets, where B refers to the signal type.



- $g_R(\theta, f_c)$: Normalized receive partial gain pattern for linear polarization
- Receiver domain of operation (Derived from a limiting use case for the category considered in current iteration of the analysis):
  - $h_{R,Min}, h_{R,Max}$: Limits on GNSS receiver operational heights (**if any**)
  - $h_{e,Min}, h_{e,Max}, d_{e,Min}$: Limits on receiver proximity to a transmitter in the application (**if any**)

Receiver Domain of Operation

- This is geometric information that pertains the use case for a particular category (or most susceptible use case within a category).



Environmental parameter

- Terrain details: Assumed flat
- Urbanization level: Rural, suburban, urban,
- Representative electrical parameters: for the case of two or multi-ray propagation.
- Define propagation model selection approach based on above parameters

Example Analysis to Determine $EIRP_{Tol}(f_c)$

- Two sample analyses are presented for a generic LTE downlink for illustration purposes:
  - Case-1: Single transmitter
  - Case-2: Multiple transmitters

- f_c=1500 MHz assumed.

- The DL transmitter characteristics used here are from CSMAC 03/01/2012 white paper titled LTE (FDD) Transmitter Characteristics. ***<u>This does not necessarily represent the DL parameters used in the final analysis</u>.*** (details on next slide).

- For the purpose of this analysis the receiver is assumed to be at height of up to 1 meter below the transmit antenna:$h_{r,Max} = h_{e,Min} = h_T - 1m$, and the minimum horizontal distance to the transmitter is $d_{e,Min} = 5$ m.

- $h_{r,Min}$ and $h_{e,Min}$ are of no consequence to this particular analysis

- For simplicity the GNSS receiver relative antenna gain is assumed omni directional $g_R(\theta, f_c)$=1

- A hypothetical $ITM(f_c = 1500, B = 10MHz)$ = -50dBm is used.

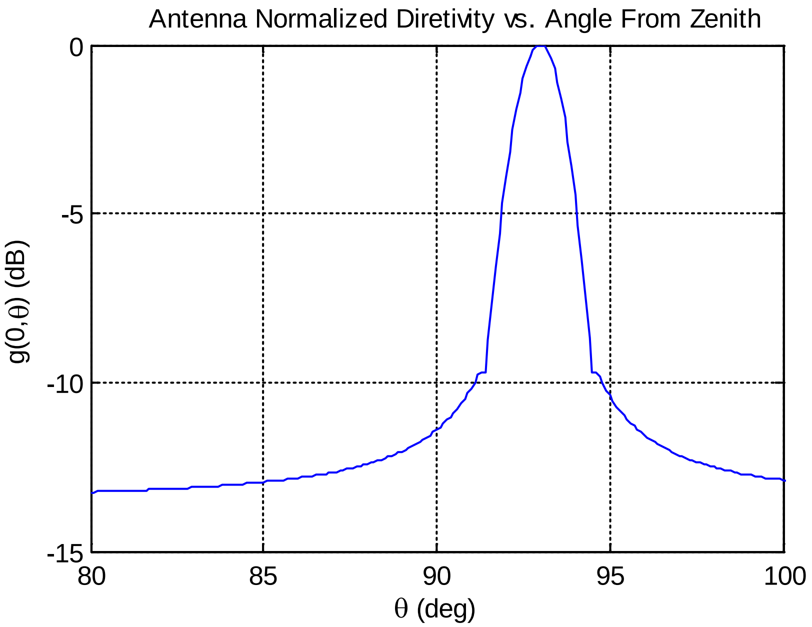
- Free space loss assumed here: $PL(\vec{r}_k, \vec{r}) = \left(\frac{4\pi.|\vec{r}-\vec{r}_k|}{\lambda}\right)^2$

DL Transmitter Characteristics

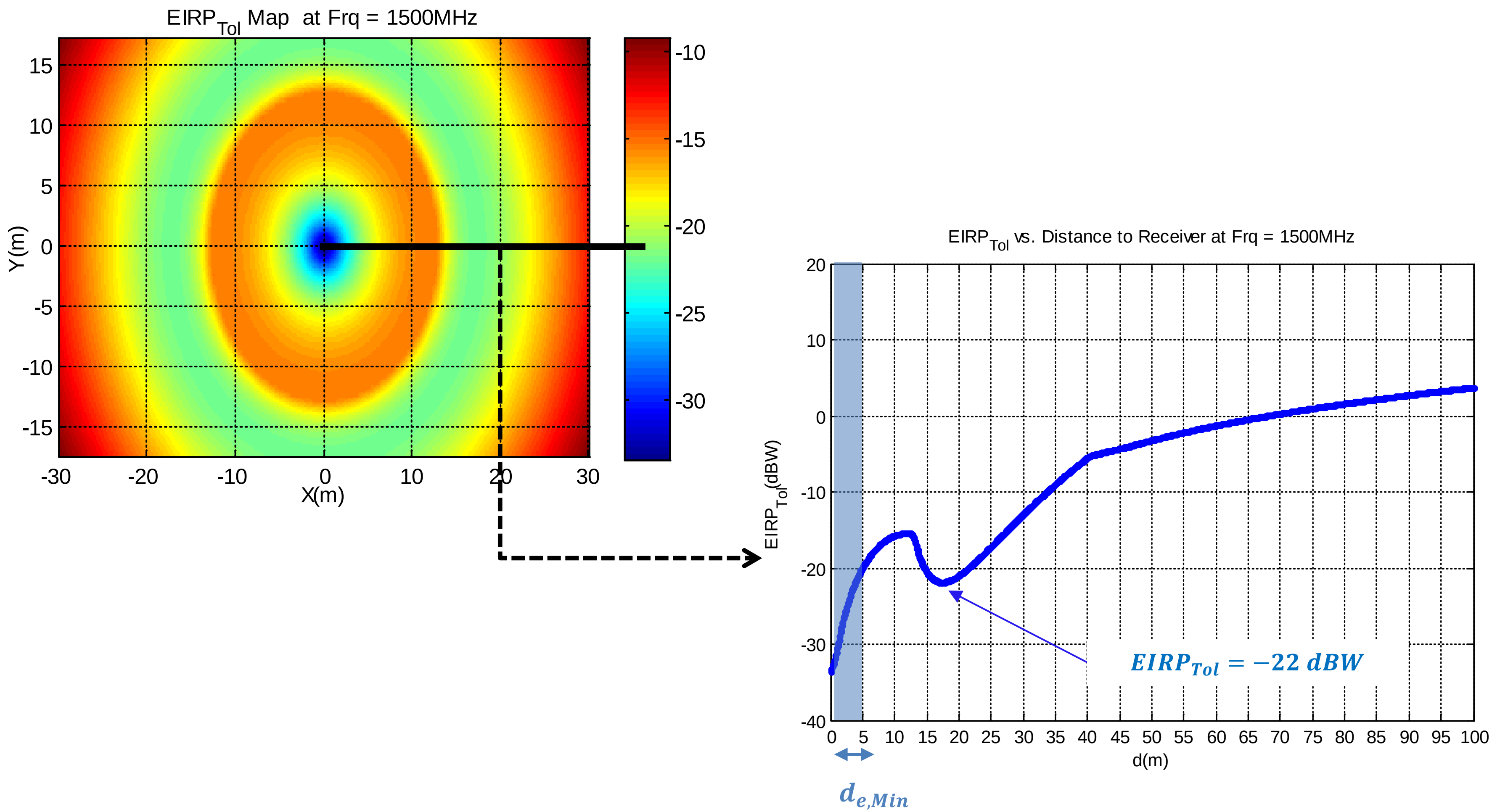
	DL Parameters (CSMAC white paper)	DL Parameters (used in this analysis)
Emission Bandwidth	1.4, 3, 5, 10, 15 and 20 MHz	10 MHz
EIRP	31 dBW (up to 5MHz channel) 34 dBW (>10MHz channel)	Tolerable EIRP is an output computed based on ITM(fc,B)
$G_{T,Max}$	18(dBi)	Only normalized gain pattern is needed, but $G_{T,Max}$ was used to get the 3dB beam width using equations in ITU-R recommendation F.1336-2.
Elevation Off-Axis Antenna Pattern (dBi as a function of off-axis angle in degrees)	ITU-R Recommendation F.1336-2	ITU-R Recommendation F.1336-2
h_T	30 (m) Urban/Suburban 60(m) Rural	30 (m)
Antenna Polarization	Linear	Linear
Azimuth 3dB Beamwidth	70°	Omni directional
$\theta_{DownTilt}$	3^o	3^o

Vertical Transmitter Antenna Pattern

- θ in this plot is defined as angle from zenith (i.e. 90+angle defined in the equations on previous slides



Tolerable EIRP as a Function of Distance for ITM=-50dBm

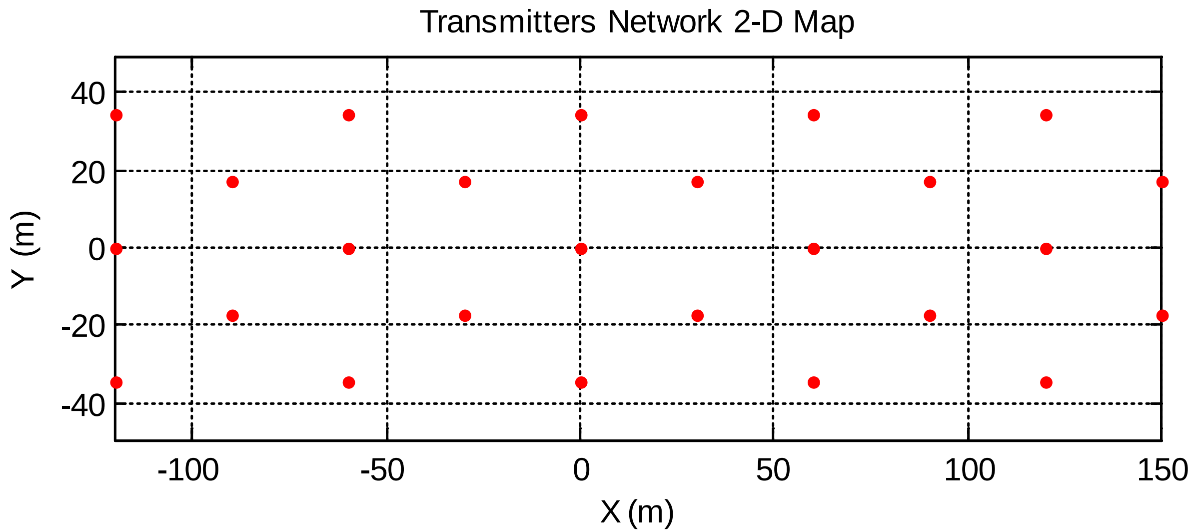


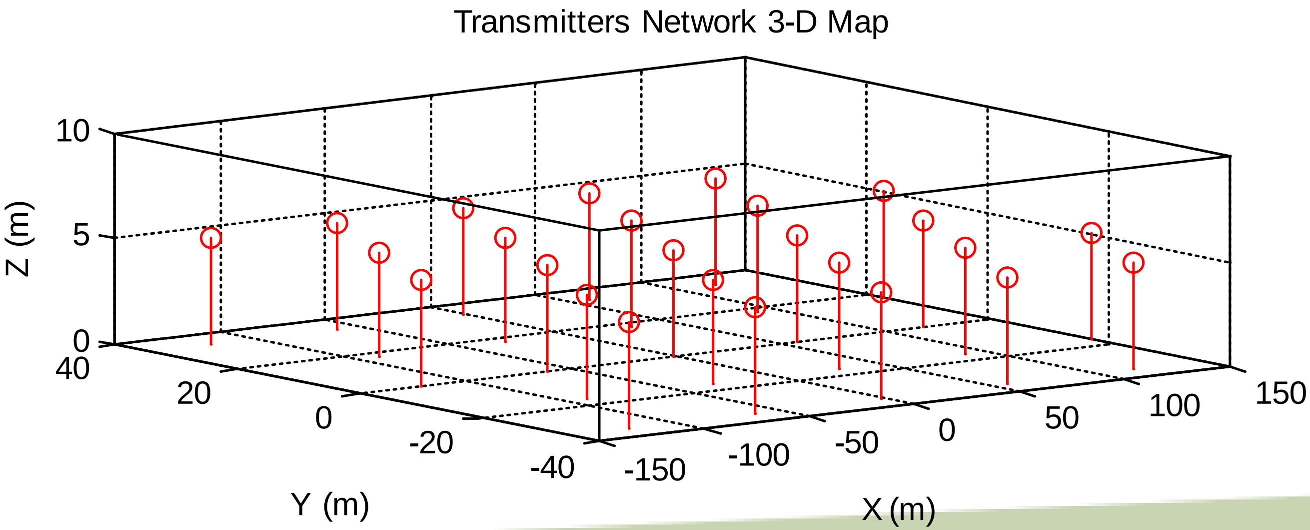
Case 2: Tolerable EIRP for the Case of a Multiple Transmitters

- A hypothetical network of 25 base station transmitters with R=20m distance between transmitters I considered.
- All transmitter have the same altitude of $h_T = 5m$
- All transmitter are at the same EIRP level. $\alpha_k = 1 \; for \; all \; k$
- Rest of transmit, receive and environmental parameters are the same as the single transmitter case

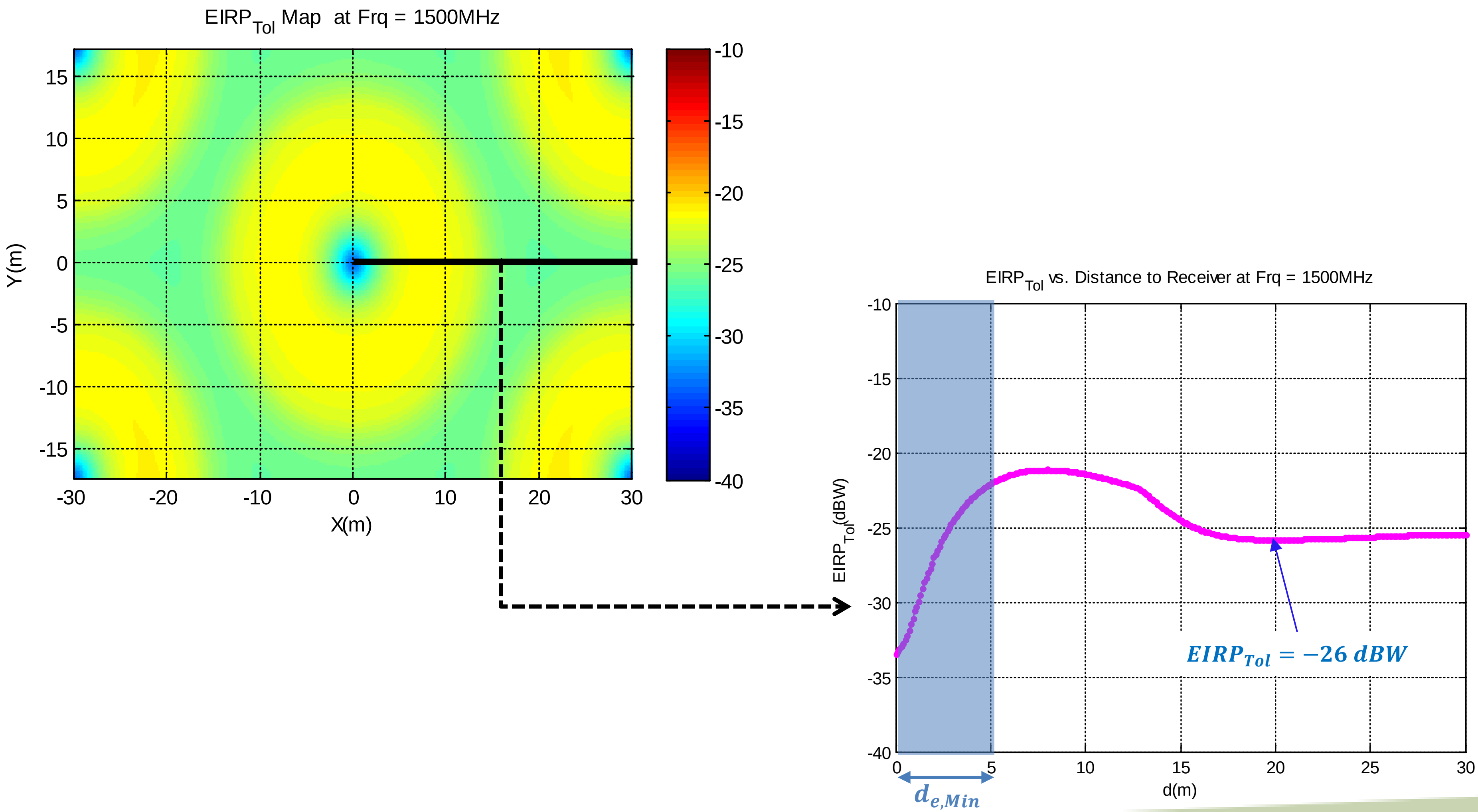
Note: These parameters are not representative of deployed or known proposed networks. They were selected for the purpose of illustrating the analytical framework

Transmitters Placement

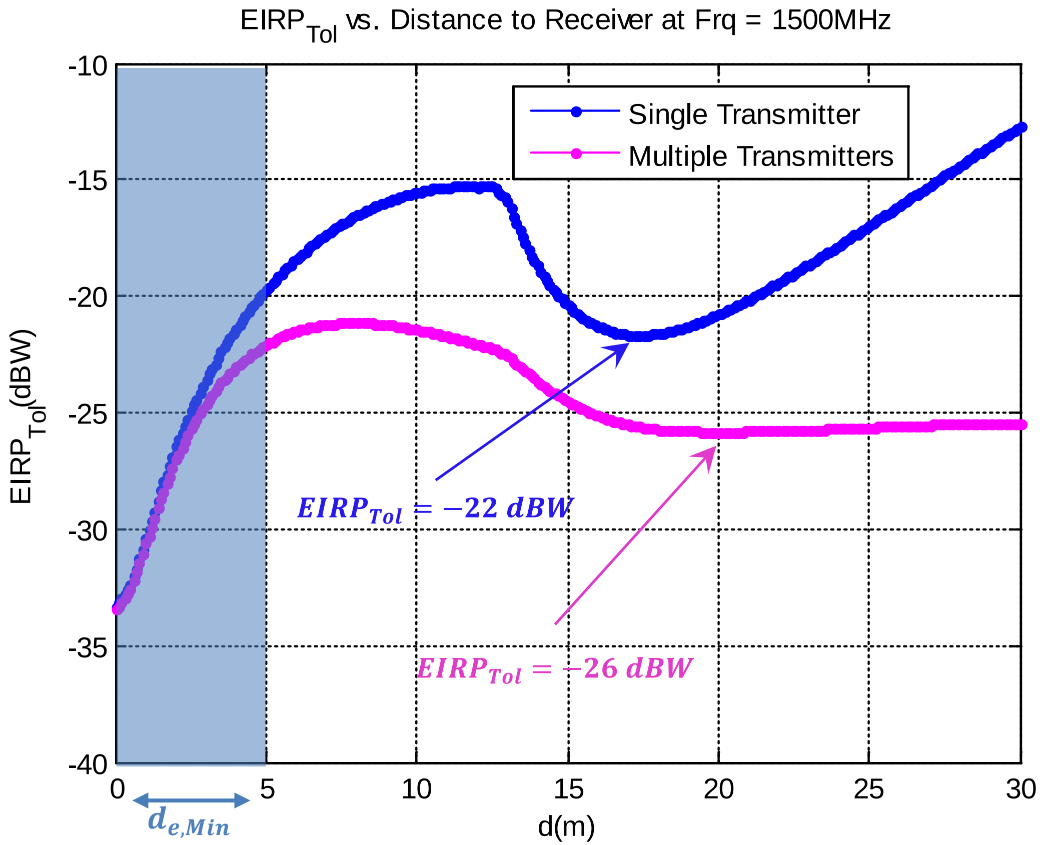




$EIRP_{Tol}\ (f_c)$ for the Multiple Transmitter Case for $ITM(f_c) = -50dBm$



$EIRP_{Tol}$ for an Example Case of ITM = -50dBm



- Given the current use case parameters, the denser network (20 m between base-stations) results in a lower limit on tolerable EIRP on the order of 4 dB.

Summary

- A proposed framework to be used in calculating tolerable EIRP for a given application has been described.
- The assumptions used in this framework along with the needed input parameters have been stated
- The next step is to define a representative use case for each receiver category and the transmit applications parameters to perform the analysis
- Transmit application parameter definitions will include one case for DL and another for an UL LTE signal.
- The development of draft receiver use cases will take into account input received so far and any input provided during the development.