A Brief Introduction to Ranplan's Radiowave Propagation Simulator- *RRPS*

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Outline

- Importance of Radiowave Propagation Modelling
  - What are they and what they do
- Existing propagation models
- Ranplan Radiowave Propagation Simulator

Radiowave Propagation Modelling: Basics

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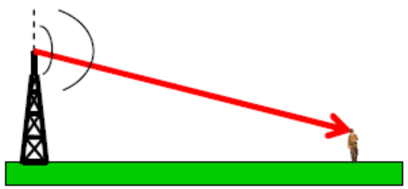
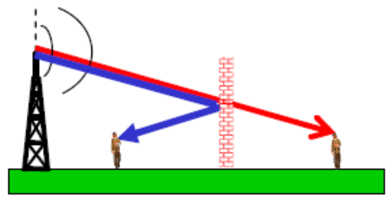
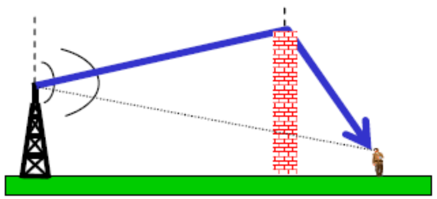
- Radiowave attenuates when they propagate
- Four main mechanism: reflection, diffraction, transmission and scattering
- Long term fading, shadowing.. Path loss computation



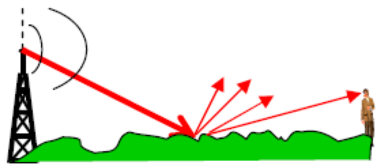
free-space propagation



reflection and transmission



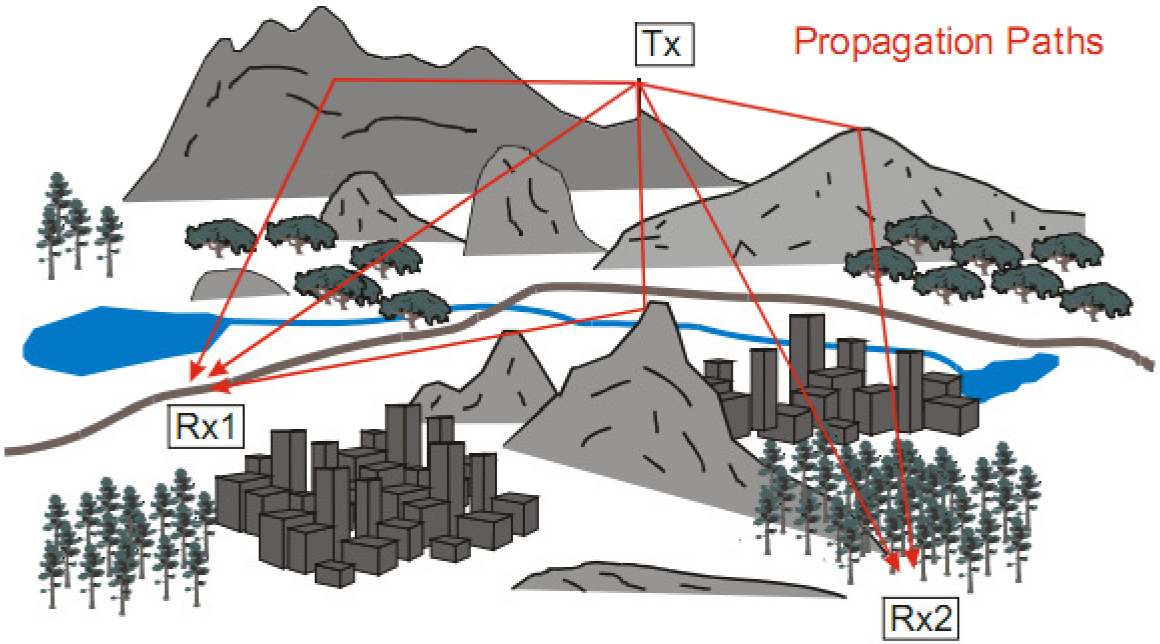
diffraction



scattering

Radiowave Multipath Reception

- Reception due to multipath propagation



Why propagation modelling

- Path Loss Computation
  - Link Budget , Best Server etc..
- Compute the received signal power, Obtain a coverage prediction
- Study the statistics of the channel
- -> depending on
  - The emitters (radiated power, antenna pattern…)
  - The environment (buildings, materials…)
  - -> necessary for:
    - Wireless Network Planning (find the best parameters for the network)
    - Performances analysis (system level simulations)
    - Test different technologies

Existing Propagation Models

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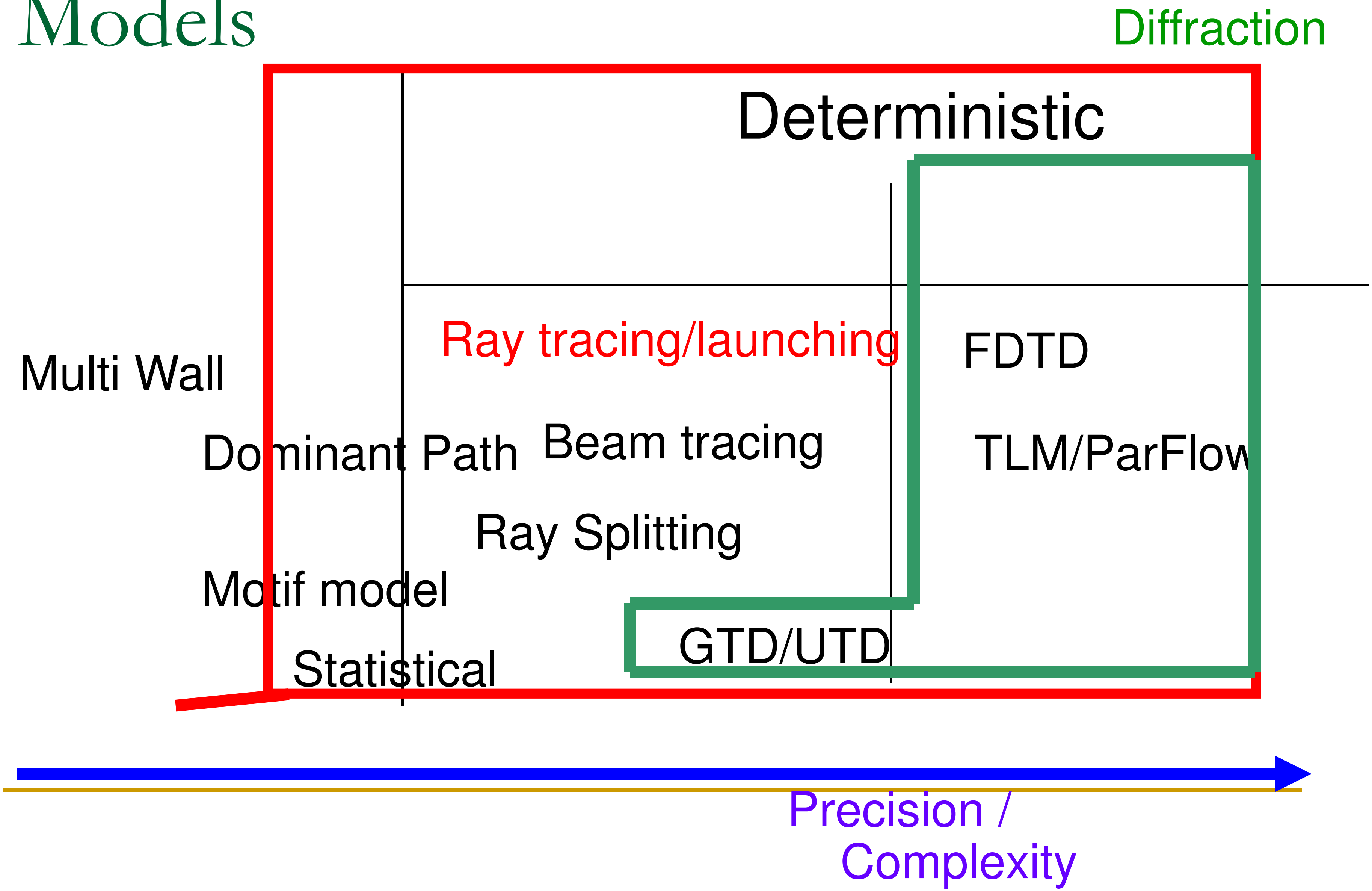
- Empirical
  - Does not consider environmental information: fast but inaccurate
- Semi-empirical / Semi-deterministic
  - Trade-off between accuracy and speed
- Deterministic
  - Slow but high accuracy can be obtained

Categories of Propagation Models

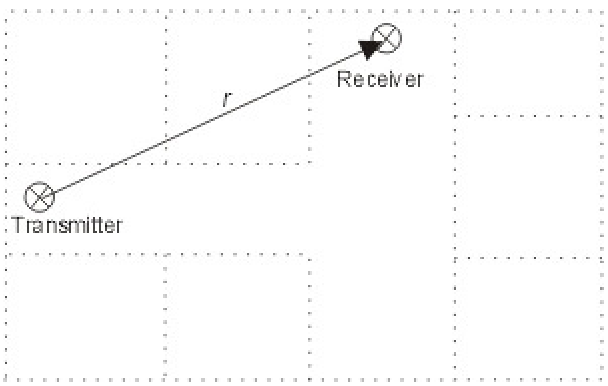


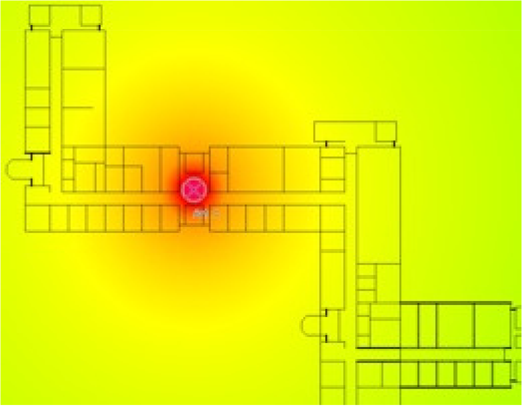
One Example of Empirical Model

- One Slope

  considers distance and path loss exponent

  fast but inaccurate

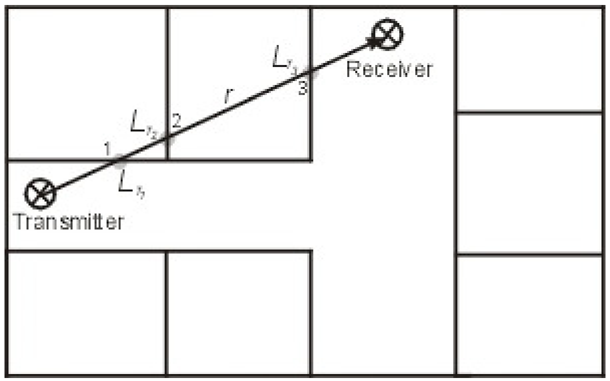


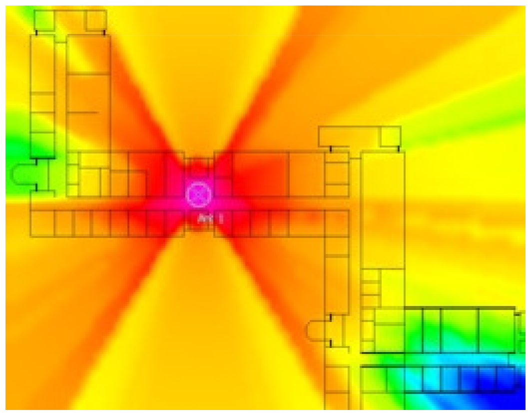


From AWE communication

One example of Semi-empirical/deterministic Model

- COST 231 Multi-Wall
  - often pessimistic
  - considers the number of walls and floors between emitter and receiver
  - considers material

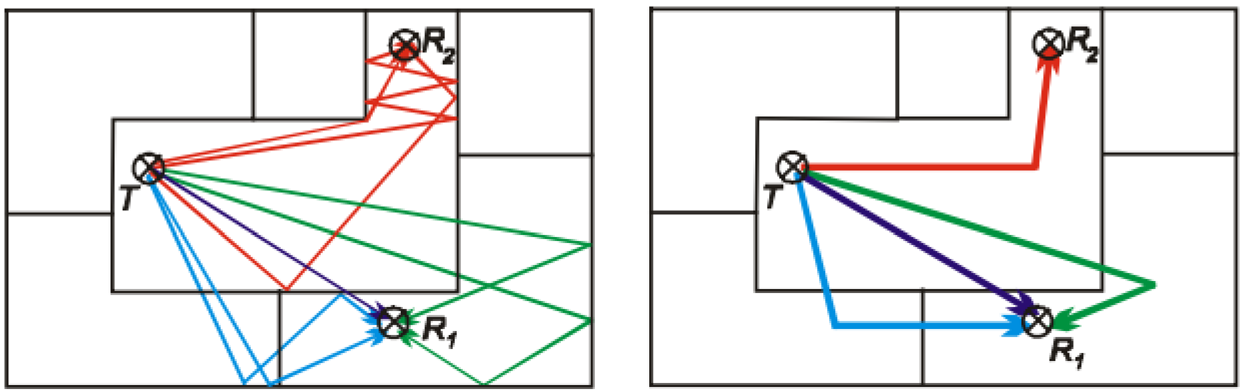




From AWE communication

Deterministic Models

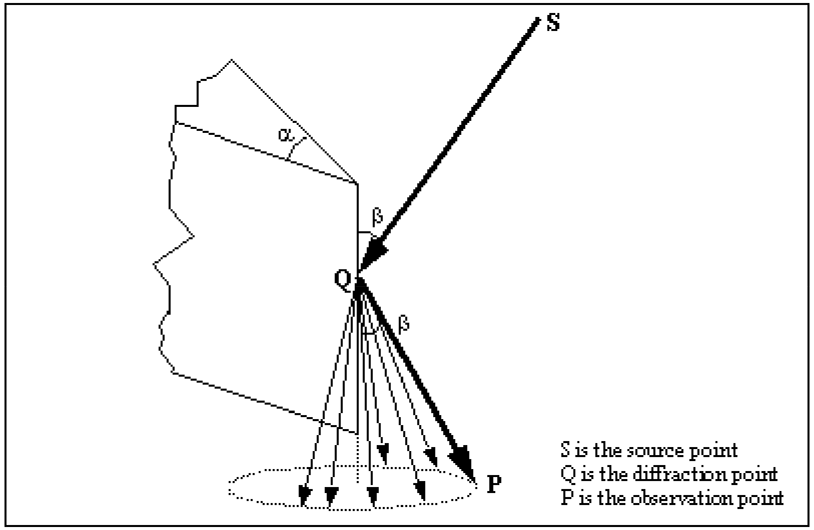
- Ray-based
  - Ray Launching, Ray Tracing, Dominant Ray
  - Need to include the use of GTD / UTD
    (Geometry Theory of Diffraction) / (Uniformed Theory of Diffraction)

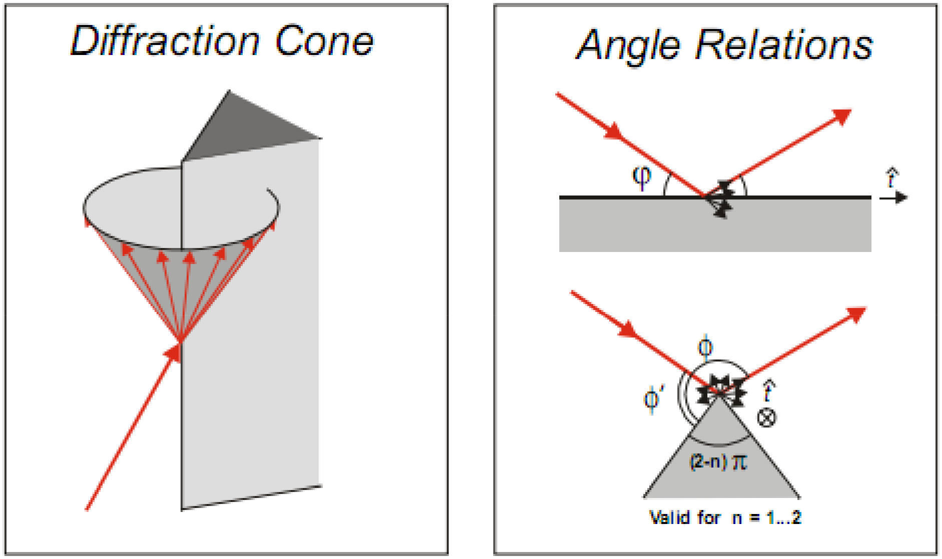


Multipath propagation in an indoor scenario and dominant paths

GTD / UTD

(Geometry Theory of Diffraction) / (Uniformed Theory of Diffraction)

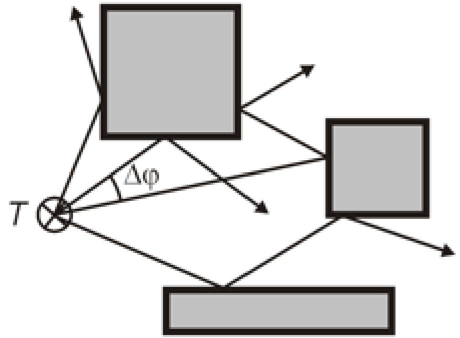


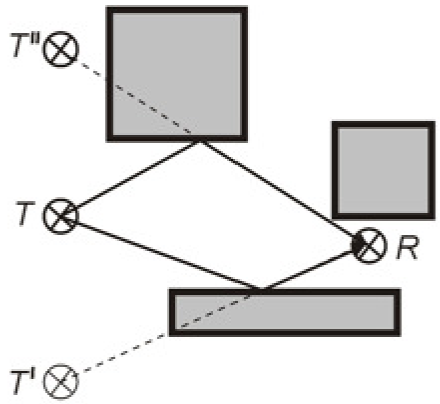


Occurring angles for a diffraction on a wedge

Ray-based Models

- Ray Tracing & Ray Launching
  - Difficult to program (ray-object intersection test)
  - Time-consuming (expensive ray-object intersection test)
  - Need GTD/UTD
  - The problem can be split into parts
  - Frequency domain
  - Narrowband
  - Database pre-processed
- Ray Launching
  - Consider rays from emitter
  - Suitable for large area coverage
  - Rays may be missed due to angle separation
  - Complexity linear with ray iterations
  - Limited iterations considered
- Ray Tracing
  - Image based (consider rays backwards)
  - Suitable for few locations prediction
  - Precisely calculate dominant rays
  - Complexity exponentially increases with ray iterations
  - Limited iterations considered





Computation of reflection and diffraction

- Empirical Interaction Model
  - reflection loss (in dB)
  - penetration loss (in dB)
  - min. diffraction loss (in dB)
  - max. diffraction loss (in dB)
  - diffraction loss of diffracted ray (in dB)
- Deterministic Interaction Model
  - Fresnel Equations for the determination of the reflection and transmission loss
  - GTD/UTD for the determination of the diffraction loss.
  - (relative) permittivity
  - (relative) permeability
  - Conductivity
  - Thickness of walls (roofs etc)

FDTD

- Finite Difference Time Domain (FDTD)
  - Solves Maxwell Equations
  - Time domain
  - Broadband
  - Close to physics (inherently includes diffractions etc)
  - No special need to take care of Fresnel Zones
  - Simple programming (recursive)
  - Simple database structures with volume elements
  - Tremendous running time and memory requirement
  - Often 2D, usually 3D is not feasible (time and memory)
  - Frequency -> wavelength -> spatial step (grid size)
    - Fake frequency and calibration

Ranplan Radiowave Propagation Simulator (RRPS)

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- Ray-based: Ray Launching + Ray Tracing
- Accurate
  - 6-8 dB RMSE
- Fast (Millions of receiver locations within few minutes (on standard PCs)
  - Distributed/Parallel implementation
  - Multithreading
- Designed for outdoor, indoor, indoor-to-outdoor and outdoor-to-indoor scenarios
- Field Strength (Path Loss), Multipath (Delay Spread …)
- Full 3D
- No need to pre-process visibility tree
- Propagation library
  - A full range of API supported (e.g. invoking RRPS)

RRPS - Overview

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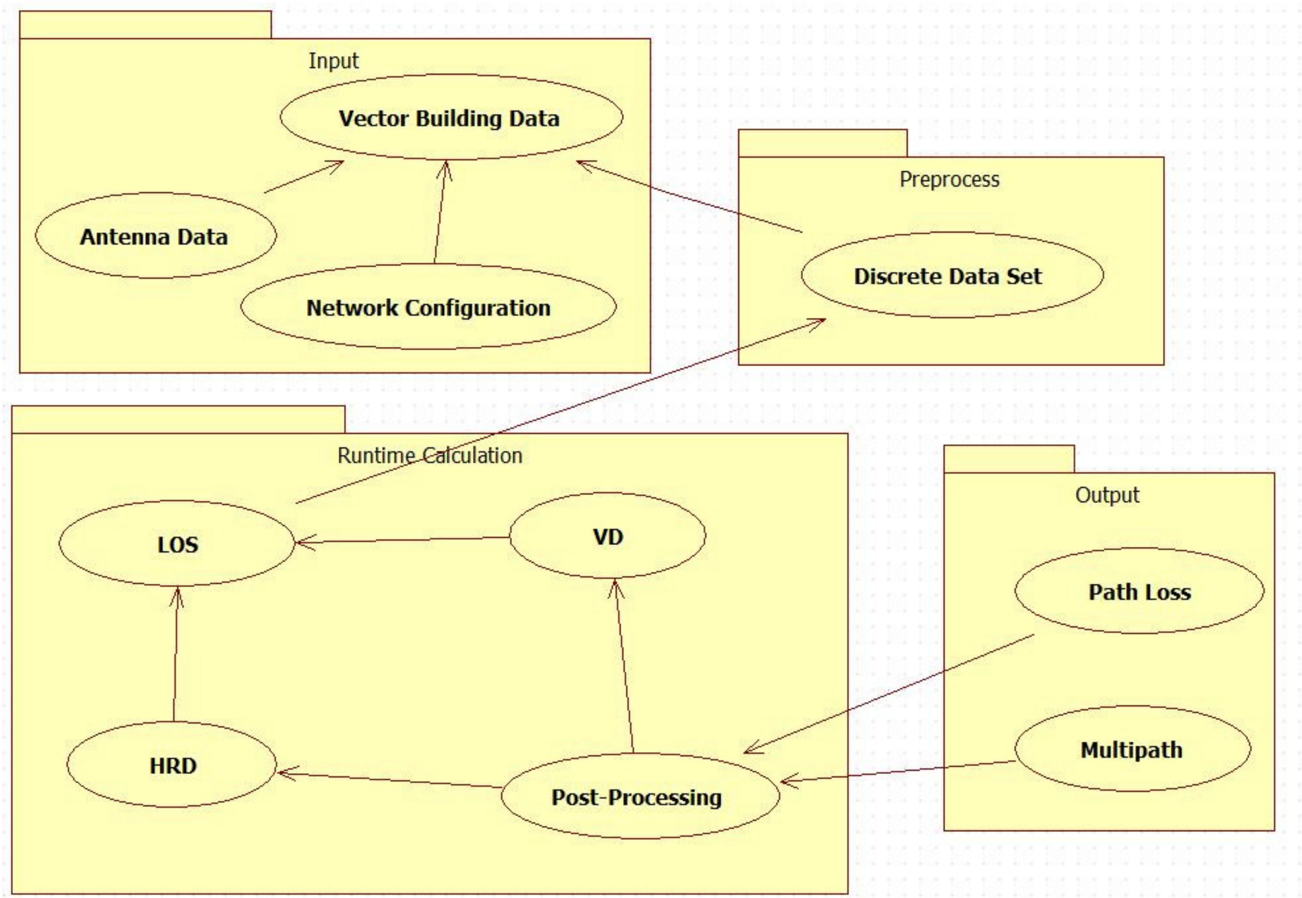
- Input from Building Data (Vector), Antenna, and Network Configuration
- Preprocess into a discrete data set
- Computation via Vertical Diffraction (VD), Horizontal Reflection and Diffraction (HRD), Line-Of-Sight (LOS).
- Post-processing
- Output to 3D path loss matrix and multipath components

RRPS – Overview contd.



RRPS – Acceleration Overview

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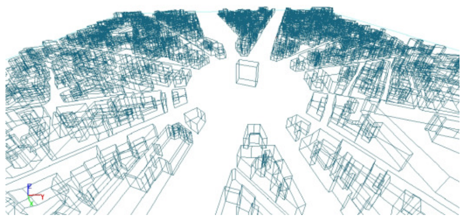
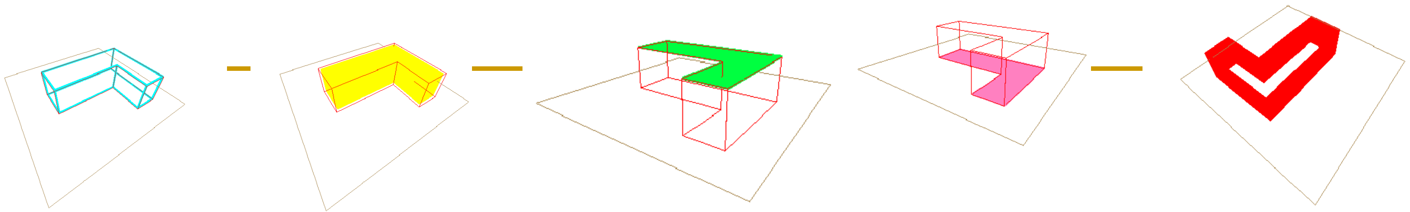
1. Intelligent Algorithms (ref [2][5])
2. Avoid Angular Dispersion / Double Counting of rays (ref[3])
3. Parallelisation via Multithreading/POP-C++ [4]
4. The use of Ray Tracing and Ray Launching + Vector and Raster
5. The use of Breadth-First and Deep-First Search

Input of the model

- Raw 2.5D/3D Building Data (Vector)
  - Vector / Raster Terrain Data
- Discrete Cubic Data (Raster)
  - Roofs
  - Walls
  - Grounds
  - Corner
  - Edges
  - Inner Building





Output of the model

- 3D Path Loss Matrix
- Multi-Paths information
  - Total length of a ray
  - The number of diffractions
  - The number of reflections
  - The number of transmission

Outline of the model

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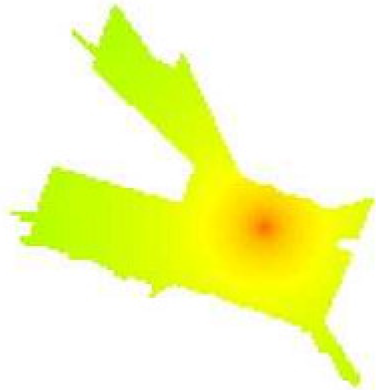
- L-O-S computation
- Horizontal reflection and diffraction (Non-roof top)
- Roof top diffraction
- Post-processing

Collection L-O-S pixels

- Mark visible area of emitter
- Add LOS paths
- Collect first-filled pixels
  - Building edges (corner)
  - Building walls
  - Building roofs



None-roof top 3D ray launching

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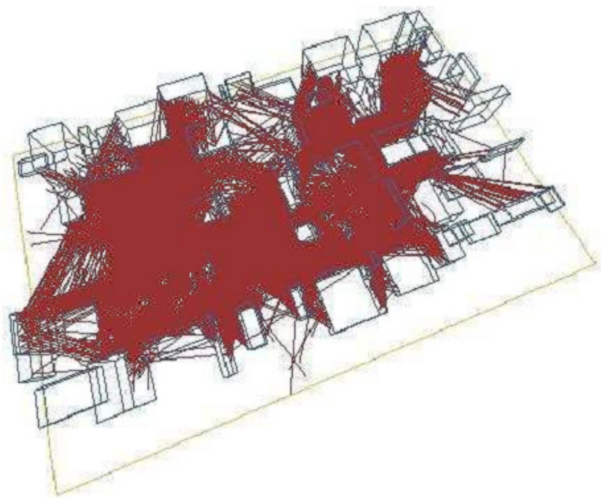
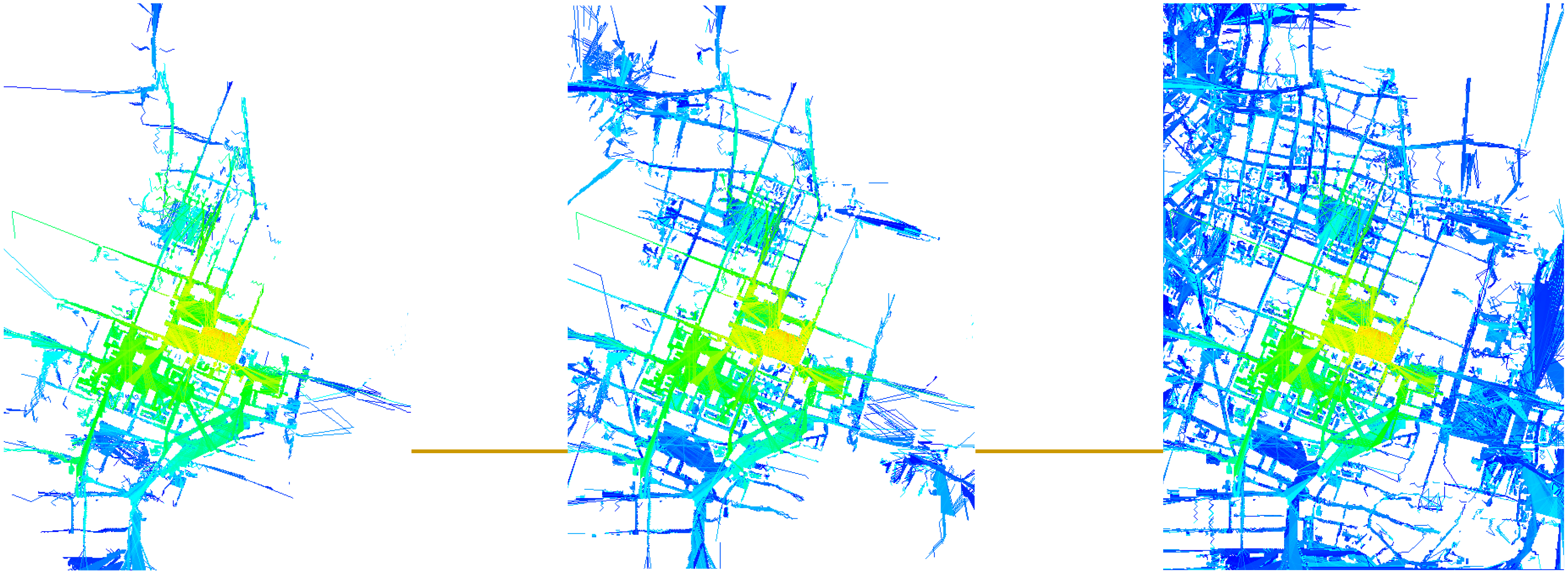
- Reflections and diffractions
  - No transmission if no indoor prediction
  - Roof-top diffractions excluded
  - Disable ray loops
  - Path loss threshold
  - Law of diffractions
    - (Keller Cone)



Propagation via HRD

- Observation of reflection & diffractions (without roof-top diffractions)
- Set a maximum path loss threshold
- R5D5, R8D8, R15D15



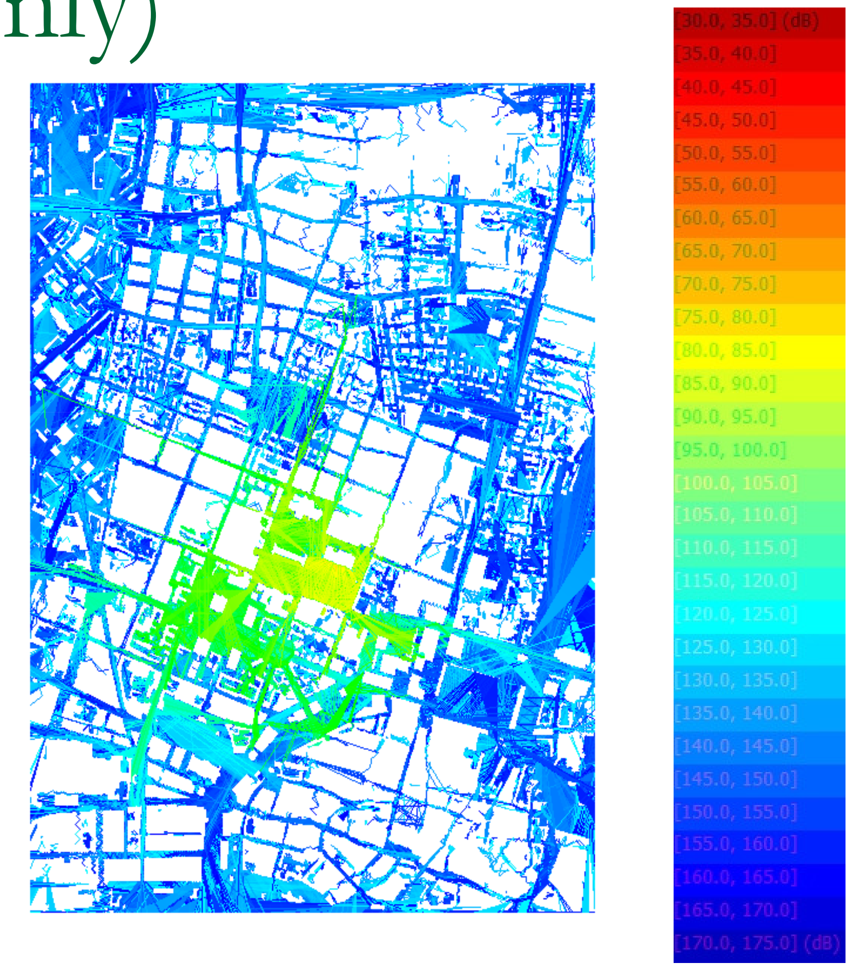
Running Time (seconds)

- A: 2 Cores, 2.5GHz, 4GB
- B: 2 Cores, 2.2GHz, 2GB
- C: 1 Core, 1.7GHz, 512MB

	A	B	C
R3D3	1.2	1.5	3.7
R5D5	4.1	5.5	13.0
R7D7	4.3	5.7	20.5
R8D8	7.3	8.7	21.0
R15D15	20.6	32.6	72.3

An extreme test (for demonstration only)

- 300dB maximum
- Loss Refl = 3dB
- Loss Diff = 6dB
- Maximum 30 refl
- Maximum 30 diff
- In 5 minutes on
  - 2.4GHz
  - Dual Core, 4G RAM



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Roof-top (vertical) diffractions

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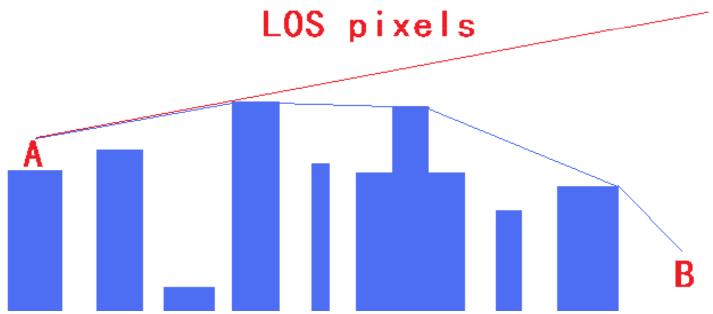
- A fast pixel-checking-based calculation
  - Runtime complexity O(n3)
    - Assume flat ground but support terrain and vegetation data
    - Complexity does not grow by the number of buildings (objects)
    - Machine A (4 seconds), B (7), C(13)

Roof-top (vertical) diffractions

- Preprocess the height of building pixels
- Group building pixels
- To obtain the number of minimal diffractions needed between A and B
  - Launch a ray to the farthest building it can see
    - Move to the top of this building and iterate until it sees B
    - Cache "visible" function (speed up 60%)
    - Speed up around 40% if you know
      - Building A and B are adjacent
      - Highest Building C between A and B
        - If C is higher than both A and B
        - If C is lower than both A and B



  - Add one more diffraction if a ray goes up and down (walk along building roofs)
  - Stop until marked LOS pixels

Add indoor prediction

- Indoor prediction added from
  - Path loss at building roofs + 1 transmission
  - Path loss around building walls + 1 transmission

Pre & Post-processing

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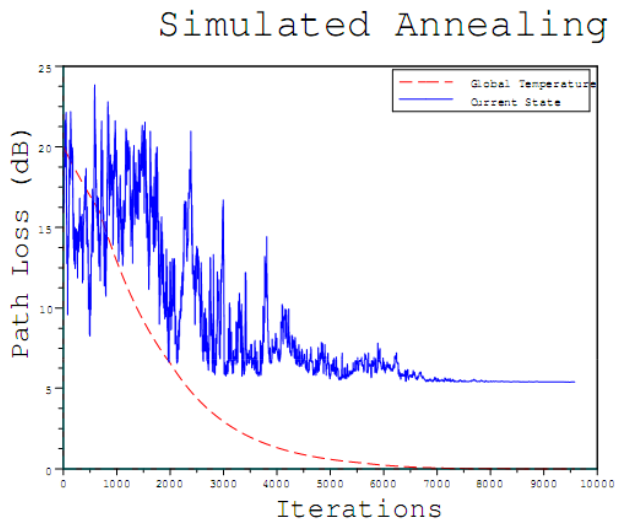
- Constructing cubic rasterized data
- Post-processing
  - Antenna pattern adjustment
  - Indoor prediction
  - Global adjustment

Calibration

- Parameters
  - Path Loss Coefficient
  - Loss for Reflection
  - Loss for Diffraction
  - Loss for Roof-top Diffraction
  - Loss for Transmission
  - Global Adjustment

  - Improve the accuracy



Results - outdoor

TABLE II
NETWORK CONFIGURATIONS

Area	8.1 km^2
Resolution	5 X 5 X 5
Maximum Reflection	3
Maximum Horizontal Diffraction	7
Maximum Vertical Diffraction	**Unlimited** *
Maximum Transmission	**Unlimited** *
Tuning Iterations	10, 000 **

* until signal strength is under threshold
* until temperature falls below threshold

TABLE III
ACCURACY OF IRLA ON COST-MUNICH

Routes	STD	RMSE	Mean Error	Correlation
1	6.889	6.884	0.001	93.315
2	4.950	4.914	-0.011	88.767
3	6.035	6.021	-0.006	94.153

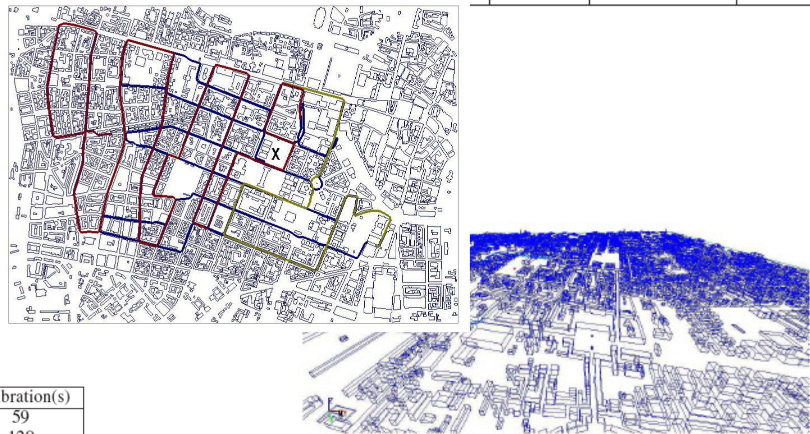


Fig. 2. 2.5D Building Data of COST Munich

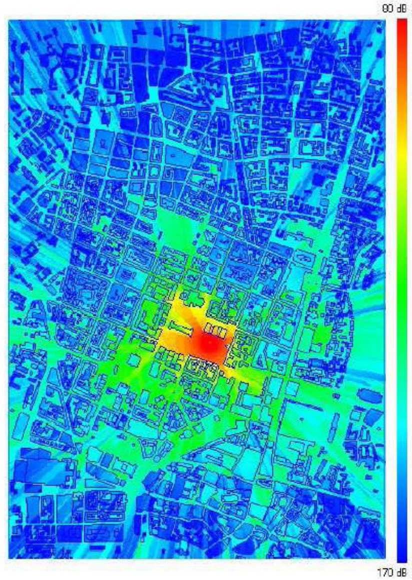
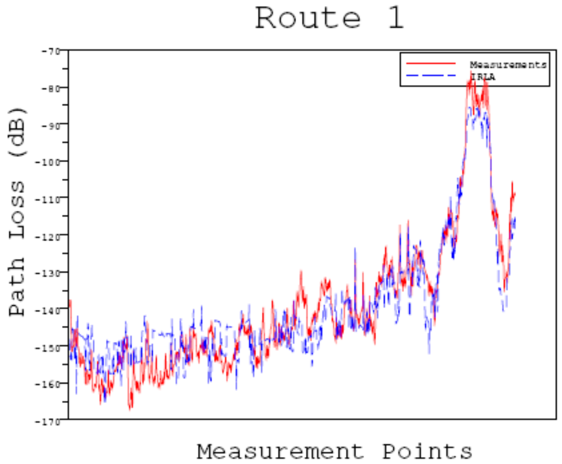
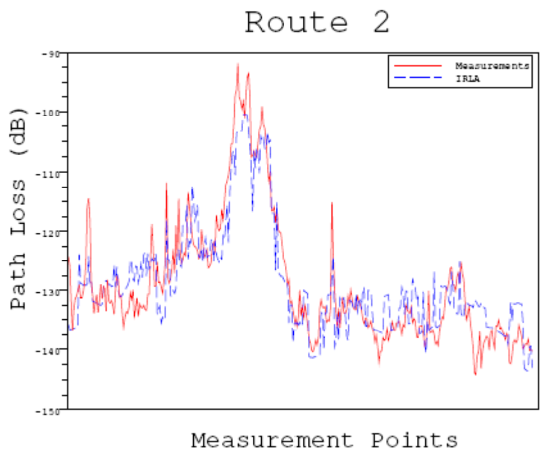


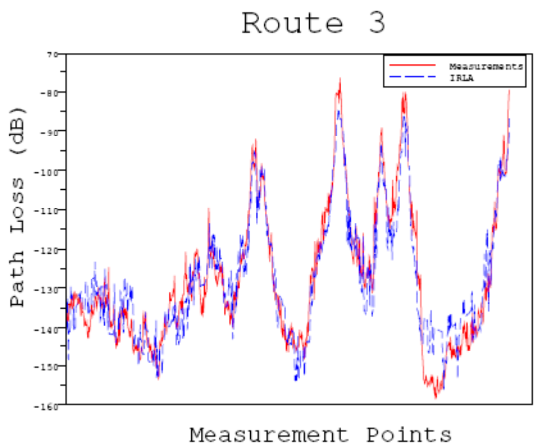
Fig. 4. Munich Signal Strength Prediction, $8.1km^2$

TABLE I
RUNNING TIME OF IRLA

CPU	Memory	Computation(s)	Calibration(s)
AMD64 Dual, 2 X 2.6GHz	3.25GB	19	59
AMD2600+, 1 X 1.9GHz	756MB	27	120

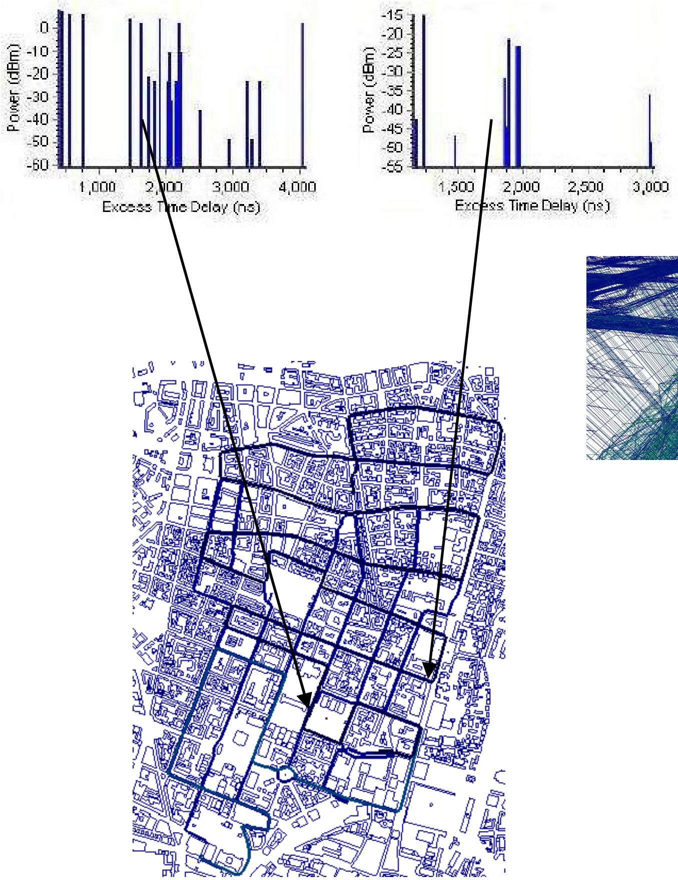


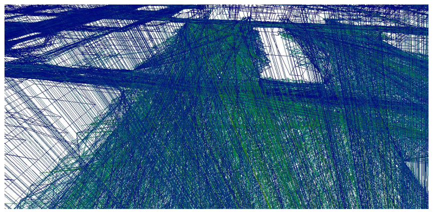


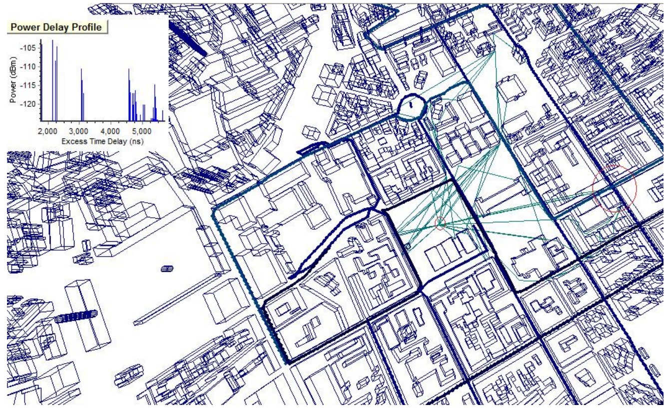


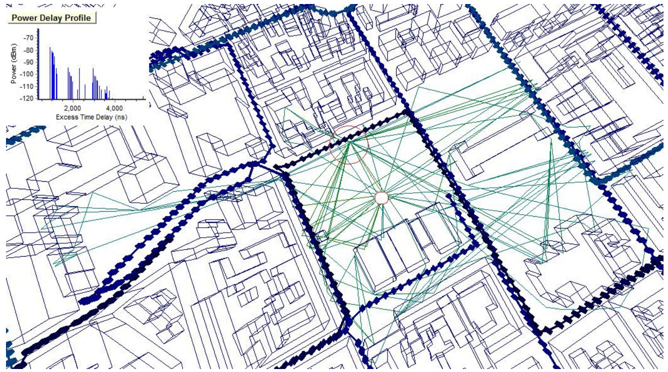
Results - Outdoor

Fig. 6. Power Delay Profile for LOS, N-LOS









Results – Indoor

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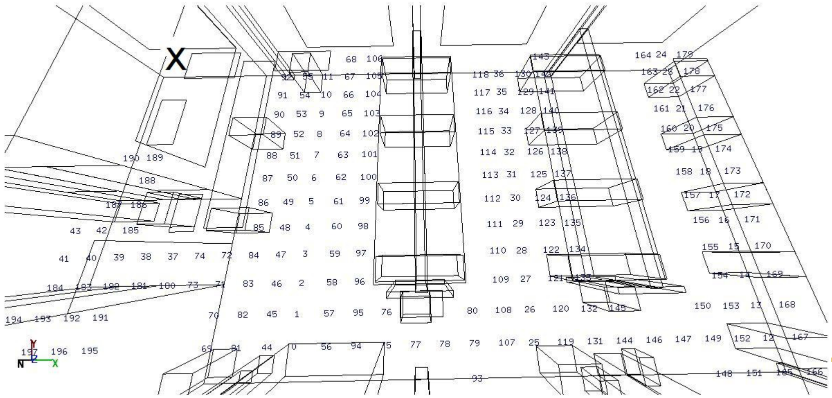
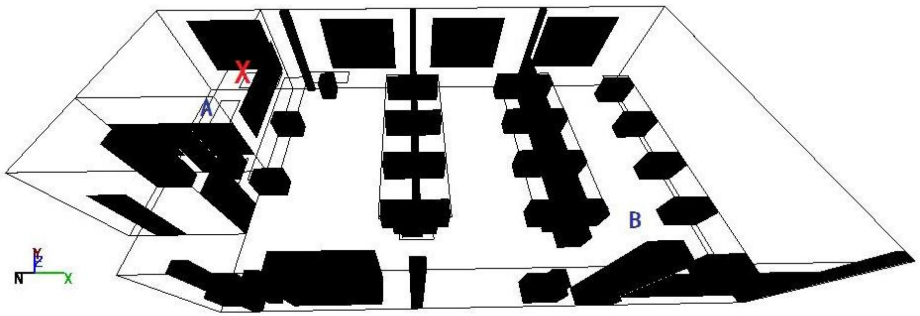




Results - Indoor

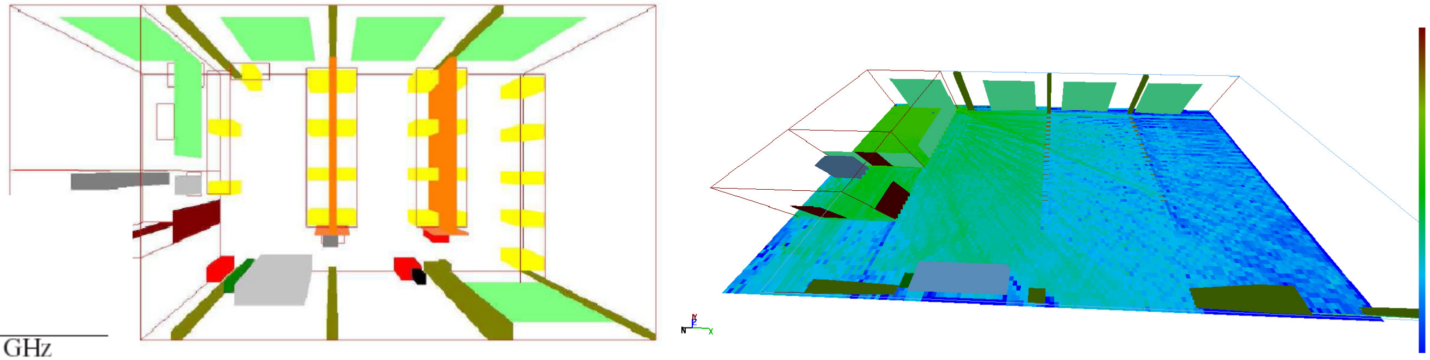


Fig. 1. Indoor Scenario (3D)

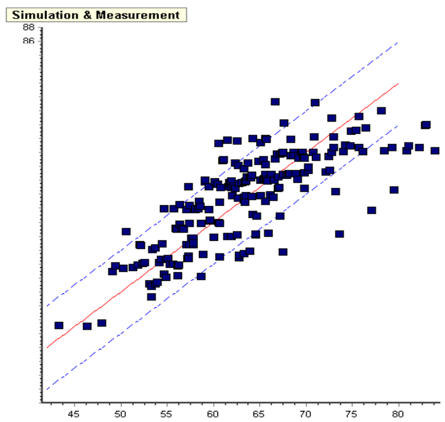
TABLE II
NETWORK PARAMETERS

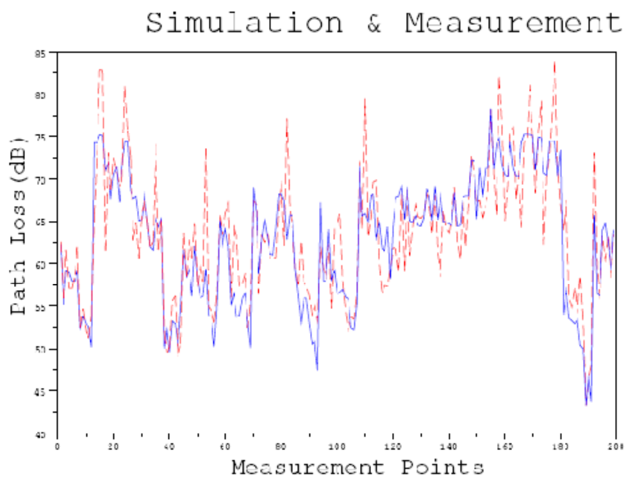
Emitter Frequency	3.525 GHz
Emitter Power Level	6 dBm
EIRP	8.8 dBm
Receiver Height	0.98 m
Emitter Height	1.35 m
Antenna Pattern	Omni-Directional
Antenna Gain	2.8 dBi

TABLE III
NETWORK CONFIGURATIONS

Area	384 m^3
Resolution	0.05 X 0.05 X 0.05
Maximum Reflection	7
Maximum Diffraction	3
Maximum Transmission	**Unlimited** *
Tuning Iterations	15, 000 **

* until signal strength is under threshold
* until temperature falls below threshold





Results - Indoor

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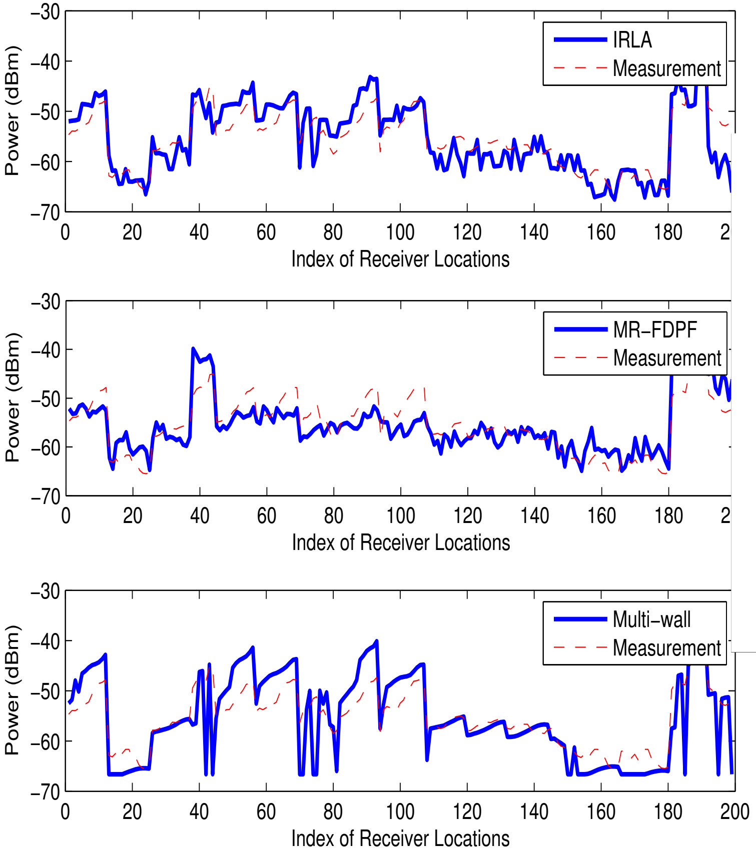

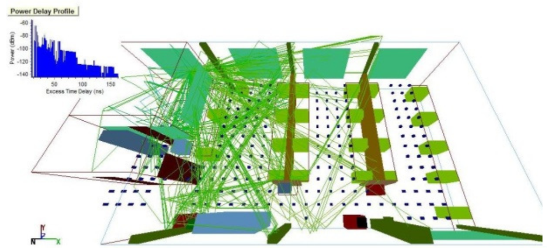

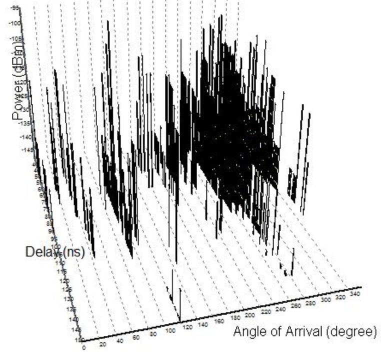

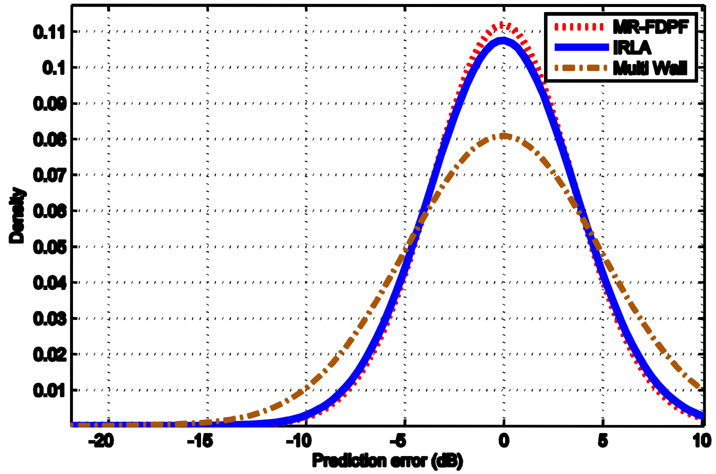

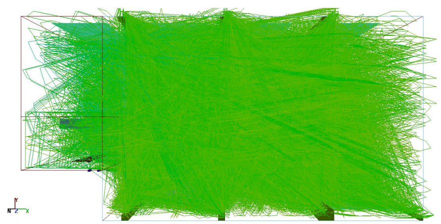

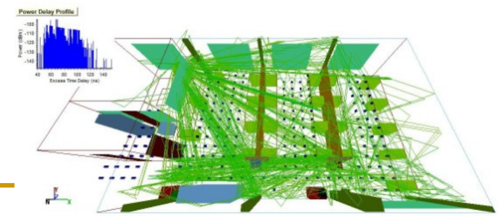

Results – Indoor to Outdoor

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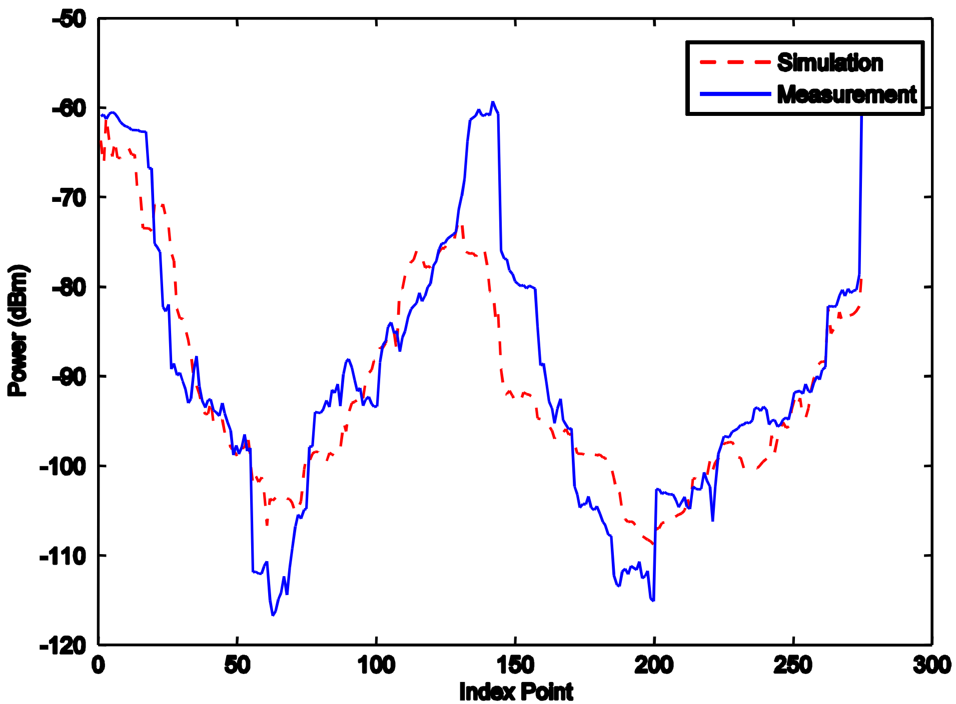
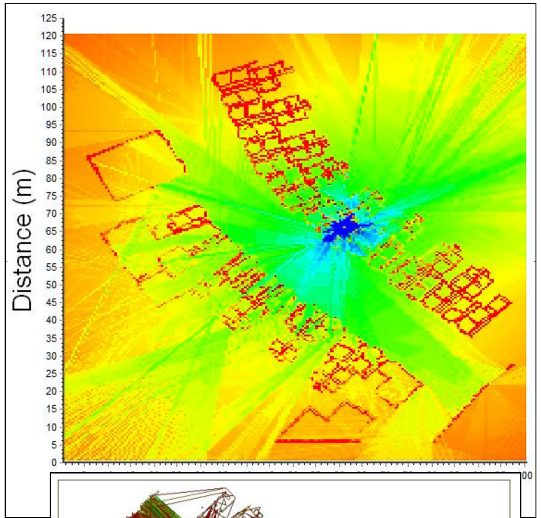
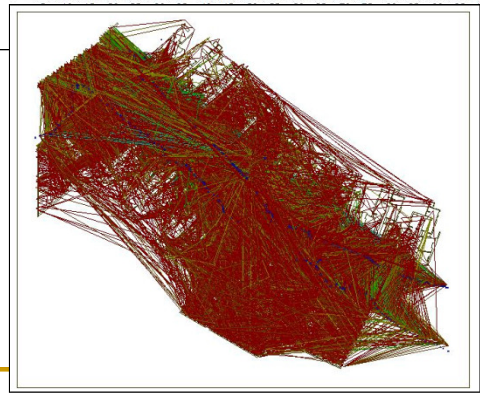
- Less than 1 minute.
  - Millions of rays







Results – Outdoor to Indoor

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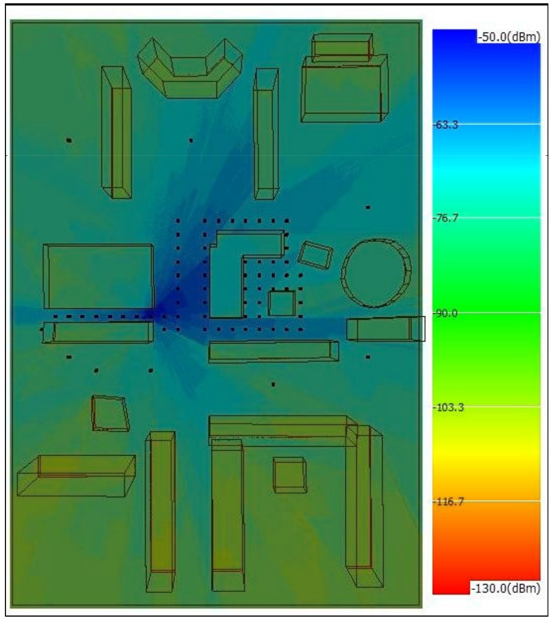
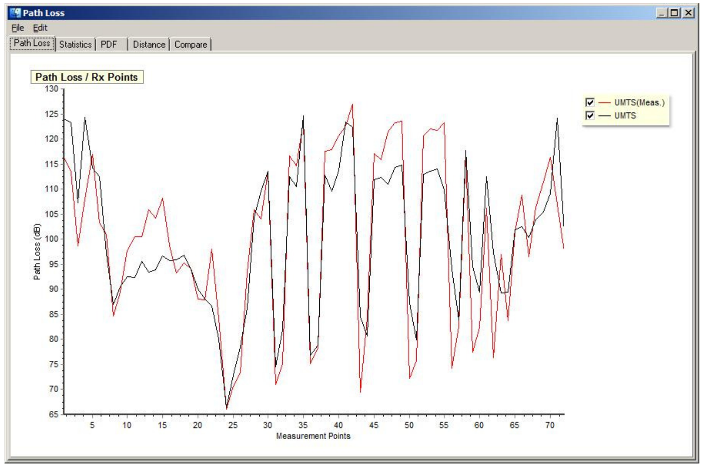
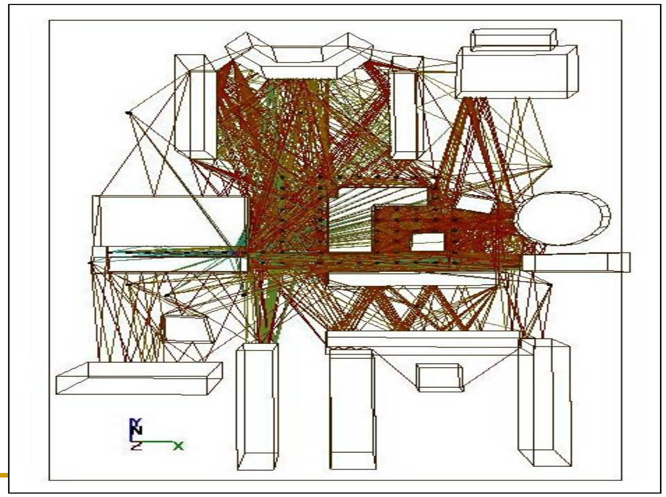
- Ref: [5][7][8]

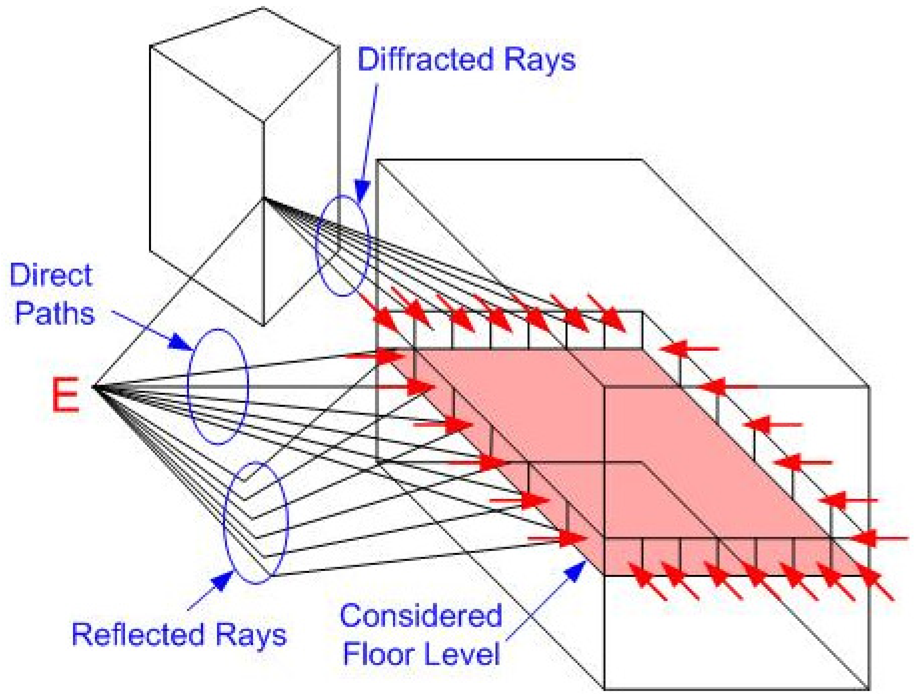


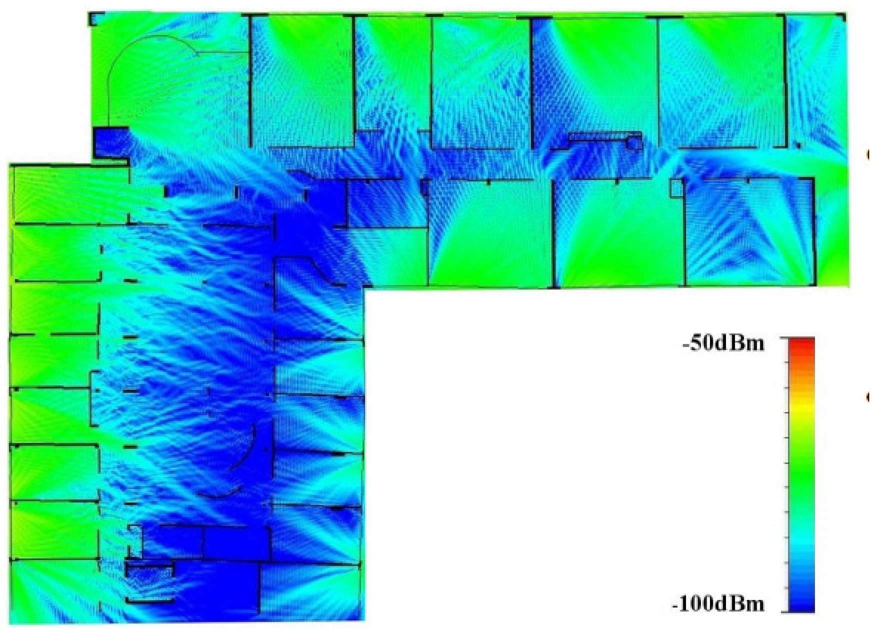




Results – Outdoor to Indoor

- Ref: [5][7][8]





Parallelisation

1. Why ?
   1. To be faster (for Automated Cell Planning)
2. How ?
   1. Static data distribution (distributed)
      1. Each processor has been assigned a fixed number of computation in advance
   2. Dynamic data distribution (multithreading)
      1. Threads are assigned a task whenever idle.
   3. Every object has accessed same data (antenna, building, network parameters …)
   4. Collect results (multipath, path loss)

POP-C++ (Parallel Object-oriented Programming in C++)

1. Implementation of parallel object model as an extension of C++
2. Implicit message-passing via object-oriented design
3. Grid-enable (can be used together with Globus Toolkit 4)
4. Various method invocation semantics
5. http://www.eif.ch/gridgroup/popc/

Parallelisation without Job Mgr

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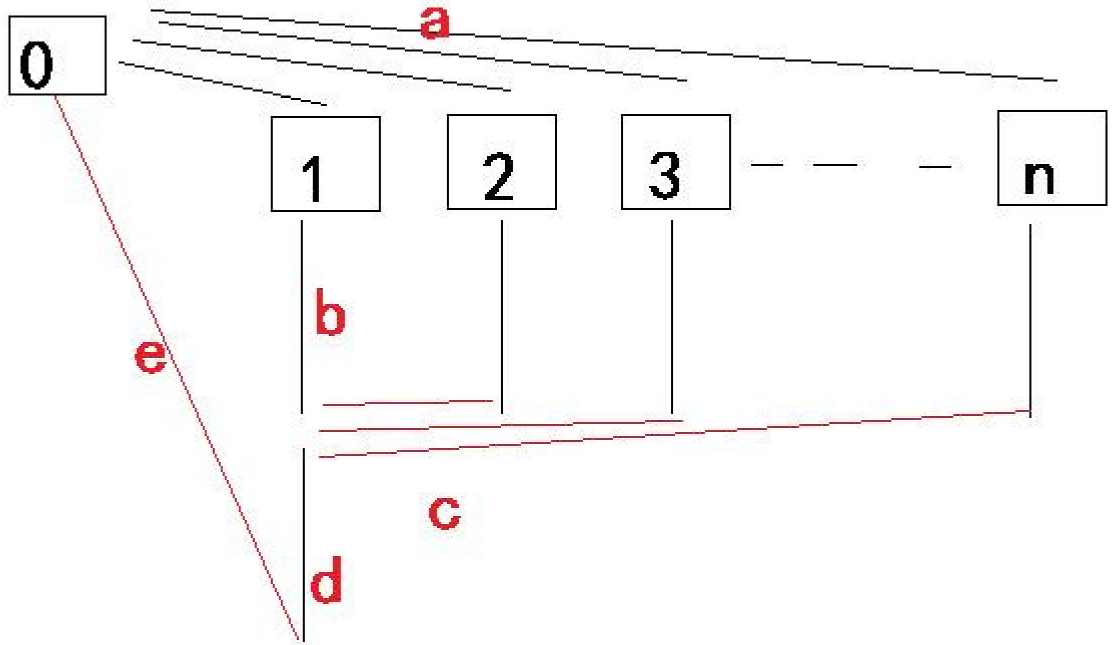
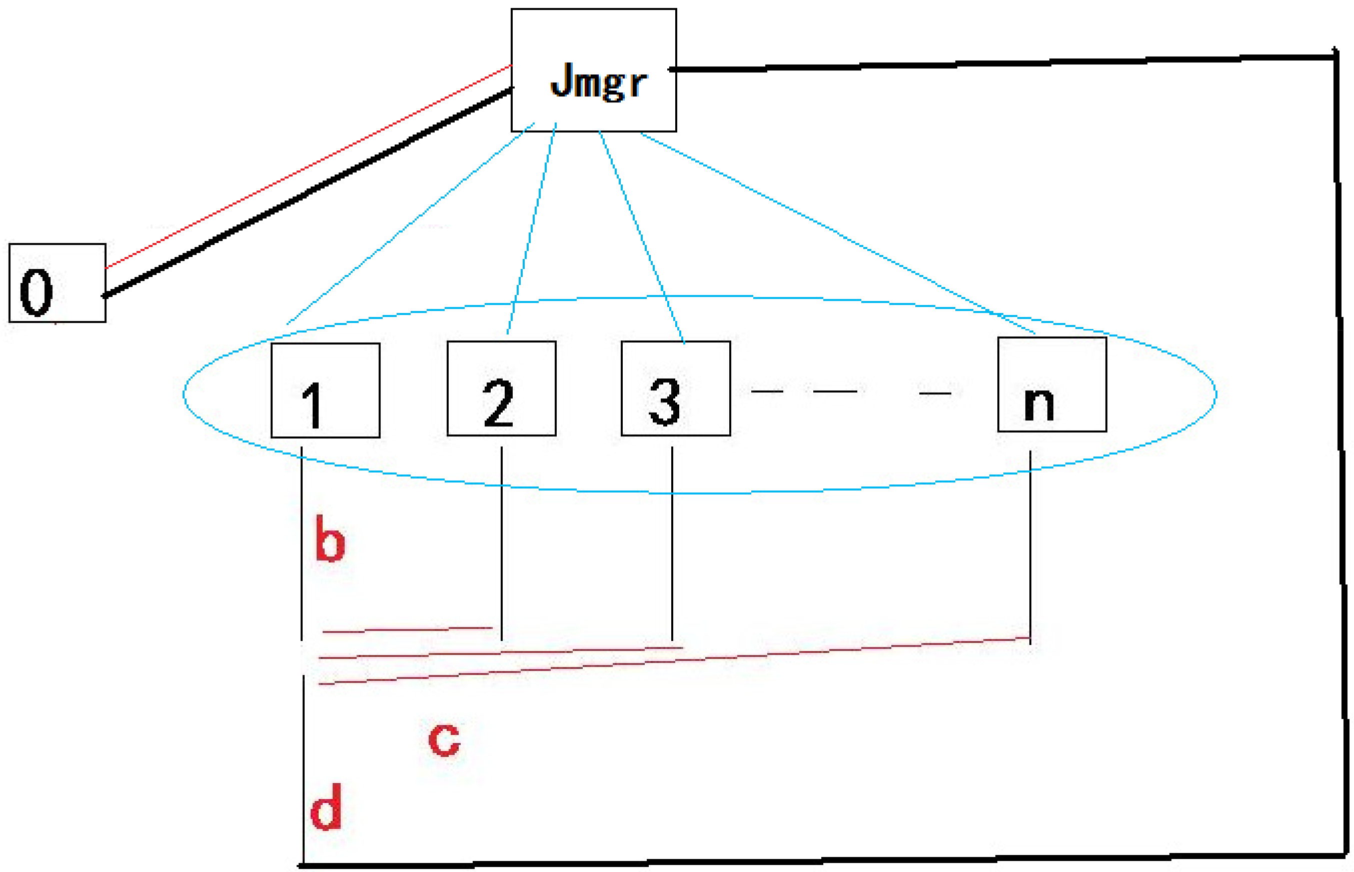


Parallelisation with Job Mgr

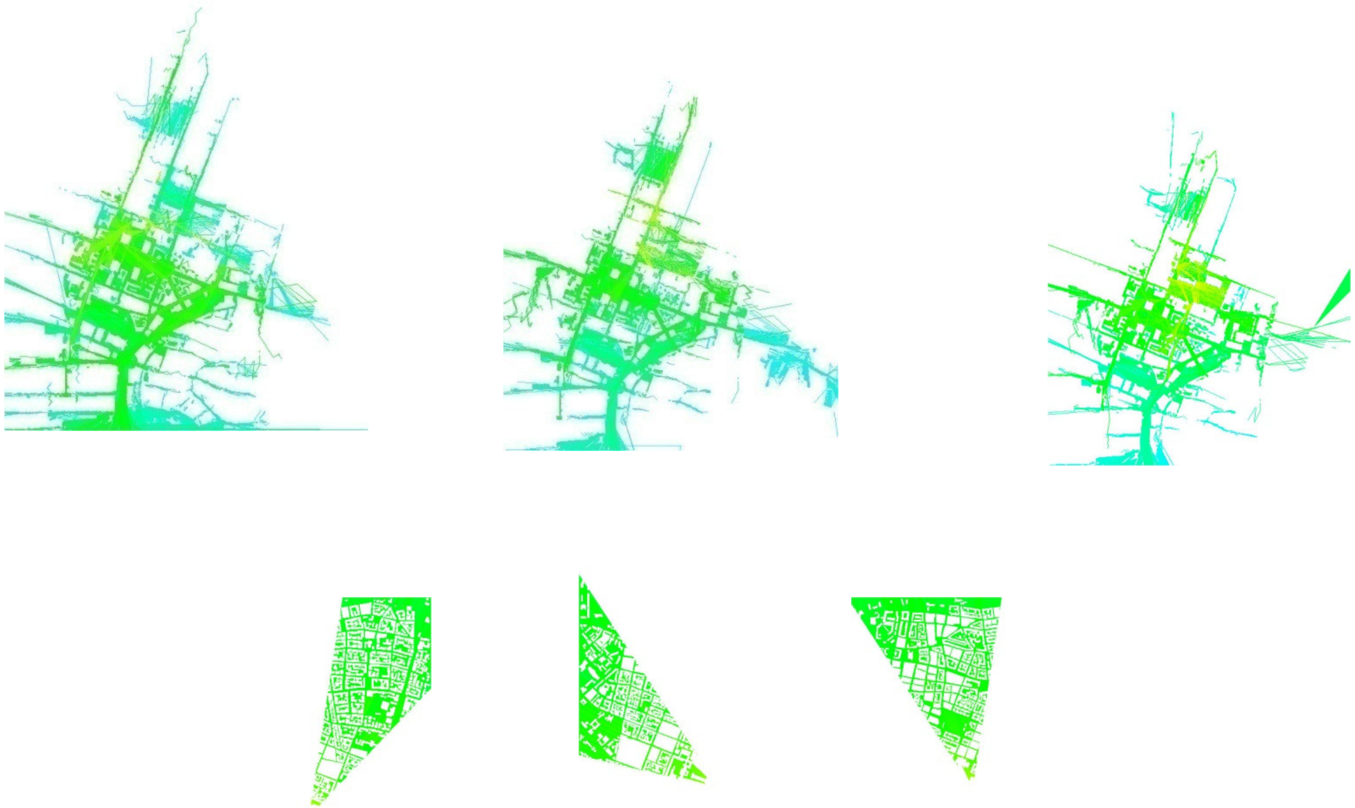


More details

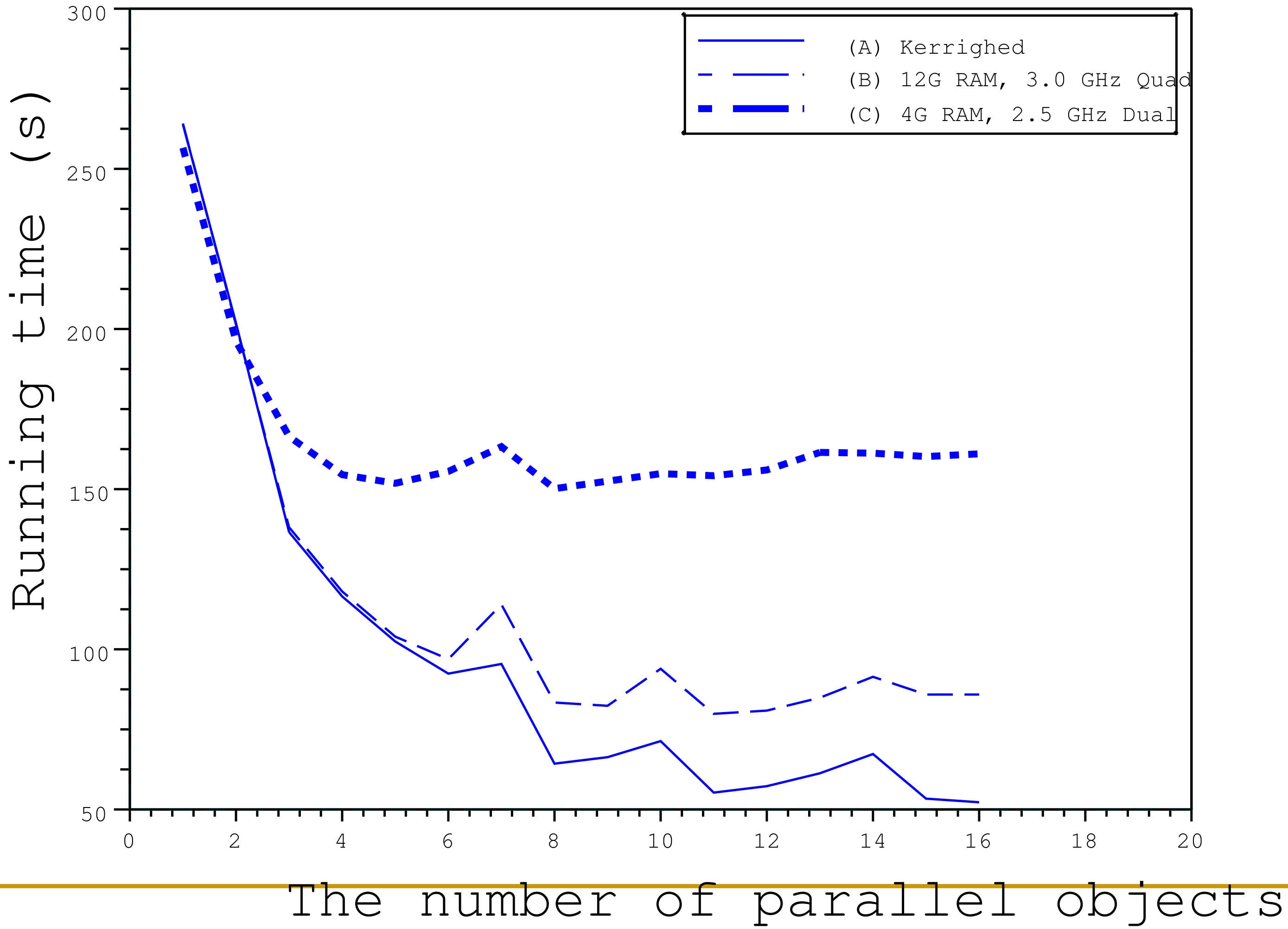
1. Job distribution is not necessary equal
2. Small jobs can be handled on one processor rather than in parallel (or run reduced function at other processors)
   1. LOS, post-processing

$$J_i = \frac{p_i}{\sum_{i=1}^{N_P} p_i}$$

Intermediate Results



Experiments - Parallelisation



Experiments – Best Servers

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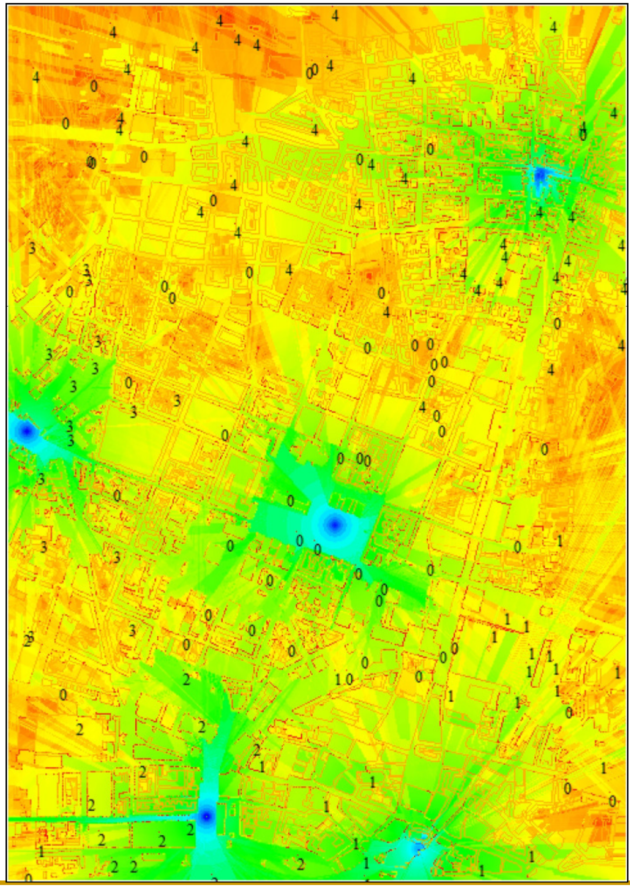

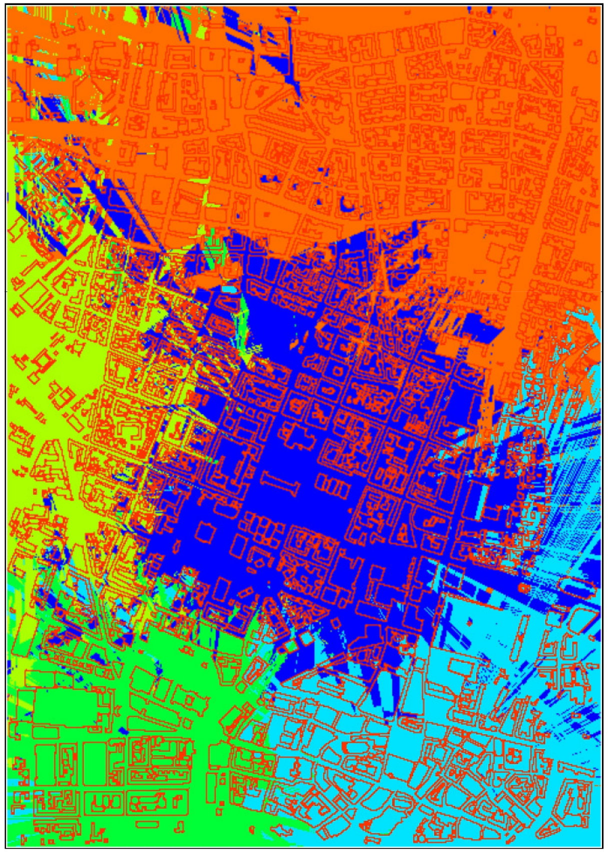

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Thanks!

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