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INRIA-CNRS-UNSA. Sophia Antipolis. France

Extending INET Framework for Directional and Asymmetrical Wireless Communications

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Outline

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Introduction

Motivation

Main Motivation

- To Extend the *OMNeT++ INET/INETMANET Framework* with a **directional radio** model.

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Motivation

Main Motivation

- To Extend the *OMNeT++ INET/INETMANET Framework* with a **directional radio** model.

Secondary Motivation

- To Support **asymmetrical wireless communications** within the *OMNeT++ INET/INETMANET Framework* Radio Model.

Introduction

Why is Important a Directional Radio Model

- Emerging Multi-Radio MESH Nodes equipped with Directional Antennas.

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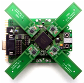

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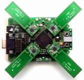


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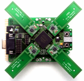


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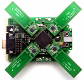


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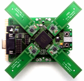


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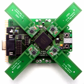


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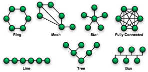
- Simulation assisted design of new MANET/MESH protocols/algorithms.



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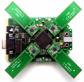
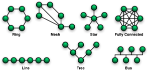



- Directional Antennas increase the radio link range using the same transmission power and reduce the interference effects on neighbor devices.

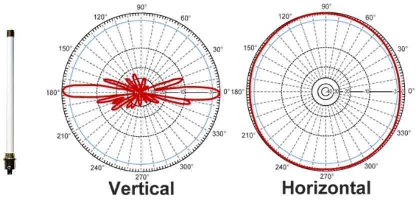


- Simulation assisted design of new MANET/MESH protocols/algorithms.
- The absence of a directional radio model in the *INET/INETMANET Framework*.

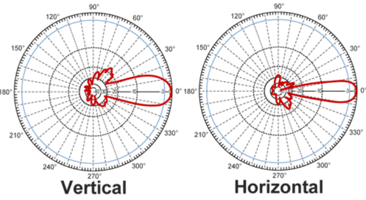


Modelling Directional Antennas

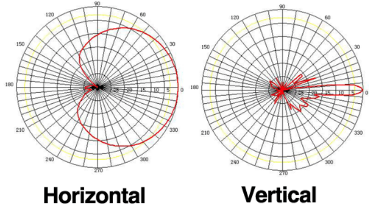
Antenna Patterns



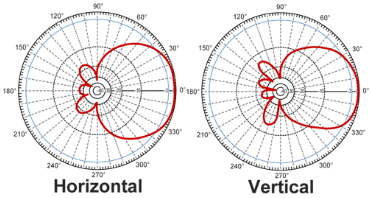
(a) Omni-Directional



(b) Directional-Grid Antenna



(c) Directional-Sector Panel Antenna



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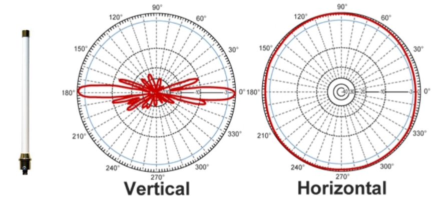

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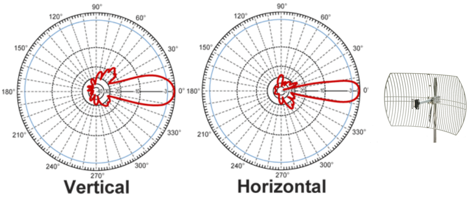

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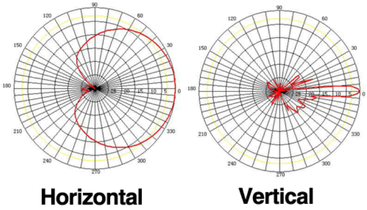

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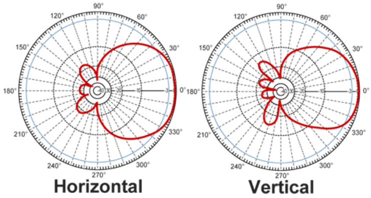

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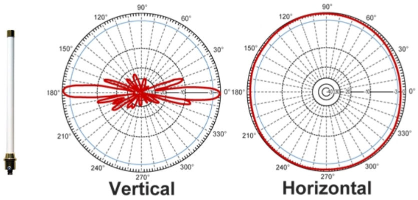

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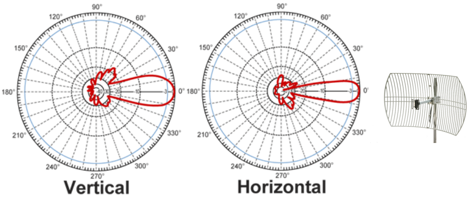

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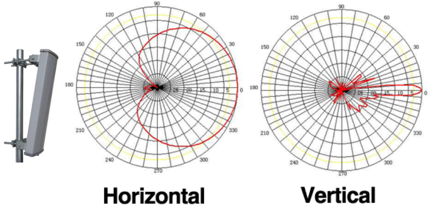

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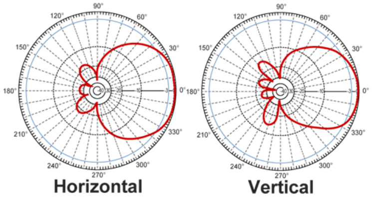

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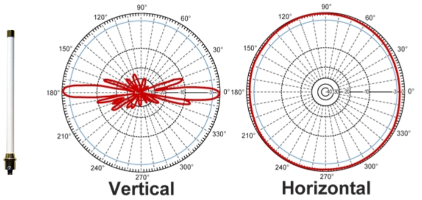

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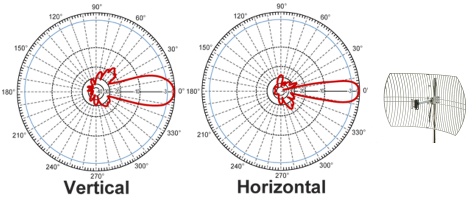

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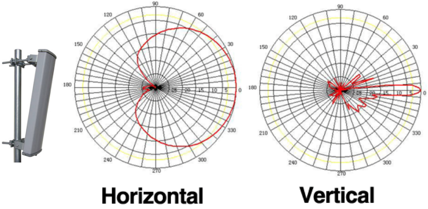

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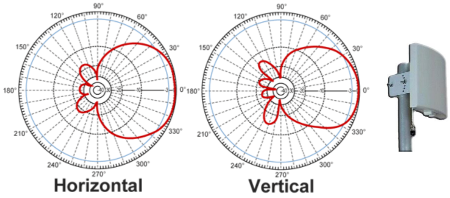

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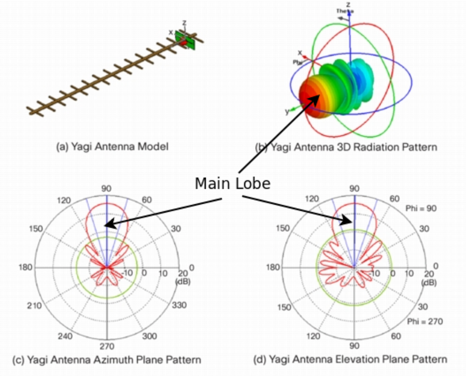
Modelling Directional Antennas

Theoretical Model

- Consists of:
  - Main Lobe.
  - Side Lobes.
  - Back Lobes.



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  - Beamwidth: Measure of the main lobe width.
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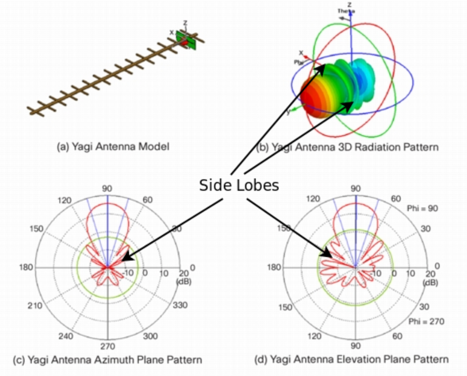

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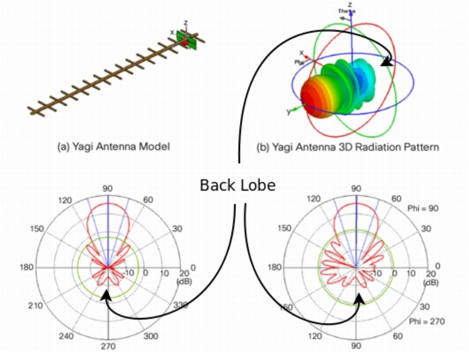

(a) Yagi Antenna Model
(b) Yagi Antenna 3D Radiation Pattern
(c) Yagi Antenna Azimuth Plane Pattern
(d) Yagi Antenna Elevation Plane Pattern

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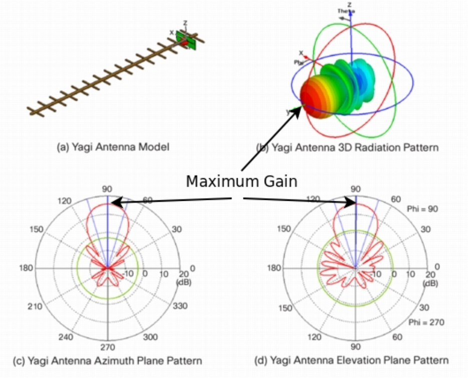

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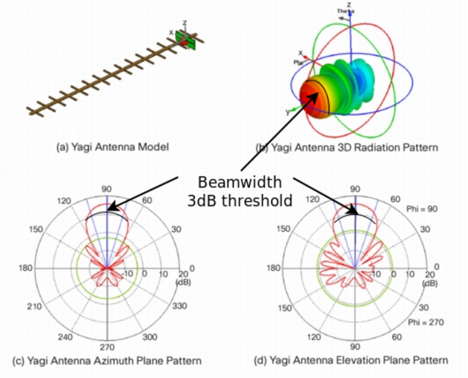

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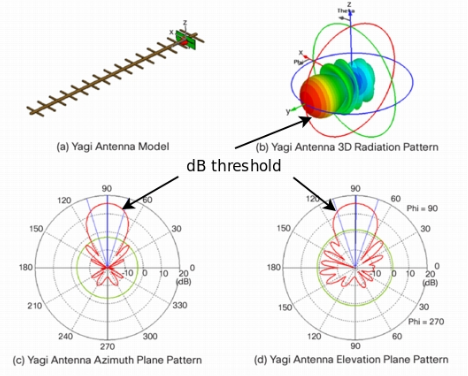

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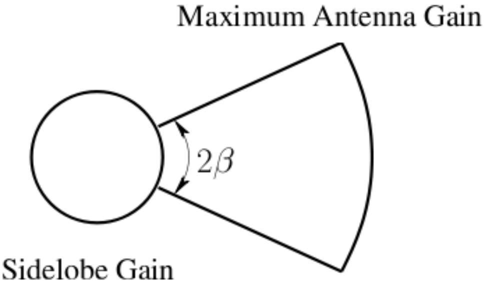
Modelling Directional Antennas

Theoretical Model

- Based on the ”pie-wedge“ antenna model presented by Gharavi et al. (two components: main lobe and back/side lobes).
- Tx and Rx gains are assumed equal (reciprocity theorem).
- Radio model is based on a simplified Link Budged calculation:



$$P_{rx} = P_{tx} + G_{tx} - PL + G_{rx} \quad (1)$$

Status of the INET/INETMANET Model

Current Radio Model (at least at last time I checked)

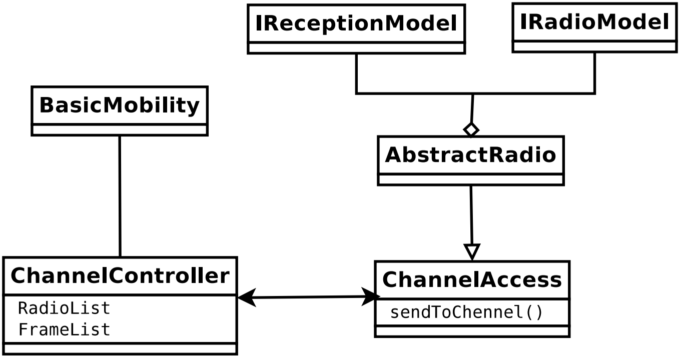
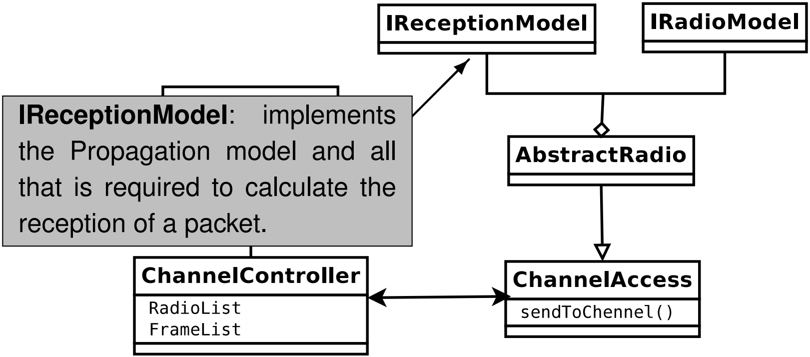


Figure: (Very) Simplified Class Diagram of INET/INETMANET radio model

Status of the INET/INETMANET Model

Roles within the Radio Model



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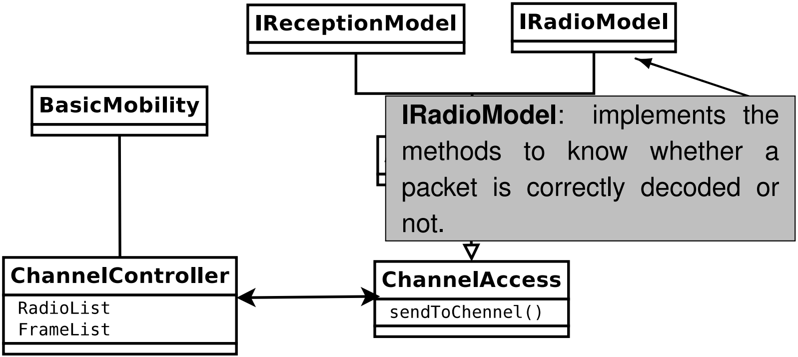

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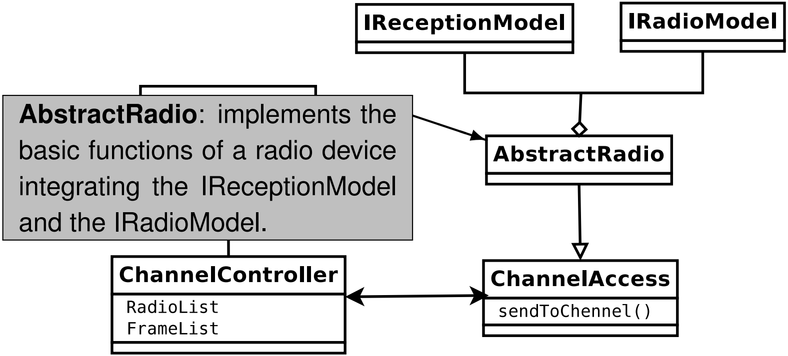

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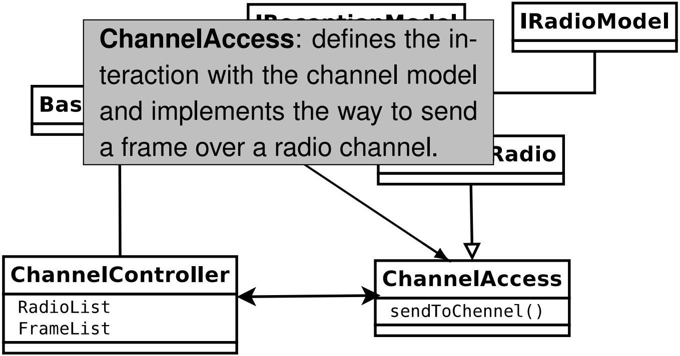

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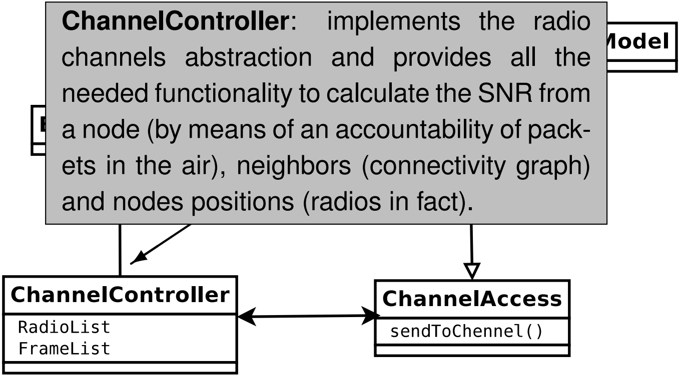

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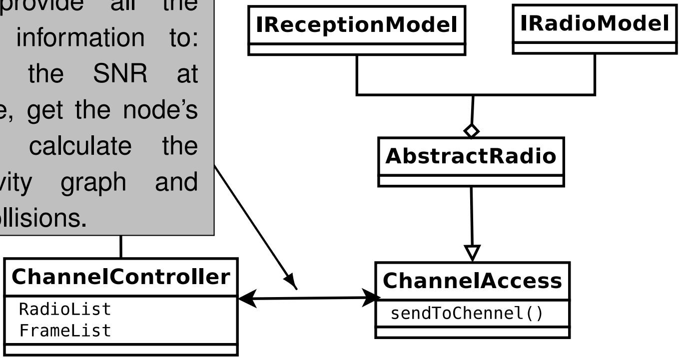
Status of the INET/INETMANET Model

Contracts between classes defined by the Radio Model

ChannelController

should provide all the required information to: calculate the SNR at any node, get the node's position, calculate the connectivity graph and detect collisions.



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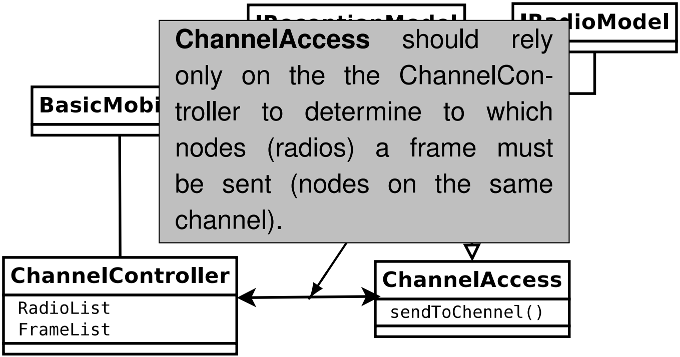

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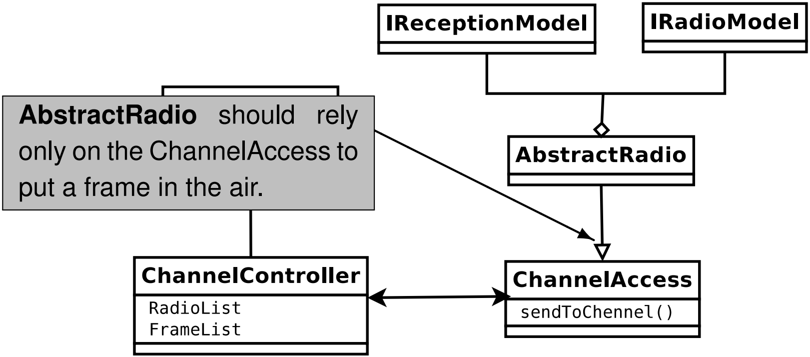

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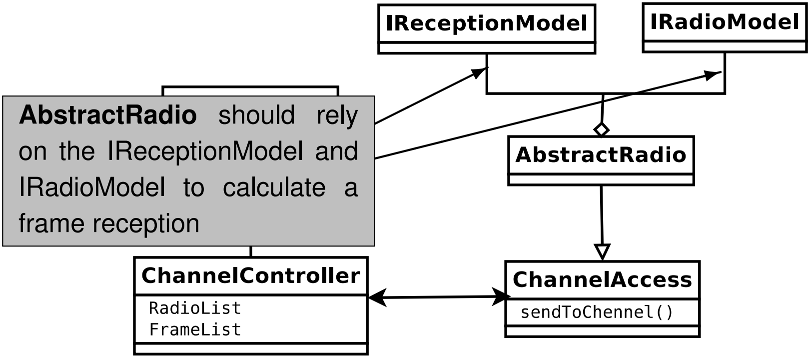

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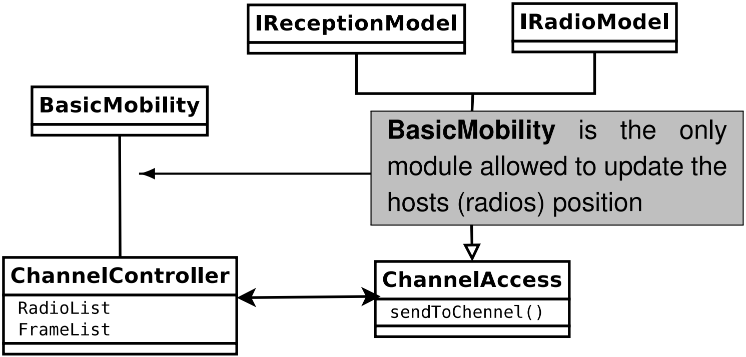

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Proposed Extended Radio Model

The Antenna Pattern and the Link Budget

- New class interface proposed: **IAntennaPattern** assuming the role of delivering the antenna gain given a direction of communication (angle).
- When transmitting a frame, effective transmission power is based on the equation:

$$P_{effective} = P_{nominal} + G_{txAngle} \tag{2}$$

- When receiving a frame, the **Link Budget** calculation is based on the equation:

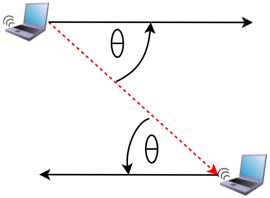
$$P_{rx} = P_{effective} - PL + G_{rxAngle} \tag{3}$$

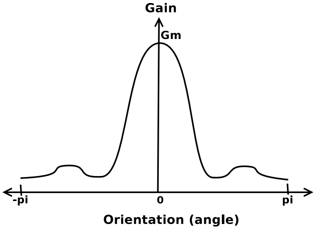
- **Remainder**: each airframe carries the transmission power (effective, considering antenna gain) and the node's position where the frame was sent.

Proposed Extended Radio Model

Directional Radio Model

- AbstractRadio will use the IAntennaPattern to calculate the gain given the angle of transmission/reception.



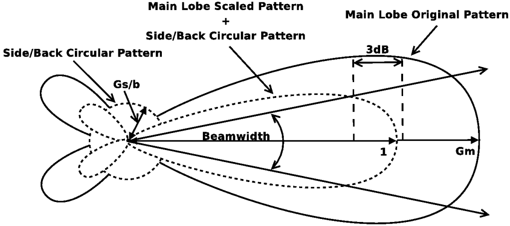


- Antenna gain will vary according to the orientation angle θ.

Proposed Extended Radio Model

Directional Radio Model

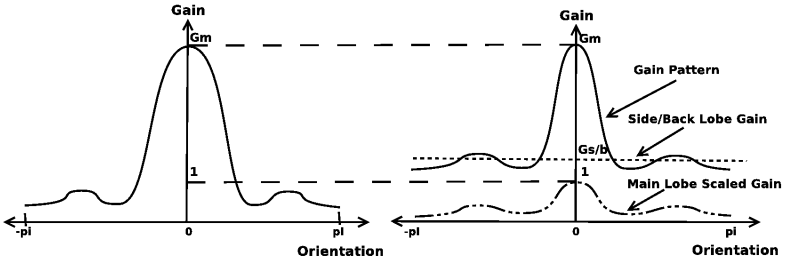
- IAntennaPattern will use the ”pie-wedge“ model to represent main lobe and side/back lobes.
- Side/back lobes are represented by an unity-gain circular pattern.
- The analytical curve (original pattern) will be **scaled** to fit it to the maximum gain (G_m)



Proposed Extended Radio Model

Directional Radio Model

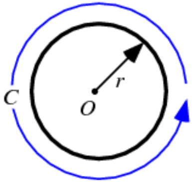
- The **scaling** of the original pattern (main and side/back lobes) are normalized to the **maximum gain** (radio parameter) and to fit the curve to the required **beamwidth**.



Proposed Extended Radio Model

Directional Radio Model

Some patterns represented by this model are



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Proposed Extended Radio Model

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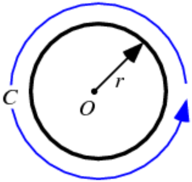

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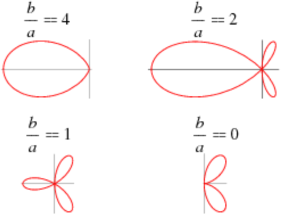

(b) Folium

Proposed Extended Radio Model

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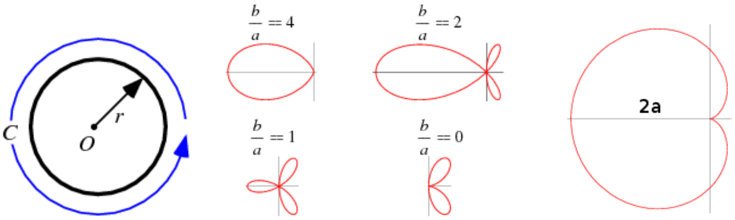
Some patterns represented by this model are

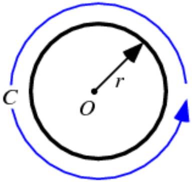


(a) Omni-directional (b) Folium (c) Cardioid

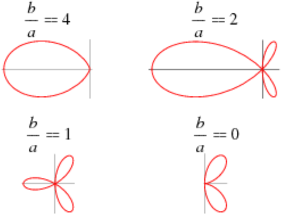
Proposed Extended Radio Model

Directional Radio Model

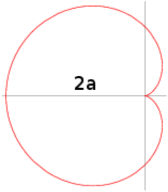
Some patterns represented by this model are



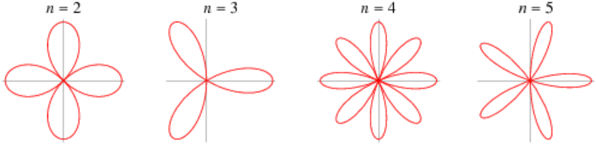
(a) Omni-directional



(b) Folium



(c) Cardioid



(d) Rose

Model Implementation

How to implement the proposed radio model?

How to Do it??

Model Implementation

How to implement the proposed radio model?

How to Do it??

- Current Status of INET/INETMANET asummes symmetry on the communication
- First, we need to support Asymmetrical communication. Specially, each radio need to decide its own connectivity graph.
- Second, add the required elements to represent an antenna pattern.

Model Implementation

Problems to address

- Two methods calculating the RF Propagation. One in the ChannelController, to determine the connectivity graph (neighbors) and one in the IReceptionModel to calculate the reception power when a frame is received.
- No Single Role assigned for Propagation Model (not completely true).
- ChannelController assumes symmetry when calculating the neighbors list. *If you can hear me, I can hear you*.
- There is no responsibility assigned on the Link Budget calculation.
- Misassigned responsibility of the neighbors calculation. Currently assigned to the ChannelController. It should be responsibility of each radio.

Model Implementation

Asymmetrical Communications Support

- Neighbors lists are **no longer only ChannelController' s resposability**. A new contract is created between the AbstractRadio and the ChannelController to allow the AbstractRadio to tell the ChannelController when a node **isInCoverageArea**.
- New Role for the IReceptionModel (supplanting the missing IPropagationModel) to calculate the interferenceDistance and the received power given by using a any propagation model.
- A class interface called **IAntennaPattern** was added, providing the antenna pattern calculation interface.
- **Link Budget** separation implemented in the AbstractRadio. New contract created between the AbstractRadio, the IReceptionModel and the the IAntennaPattern to determine the Link Budget when transmitting and receiving a frame.

Model Implementation

Impact of these changes

Requirement

every neighbors lists, for every node in the simulation playground, **must** be updated when a **node** moves.

For **Symmetrical Model**:

- From the perspective when a single host moves:
  - getNeighbors complexity: $O(m * n)$
- When updating every nodes position in a single time-step:
  - getNeighbors complexity: $O(m * n)$
  - Because symmetry is assumed, if you are my neighbor, I am your neighbor.

m = number of radios, n = number of hosts

Model Implementation

Neighbors Lists calculation Analysis

Requirement

every neighbors lists, for every node in the simulation playground, **must** be updated when a node **moves** or **transmits** a frame.

For **Asymmetrical Model**:

- From the perspective when a single host moves:
  - getNeighbors complexity: $O(m * n)$
- When updating every nodes position in a single time-step:
  - getNeighbors complexity: $O(2 * m * n)$
  - Due to the asymmetry, if you are my neighbor, I am not necesarily your neighbor, so we need to update all the nodes.

m = number of radios, n = number of hosts

Model Implementation

Neighbors Lists calculation Analysis

Discussion

As the getNeigbors complexity is higher, and we call this method more often (now, not only when a node moves, but when moves or transmits), the overall execution time is be higher, but how much?

- Execution time will depend more hardly on the amount of transmitted packets. Not even think on the amount of nodes!!!
- The exact bound is not clear (or not easy to find)

Model Implementation

Neighbors Lists calculation Analysis

Discussion

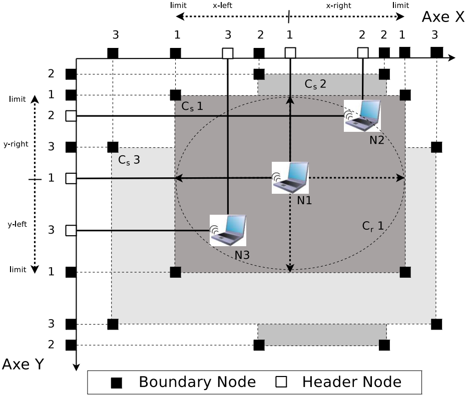
As the getNeigbors complexity is higher, and we call this method more often (now, not only when a node moves, but when moves or transmits), the overall execution time is be higher, but how much?

- Execution time will depend more hardly on the amount of transmitted packets. Not even think on the amount of nodes!!!
- The exact bound is not clear (or not easy to find)
- **So, a new strategy to calculate the neighbors lists is required to overcome the increment of the execution time.**

Model Implementation

The NeighborsGraph Algorithm

- Inspired on a Sparse Matrix.
- Returns the neighbors list and the list of nodes to be updated (invalidate list).
- Real Coverage Area C_r represented by a Squared Coverage Area C_s.
- Axes are Red-Black Trees.



- Four directions to evaluate: X-left, Y-right, X-right, Y-left.
- Just nodes within C_s are evaluated to know if they are within C_r also.

Model Implementation

The NeighborsGraph Algorithm

- The NeighborsGraph will determine which nodes are in the node's neighbors list and which other nodes need to be updated (due the node's movement).

- The Algorithm inside the packet delivery process.
  - Is my neighbors list invalidated?
    - neighborsGraph(myList,toUpdate)
    - $\forall$ node toUpdate $\longrightarrow$ invalidate the list.
- The Algorithm inside mobility.
  - Is my former position different to my current one?
    - neighborsGraph(myList,toUpdate)
    - $\forall$ node toUpdate $\longrightarrow$ invalidate the list.

Model Evaluation

Evaluation Strategy

- Correctness of the implemented directional radio module.
  - Reproduce an Antenna Pattern by simulation.
  - Omni-directional versus directional communications.

- Computational Cost analysis.
  - Symmetrical communication case (reference).
  - Asymmetrical communication case (fixing the neighbors list calculation)
  - Asymmetrical communication case (using the NeighborGraph algorithm)

Model Evaluation

Reproducing an Antenna Pattern by Simulation

Objective

Reproduce by simulation a given antenna pattern by measuring the space in different places.

Expected Results

Obtain the same antenna pattern specified in the configuration file

Methodology

One Access Point (AP) with equipped with a Directional Antenna, 10 wireless hosts, with omni-directional antennas, moving around with circular mobility centered on the AP, separated by 10 meters each. Log the beacon reception power and make a polar chart of the reception power versus the angle by host.

Excerpt of the configuration file

```
# Antenna Pattern Parameters
**.ap1.wlan.radio.transmitterPower = 40.0mW
**.ap1.wlan.radio.beamWidth = 40deg
**.ap1.wlan.radio.mainLobeGain = 15dB
**.ap1.wlan.radio.sideLobeGain = -5dBi
**.ap1.wlan.radio.mainLobeOrientation = 90deg
**.ap1.wlan.radio.dBThreshold = 3dB

# Folium Pattern
**.ap1.wlan.radio.patternType = "FoliumPattern"
**.ap1.wlan.radio.FoliumPattern.a = 1
**.ap1.wlan.radio.FoliumPattern.b = 3
```

Model Evaluation

Reproducing an Antenna Pattern by Simulation

Excerpt of the configuration file

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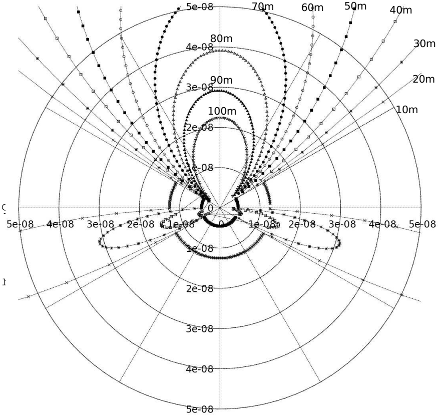
**.ap1.wlan.radio.FoliumPattern.a = 1
**.ap1.wlan.radio.FoliumPattern.b = 3
```



Model Evaluation

Omni-directional versus directional communications

Objective

To reproduce well known results in the liretature comparing the effect of using directional antennas versus omni-directional antennas.

Expected Results

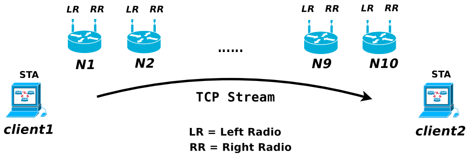
To obtain similar resutls between our model and the the literature.

Methodology

To simulate a 10 dual-radio nodes mesh network (linear topology) and measure the TCP througput end to end with omni-directional and directional antennas.

Model Evaluation

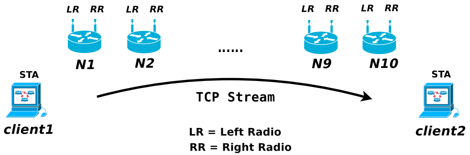
Omni-directional versus directional communications



10 Nodes Mesh topology simulated model

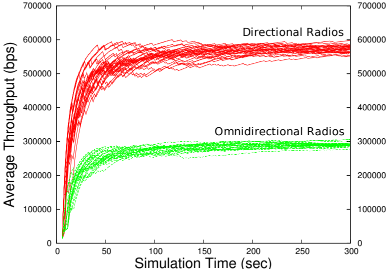
Model Evaluation

Omni-directional versus directional communications

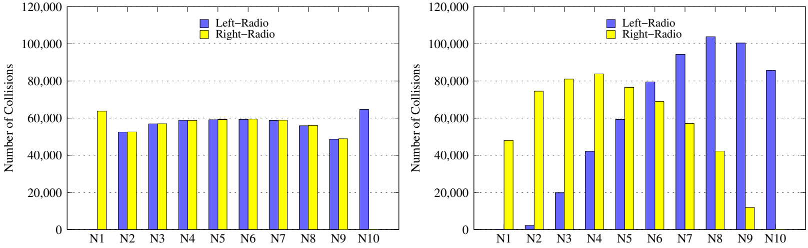


10 Nodes Mesh topology simulated model

The bandwidth is about the half when using omni-directional antennas.



Collision Number between Mesh Nodes



(a) Omni-directional Antenna

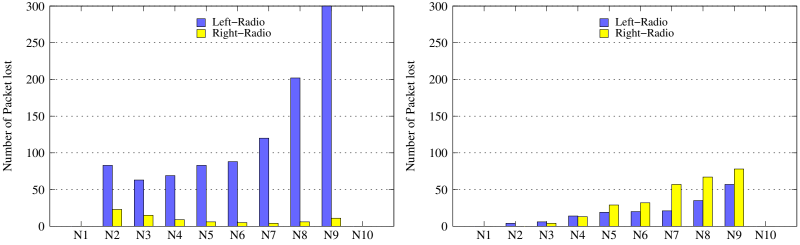
(b) Directional Antenna

Directional antennas case shows an increasing/decreasing pattern of collisions

Model Evaluation

Omni-directional versus directional communications

Packet Losses



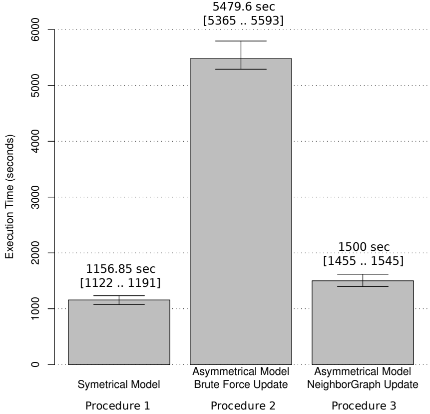
(a) Omni-directional Antenna (b) Directional Antenna

Directional Antennas show less packet loss due to the reduction on the interference effects produced by the neighbor nodes

Model Evaluation

Computational Cost Analysis

- Three procedures:
  - Symmetric case
  - Asymetric case
  - Asymmetric case with NeighborGraph Algorithm.
- Simulation
  - 100 nodes.
  - Random positions
  - Speed of 40 Km/h.
  - 4 Access Points
  - ICMP Ping to a central server each 0.1 sec.
  - 500 seconds, 10 replicas.



Conclusions

- An extended Radio Model has been proposed to INET/INETMANET Frameworks.
  - Support of asymmetrical communications.
  - Support any shape of antenna (implemented: Circular, Folium, Cardioid, Rose)
- Simulated results have been compared agains the literature, finding similar results. So, the proposed model seems to work properly.
- The increment of the computational cost when including asymmetrical communications have been reasonably reduced by introducing the NeighborGraph algorithm to calculate the connectivity graph.

Conclusions

Continuation

- Open issues:
  - Accuracy of the antenna gain in the 2D plane. Mapping techniques?
  - The use of multicore to speed-up the calculation of the connectivity graph. Parallel NeighborGraph Algorithm?
- Further work:
  - Implement more Antenna Patterns.
  - Improve the NeighborGraph Algorithm.
  - Improve the Interference model to obtain a irregular (and time changing) coverage area.