Medium Access Control for 60 GHz Outdoor Mesh Networks with Highly Directional Links

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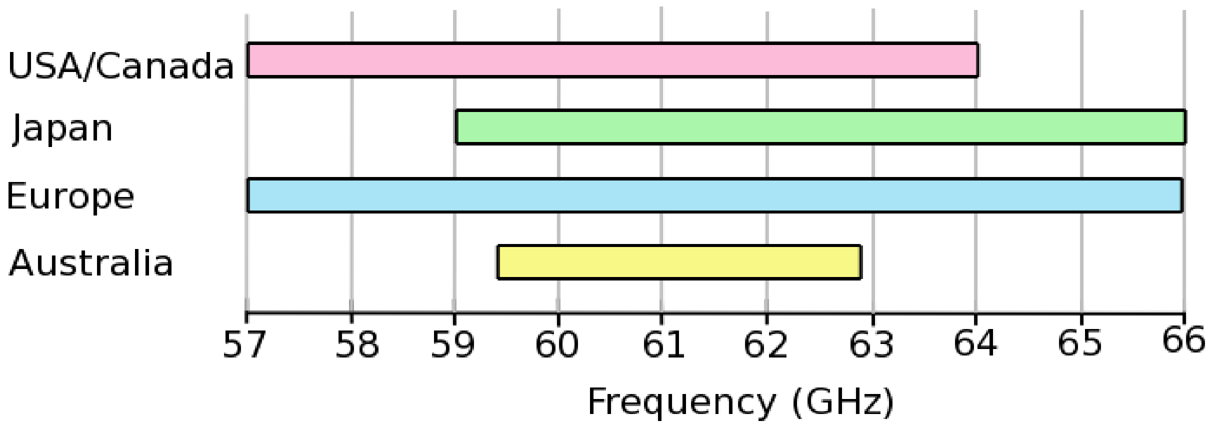
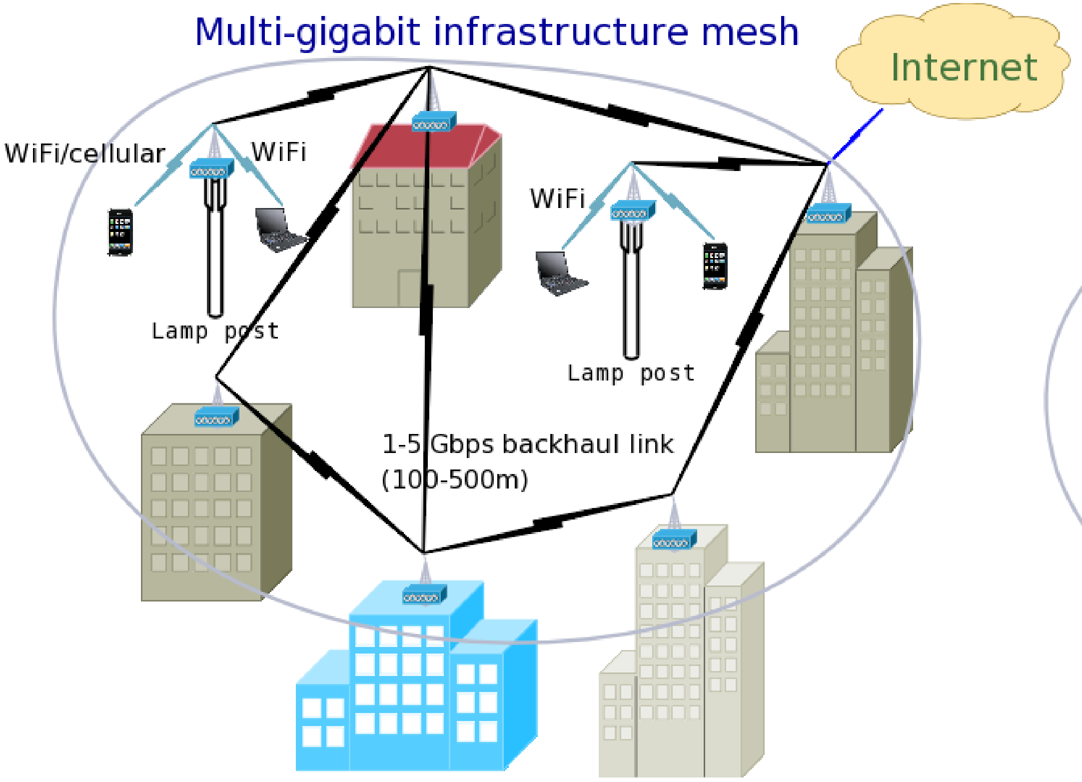
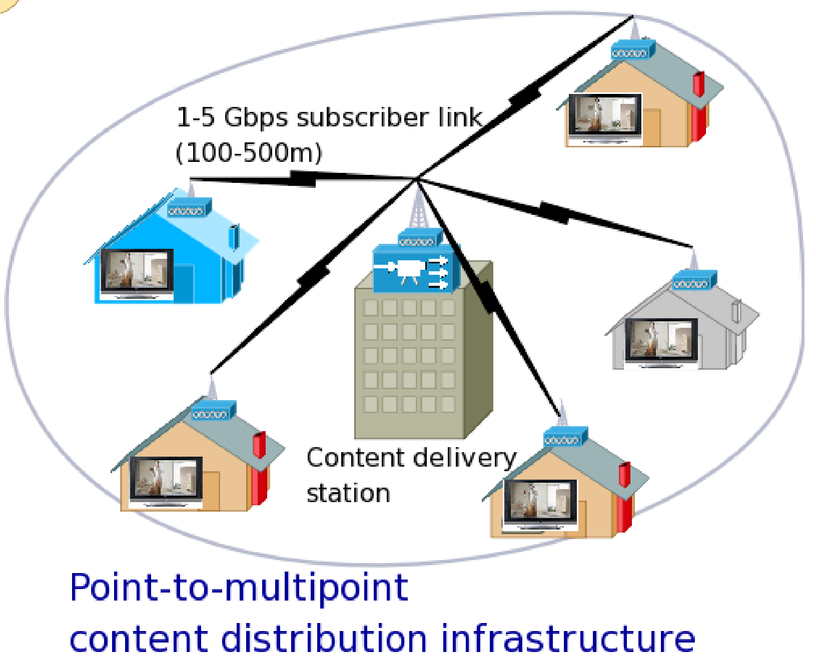
The 60 GHz Band

- Unlicensed short range transmissions
- Small wavelength + oxygen absorption => high propagation loss



60 GHz Outdoor Mesh Networks





Path loss for mm waves

- Free space path loss

$$\frac{P_r}{P_t} = \lambda^2 \frac{G_t G_r}{(4\pi r)^2} \propto \frac{1}{f^2}$$

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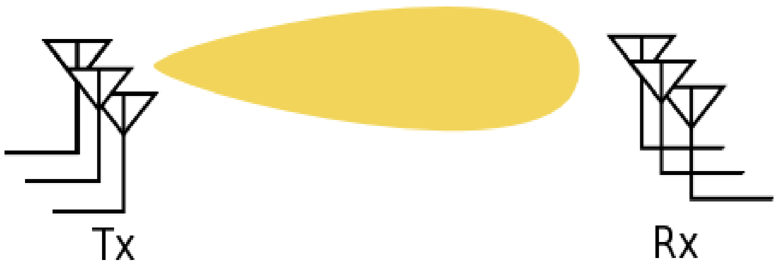
- For a fixed antenna aperture size A

$$G = \frac{4\pi A}{\lambda^2} \propto f^2$$



=> $$\frac{P_r}{P_t} = \frac{A_t A_r}{\lambda^2 r^2} \propto f^2$$

gain in received power with increase in frequency!

Directional communication is essential!

- RF power constraints
- Simpler PHY
- Nodes with compact form factors

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High directionality => new challenges in network design!

Questions in mm wave network design

- Medium access control
  - Can no longer rely on carrier sensing
  - No *omnidirectional* mode
  - Vastly reduced interference!

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High level of interference management may not be needed?

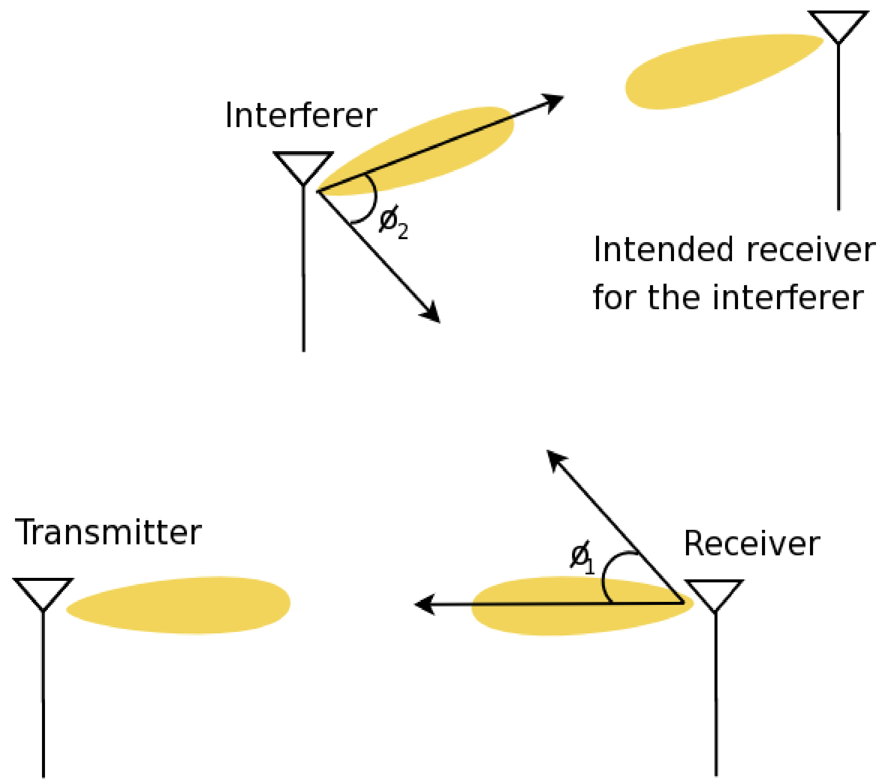
The implications of reduced interference

- Statistical analysis of interference
- *Pseudo-wired* abstraction
  - Verification via a directional slotted Aloha protocol

Interference with highly directional antennas

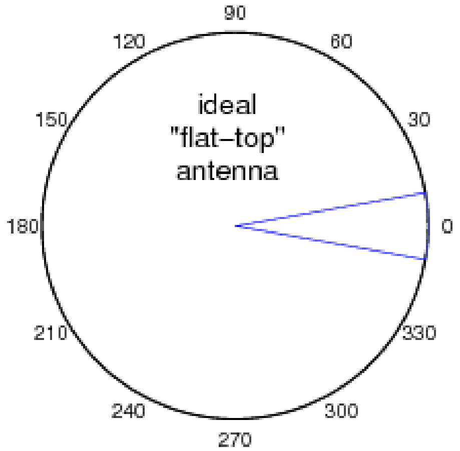
- Collision probability?
  - Dependence on beamwidth?

- Interference models?
  - Protocol model
  - Physical model



Flat top antenna idealization

- Constant gain within azimuthal angle Φ and zero outside
  - Analytically convenient
  - What about side-lobes?



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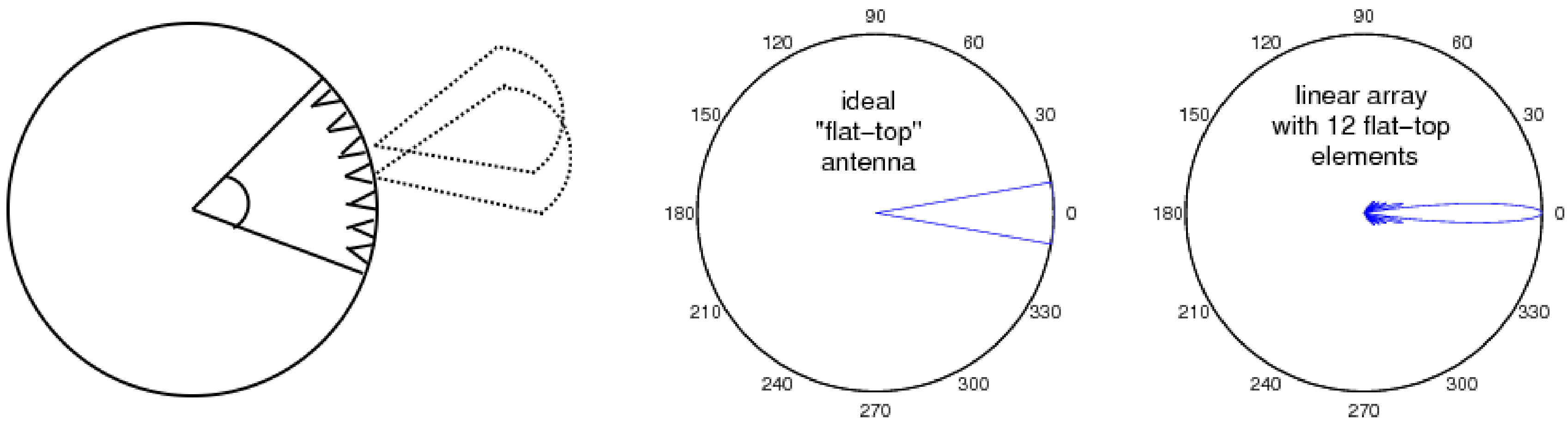
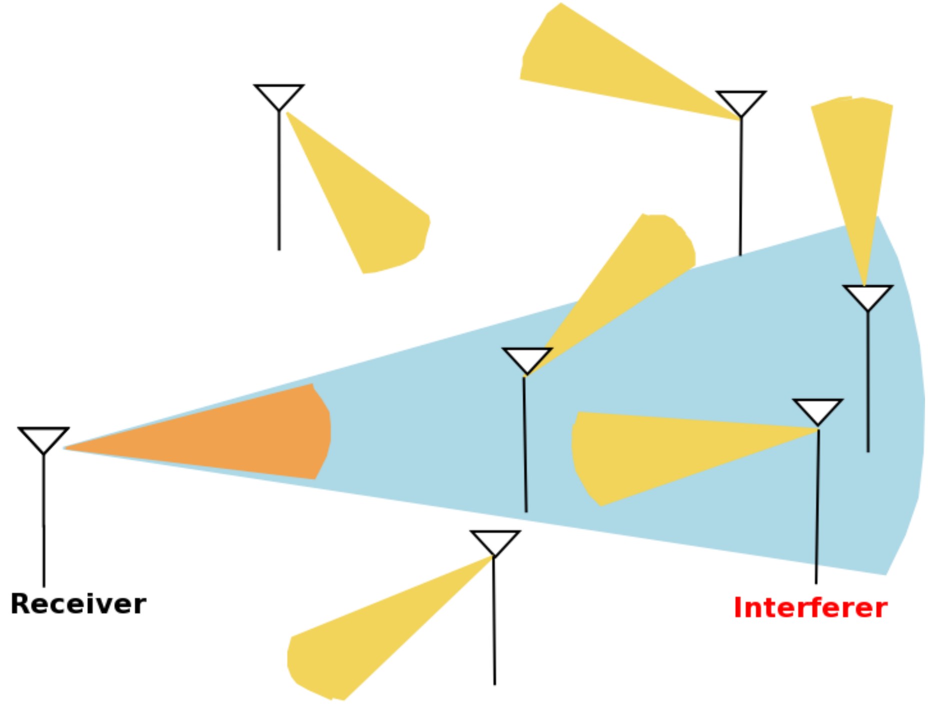
Hybrid linear - flat top model for circular array



Interference under the protocol model

- Flat top antenna
- Interference loss iff there exists at least one interferer
  - within the interference range
  - within the receiver's bea mwidth
  - pointing in the direction of the receiver



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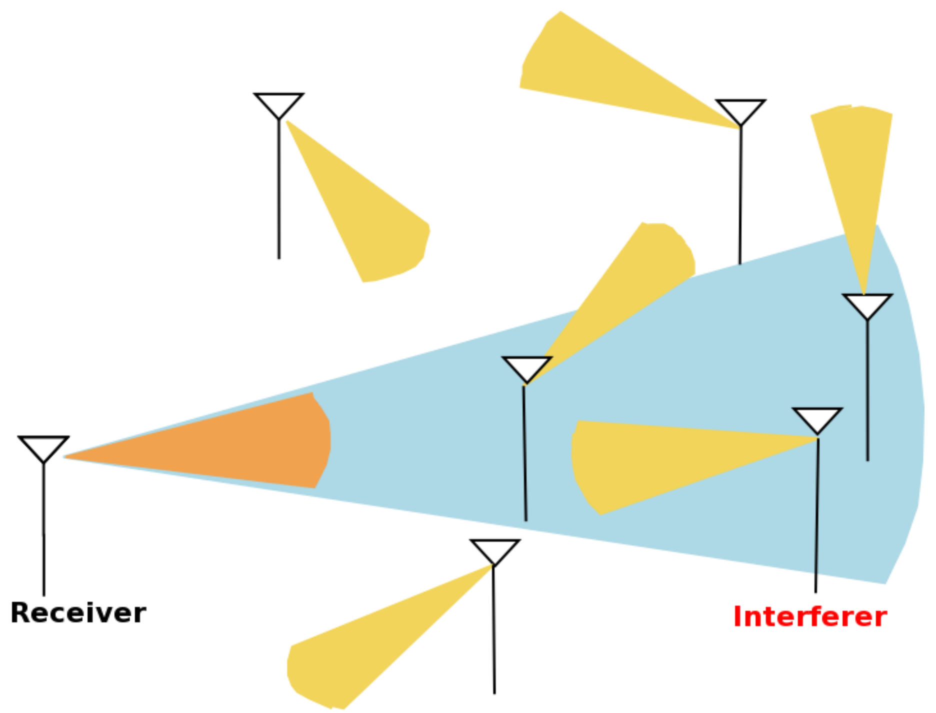
$$\Pr(\text{collision}) = 1 - e^{-\lambda(\mathrm{SINR}_{\mathrm{th}})A_c}$$

$$A_c = \frac{(R_0 \Delta\phi)^2}{4\pi} e^{-\alpha(R_i - R_0)}$$

λ = density of transmitting nodes
$\Delta\Phi$ = (azimuthal) beamwidth
R_0 = nominal link range
R_i = interference range



Protocol model: general directional antennas

- Arbitrary antenna patterns

$$\Pr(\text{collision}) = 1 - e^{-\lambda(\mathrm{SINR}_{\mathrm{th}})A_c}$$

- Parameter A_c
  - depends on the antenna directivity pattern
  - dimensions of an area

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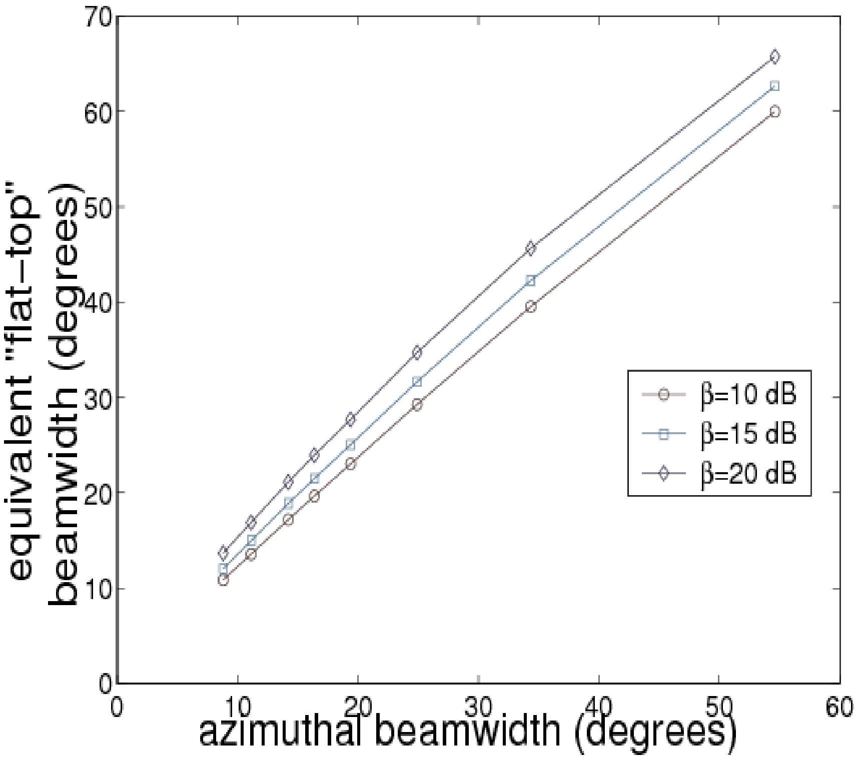
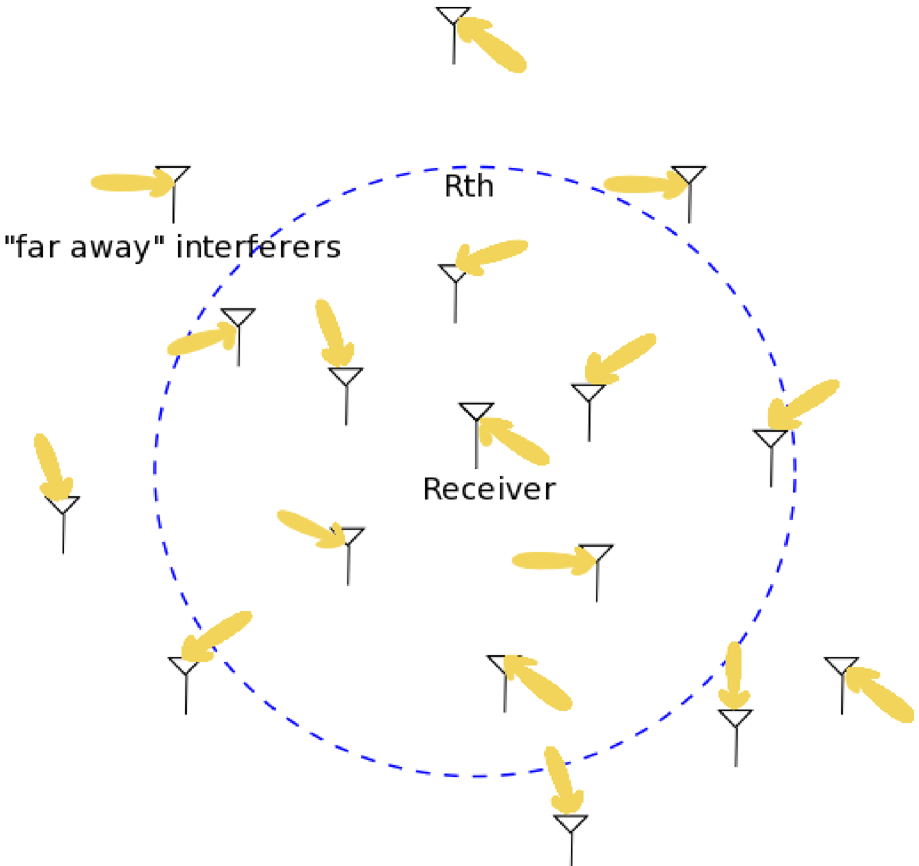
- Comparison with the flat top model

  => equivalent *flat top* beamwidth



Physical model

- A hybrid approach
  - *far-away* interferers: Markov upper bound
  - within a bounded region: Monte-Carlo simulations



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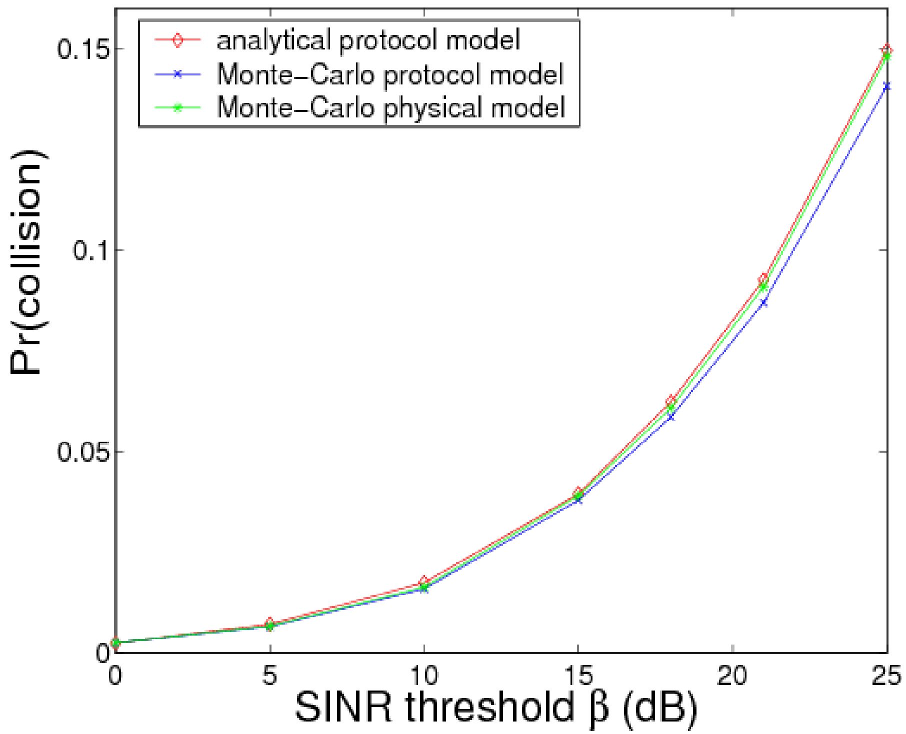
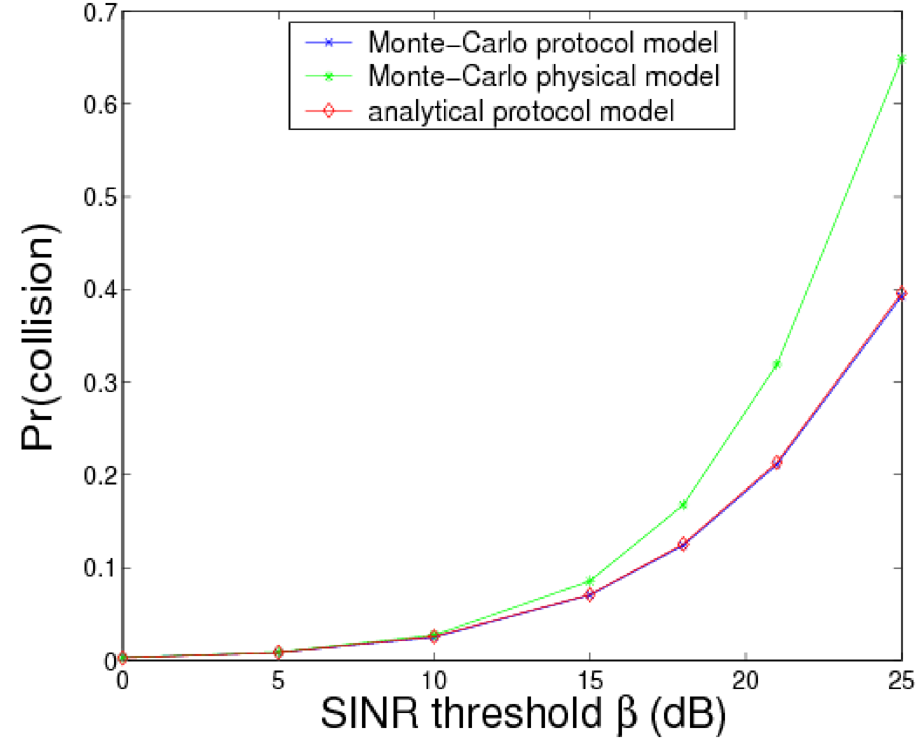


Pr(collision) for flat-top antenna



Pr(collision) for linear array

- Sidelobes matter!
- For small $SINR_{th}$ or smaller beamwidths
  - Usually one dominant interferer
  - Protocol model acceptable approximation

Pseudo-wired abstraction

- Transmissions unlikely to interfere
- Half-duplex constraint

Pseudo-wired abstraction with directional slotted ALOHA

- Simulation model
  - 25 and 50 node random topologies
  - Sectorized antenna model

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- Packet loss profile

	25 nodes	50 nodes
Interference	*2.20%*	*5.60%*
Failed coordination	*35.70%*	*47.20%*

Packet losses from failed coordination are an order of magnitude higher!

Pseudo-wired abstraction with directional slotted ALOHA

- Simulation model
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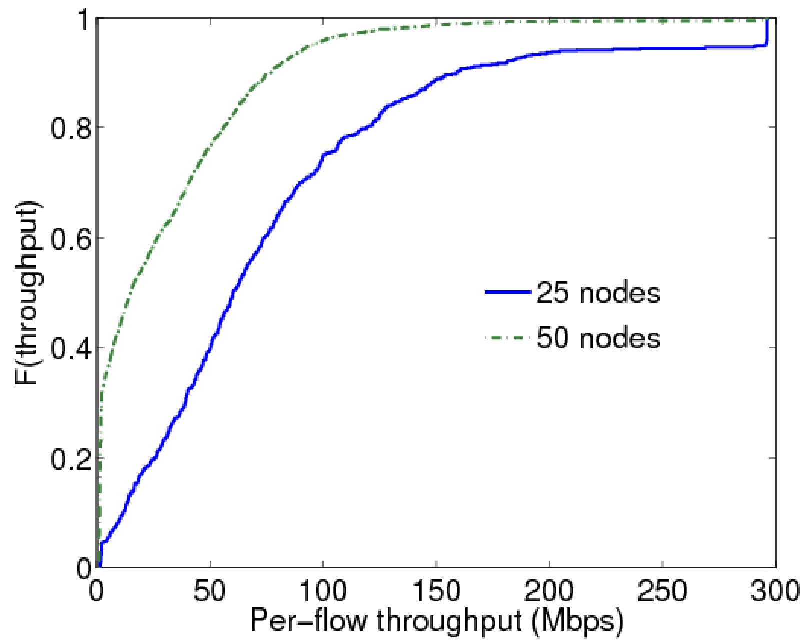

Per-flow throughput empirical CDF

- Packet loss profile

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Conclusions

- Are highly directional mm wave links like wires?
  - A qualified yes
- Pseudo wired abstraction for MAC design
- Ongoing efforts
  - It pays to drastically rethink MAC!
  - Effect of building reflections and blockage

Thank you

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