Uplink Capacity of IEEE 802.16 under Frequency Reuse-1

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Outline

- Motivation
- IMT-Advanced Evaluation
  - Scenarios
  - Channel Model
- Uplink Capacity Calculation
- Results
- Conclusion & Outlook

Motivation

- World Radio Conference 2007 (WRC-07) has identified new spectrum for mobile radio communication
- ITU-R controls the allocation of this spectrum
- Issued the IMT-Advanced process to evaluate candidate systems
- One goal for future wireless systems is high spectral efficiency
- Spectral efficiency is evaluated in defined scenarios:
  - Should be done by system level simulation
  - Still analytical models can help to verify and understand the results

Scenario

- Four hexagonal deployment scenarios:
  - Urban Micro (UMi)
  - Urban Macro (UMa)
  - Rural Macro (RMa)
  - Suburban Macro (SMa) (optional)
- Each has different inter-site distance D and radius R = D / Sqrt(3)
- 3D antenna patterns forming 3 sectors per cell

Scenario

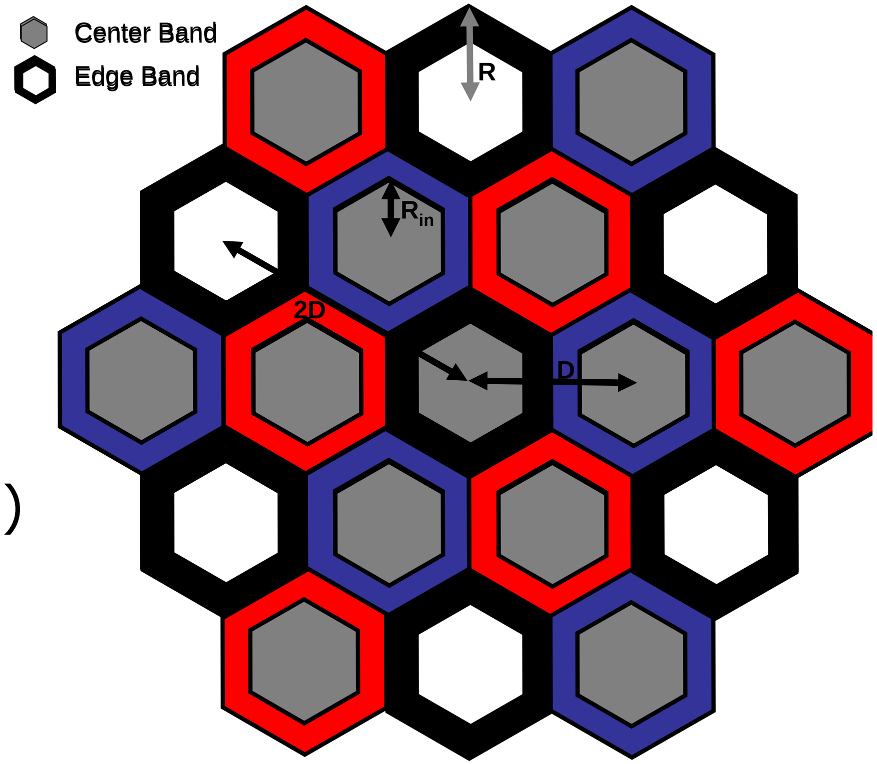
Channel model:

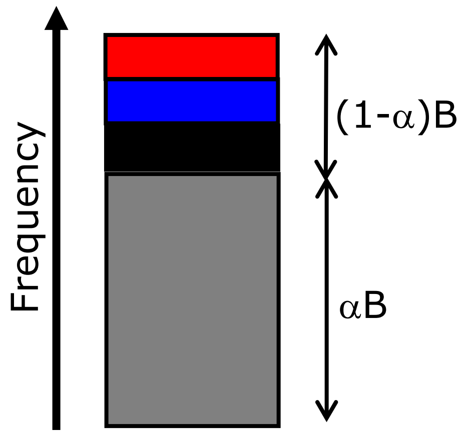
- Large time scale channel model for path-loss
  - d: distance between transceivers
  - Deterministic component: $PL_D = \beta + \gamma \log(d)$
  - Lognormally distributed random component (~Norm in dB)
    - $\Rightarrow$ Received power $P_{RX} \sim Norm(P_{TX}-PL_D,\sigma)$
  - β, γ, σ depend on the scenario and channel condition
  - Channel condition can be line-of-sight (LoS) or non line-of-sight (NLoS)
  - Condition is chosen randomly, the shorter d, the higher the LoS probability

Scenario

Fractional Frequency Reuse (FFR)

- Results in non-integer reuse distance
- Special case: Partial Frequency Reuse
- Fraction: $\alpha = R_{in}^2 / R^2$
- Reuse distance: $B / (\alpha + (1 - \alpha) / 3)$
- $\alpha = 1$: Reuse-1, $\alpha = 0$: Reuse-3



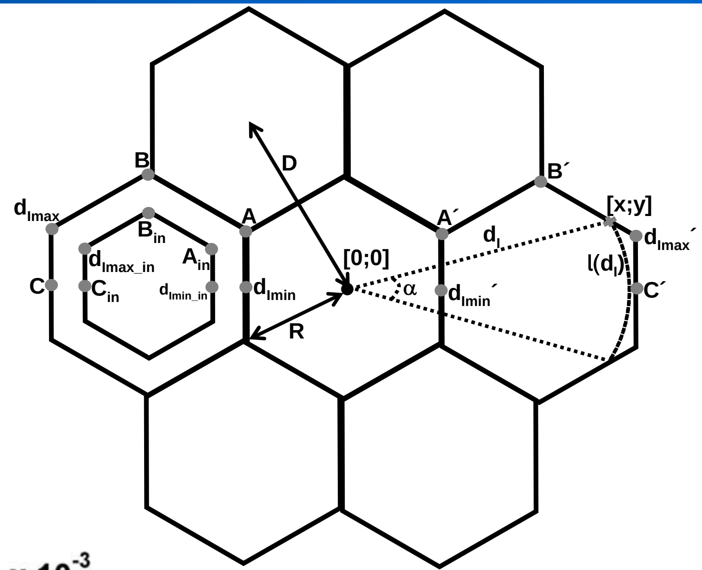


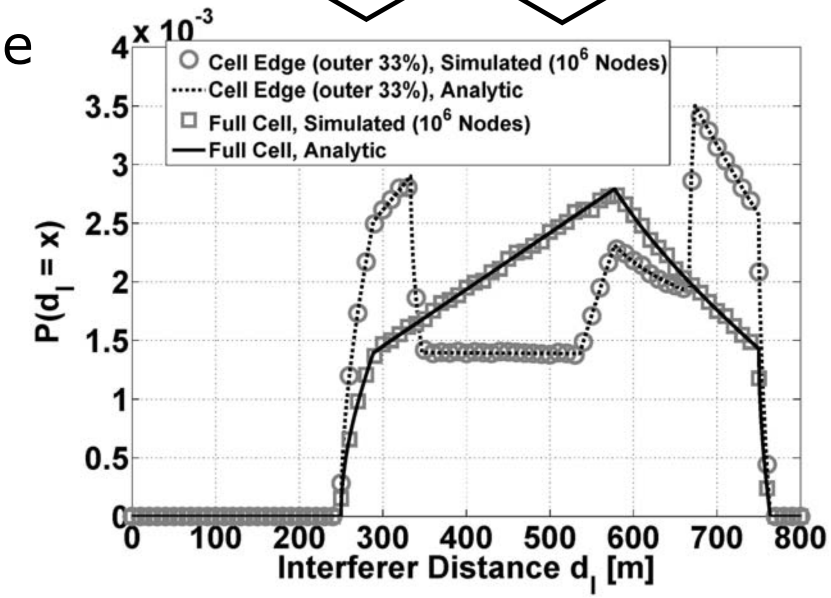
B: Bandwidth

Uplink Capacity Calculation

- What is the ratio of UTs at distance d_I?
  - $P(d_I) = l(d_I) / A_{Hex}$, $l(d_I) = d_I\alpha$
- What is the received interference power from distance d_I?
  - $p(x_I|d_I)$

    $\sim Norm(P_{TX} - (\beta + \gamma \log(d_I)), \sigma)$
- How is the UL interference from one cell distributed?
  - $$p(x_I) = \int_{d_{Imin}}^{d_{Imax}} P(d_I = d)\, p(x_I \mid d_I = d)\, dd$$
  - No closed form solution known





Uplink Capacity Calculation

- A closed form solution is available, if $P(d_I)$ is polynomial
  - Approximate each partition of $P(d_I)$
  - Least mean squares method can be used

    => Faster and better scalability than numerical calculation

$$p(x_I) = \sum_{i=1}^{9} (F(d_{Imax\_i}, i) - F(d_{Imin\_i}, i)),$$

$$F(d_I, i) = \int \sum_{n=0}^{k} a_{n,i} d^n p(x_I | d_I = d)) dd$$

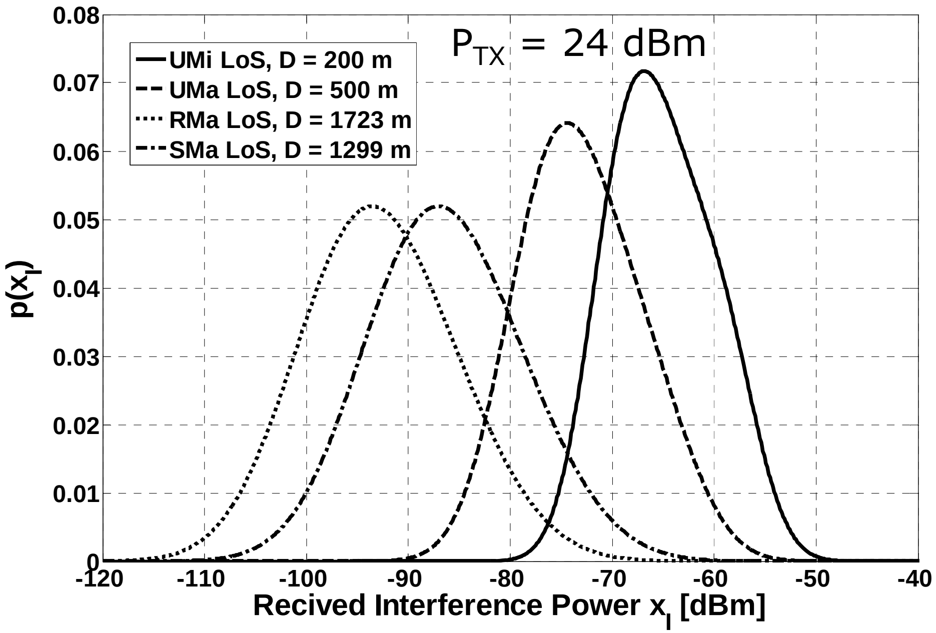
$$= \frac{1}{2\gamma} \Bigg(- a_{0,i} e^{\frac{-2\beta\gamma + \sigma^2 + 2\gamma(P_{TX} - x_I)}{2\gamma^2}}$$

$$\mathrm{erf}\left(\frac{-\beta\gamma + \gamma P_{TX} + \sigma^2 - \gamma x_I - \gamma^2 \ln d_I}{\sqrt{2}\gamma\sigma} \right) +$$

$$\sum_{n=1}^{k} \Bigg(a_{n,i} e^{(n+1)\frac{-2\beta\gamma + (n+1)\sigma^2 + 2\gamma(P_{TX} - x_I)}{2\gamma^2}}$$

$$\mathrm{erf}\left(\frac{\beta\gamma - \gamma P_{TX} - (n+1)\sigma^2 + \gamma x_I + \gamma^2 \ln d_I}{\sqrt{2}\gamma\sigma} \right)\Bigg)\Bigg)$$

$$+ const$$

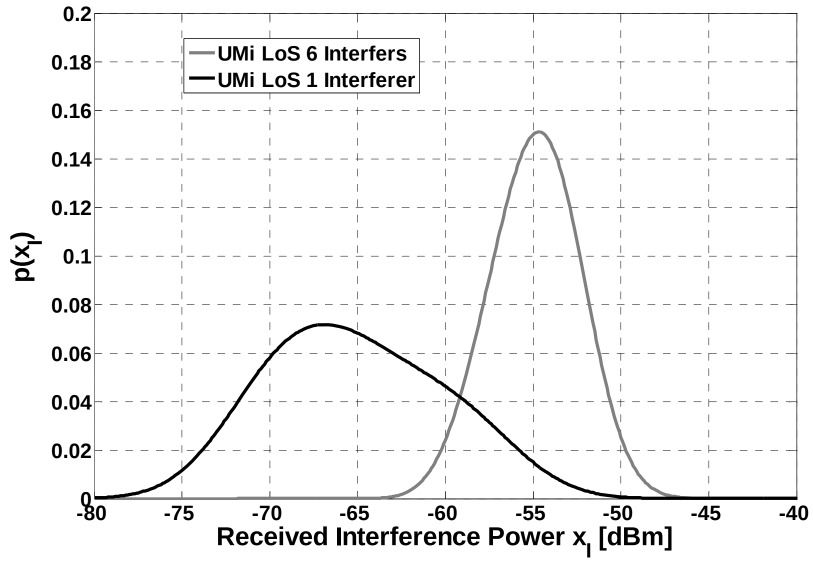


Uplink Capacity Calculation

- What is the interference power PDF of 6 interfering cells?
  - Transfer to linear domain
  - Convolute

    or
  - Transform to frequency domain and multiply
  - But:
    - No closed form solution known
    - Enormous range in linear domain cannot be handled numerically

=> Logarithmic Convolution (numeric) [1]



$$R = 10\log_{10}(10^{\frac{X}{10}} + 10^{\frac{Y}{10}})$$

$$p_R(r) = \int_{-\infty}^{r} p_X(z)p_Y(D(r,z))dz + \int_{-\infty}^{r} p_X(D(r,z))p_Y(z)dz,$$

$$D(r,z) = 10\log_{10}(10^{\frac{r}{10}} - 10^{\frac{z}{10}})$$

[1]: J. Punt and D. Sparreboom, "Summing Received Signal Powers with Arbitrary Probability Density Functions on a Logarithmic Scale," Wireless Personal Communications, vol. 3, no. 3, pp. 215–224, 1996.

Uplink Capacity Calculation

- What is the received signal power PDF?
  - Analogous to interference power
- What is the carrier to interference ratio (CIR) at distance d_S?
  - Convolute: $p(x_{CIR}|d_s) = p(x_S|d_S) - p(-x_I)$ (numeric)
- And the CIR distribution PDF of the cell is:

$$p(x_{CIR}) = \int_{d_{S\min}}^{R} P(d_S = d)\, p(x_{CIR} \mid d_S = d)\, dd$$

- Use table to map to data rate

MCS	min. CIR [dB]	PHY Data Rate [Mbps]
None	$-\infty$	0
QPSK $\frac{1}{2}$	5	14.93
QPSK $\frac{3}{4}$	8	22.40
16QAM $\frac{1}{2}$	10.5	29.86
16QAM $\frac{3}{4}$	14	44.80
64QAM $\frac{1}{2}$	16	44.80
64QAM $\frac{2}{3}$	18	59.73
64QAM $\frac{3}{4}$	20	67.20

From IEEE 802.16-2009

Assumption:

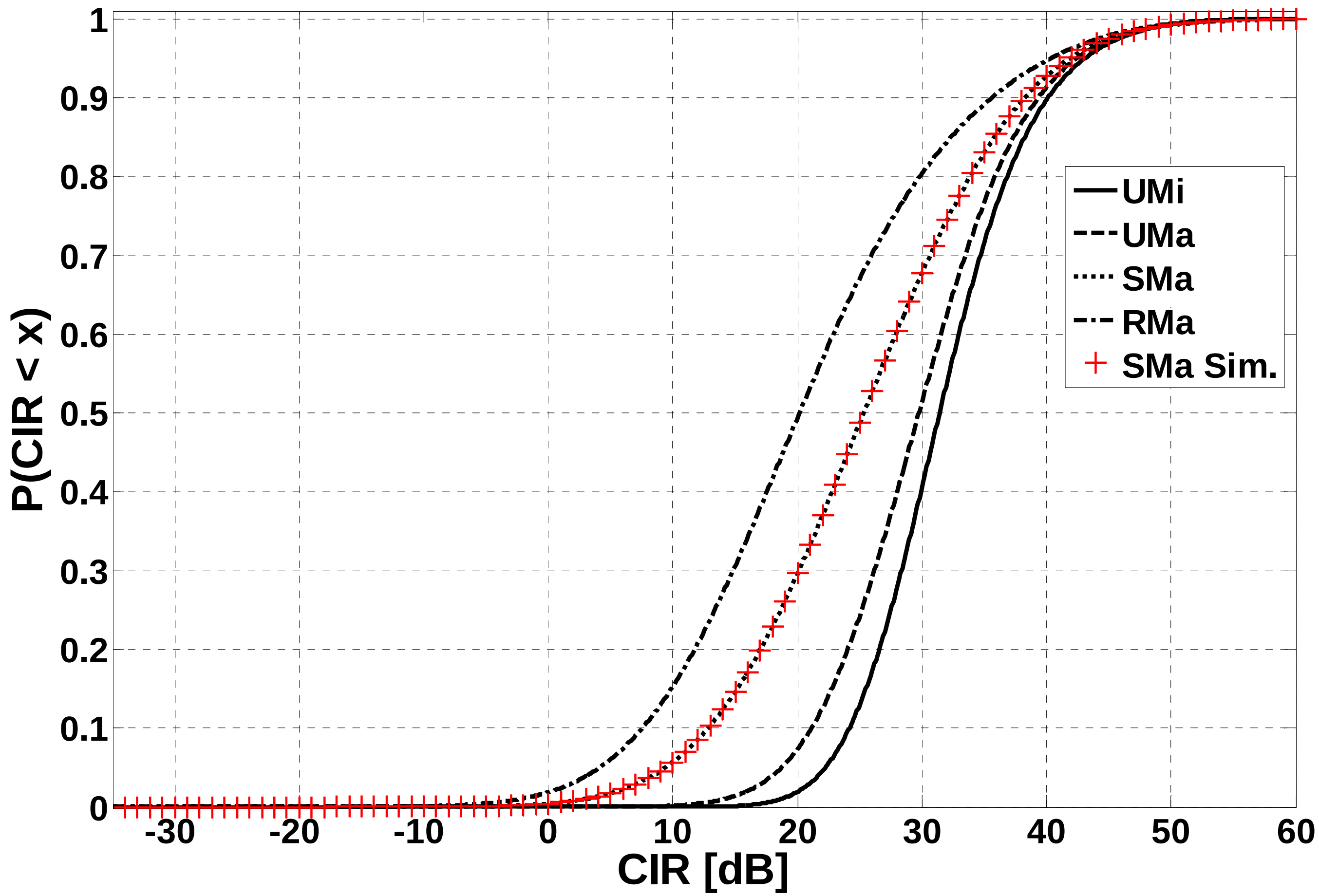
- Scheduler can predict shadow-fading
- Scheduler knows UL schedule of interferers

Results

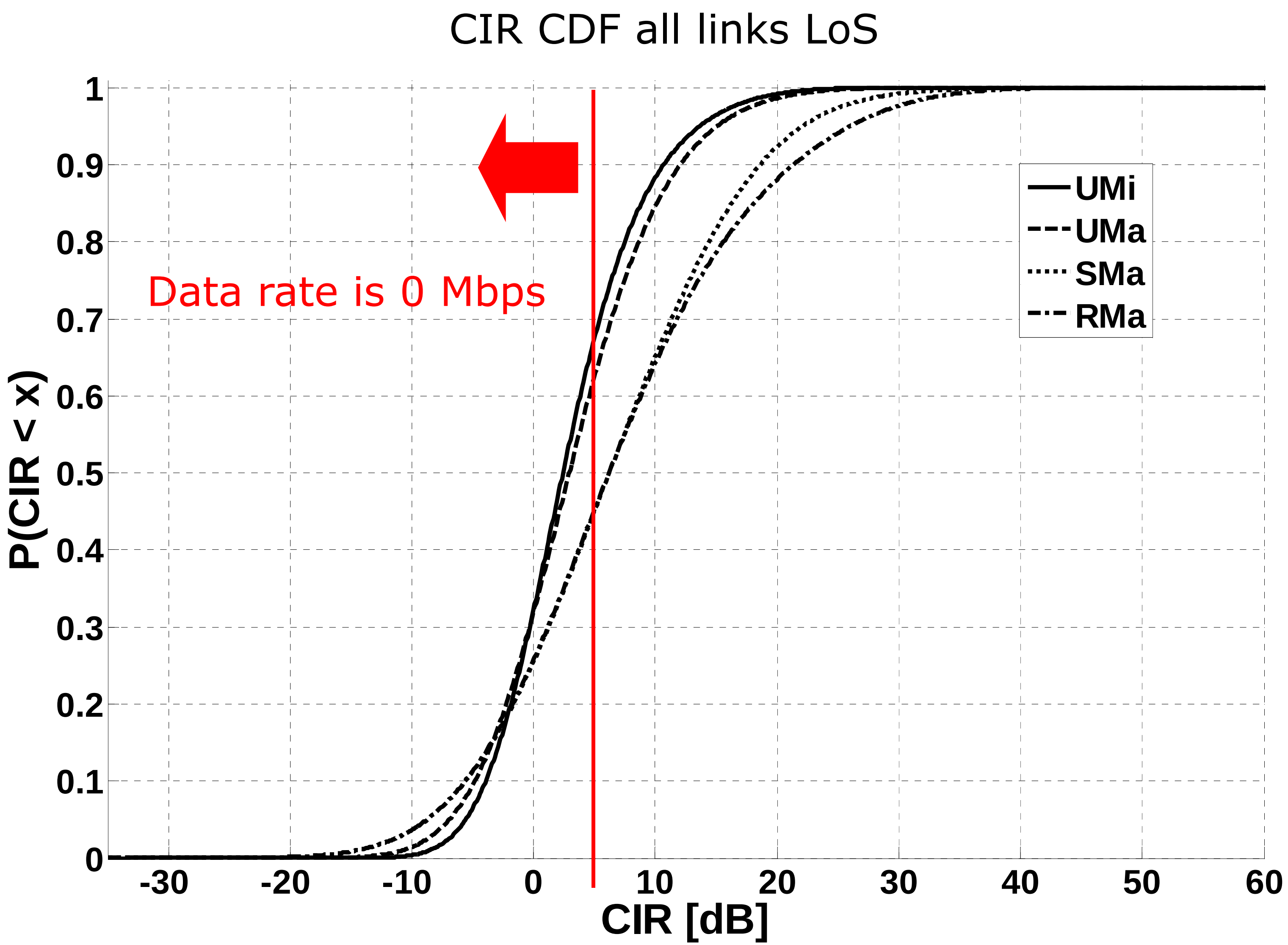
- CIR CDF all interfering links NLoS, serving link LoS

This is the optimal channel condition:

- UMi: 67.01 Mbps
- UMa: 66.07 Mbps
- RMa: 50.71 Mbps
- SMa: 59.07 Mbps

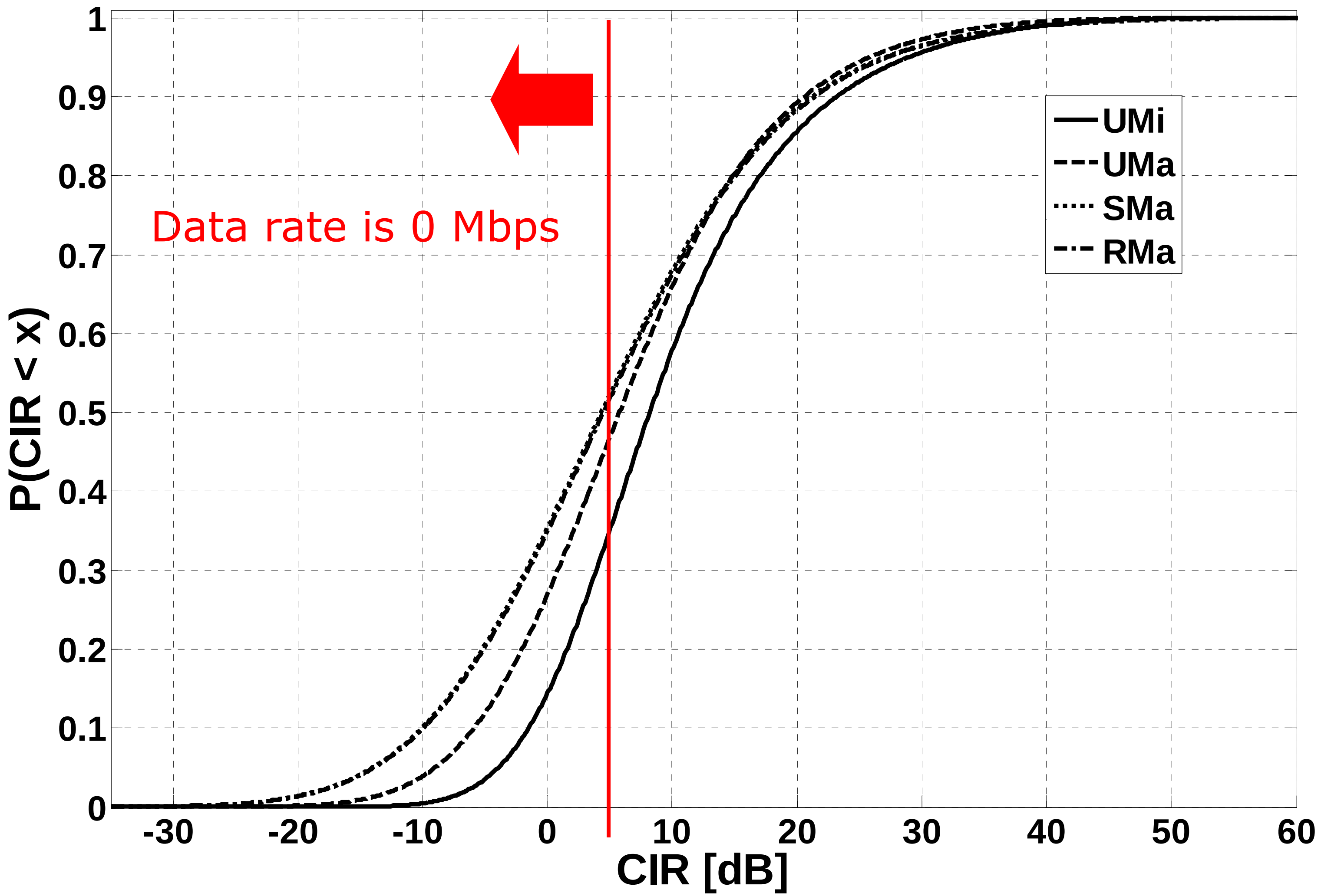


Results


CIR CDF all links LoS
Data rate is 0 Mbps
P(CIR < x)
CIR [dB]
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-30
-20
-10
0
10
20
30
40
50
60
UMi
UMa
SMa
RMa

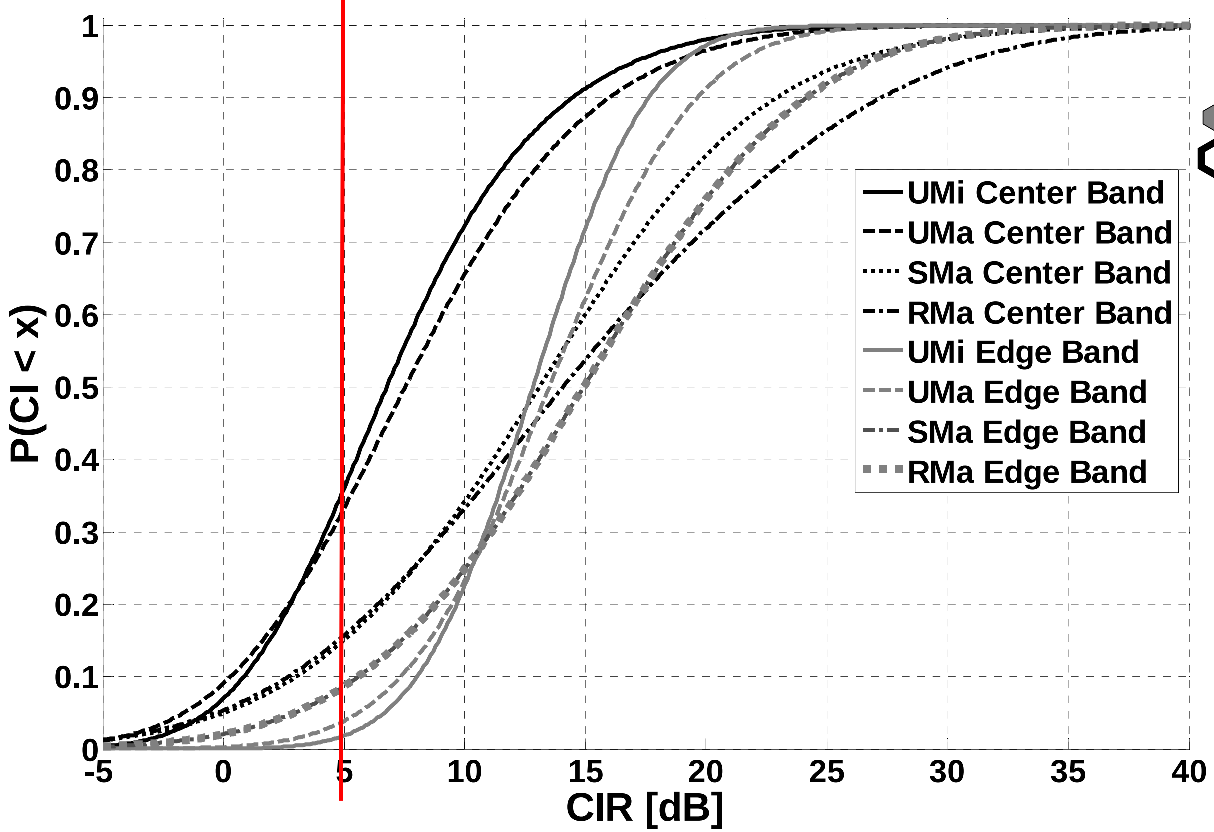
Results

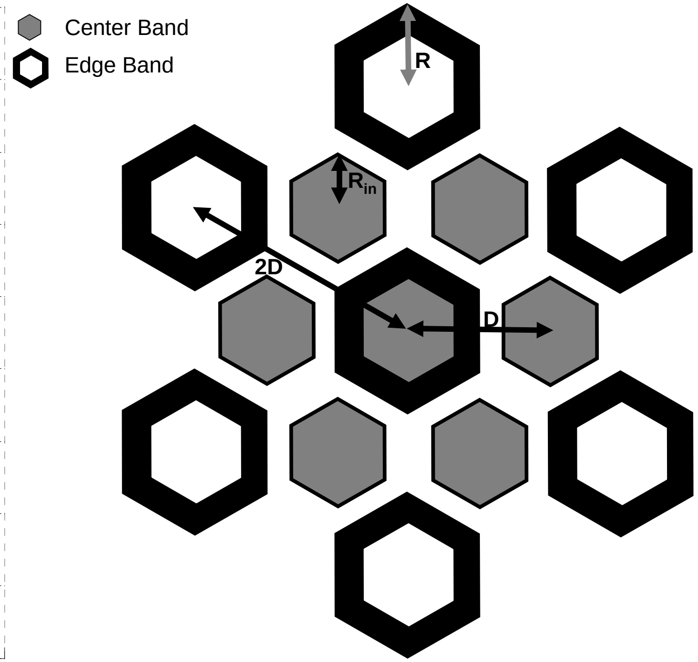
CIR CDF all links NLoS



Results

CIR CDF all links LoS with FFR

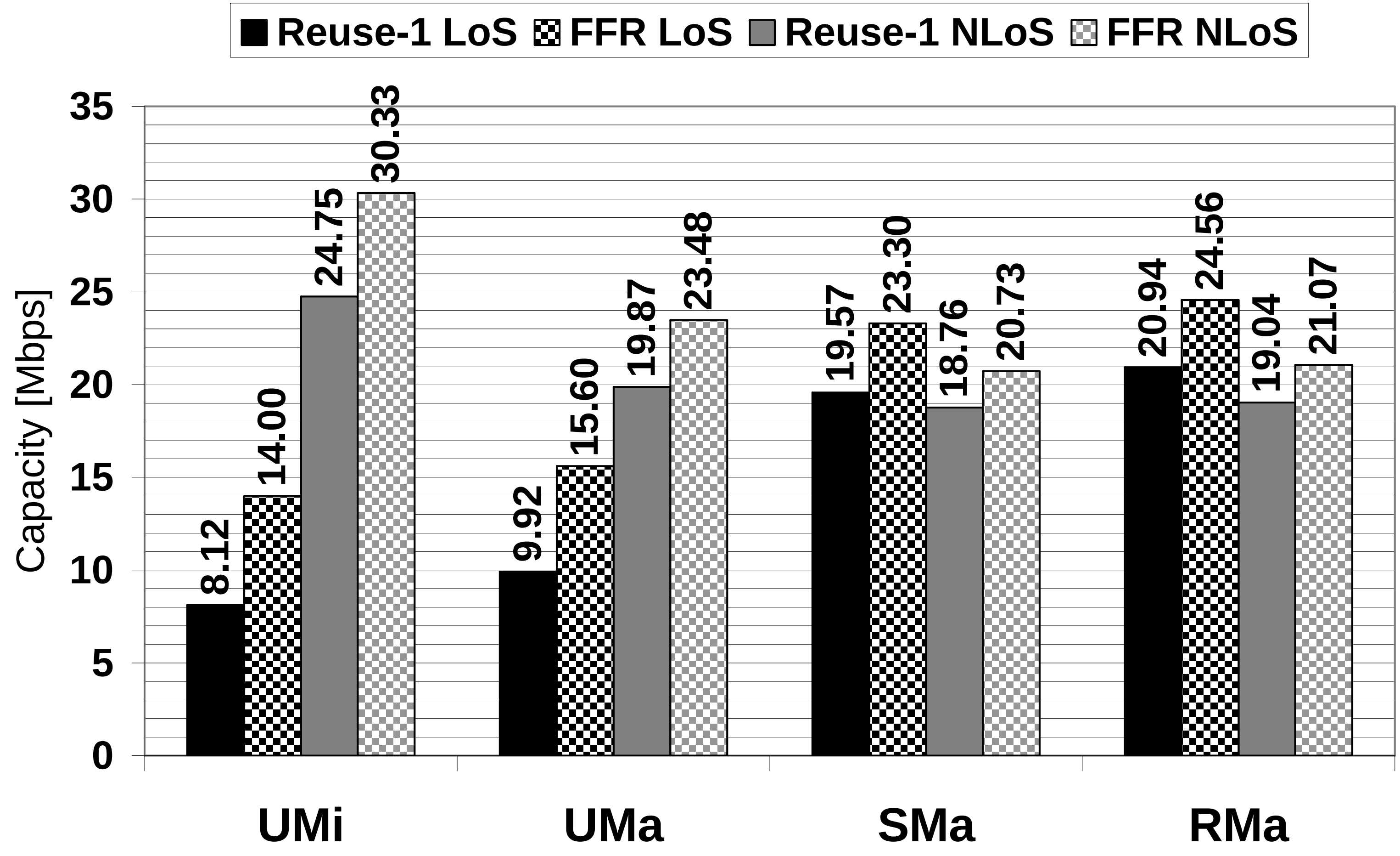




LoS-LoS FFR $\alpha = (2/3)^2$

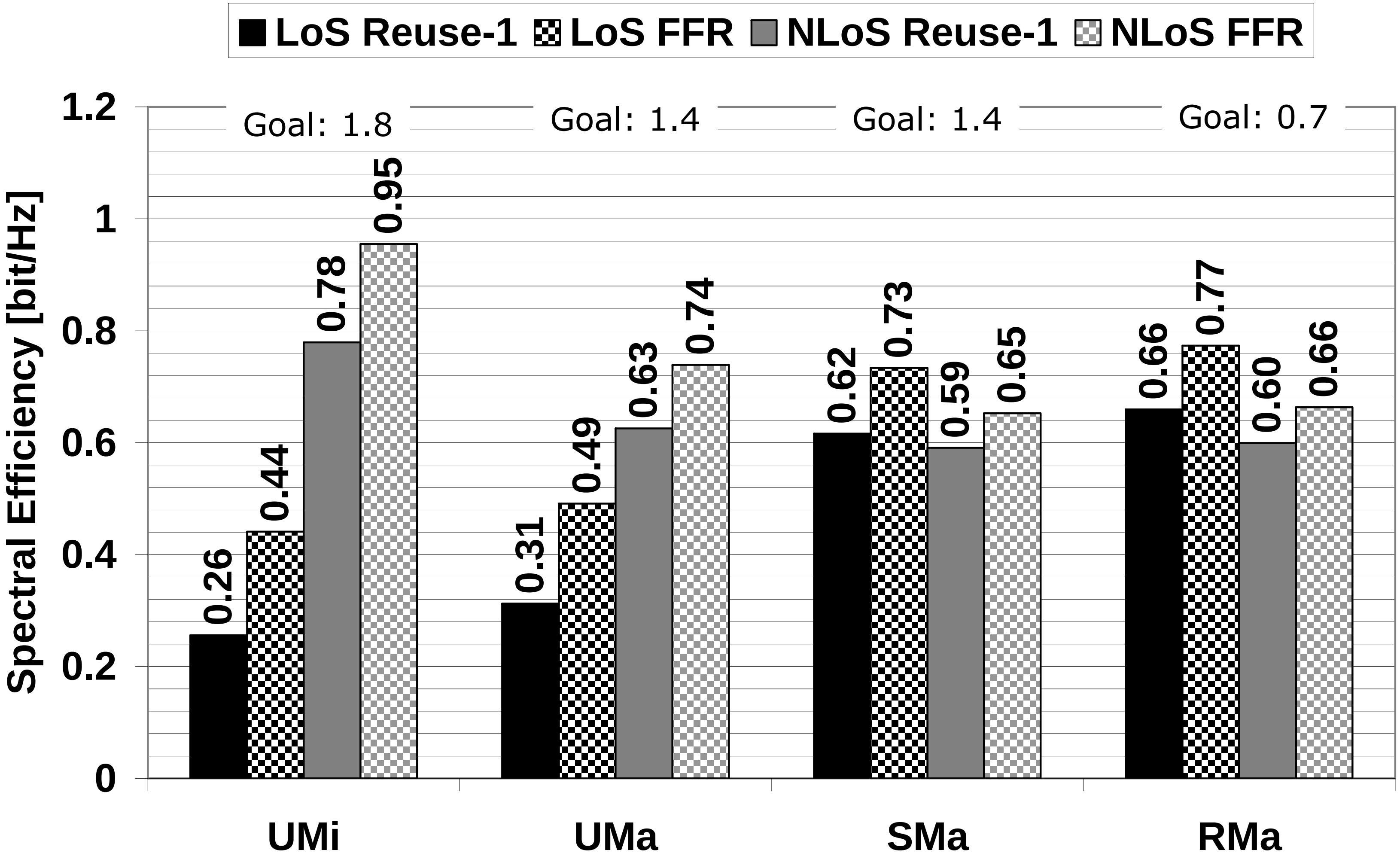
Results

Capacity with and without FFR



Results

Spectral Efficiency with and without FFR



Conclusion & Outlook

Conclusion:

- The developed model can be used to calculate the uplink capacity of IMT-A like scenarios
- Applying a fractional reuse factor by partial frequency reuse can increase system capacity

Outlook:

- Determine an optimal partitioning α_{Opt}
- **Find solution for random LoS / NLoS selection**
- Sectorization and therefore antenna patterns need to be included
- Evaluate impact of power boost in the edge band

Thank you for your attention !

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Results

Spectral Efficiency with FFR