Capacity Analysis and Improvement for Coexisting IEEE 802.16 Systems in Unlicensed Spectrum

by Maciej Mühleisen

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Outline

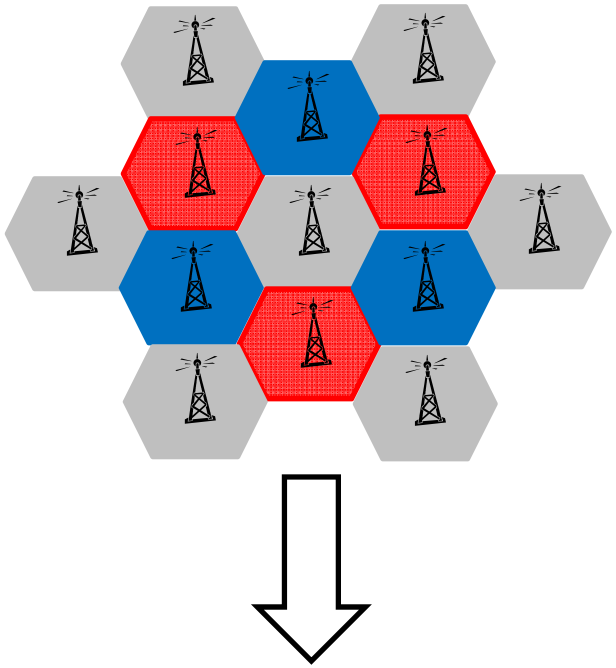
- Motivation
- Related Work & Standards
- Capacity Estimation
  - In Planned Cellular Scenarios
  - In Unplanned Coexistence Scenarios
- Results
  - System Capacity
  - Improved System Capacity
- Conclusion & Outlook

Motivation

- Spectrum demand for wireless communication is growing
- All suitable frequency bands are assigned
- Operators deploying a new system in licensed bands have to:
  - Use a license they own
  - Buy or lease a license from a license holder
  - Get a license for rededicated spectrum

- Alternative: **license-exempt operation**:
  - In bands dedicated for license-exempt operation
    - Ex. ISM at 2.4 GHz, U-NII at 5 GHz
  - In licensed bands when license holder is absent
    - Non-exclusive license: 3.650 GHz – 3.700 GHz in US

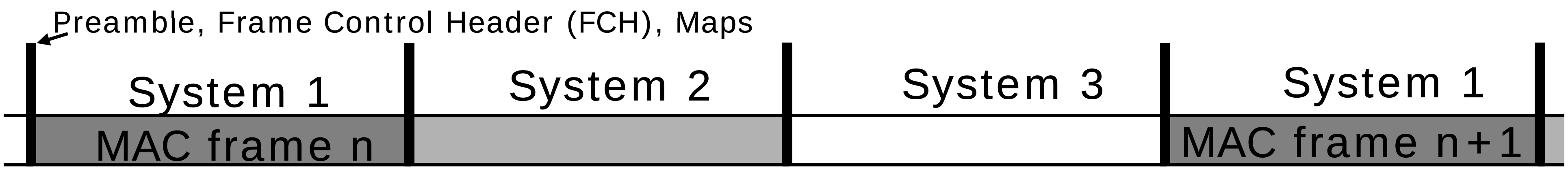
⇒ Spectrum for license-exempt operation is available
⇒ Can be used at no/low costs
⇒ Requires no/less network planning
⇒ **But: How to maintain Quality of Service (QoS) in unplanned scenario?**



Related Work and Standards

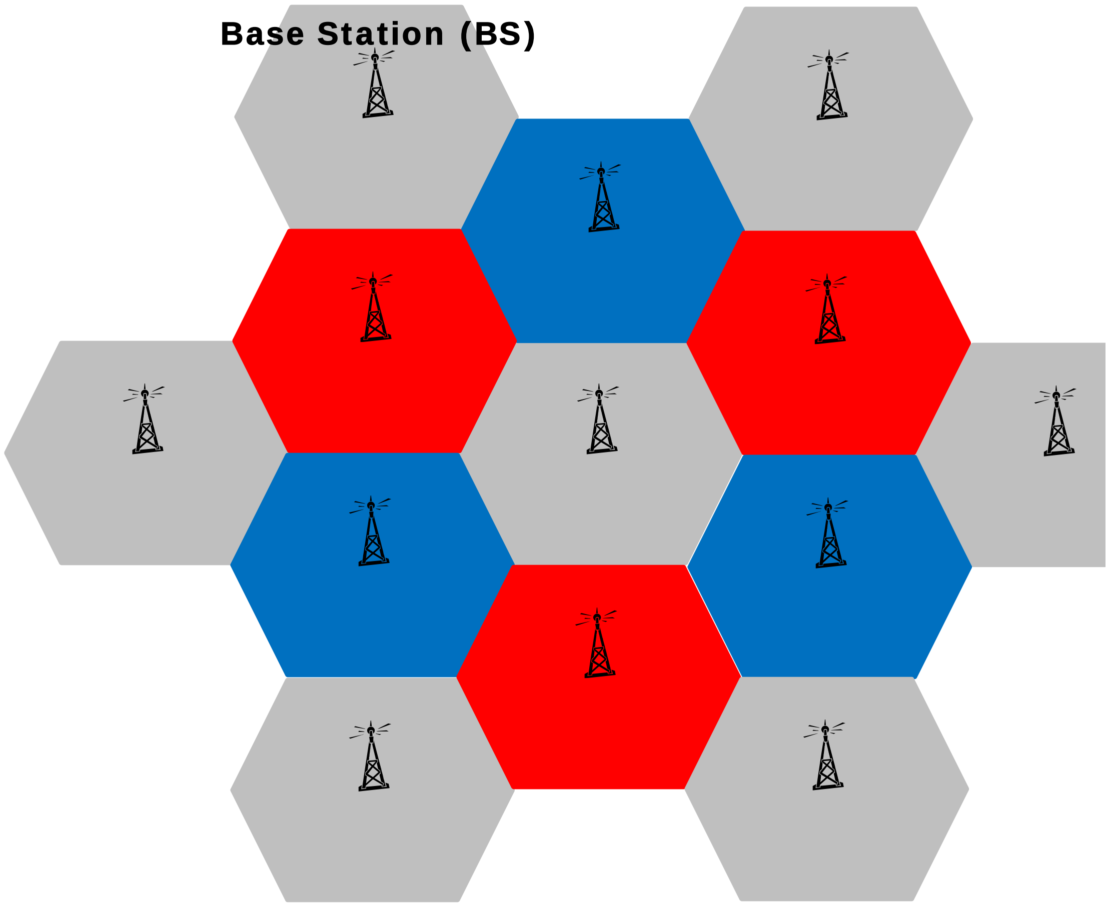
Examples for license-exempt operation:

- IEEE 802.11 (WLAN): CSMA/CA
  - Collisions & backoff reduce channel utilization
  - Unpredictable delays
  - Channel capacity depends on number of stations
- IEEE 802.16h (License-exempt WiMAX): TDMA
  - Exploit periodic MAC frame structure (5 ms – 20 ms frame duration)
  - Multiplex multiple systems in time domain
  - Separate in time **if any node** interferes with other system
    - ⇒ Delay of user data depends on MAC frame lengths and system count
    - ⇒ Reducing benefit of spatial reuse



Capacity Estimation: Cellular Scenario

- Capacity *C*:
  - —Depends on data rate *r*
  - —*r* depends on *SINR*



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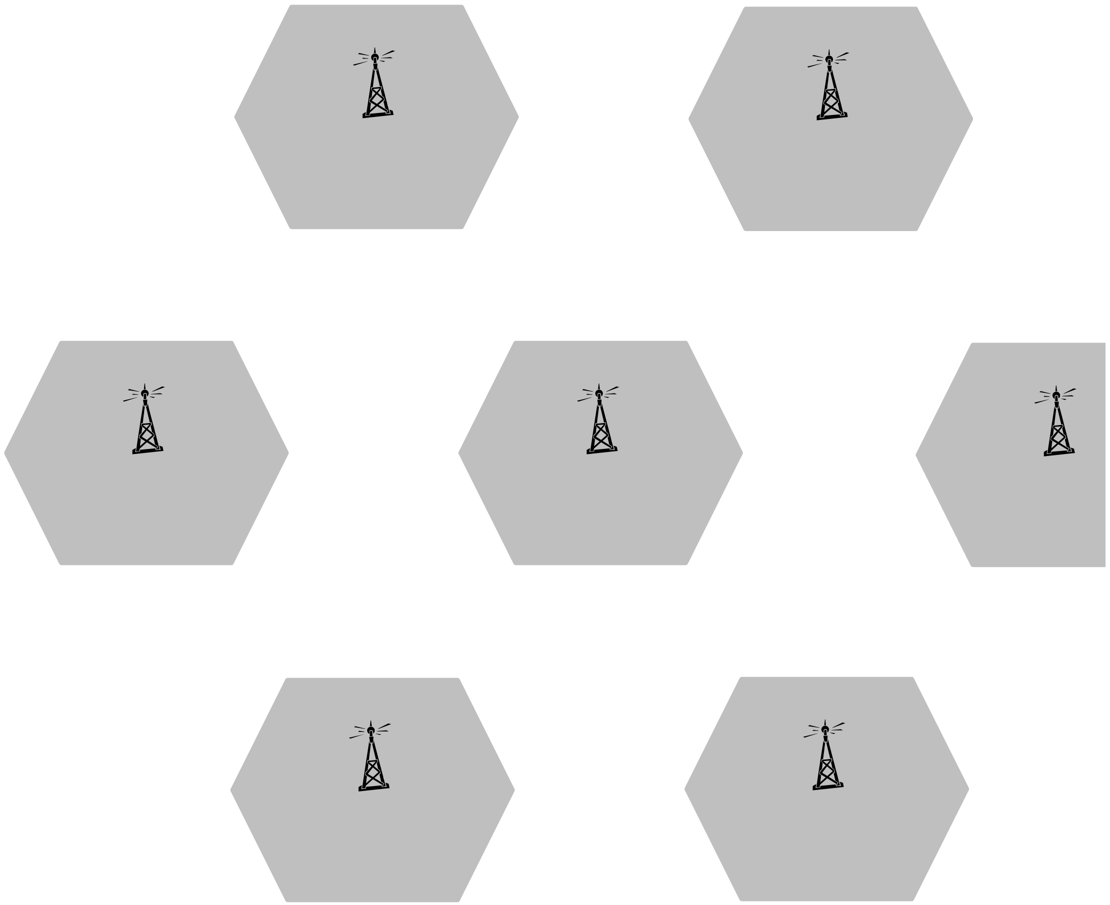

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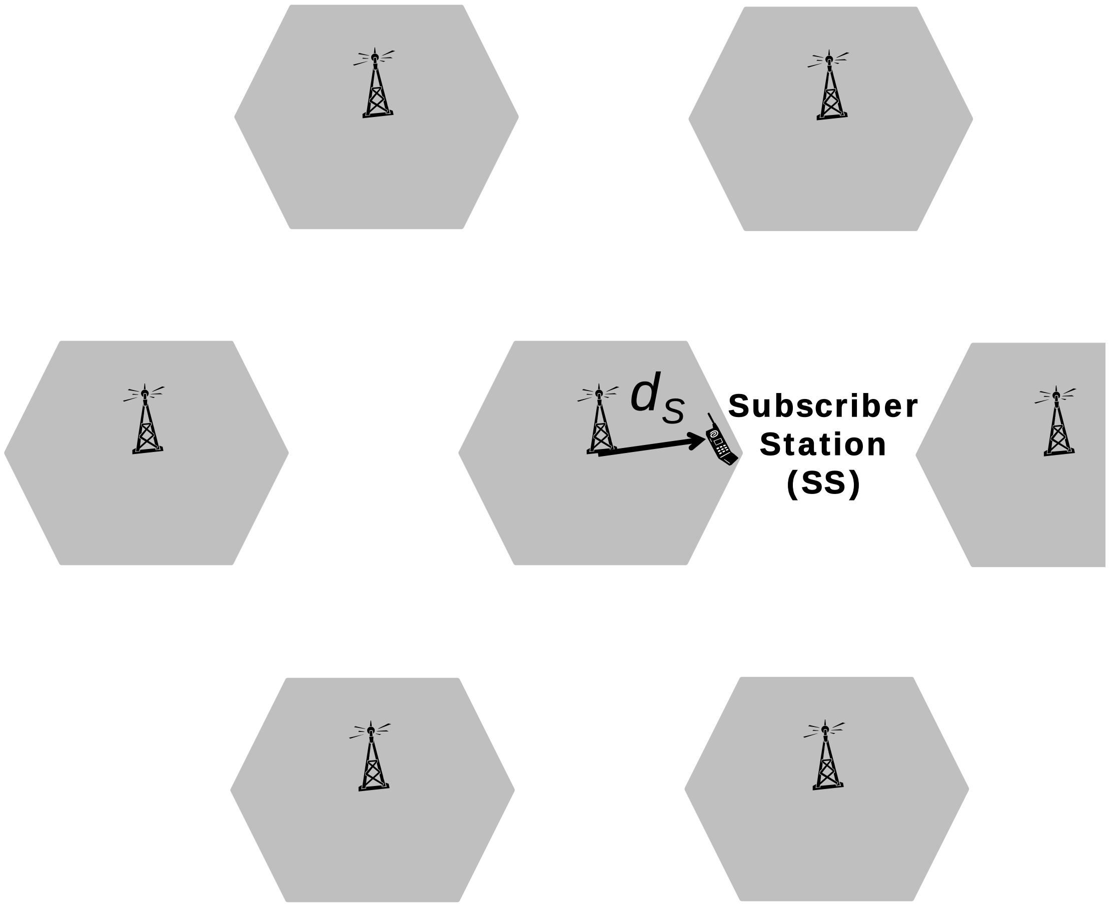

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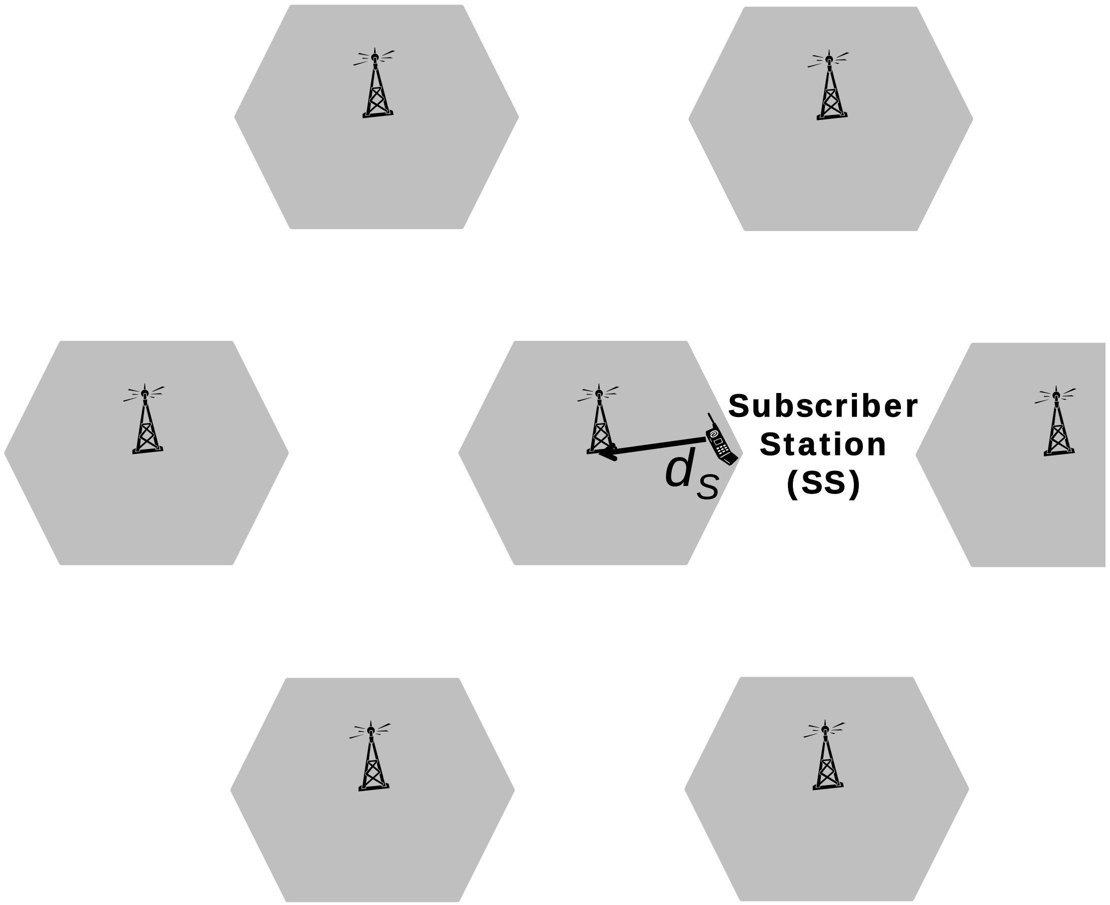

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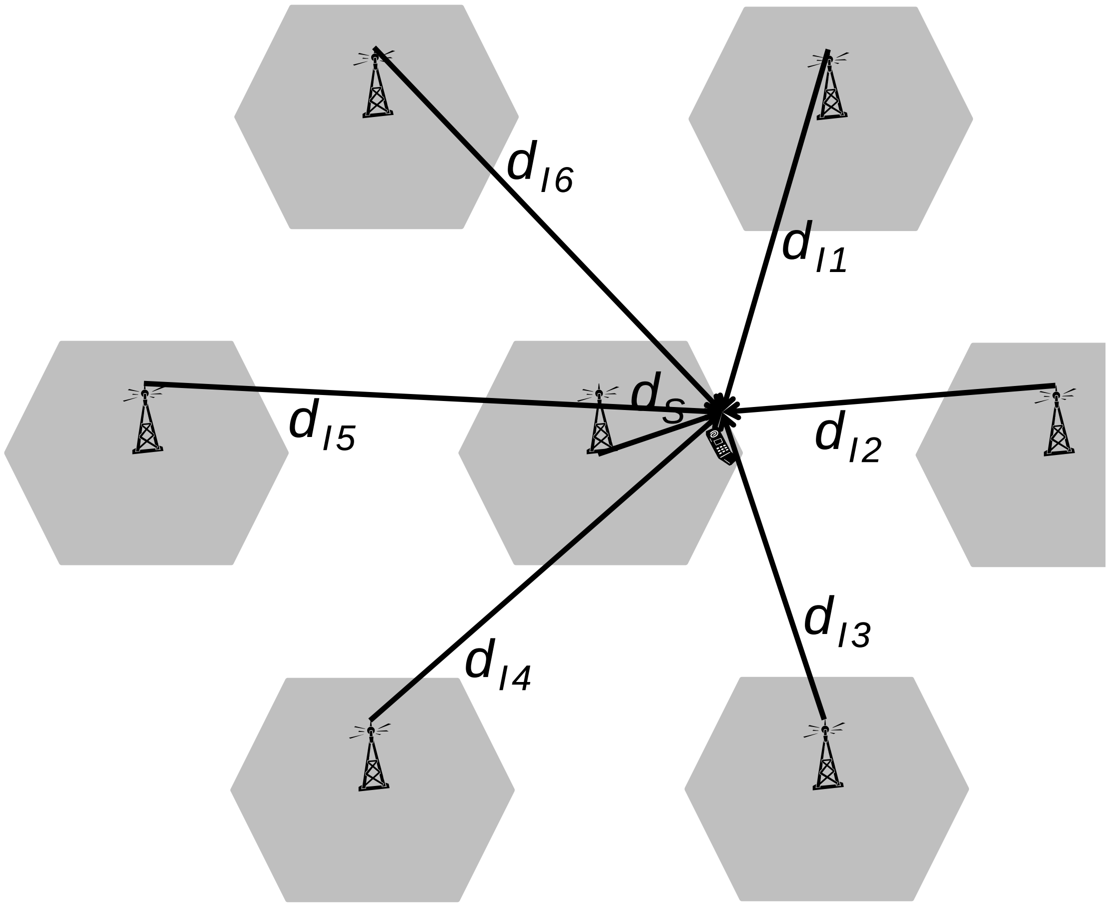

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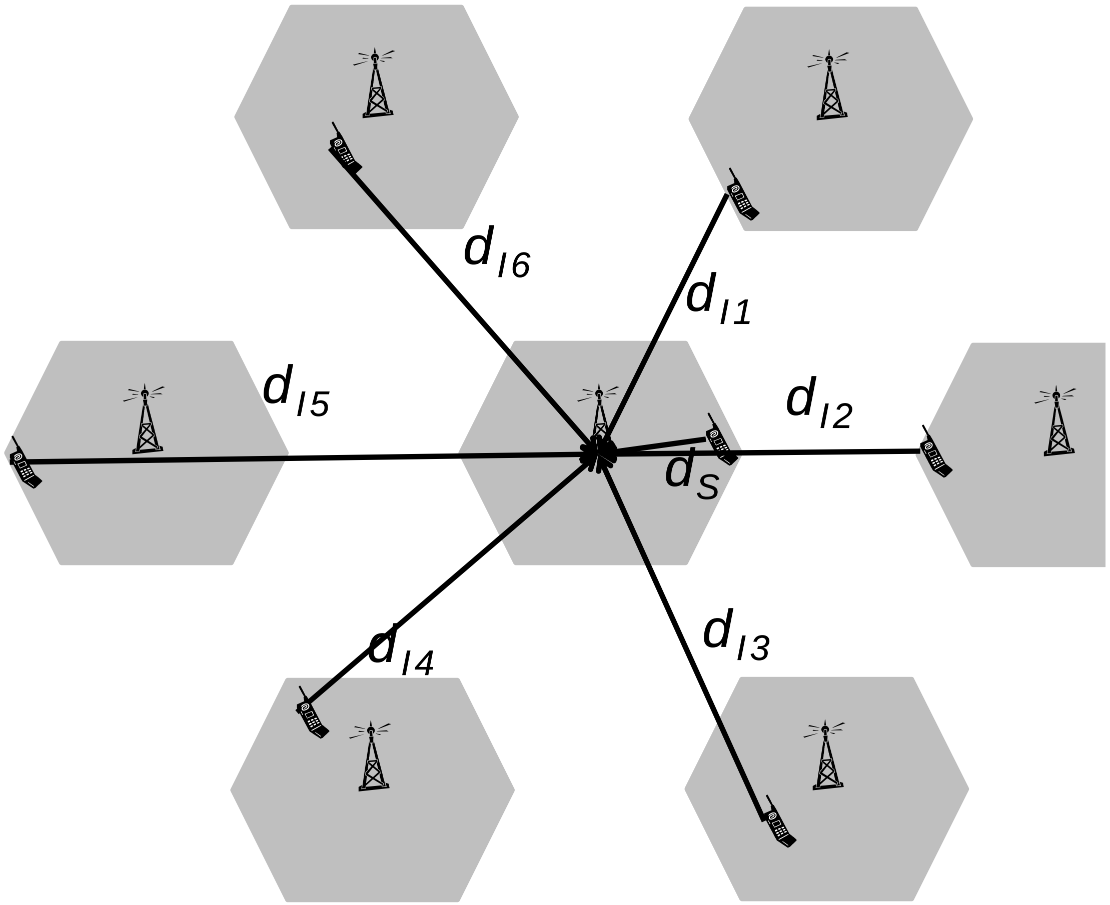

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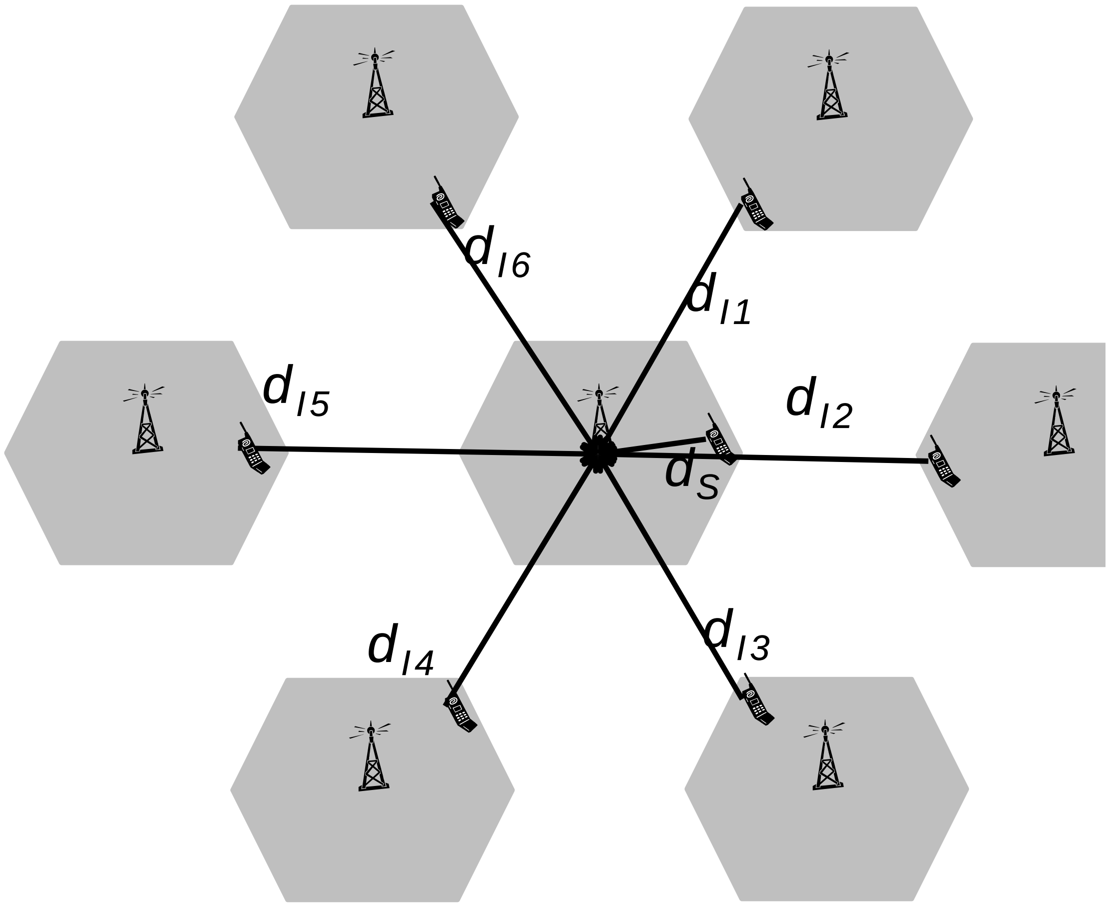

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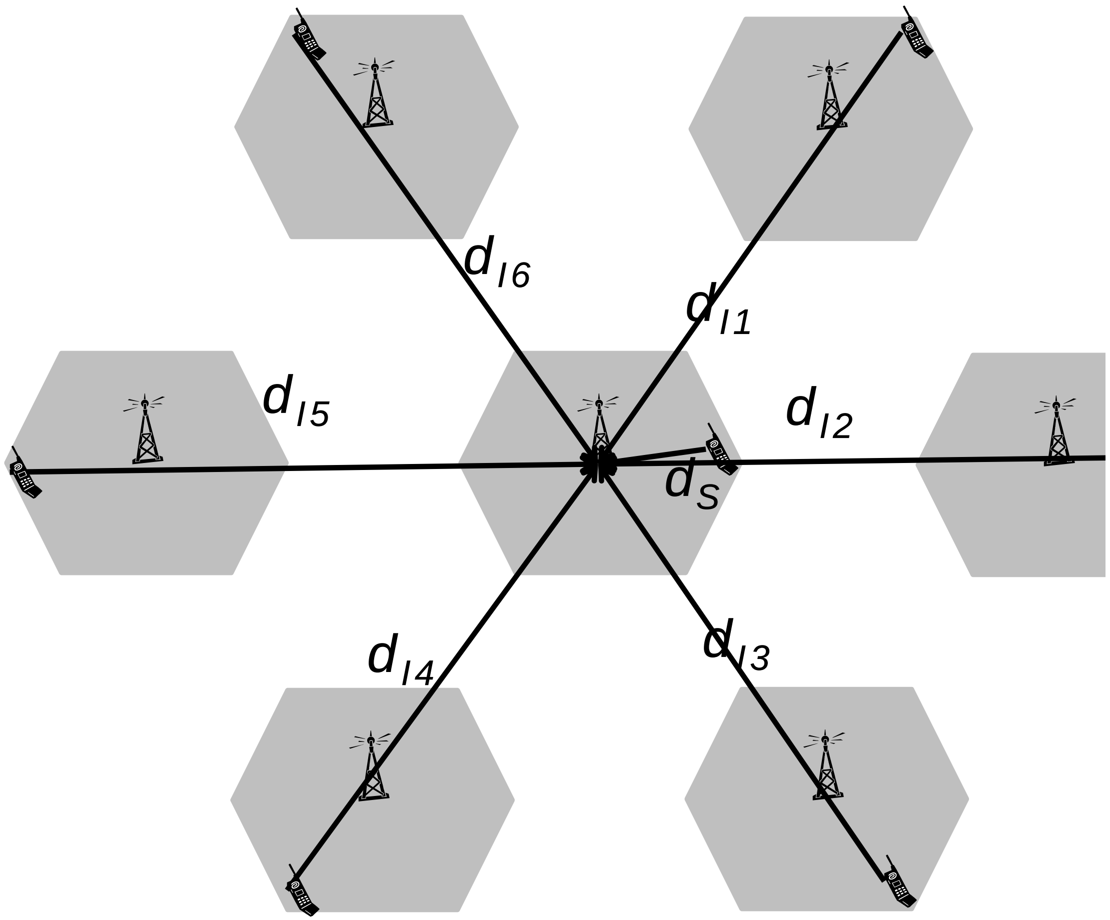

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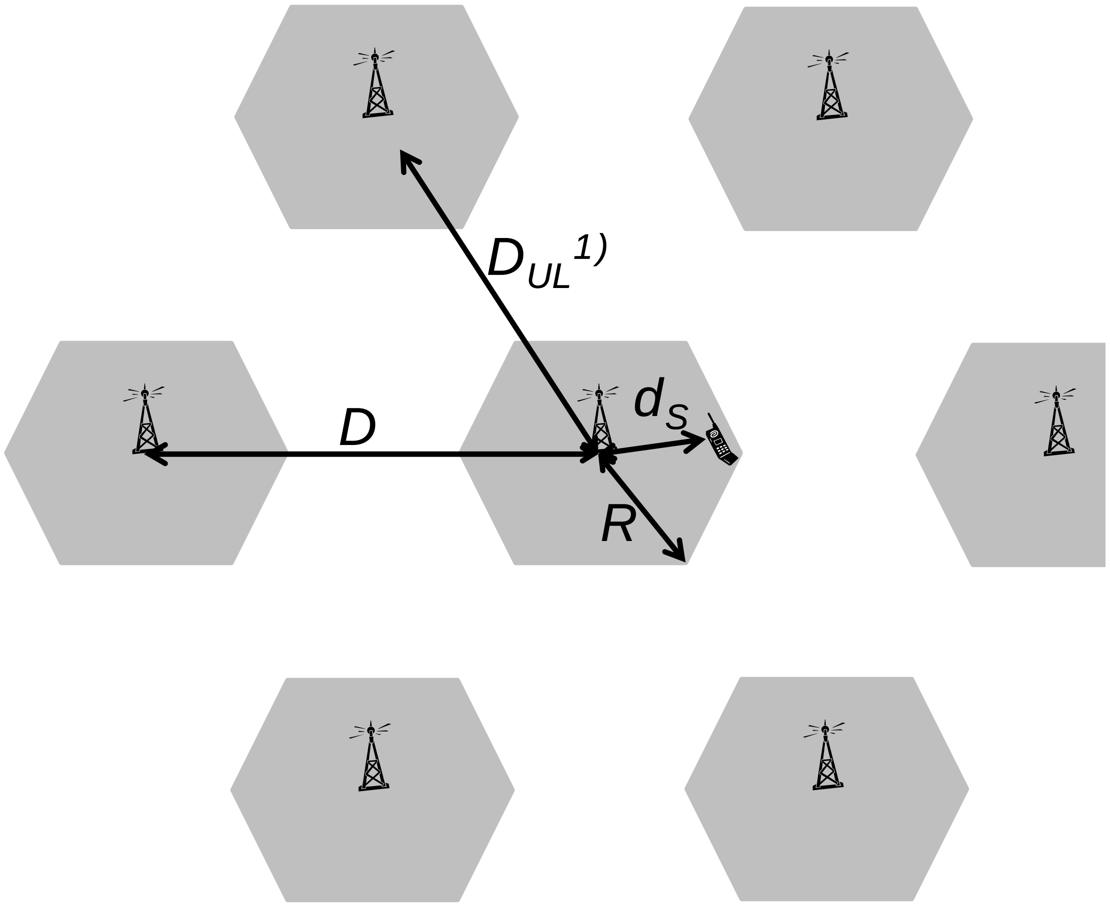
- d_{Ii}: distance to interferer *i* (base stations (BS) in DL, subscriber station (SS) in UL)
- d_{Ii} = *D* in DL $\Rightarrow \sum_{\forall i} d_{Ii}^{-\gamma} = 6D^{-\gamma}$
- d_{Ii} = D_{UL}[1)] in UL $\Rightarrow \sum_{\forall i} d_{Ii}^{-\gamma} = 6D_{UL}^{-\gamma}$



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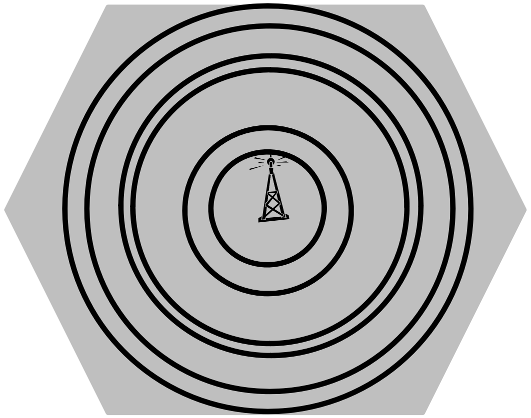
[1)] C. Hoymann: Dimensioning Cellular WiMAX Part I: Singlehop Networks, In Proceedings of European Wireless 2007, Paris France

Capacity Estimation: Cellular Scenario

- Capacity C:
  - —Depends on data rate r
  - —r depends on $SINR$
  - —$SINR \Rightarrow$ Modulation and Coding Scheme (MCS) $\Rightarrow r$ mapping



- $C = \sum_{\forall MCS} P(MCS(SINR))\, r(MCS(SINR))$

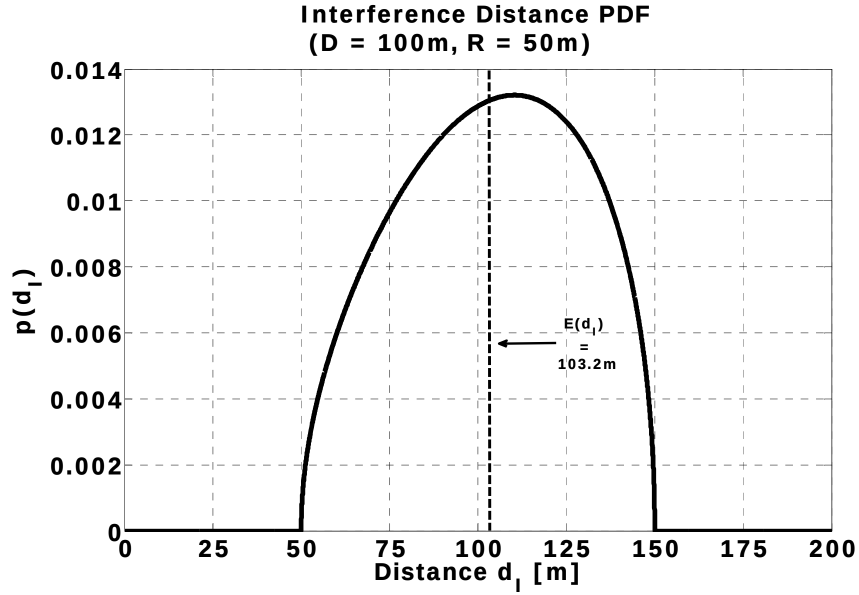
$$= \sum_{\forall MCS} P(d_{\min\_MCS(SINR)} < d_S < d_{\max\_MCS(SINR)})\, r(MCS(SINR))$$

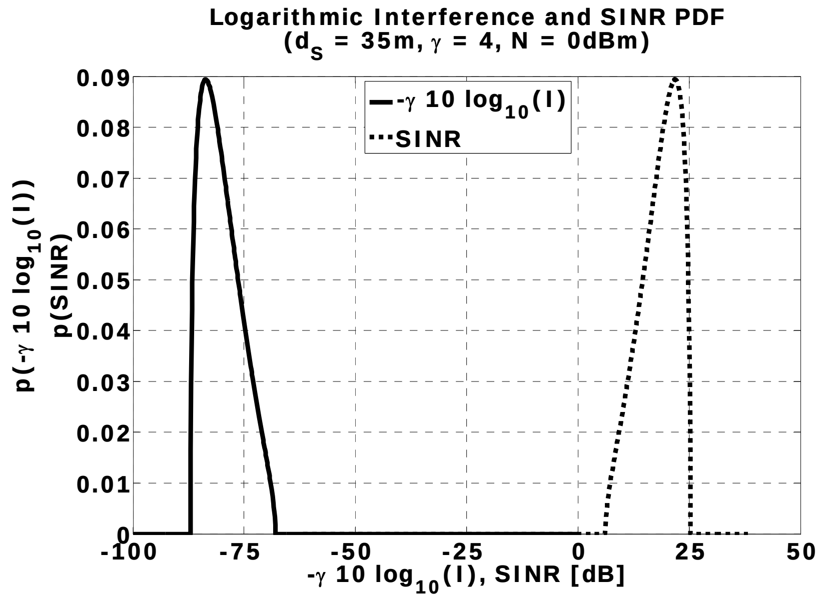
- P(MCS($SINR$)): relative circle segment area
- **Capacity C only depends on γ, D, R and $SINR$-to-data-rate r mapping**

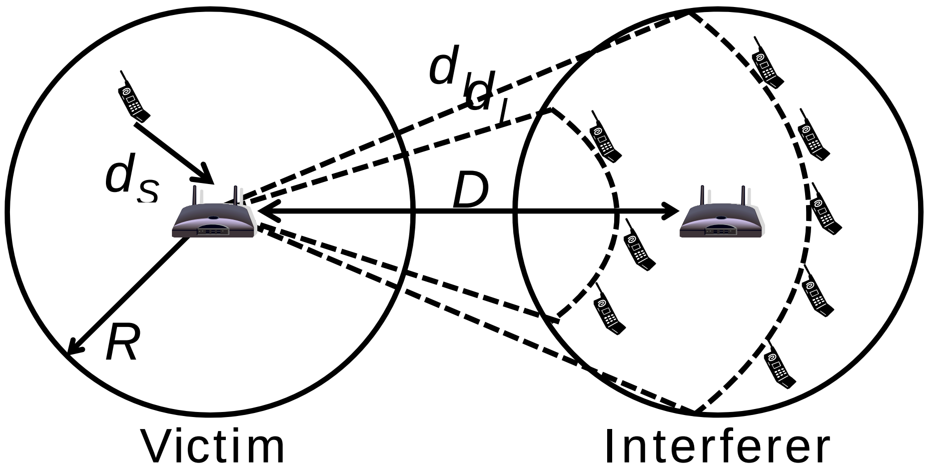
MCS	Min. SINR [dB]	Data Rate [Mbps]
BPSK ½	6.4	6.91
QPSK ½	9.4	13.82
QPSK ¾	11.2	20.74
16 QAM ½	16.4	27.65
16 QAM ¾	18.2	41.47
64 QAM $^2/_3$	22.7	55.30
64 QAM ¾	24.4	62.21

Capacity Estimation: Coexistence Scenario

- Arbitrary number of interferers i_{max}
- Arbitrary cell distances D_i
- *Radius R* comes from transmit power
- $$SINR \approx 10(-\gamma \log_{10} d_S - \log_{10} \sum_{\forall i} d_{Ii}^{-\gamma})$$
- *SINR* fix if d_{Ii} fix for given d_S
- Geometrically derive PDF $p(d_I)$
- PDF transformation & convolution
  $\Rightarrow p(SINR)$



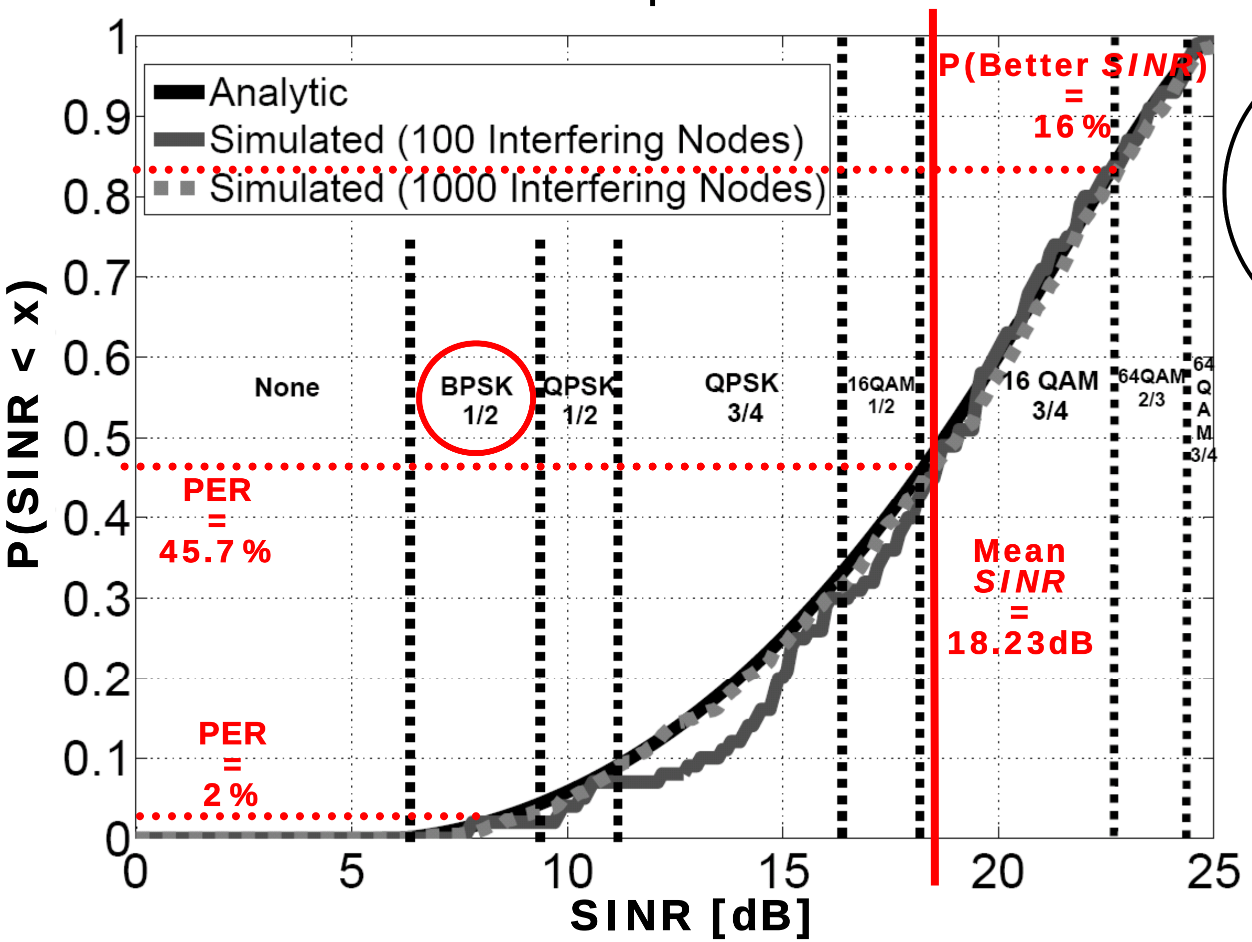


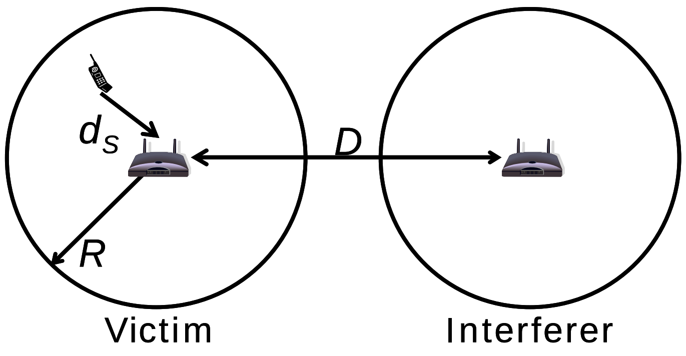


Capacity Estimation: Coexistence Scenario

- The scheduler can pick a SS at distance d_S in own cell
- It can not influence d_I (interference power)

  => Can not select optimal MCS => Decreased capacity

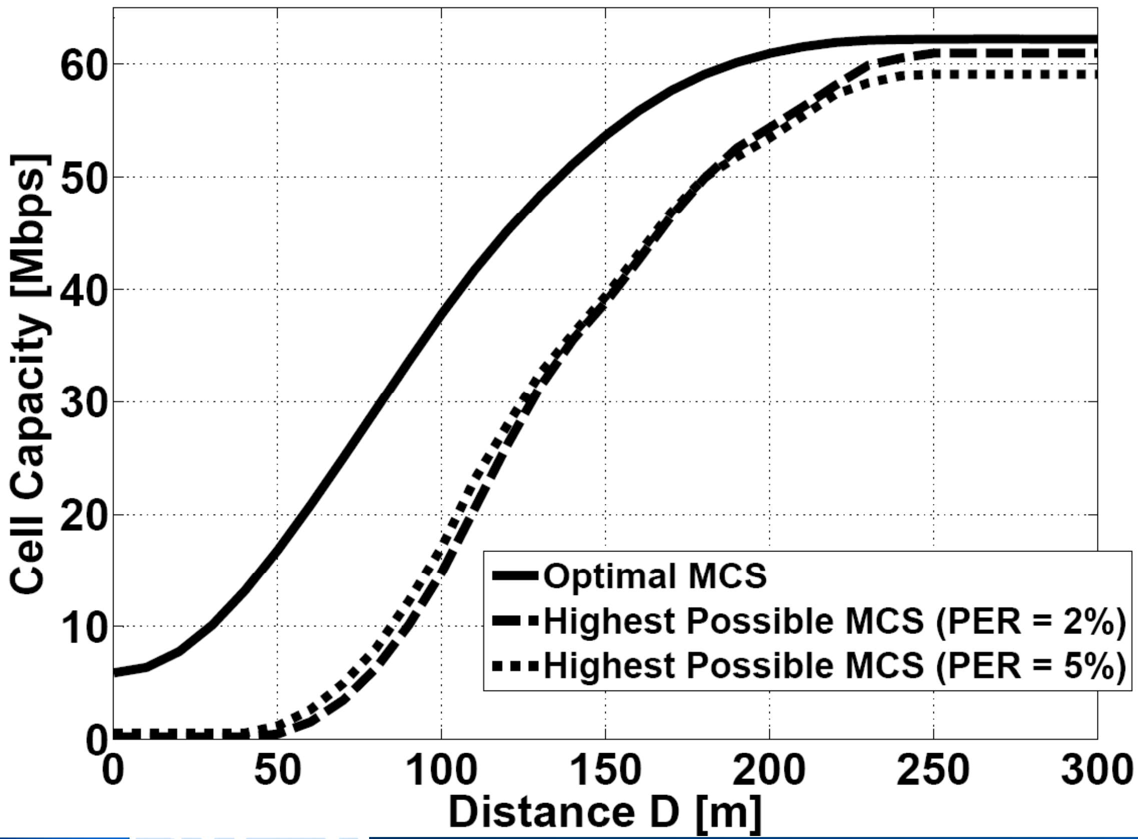


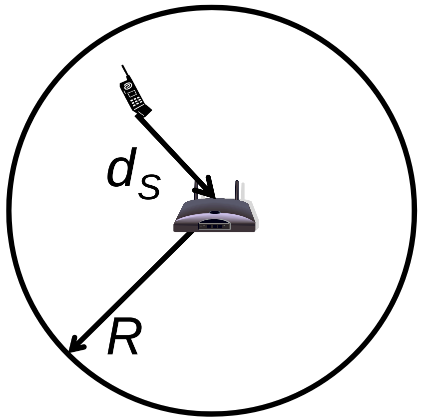


UL *SINR* distribution of a SS at distance 35m from BS and γ = 4.

Cell size *R* = 50m, interfering cell distance *D* = 100m

- Solution: Select lowest possible MCS allowing to keep defined Packet Error Rate (*PER*)
- $C = (1 - PER)\int_0^R p(d_S) r(d_S, PER) dd_S, \quad p(d_s) = \frac{2d_s}{R^2}$





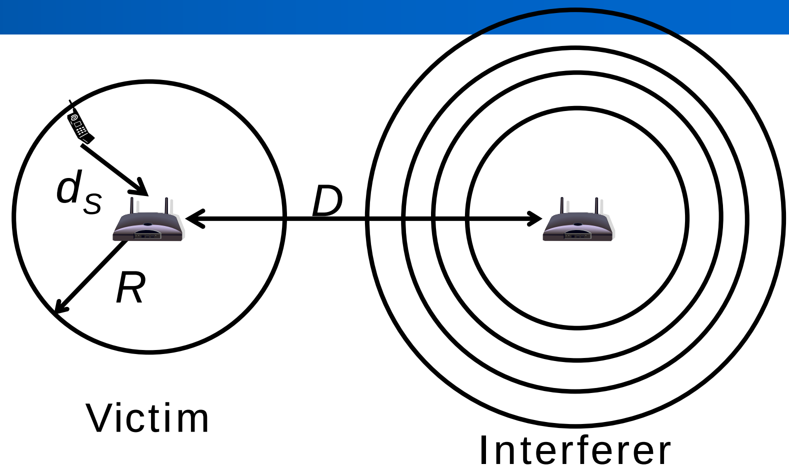
Victim cell capacity

$\gamma = 4$,

cell size $R = 50$m

Improving System Capacity

- How can we reduce *SINR* variance to increase capacity?
- Std. dev. increases as *R* increases
- We can not change *R*



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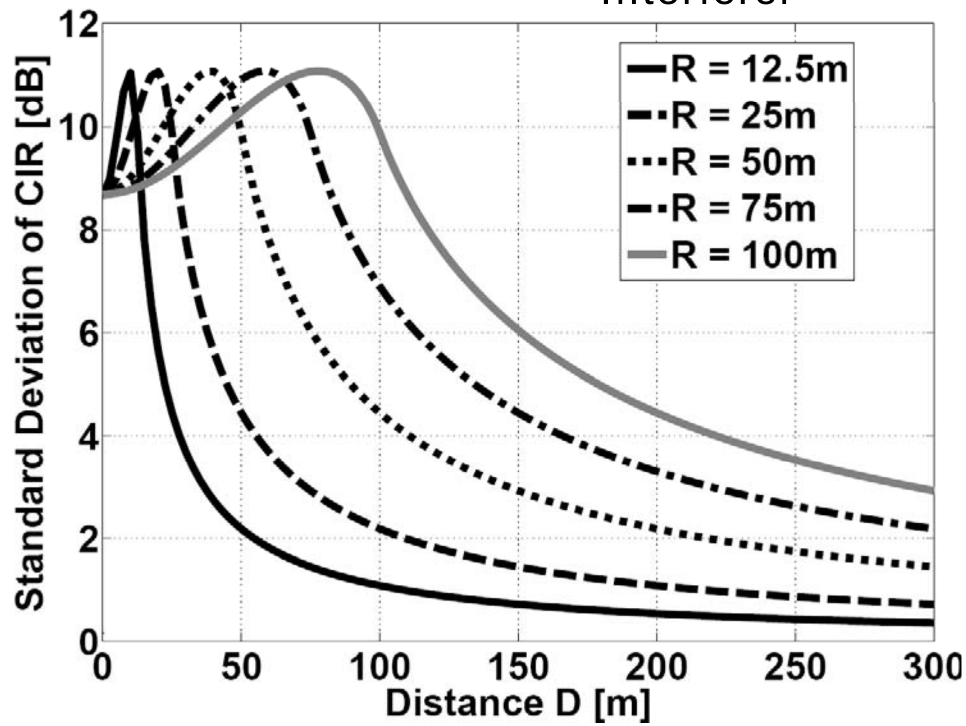
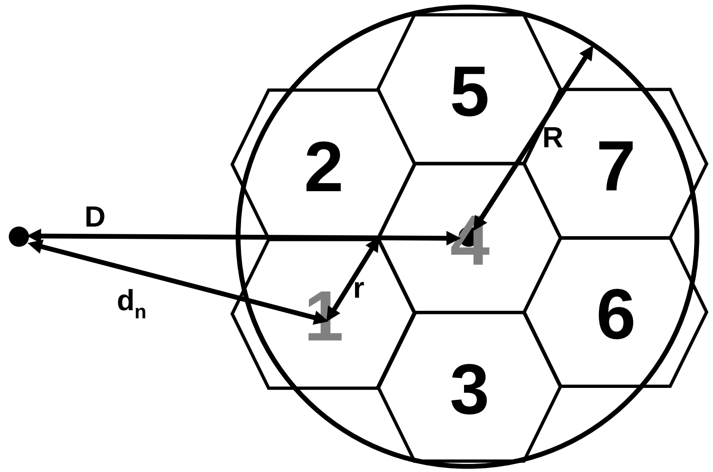
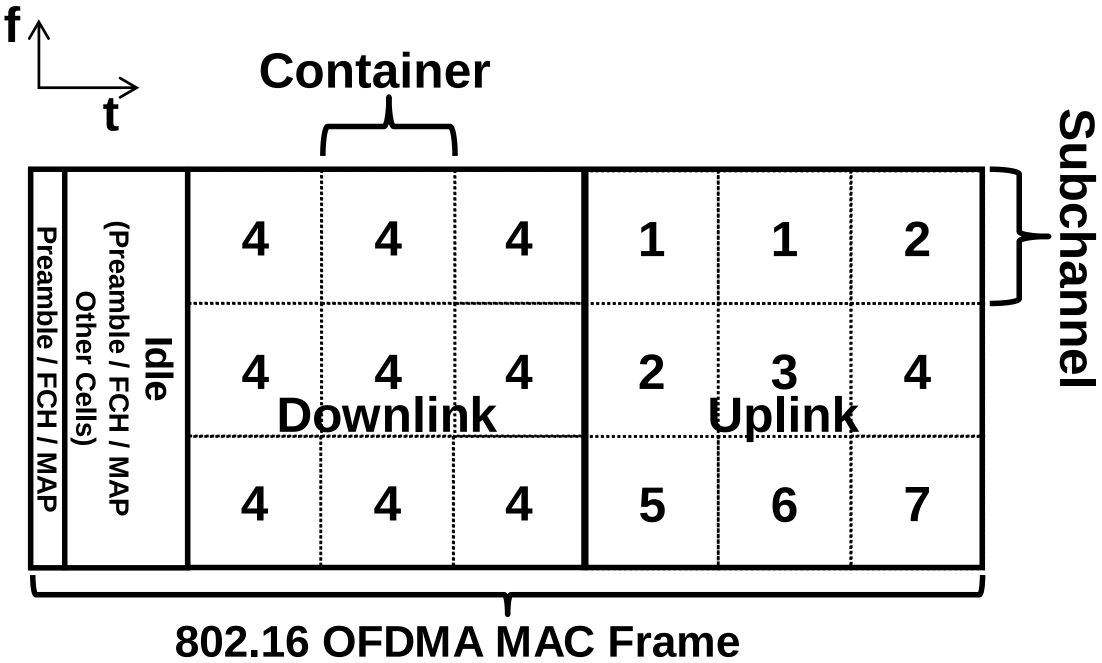
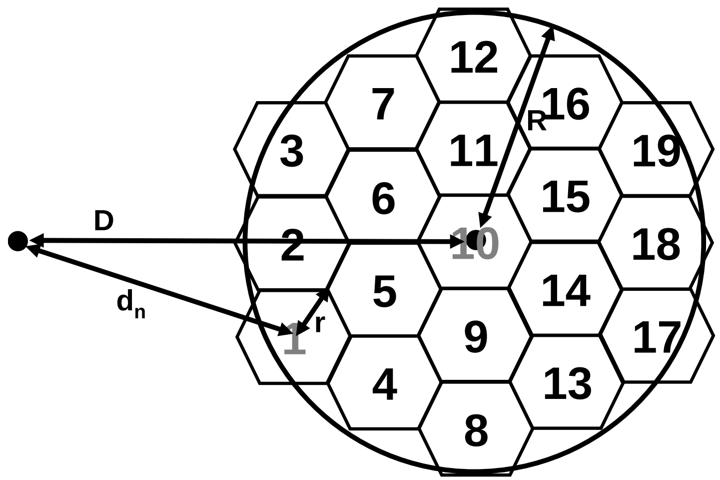


Improving System Capacity

- Virtually reduce radius *R*
  - => Define areas
  - => Schedule them at same resource every frame
  - => **More predictable for other cells**

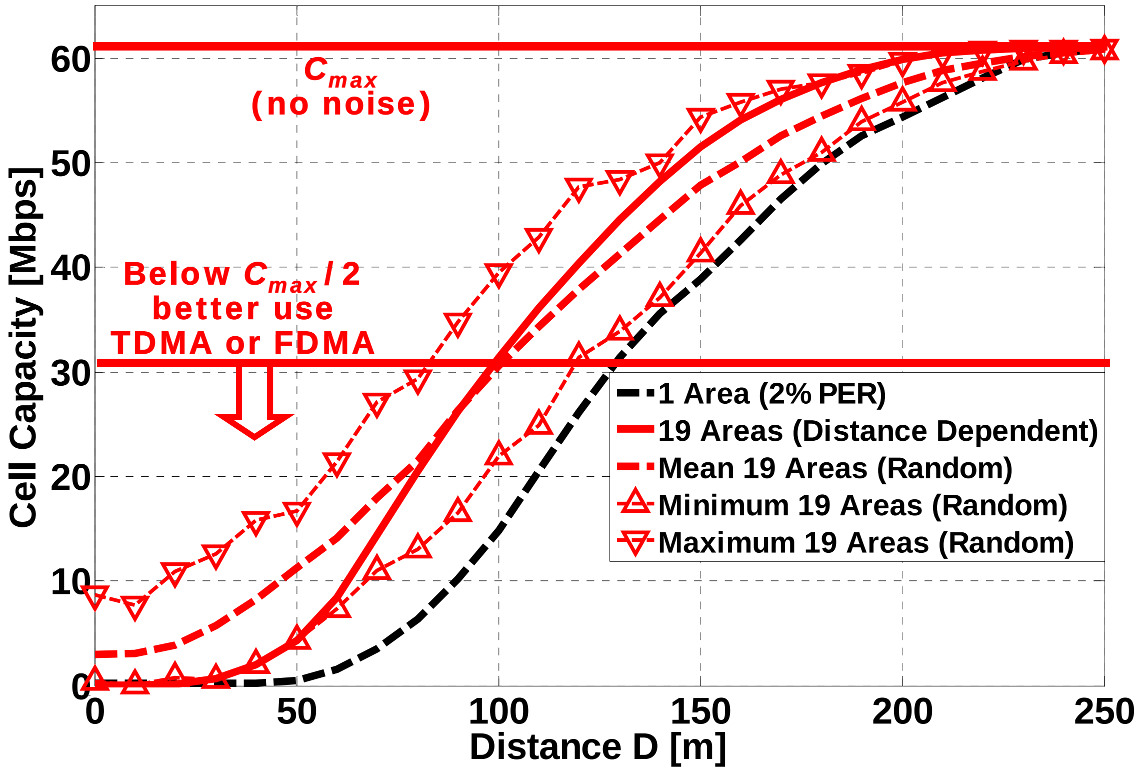


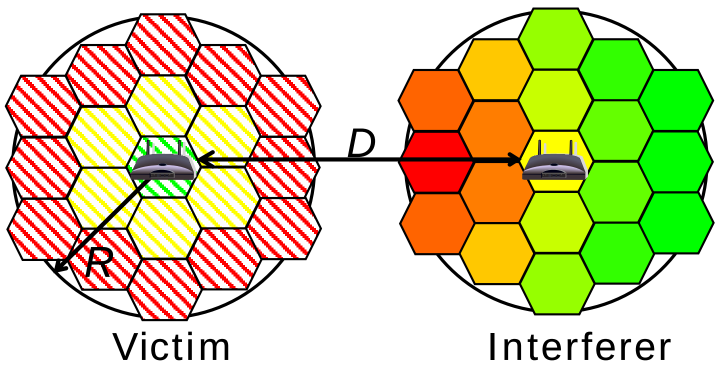




Results: Improved System Capacity

- Which resources/areas are scheduled simultaneously?
  - Optimization problem (max throughput vs. fairness)
  - Real system: Scan channel and choose resource with highest *SINR*
  - Here: Random / High "*I*" with high "*S*" (distance dependant)



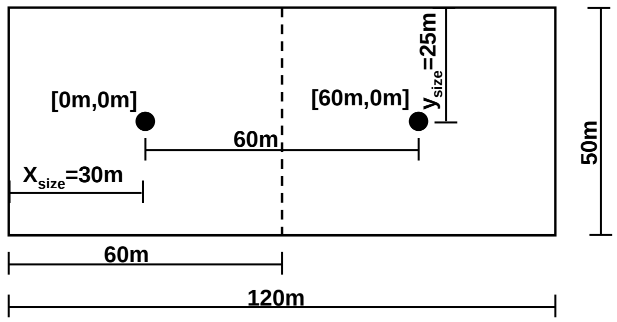


Conclusion & Outlook

- Summary:
  - A general method for capacity estimation in coexistence scenarios was developed
  - Uplink results for two cells were presented
  - Method of “virtual radius reduction” was developed and evaluated

    => Virtually reducing cell radius can improve capacity

    => If cells are very close, separating in time or frequency domain performs better



- Outlook:
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  - Implement and evaluate in system level simulator
    ex. openWNS (www.openwns.org)
  - More realistic scenarios (ex. IMT-A Indoor Hotspot)

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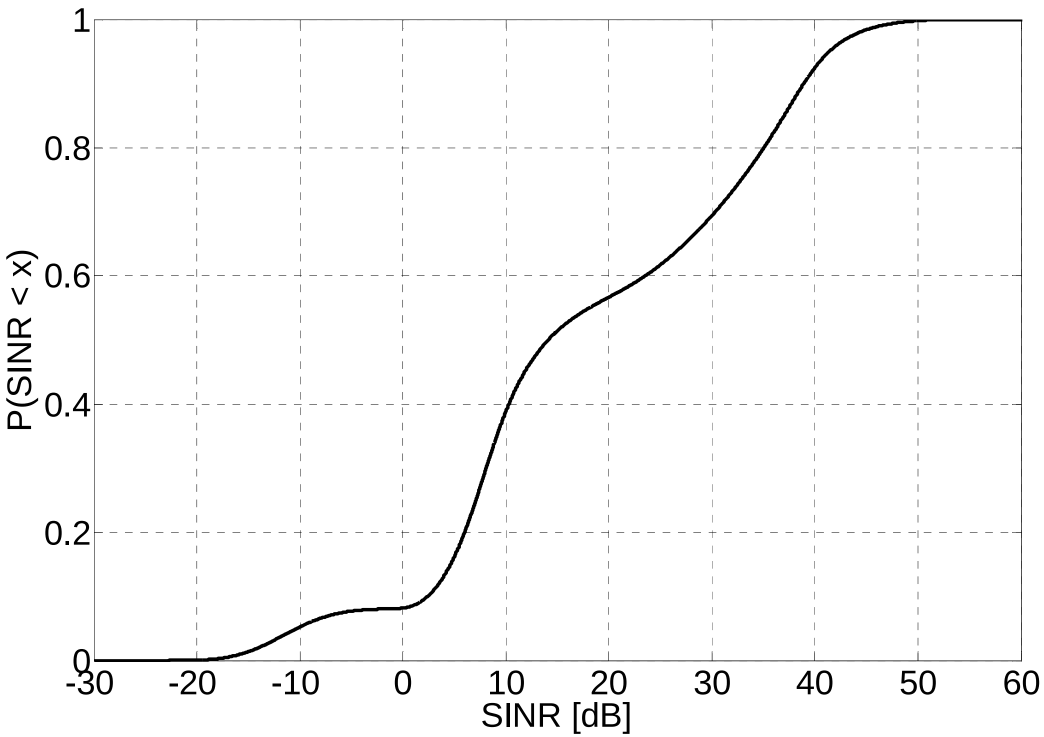

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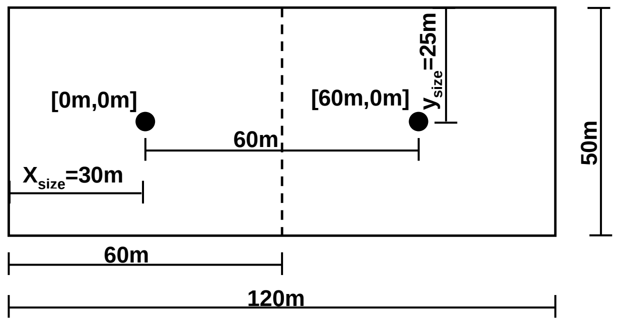

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Thank you for your attention!

Questions

Discussion

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