Interference Evaluation in ECMA-368 WPAN with DRP MAC Protocol

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Motivation

- Wireless communication in residential home environments covers wide range of applications
- Common market trend from multimedia capable devices (DEVs) towards applications demanding for very high data rate transmission service: TV and video data transmission
- Outdated Wifi's mono-cluster approach replaced by multi-cluster home networks yielding intended high data throughput in limited area [1]

➡ Motivation to use UWB ECMA-368 for short range ad-hoc communication in residential home environment

[1] P. Gandolfo. XtremeSpectrum – SG3a CFA Response. Online available: 02031r0P802-15_SGAP3-CFAReaponseAltPHY

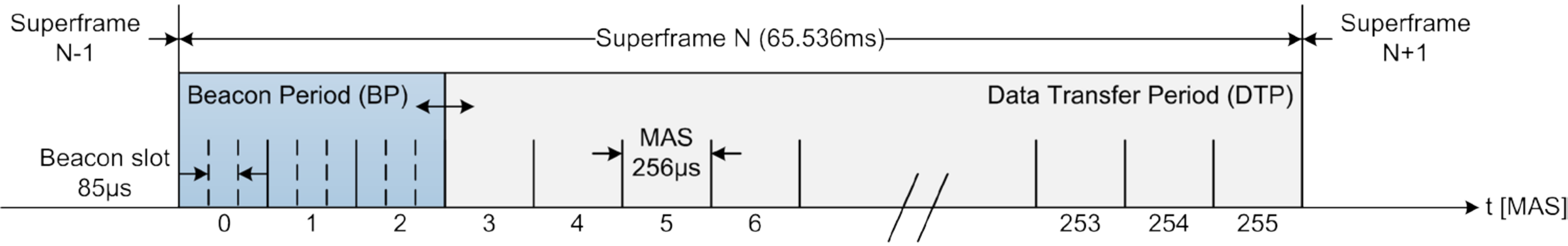
Problem Description

- Widespread use of wireless communication systems operating in license-exempt frequency bands goes along densely populated network scenarios
- DEV applies reservation based DRP controlled medium access to transmit user data reliably carried in successively recurring Medium Access Slots (MASs)
- Spatial reuse of MAS channel resources in not fully meshed network scenarios causes interference to user data frame transmission

➡ Limits achievable cluster data throughput and coverage range

ECMA-368[2]: Medium Access Control (MAC) Overview

- Fully distributed MAC:
  - DEVs unhide DEV located in the neighbourhood through short management frames broadcasted during Beacon Period (BP)
  - DEV negotiates MASs for user data frame transmission in advance to carry user data frames during Data Transfer Period (DTP)



- Management frames carried in Beacon Slots (BSs) are protected from interference caused by transmission in the two hop neighbourhood
- User data frames carried in MAS exclusively are protected from interference caused by DEVs data transmissions located in one hop Beacon Group (BG)

[2] ECMA-368: High Rate Ultra Wideband PHY and MAC Standard, 3rd Edition, December 2008.

ECMA-368: Medium Access Control
Beacon Period (BP)

- Beacons are broadcasted in recurring BSs

- Several Information Elements (IEs) compose beacon

- DEV are aware of DEVs located in one and two hop neighbourhood, defers from trying to reserve respective BSs

- Beacon Decoding Range is rather limited by noise than interference caused from data frame transmission

r_{bg} Beacon Decoding Range

Device (DEV)

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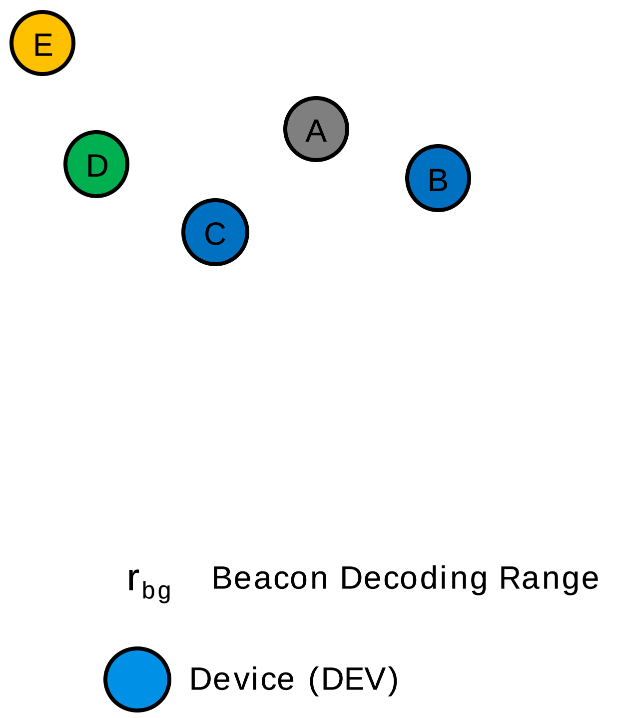

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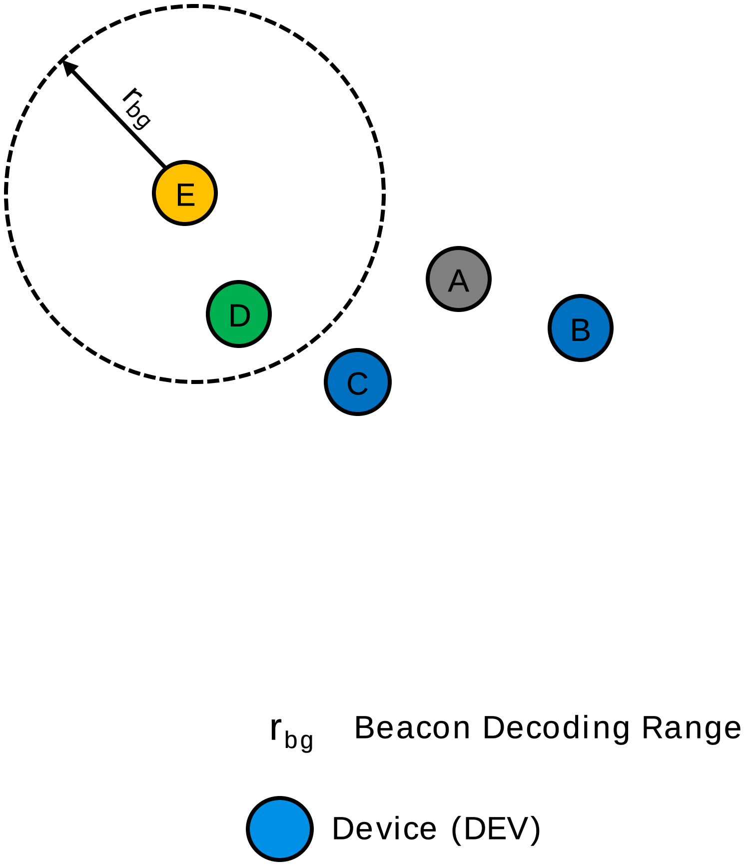

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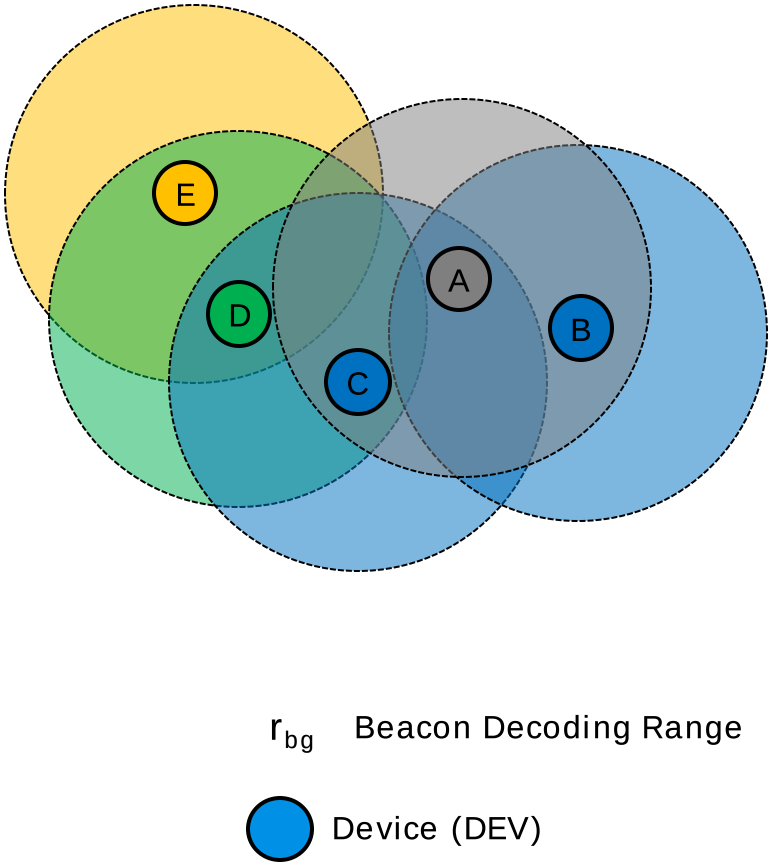
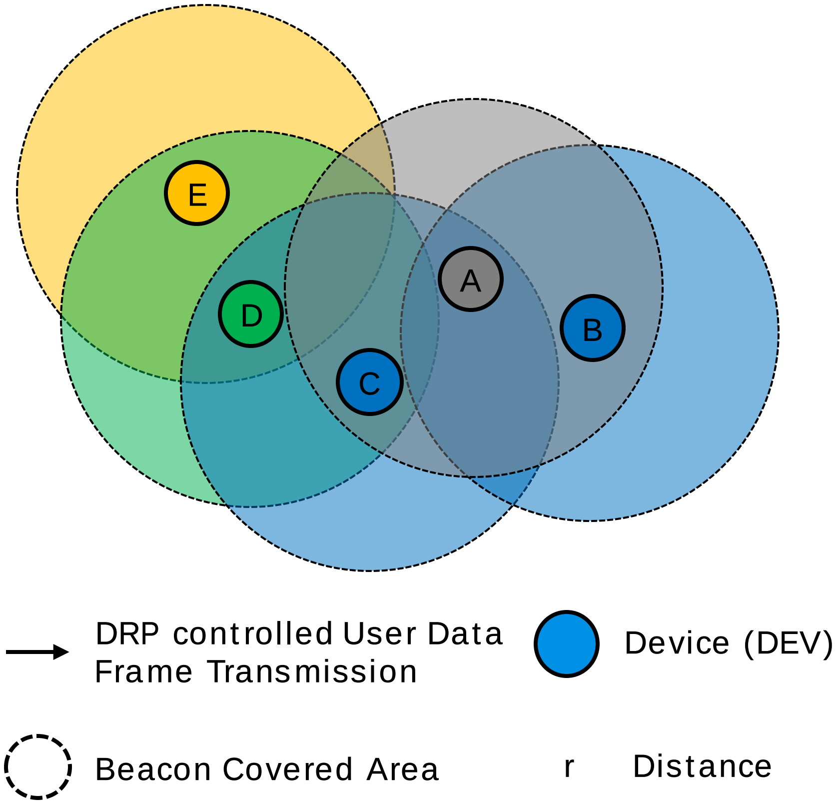


ECMA-368: Medium Access Control
Data Transfer Period (DTP)

- User Data Frames are carried in reserved MASs negotiated previously
- Management information on DRP controlled medium access is carried in Beacons
- MASs are granted exclusively until DEV suspends DRPIE from Beacon transmission
- DEVs not located in one-hop BG from owner or target may reuse MASs randomly for user data frame transmission
- Maximum interference power is expected where Beacon Decoding Range covers same area [3]



[3] H. Rosier, C. Kukla. Performance Evaluation of DRPNext in ECMA-368 Wireless Personal Area Networks," *Personal Indoor and Mobile Radio Communications (PIMRC), 2013 IEEE 24th International Symposium on*, 2013

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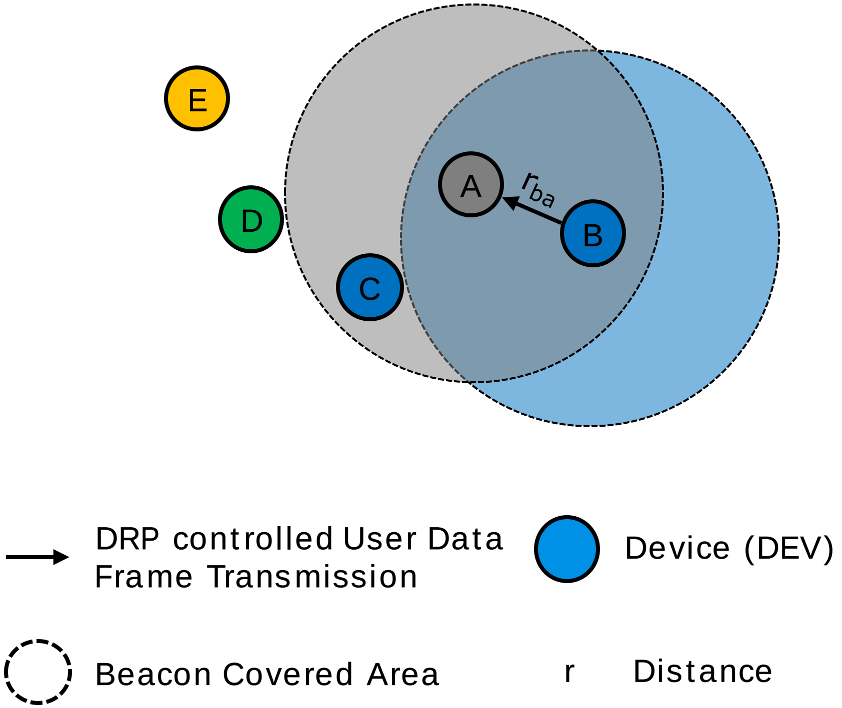

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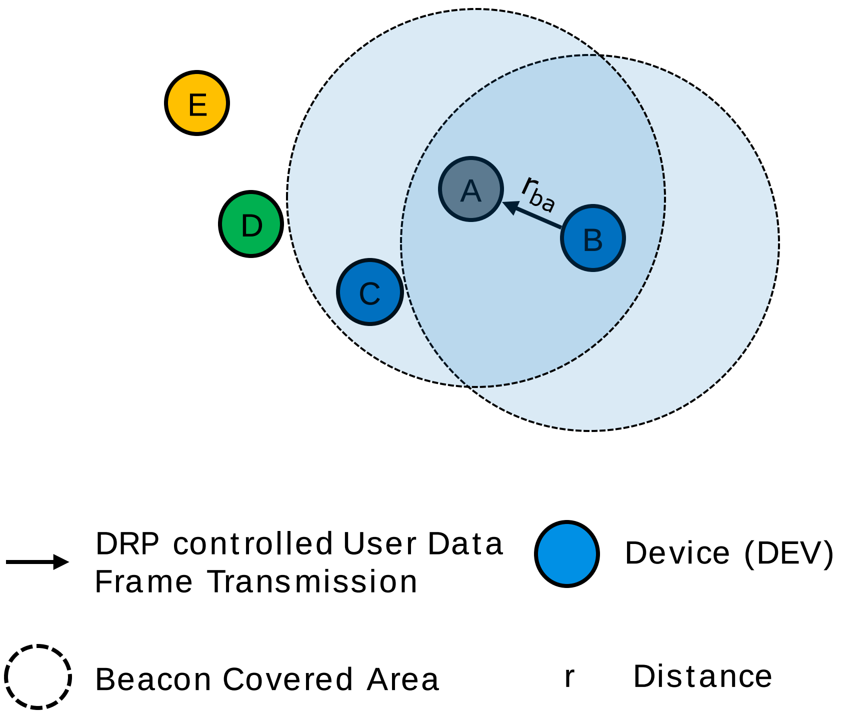

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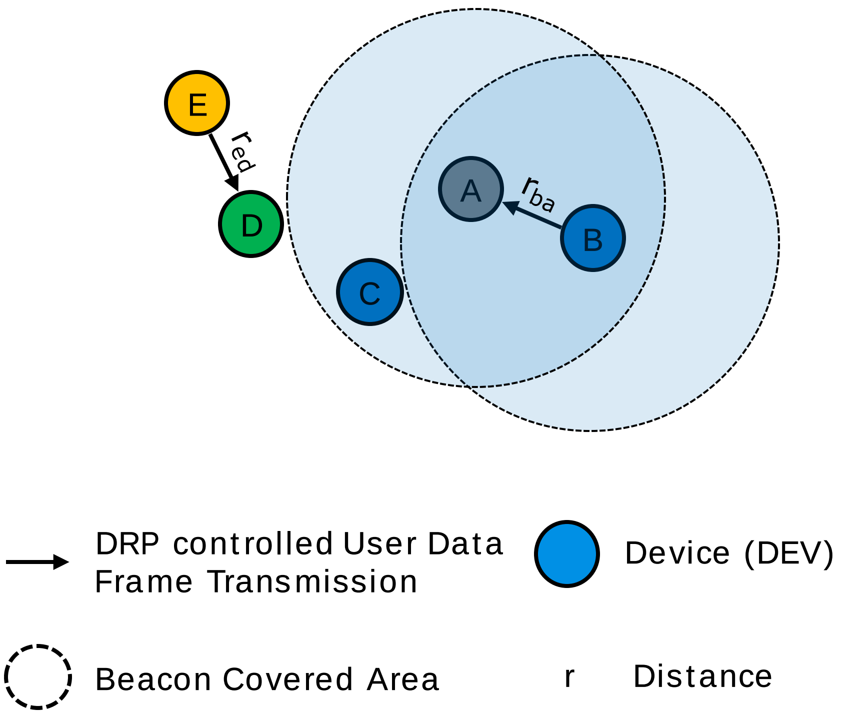

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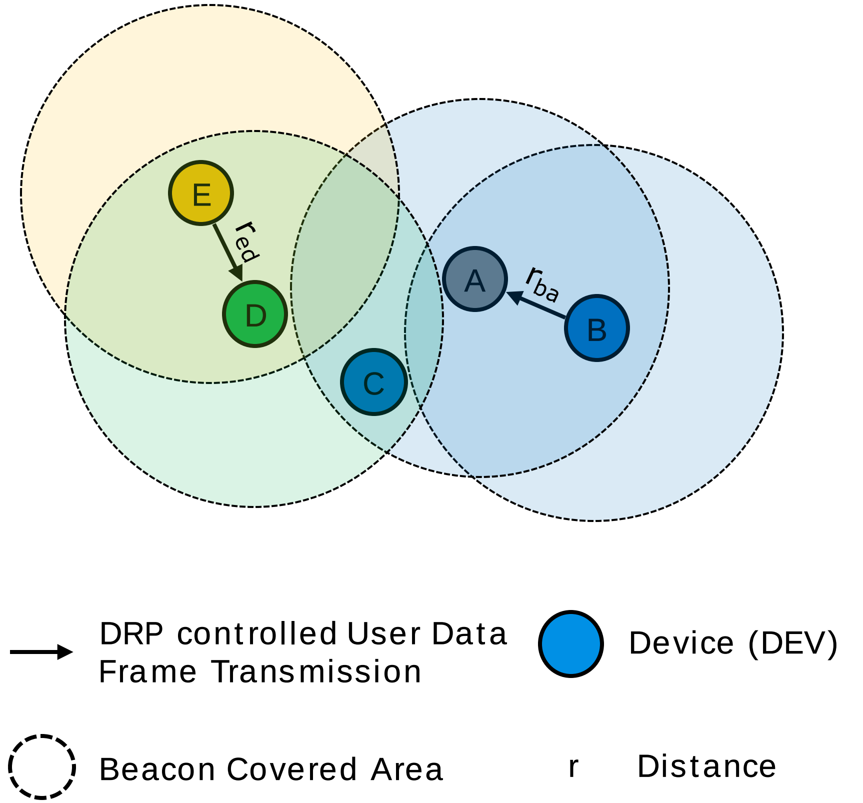

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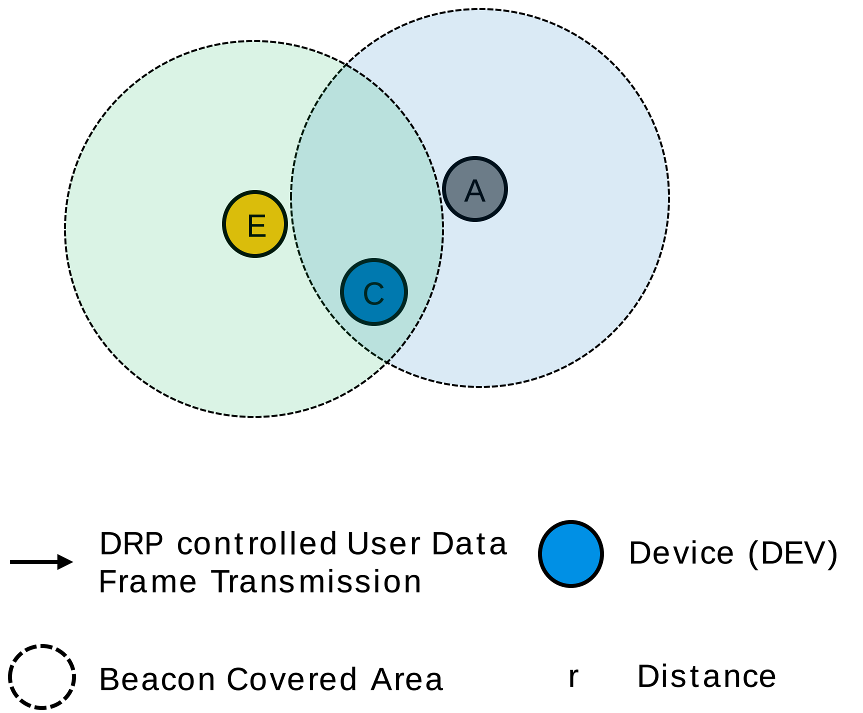

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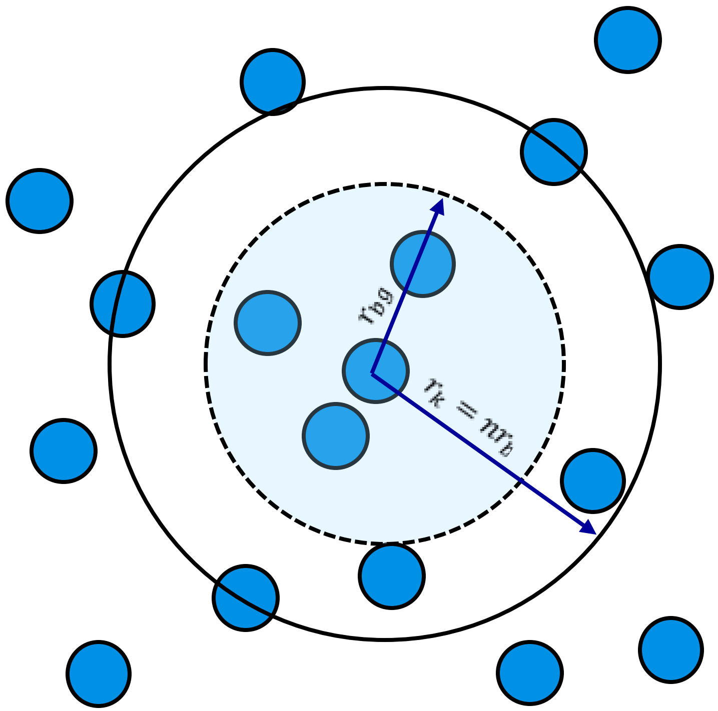
Scenario
Description & Parameters

Parameter	**Value**
Number of Devs per m^2	$\rho = 0.05 \frac{DEVs}{m^2}$
DEV Position	Random uniform distributed
Pathloss Calculation	Mean Pathloss Channel Model (MPCM)
Mean Beacon Decoding Range	$r_{bg} = 16m$
Frequency	3.96GHz
Data Frame Size	1500B
Modulation and Coding Schemes (MCS)	53.3MB/s … 480MB/s
Evaluated Scenarios Size	$r_s = n \cdot r_{gb}$ $n = 1, 2, \ldots, 5$
Target FER	3%
Distance between owner and target, considered for MCS probability distribution	0.1m,…,9m



Analytical Study
Connectivty & Beacon Group

- Connectivity depends on number of DEVs located in the BG

$$c_f = \sum_{i=1}^{N} \frac{M_i}{N(N-1)} = \frac{\rho\pi \cdot r_{bg}^2 - 1}{\rho\pi \cdot r_s^2 - 1} \approx \frac{r_{bg}^2}{r_s^2}$$

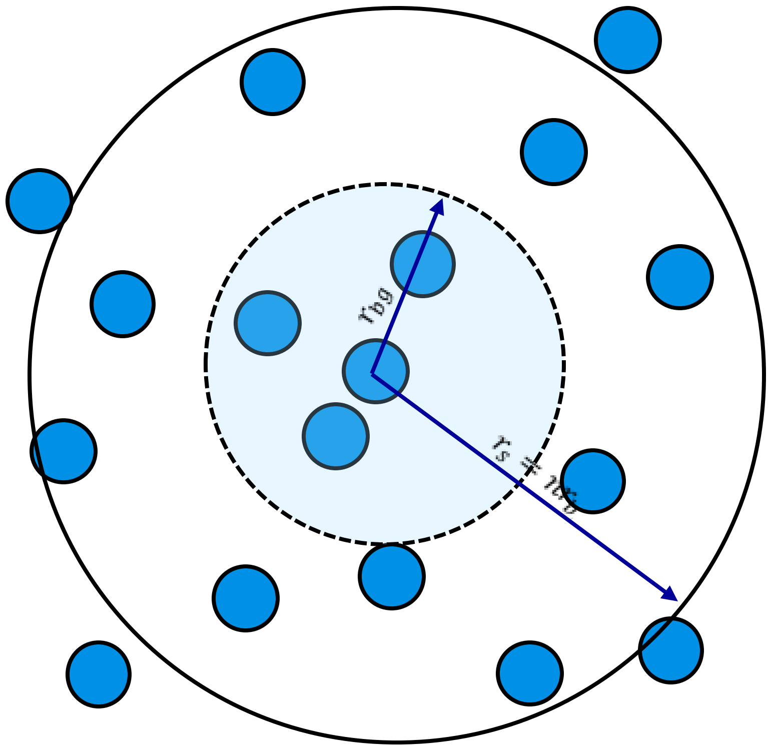
connectivity c_f, N number of DEVs located in scenario, ρ DEV density, M_i number of DEVs in one-hop BG neighborhood, r_{bg} Beacon Decoding Range, r_s evaluated scenario size

- Mean Number of DEVs located in BG

$$N_{BG} = N \cdot c_f$$

- Number of DEVs where first $k = 1$ co-channel interferer may occur

$$N_{k=1} = (1 - c_f) \cdot N$$



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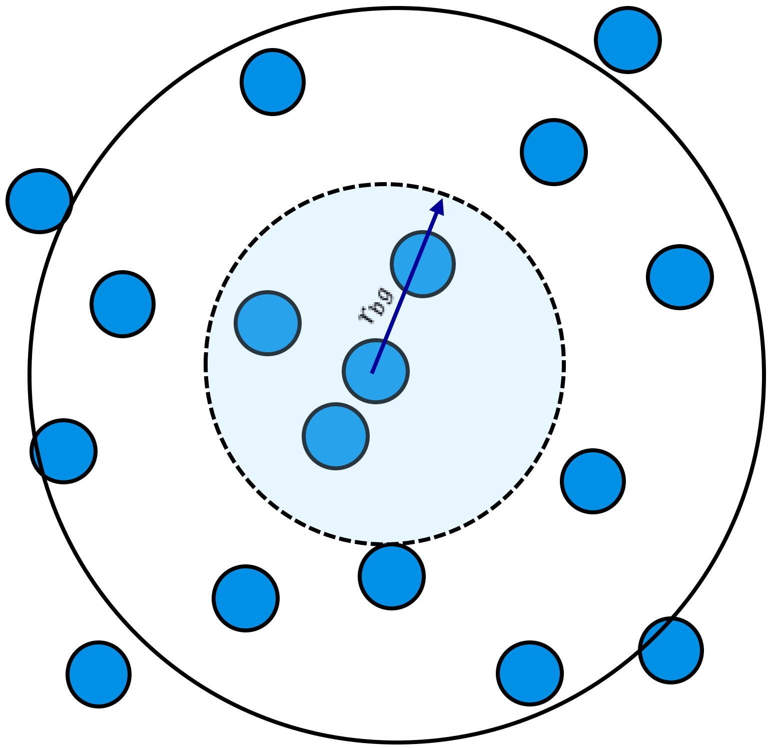

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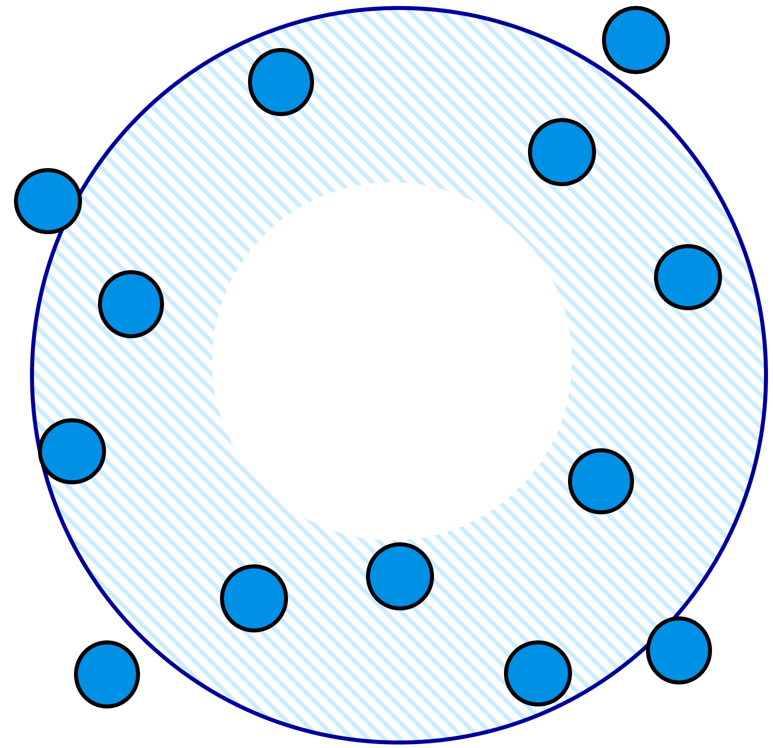

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Analytical Study
Number of DEVs able to Reuse MASs

- Number of DEVs where second $k = 2$ co-channel interferer may occur

$$N_2 = \widetilde{N_2} + \left(N_1 - \widetilde{N_2}\right) \cdot c_f$$

$$\text{where } \widetilde{N_2} = \left(1 - c_f\right)^2 \cdot N$$

- Considers DEVs located in more than one BG

$$\left(N_1 - \widetilde{N_2}\right) \cdot c_f$$

- Leads in general to [4]

$$N_k = N\left(1 - c_f\right)^{k+1}$$

$$+N_{k-1}c_f + \sum_{i=1}^{k-2} (N_i - N_{i+1})\, c_f^{\,k-i}$$

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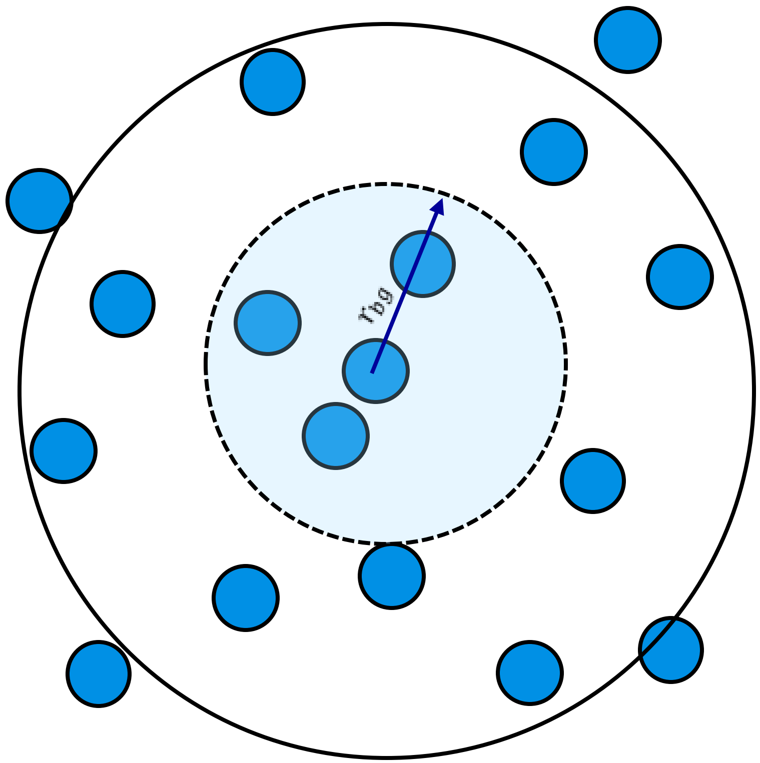

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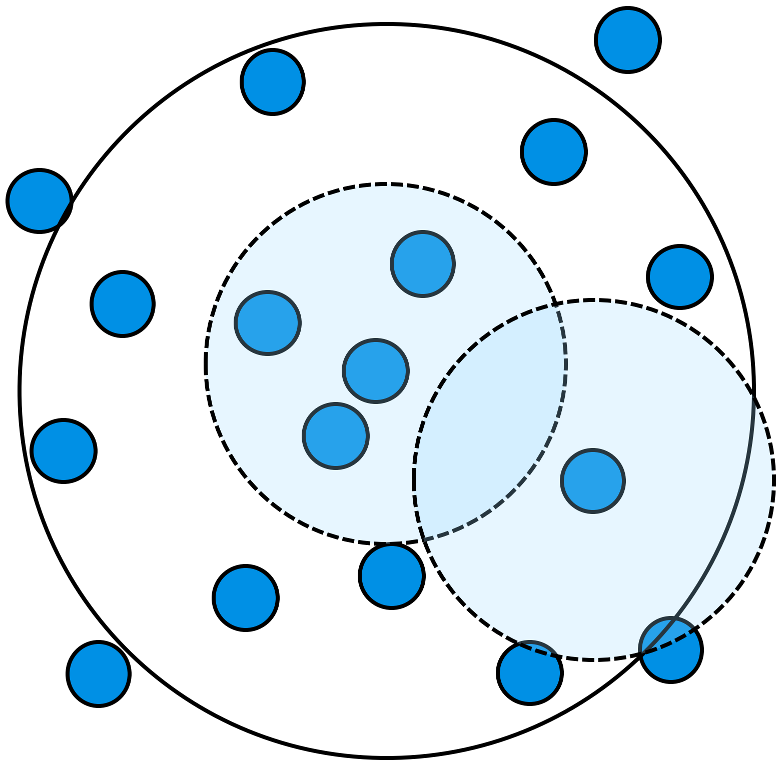

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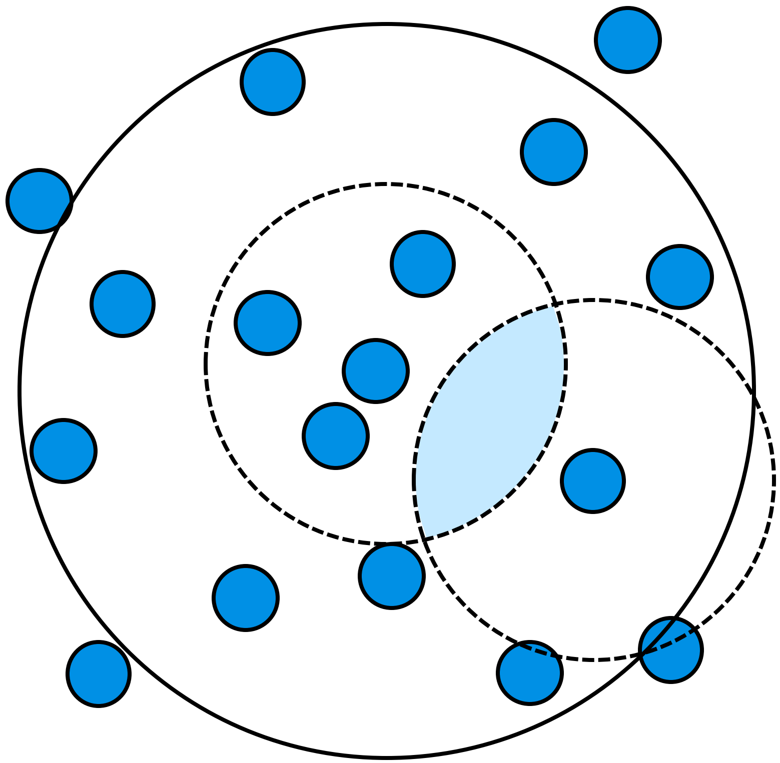

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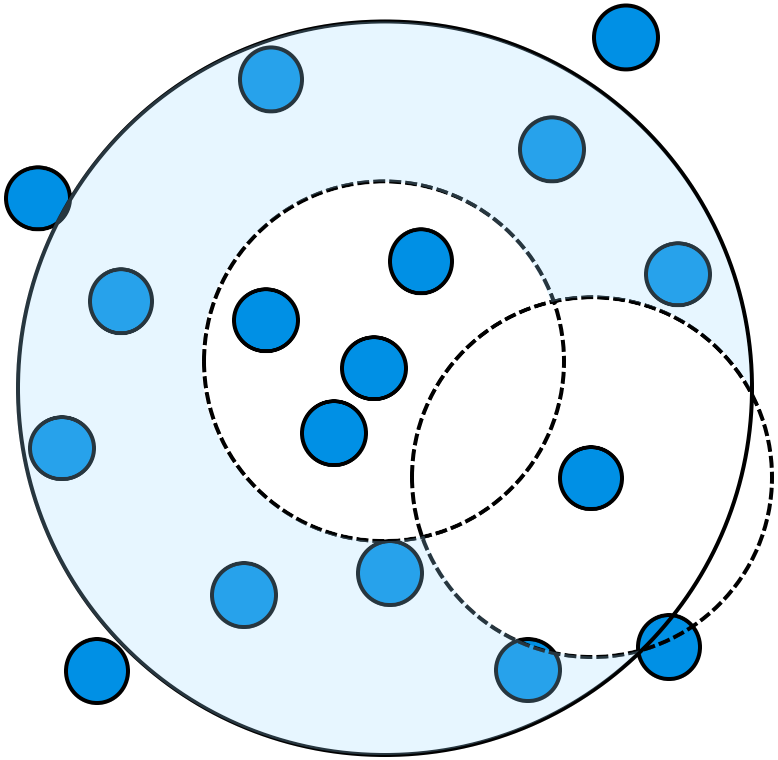

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Analytical Study
Probability of co-Channel Interferer

- Mean number of available MASs for DRP controlled user data frame transmission

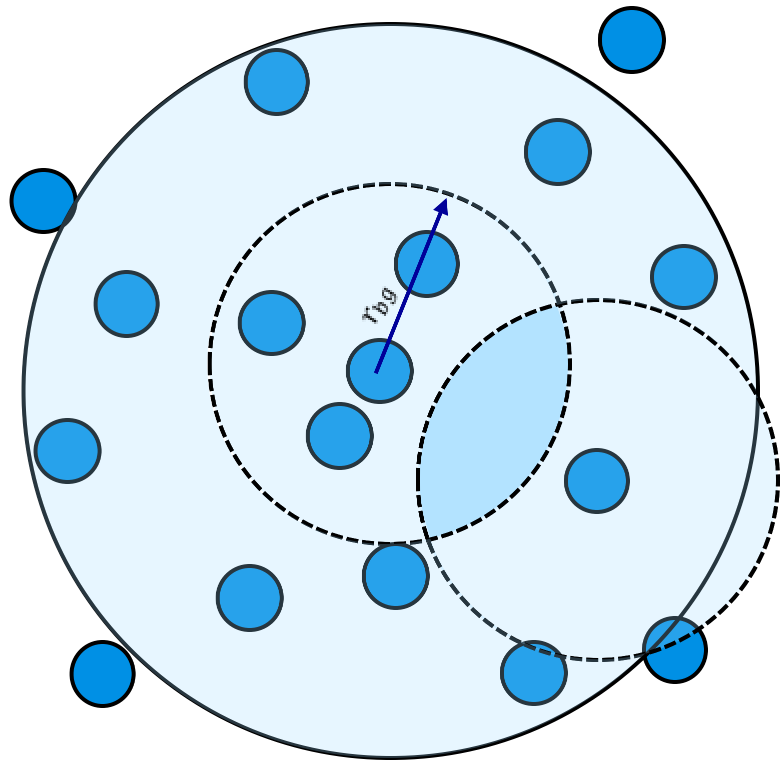
$$\bar{d} = \frac{1}{N_{BG}} \sum_{i=0}^{N_{BG}-1} I_{MAS} - i$$

- Total number of available MASs in SF $I_{MAS} = 256$

- Probability to find exactly k co-channel interferer

$$p_k = \binom{N_k}{k} \left(\frac{1}{\bar{d}}\right)^k \left(1 - \frac{1}{\bar{d}}\right)^{N_{k+1}}$$

$$p_0 = 1 - \sum_{k=1}^{\infty} p_k$$



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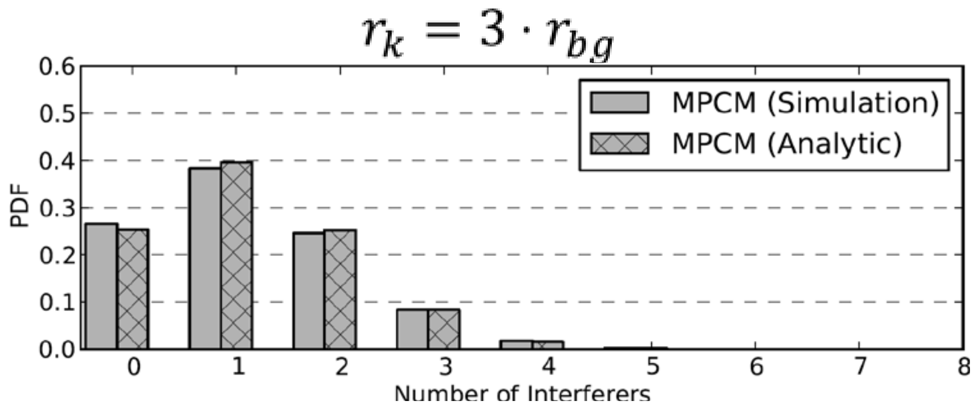
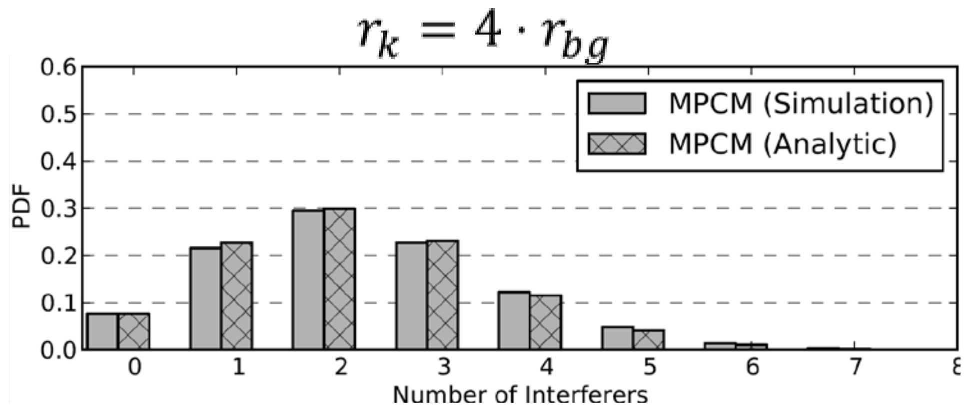
Results
Probability of Co-Channel Interferer

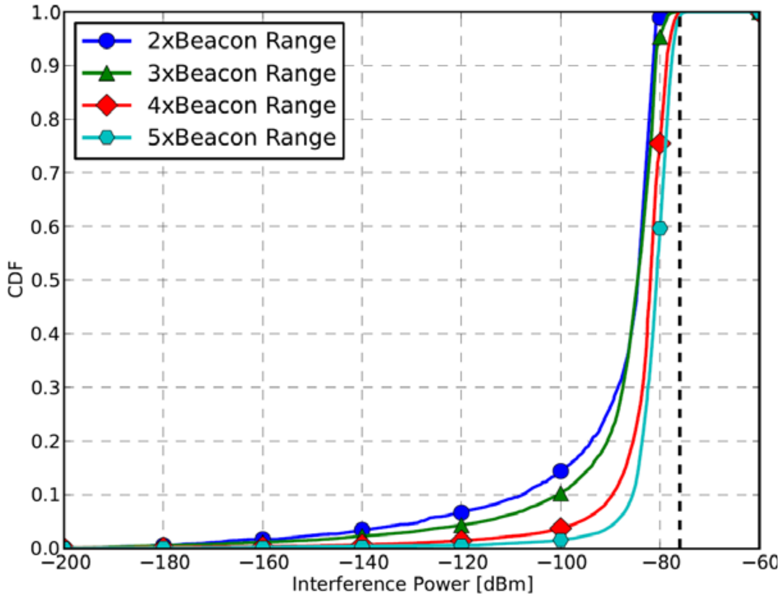




- Number of interfered DRP controlled user data frame transmissions is equivalent to MAS reuse in the scenario
- Probability that no DEV allocates MAS operated for user data frame transmission by another DEV decreases from 0.28 to 0.09 where radius r_k increases from $3 \cdot r_{bg}$ to $4 \cdot r_{bg}$
- Monte Carlo experiment complies results obtained analytically

Results
Maximum Interference Power

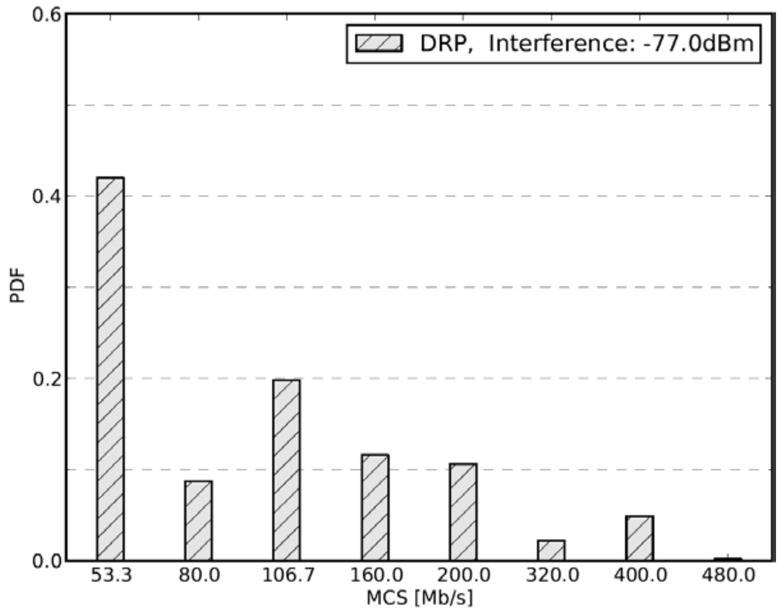
- Interference power for increasing scenario size regarding parameter value $r_k = n \cdot r_{bg}$ with $n = 2, \ldots, 5$



- CDF tends to step function in scenarios where r_k increases
- Concerning results DRP limits interference power to value $\approx -77dBm$

Results
MCS Probability Distribution & Achievable Throughput

- MCS probability results considers random distance between DRP reservation owner and DRP reservation from uniform distribution and constant interference power



- Achievable throughput concerning rate fair scheduling calculates from

$$t_{hr} = \left(N_{BG} \cdot \sum_{i=1}^{7} \frac{p(MCS_i)}{rate_i} \right)^{-1} = 2.026 \frac{\text{Mb}}{\text{s}}$$

$p(MCS_i)$ probability to operate MCS_i, $rate_i$ data rate offered from MCS_i

- Achievable throughput in Beacon Group is obtained from $N_{BG} \cdot t_{hr} = 81.47 \frac{Mb}{s}$

Conclusion & Outlook

Conclusion:

- Interference power in UWB scenarios where DEVs operate DRP for user data frame transmission and allocate MAS randomly is limited to $-77dBm$
- Throughput achieved from DRP controlled medium access in densely populated network scenarios calculates to $81.47\,\frac{Mb}{s}\frac{1}{BG}$

Outlook:

- Apply Interference Aware Scheduling to gain throughput in UWB WPAN scenarios[5]

[5] H. Rosier, J. Frerichs. "Interference Aware Scheduling for Ultra Wideband Networks," *Wireless and Mobile Computing, Networking and Communications (WiMob), IEEE 6th International Conference on, Niagra Falls 2010*

Thank you for your attention!

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