Modeling of Partially Overlapping Wireless Personal Area Networks

21. ComNets-Workshop Mobil- und Telekommunikation

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March 16, 2012

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- Motivation
- Medium Access Control (MAC) protocols in Wireless Personal Area Networks
- Channel Reuse
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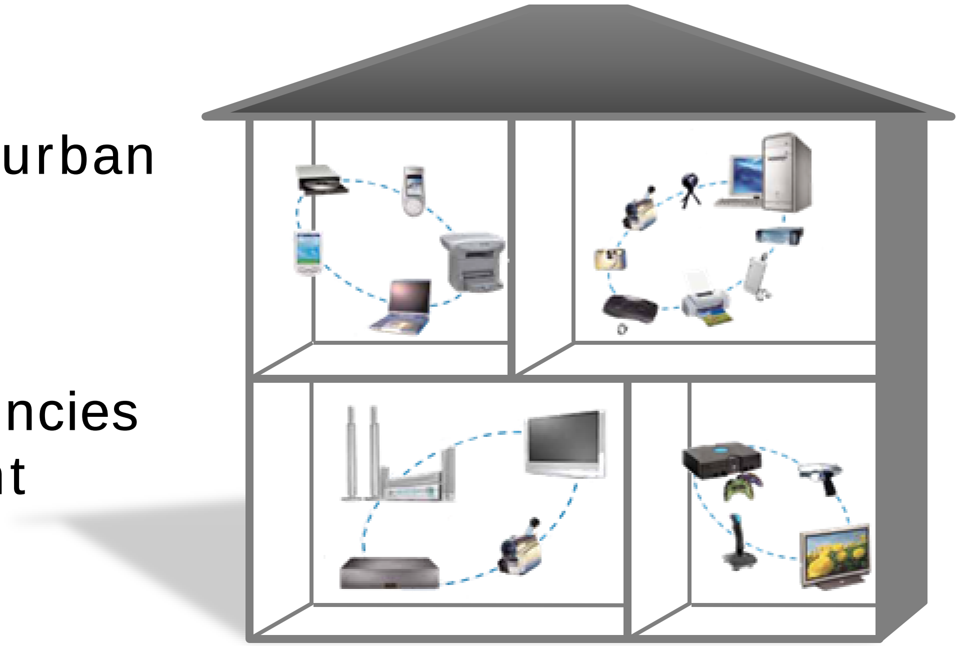
Motivation

- Today's Consumer Electronic (CE) devices are equipped with wireless interfaces (WLAN, Bluetooth, Wireless USB)
- CE Special Interest Group (CE SIG) expects six or even more Wireless Networks within the home environment
- Current contention based MAC protocols do not use channel resources efficiently
- Problem especially in dense urban scenarios
  - ➢ Scarce radio resources in license-exempt frequencies require spectrum efficient MAC Protocols



Medium Access Control for CE Devices

Medium Access Control

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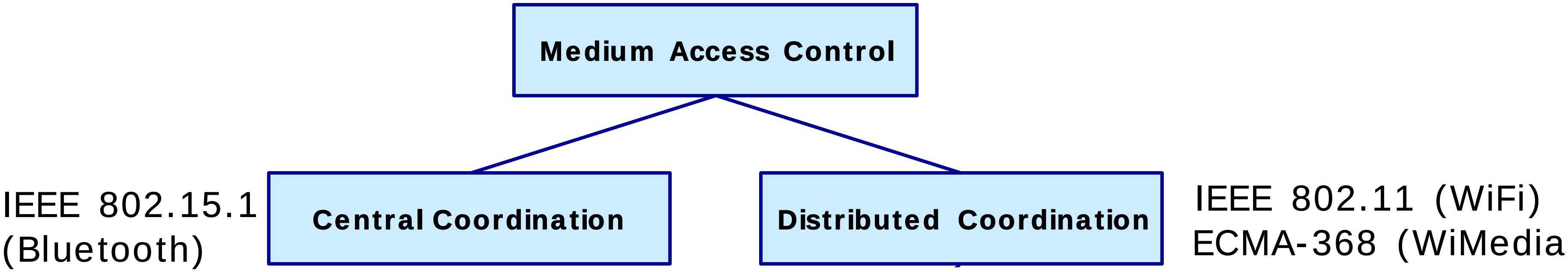

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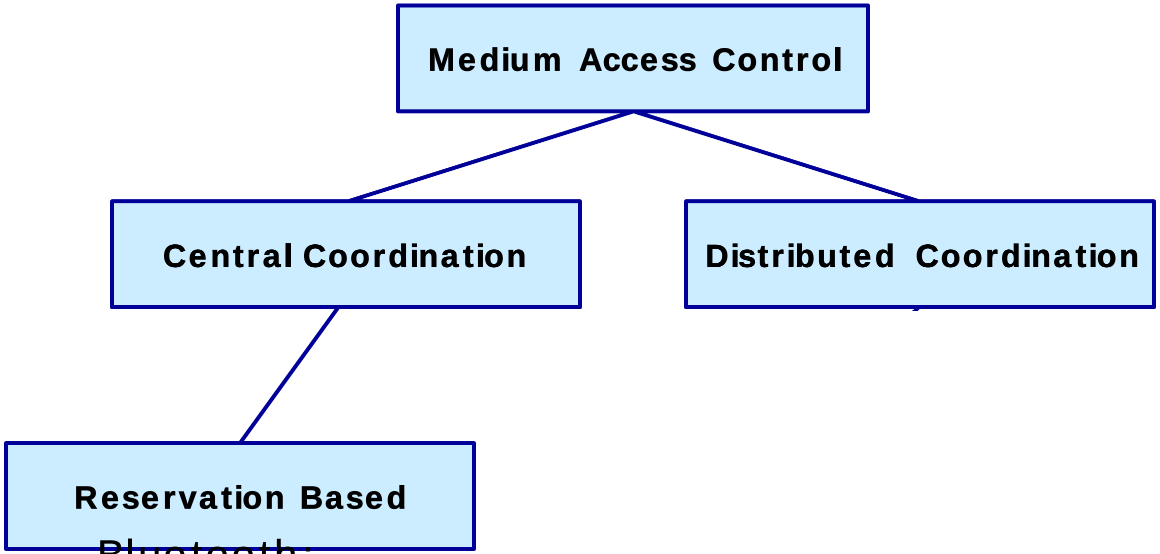
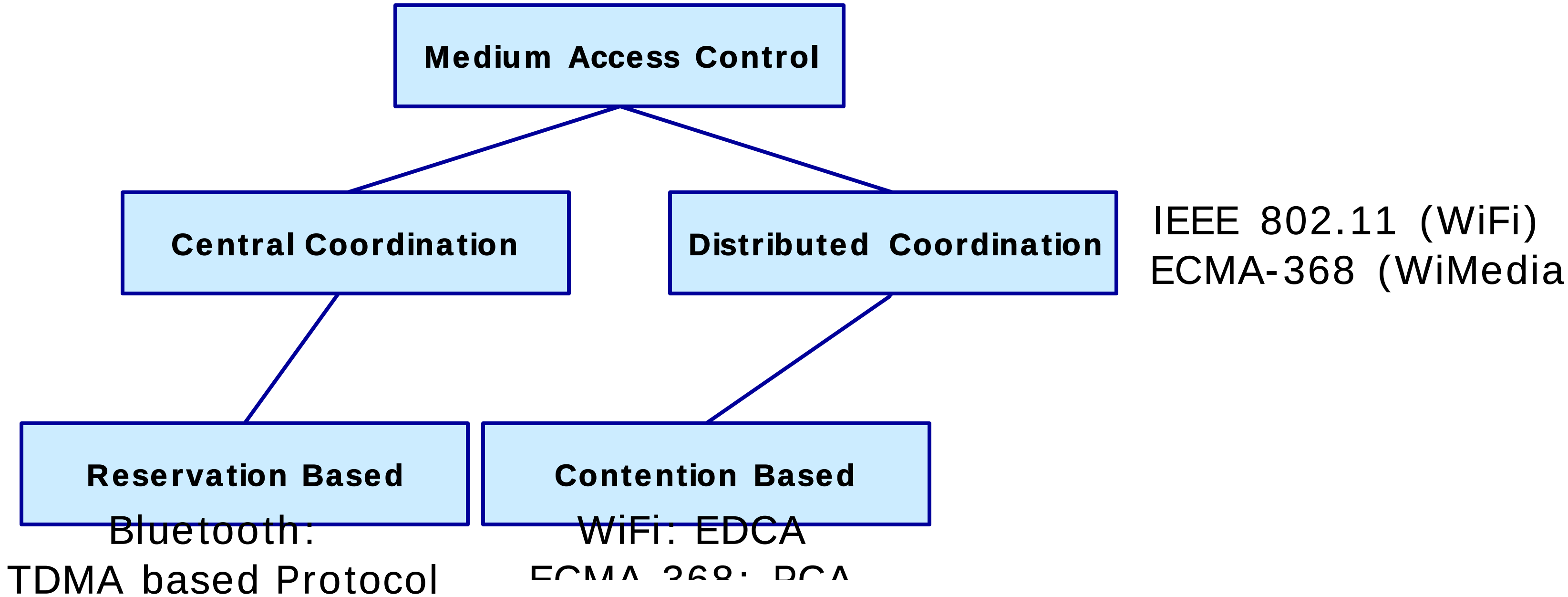


IEEE 802.11 (WiFi)
ECMA-368 (WiMedia)

Bluetooth:
TDMA based Protocol

TDMA: **T**ime **D**ivision **M**ultiple **A**ccess

Medium Access Control for CE Devices



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EDCA: **E**nhanced **D**istributed **C**hannel **A**ccess

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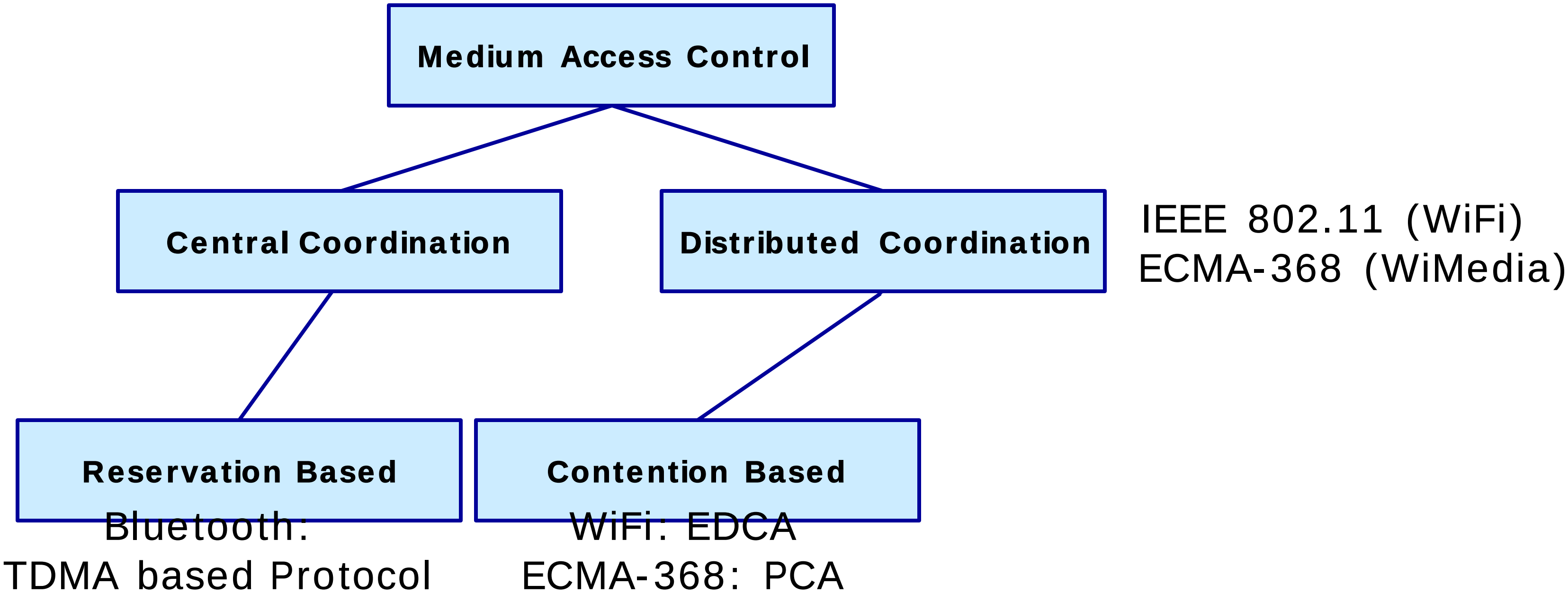

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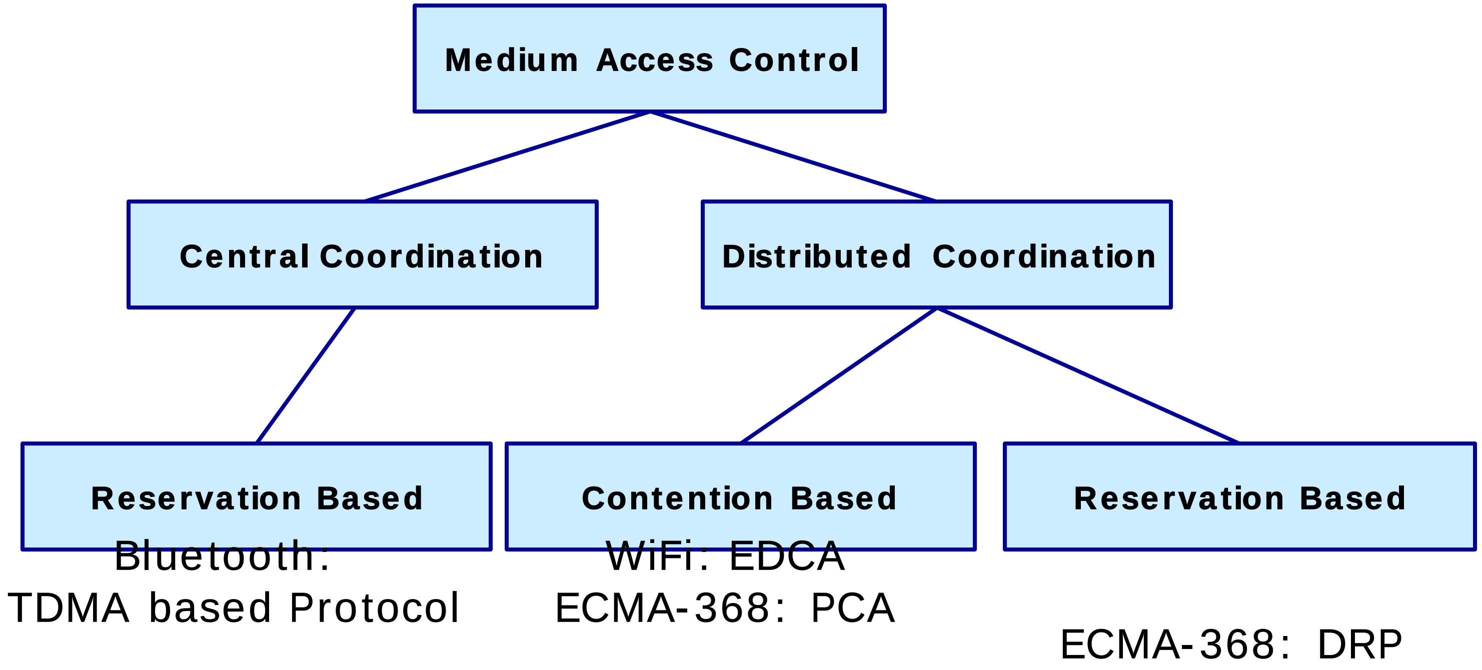

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DRP: **D**istributed **R**eservation **P**rotocol

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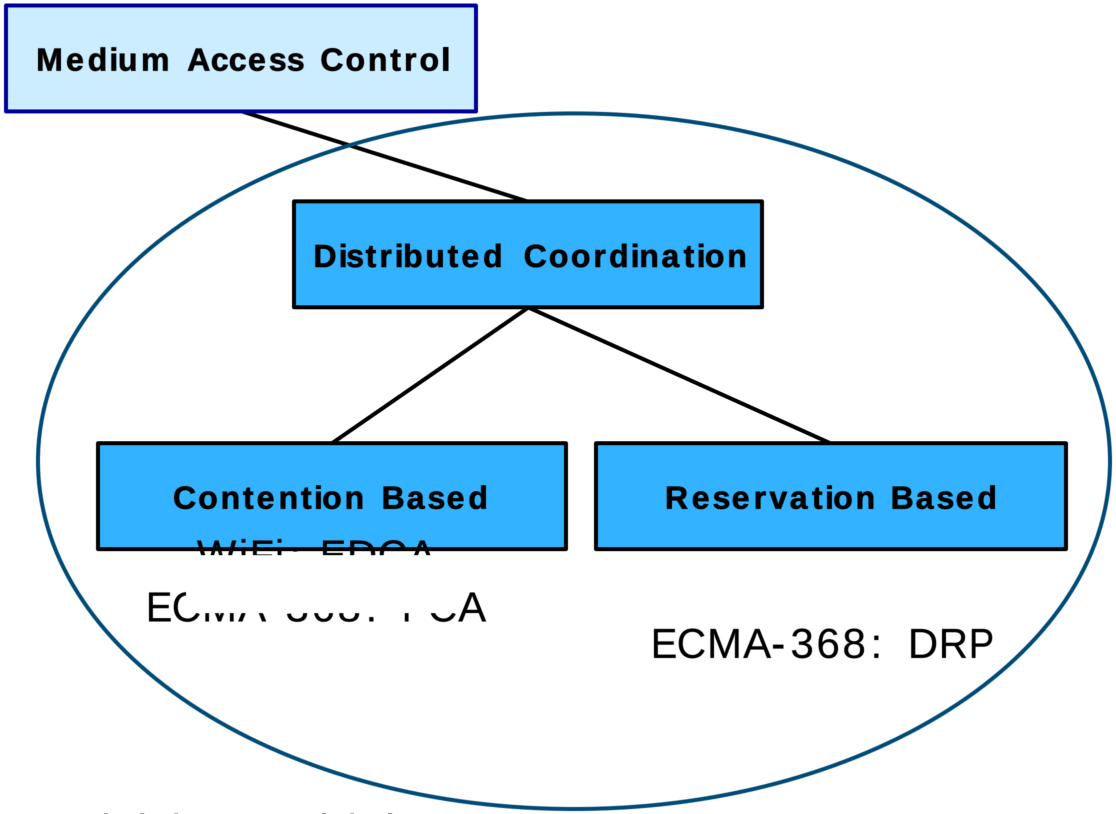

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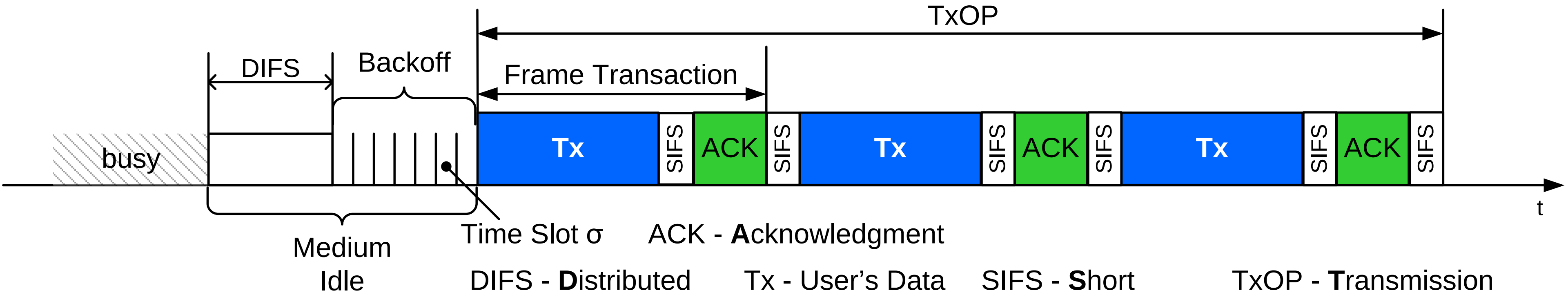
Prioritized Contention Access Protocol (PCA)

- **C**arrier **S**ense **M**ultiple **A**ccess with **C**ollision **A**voidance (CSMA/CA) Protocol derived from IEEE 802.11e
- Station chooses **B**ackoff **C**ounter (BC) uniformly from **C**ontention **W**indow ($CW_0 = 0,\ldots,CW_{min}$)
- BC is decremented as long as medium is sensed "idle"
- BC is on hold, if medium is sensed "busy"
- BC is zero, channel access is granted for Transmission Opportunity (TxOP) duration
- CW is doubled every time a collision has occured ($CW_i = 2^i CW_{min}$), $i \in (0,\ldots,m_{max})$



ACK - **A**cknowledgment

DIFS - **D**istributed **I**nterframe **S**pace

Tx - User's Data Transmission

SIFS - **S**hort **I**nterframe **S**pace

TxOP - **T**ransmission **O**pportunity

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Carrier Sense

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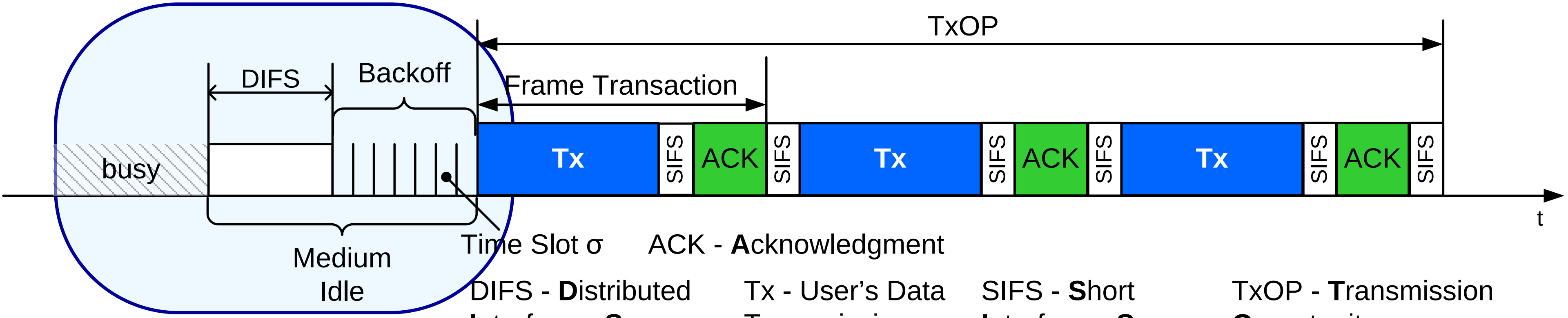

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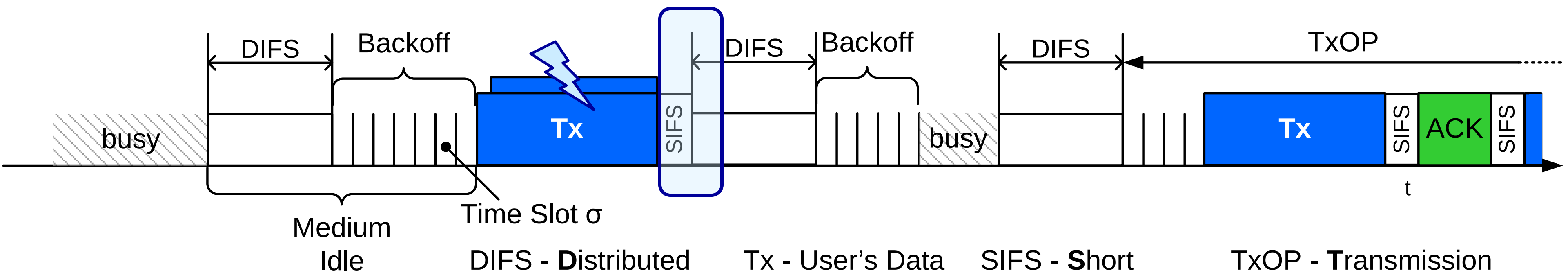
Collision Avoidance



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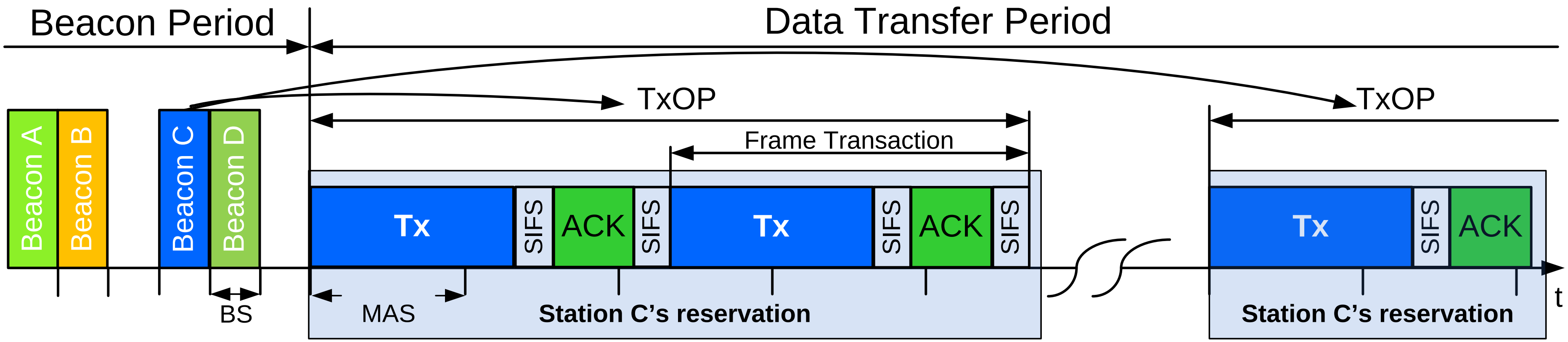
Distributed Reservation Protocol (DRP)

- Sender & receiver negotiate Medium Access Slots (MASs)
- ECMA-368 specifies Beacon Protocol for synchronization & broadcasting management information
- Reservations are announced in Beacons
- Stations in 2-hop neighborhood defer from channel access as long as sender & receiver repeat the announcement
- Data frames are sent in reserved MASs without competition

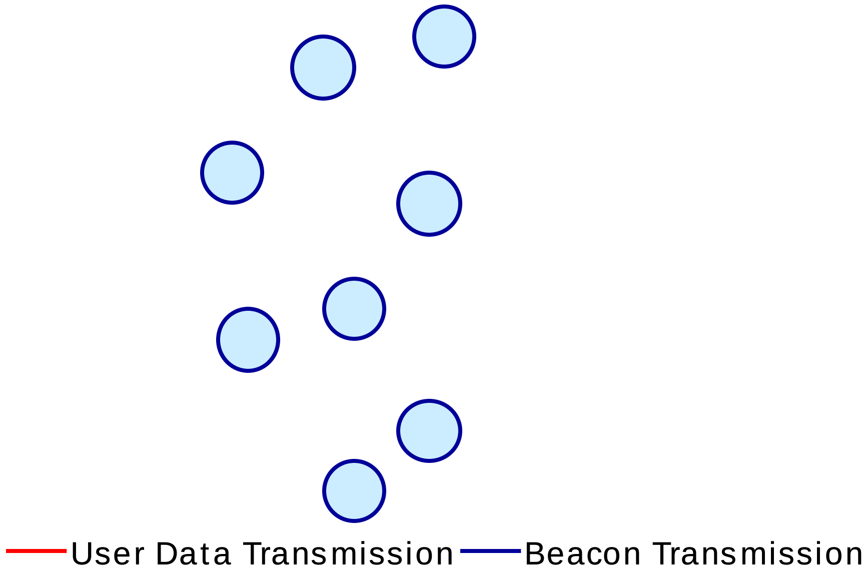


BS – Beacon Slot MAS – Medium Access Slot ACK – Acknowledgement TxOP – Transmission Opportunity SIFS – Short Interframe Space

Channel Reuse DRP & PCA

- DRP: individual 1-Hop neighborhood is called Beacon Group (BG)
- MAS reservation is protected, if Beacon is **decoded**
- PCA: Station stops decrementing BC, if transmission is **detected**
- Carrier Sense Range typically exceeds Beacon Range
- Channel reuse PCA: Distance between stations greater Carrier Sense Range
  - Reuse depends on random channel access
- Channel reuse DRP: Distance between stations greater Beacon Range
  - Reuse depends on coordinated channel access

➢ Hypothesis: DRP yields higher channel reuse gain than PCA



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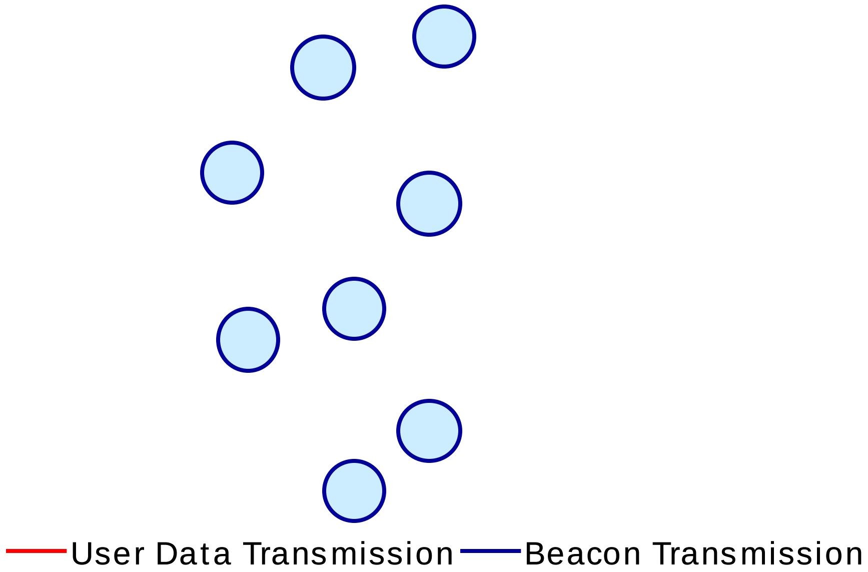

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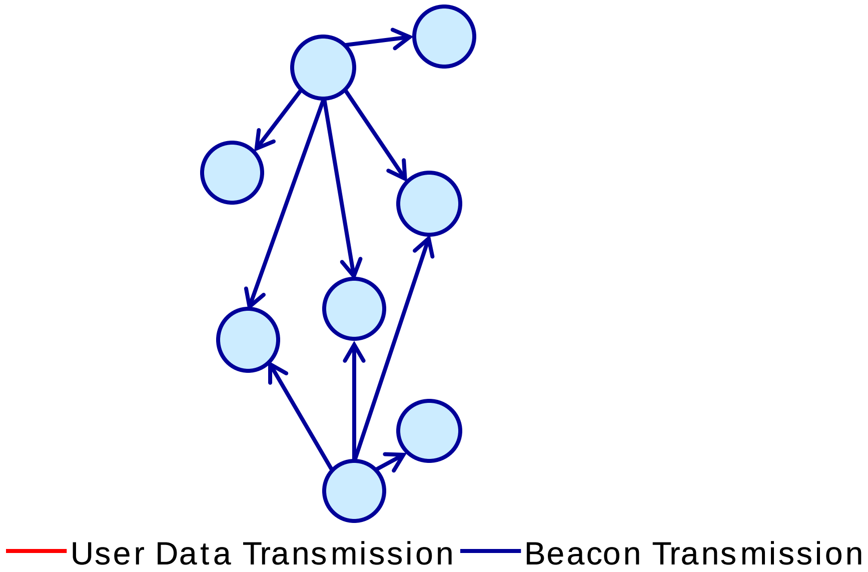

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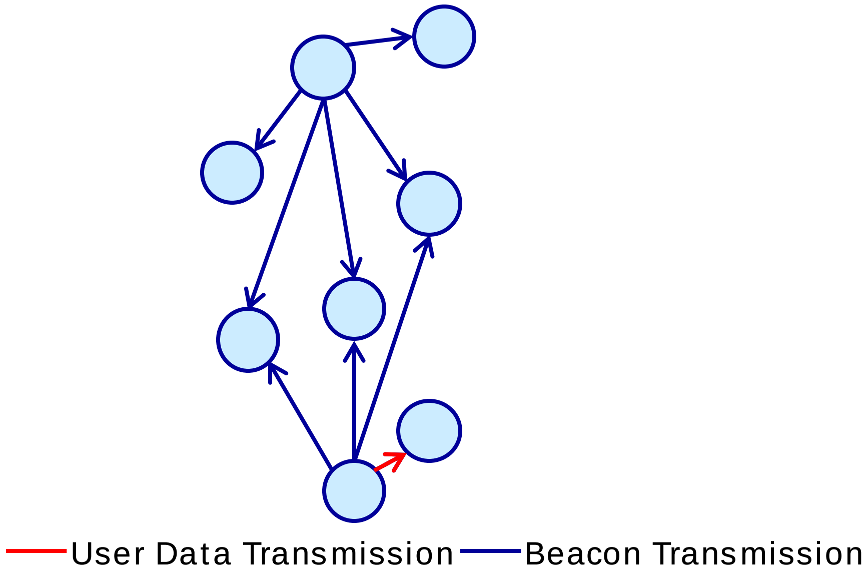

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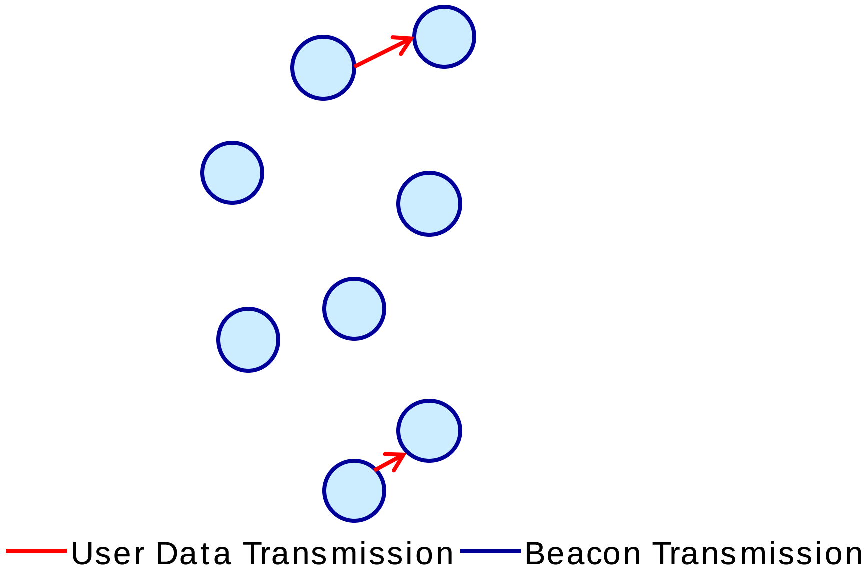

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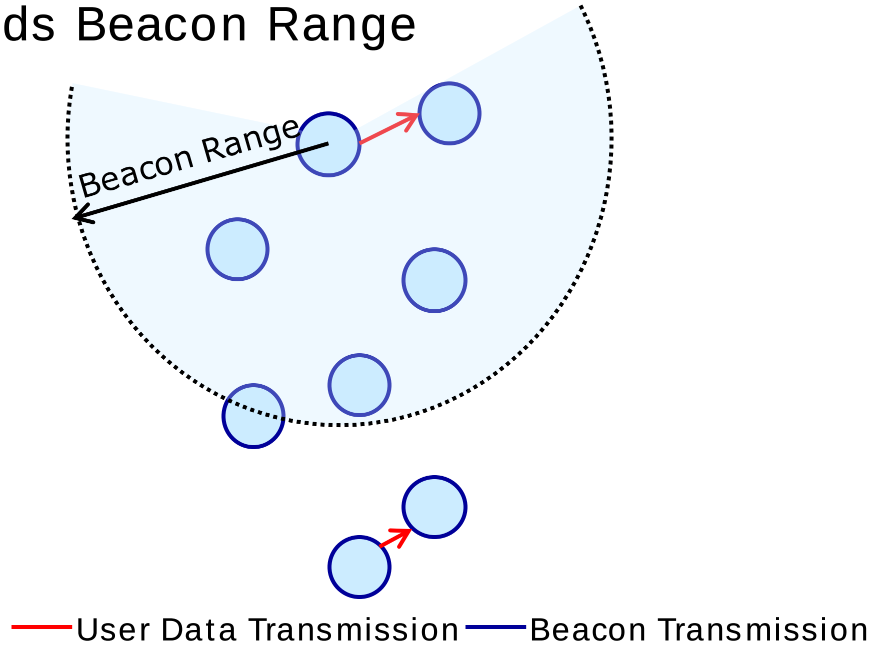

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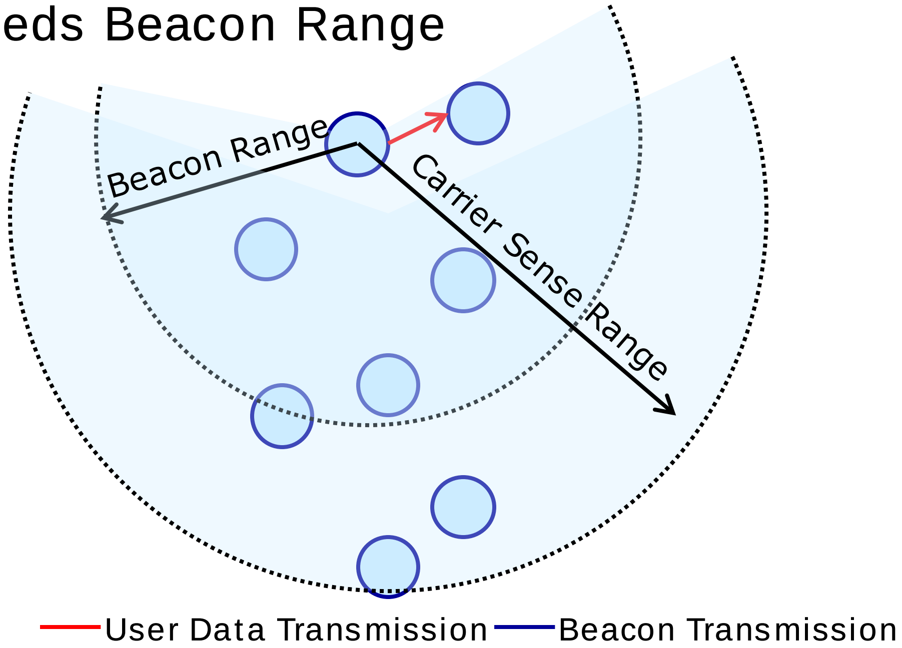

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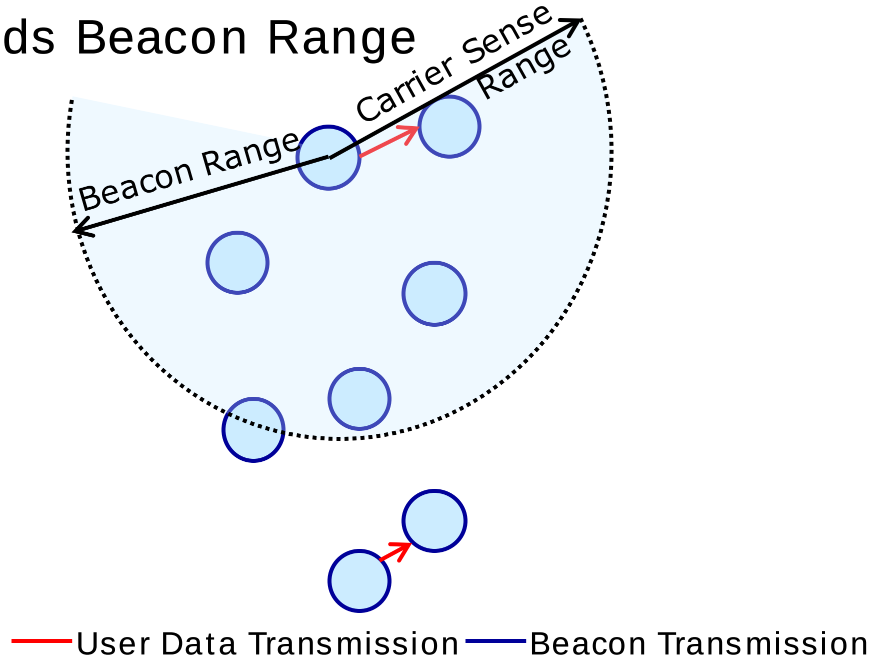

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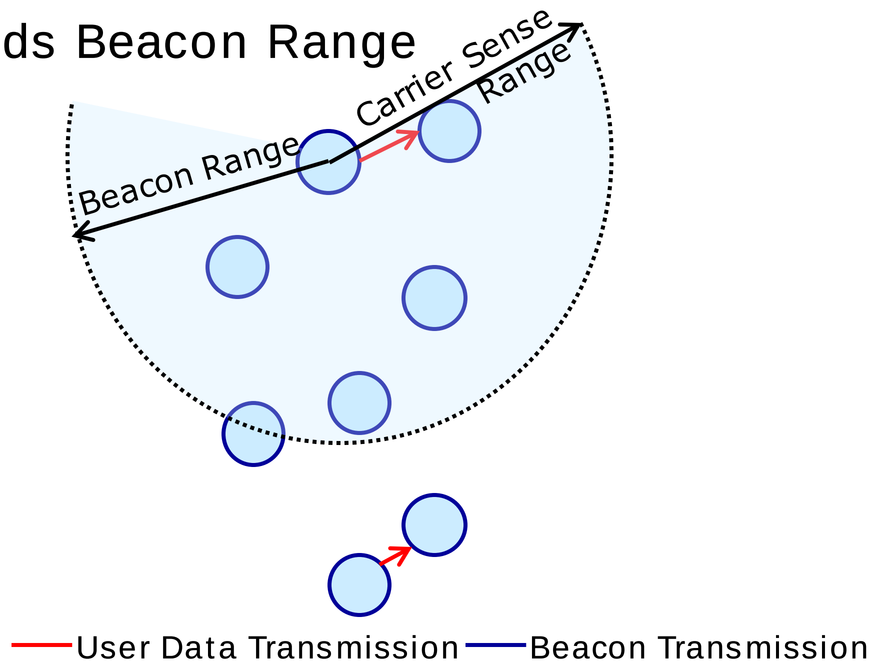


Model PCA Performance Literature

- [1] is often cited publication for modeling IEEE 802.11 performance
- Assumption: each station is in mutual Carrier Sense Range
- Solving a two-dimensional Markov chain leads to [1]:

$$\tau = \frac{2(1-2p)}{(1-2p)(W+1) + pW(1-(2p)^m)} \quad (1.1)$$

$$p = 1-(1-\tau)^{n-1} \quad (1.2)$$

τ - Transmission probability
p - Collision probability
W - Minimum Contention Window
n - Number of Stations
m - Maximal Backoff stage

- System throughput is [1]:

$$S = \frac{P_s P_{tr} L}{(1-P_{tr})\sigma + P_s P_{tr} T_s + P_{tr}(1-P_s) T_c} \quad (1.3)$$

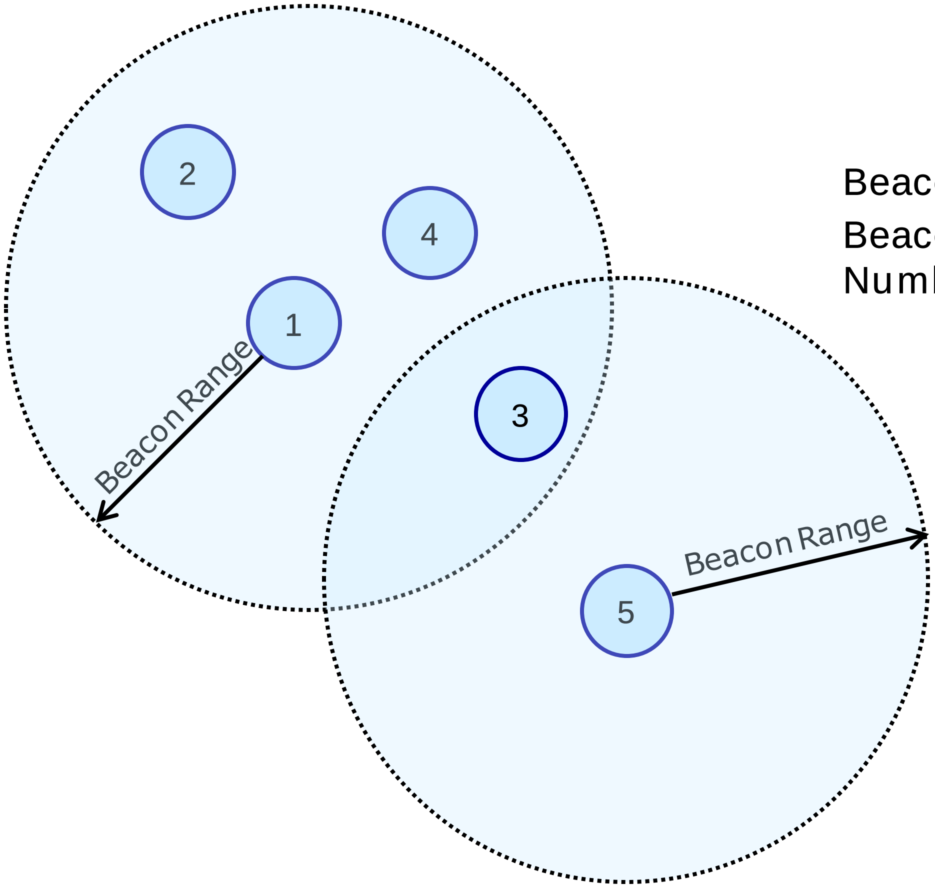
S - System throughput
P_s - Conditonal probability of successful transmission
L - Frame lenght [bit]
T_s - Frame Transaction duration
T_c - Time wasted in collision

➢ Next: stations not in mutual Carrier Sense Range

[1] Bianchi, G.: Performance analysis of the IEEE 802.11 distributed coordination function. Selected Areas in Communications, IEEE Journal on, mar 2000

Enhanced PCA Performance Model

- Probabilities become station dependant τ_i , p_i , P_{s_i} , P_{tr_i} , n_i , with $i \in (0,..,N-1)$ N - Number of stations



Beacon Group station 1: $\{1,2,3,4\}$, $n_1 = 4$
Beacon Group station 5: $\{3,5\}$, $n_5 = 2$
Number of stations in total: $N = 5$

Enhanced PCA Performance Model

- Probabilities become station dependant τ_i, p_i, P_{s_i}, P_{tr_i}, n_i, with $i \in (0,..,N-1)$ N - Number of stations
- Eq. (1.1) becomes:

$$\tau_i = \frac{2(1-2p_i)}{(1-2p_i)(W+1)+p_iW(1-(2p_i)^m)} \quad (1.4)$$

- Eq. (1.2) becomes:

$$p_i = 1-(1-\tau_i)^{n_i-1} \quad (1.5)$$

- Eq. (1.3) considering TxOP length becomes:

$$S = \sum_{i=0}^{N-1} \frac{LN_f P_{s_i} P_{tr_i}}{(1-P_{tr_i})\sigma + P_{s_i}P_{tr_i}T_{TxOP} + P_{tr_i}(1-P_{s_i})T_c}$$
$$= \frac{L}{T_{ft}} \cdot \sum_{i=0}^{N-1} \frac{N_f T_{ft} P_{s_i} P_{tr_i}}{(1-P_{tr_i})\sigma + P_{s_i}P_{tr_i}T_{TxOP} + P_{tr_i}(1-P_{s_i})T_c} = \frac{L}{T_{ft}} \cdot k_{PCA} \quad (1.6)$$

τ_i - Transmission probability
p_i - Collision probability
W - Minimal Contention Window
n_i - Number of Stations
m - Maximal Backoff stage

S - System throughput
P_{si} - Conditonal probability of successful transmission
L - Frame length [bit]
T_{TxOP} - TxOP duration
T_c - Time wasted in collision
N_f - Number of frames in TxOP
T_{ft} - Frame Transaction duration

➢ Eqs. (1.4), (1.5) are solved numerically by Monte Carlo Experiment

Model DRP Performance

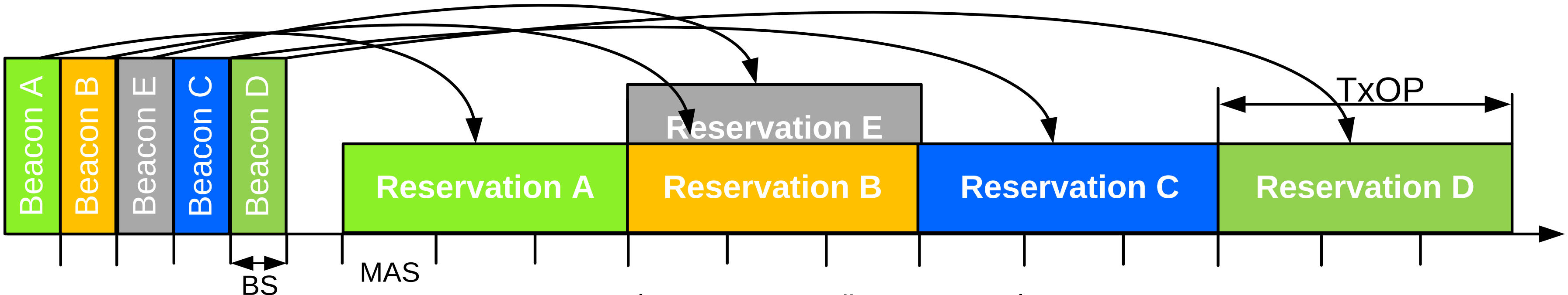
- Contention free channel access: No performance degradation through collisions
- Beacon overhead depends on number of stations, neglected in the following: 45 stations in fully meshed network, approx. 6%
- Assumptions: optimal channel resource (re-)use
- Throughput:

$$S = \frac{L}{T_{ft}} \cdot k_{drp} \qquad (1.8)$$

with

$$k_{drp} = \sum_{i=0}^{N-1} \frac{1}{n_i} \qquad (1.9)$$

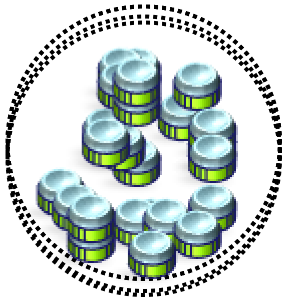
S - System throughput
L - Frame length [bit]
T_{ft} - Frame Transaction duration
n_i - Number Beacon Group Members
N - Total number of Stations



BS – Beacon Slot MAS – Medium Access Slot TxOP – Transmission Opportunity

Scenario

- 2, 5, 9 overlapping Wireless Personal Area Networks (WPANs)
  - Stations within a WPAN are placed in mutual decoding range
- 5 Stations are randomly placed in each WPAN (250 seeds)
- Center distance (d) between WPANs is increased
- For each distance, k_{drp} and k_{pca} are calculated by Monte Carlo Experiment
- Beacon Range: 14m
- MCS: 160Mb/s
- Frame Length: 1500B
- PCA related parameters:
  - CW_{min}: 16
  - CW_{max}: 1024
  - DIFS: 46µs
  - TxOP: 512µs



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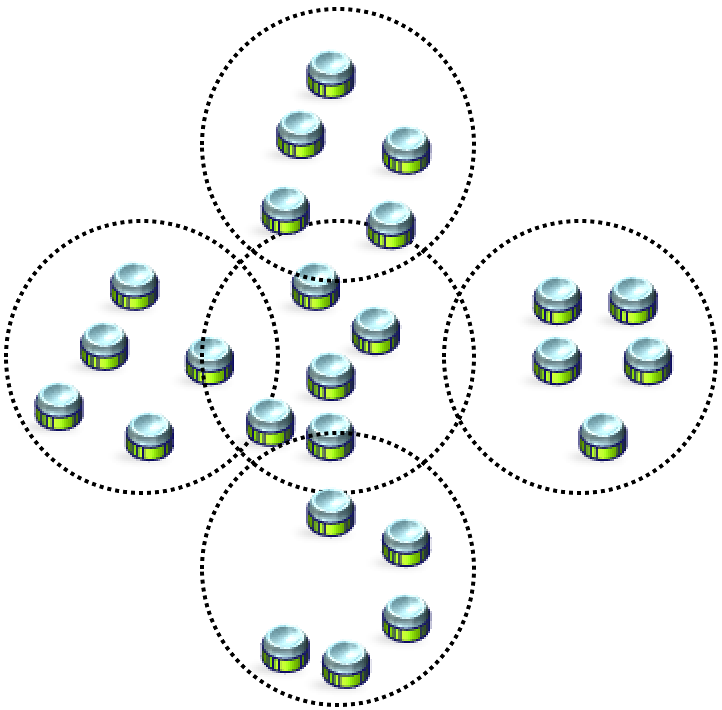

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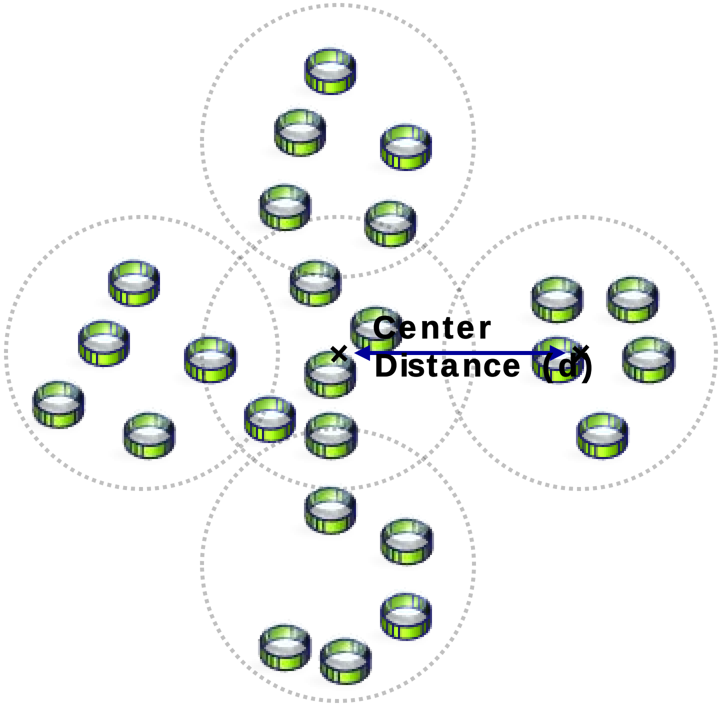
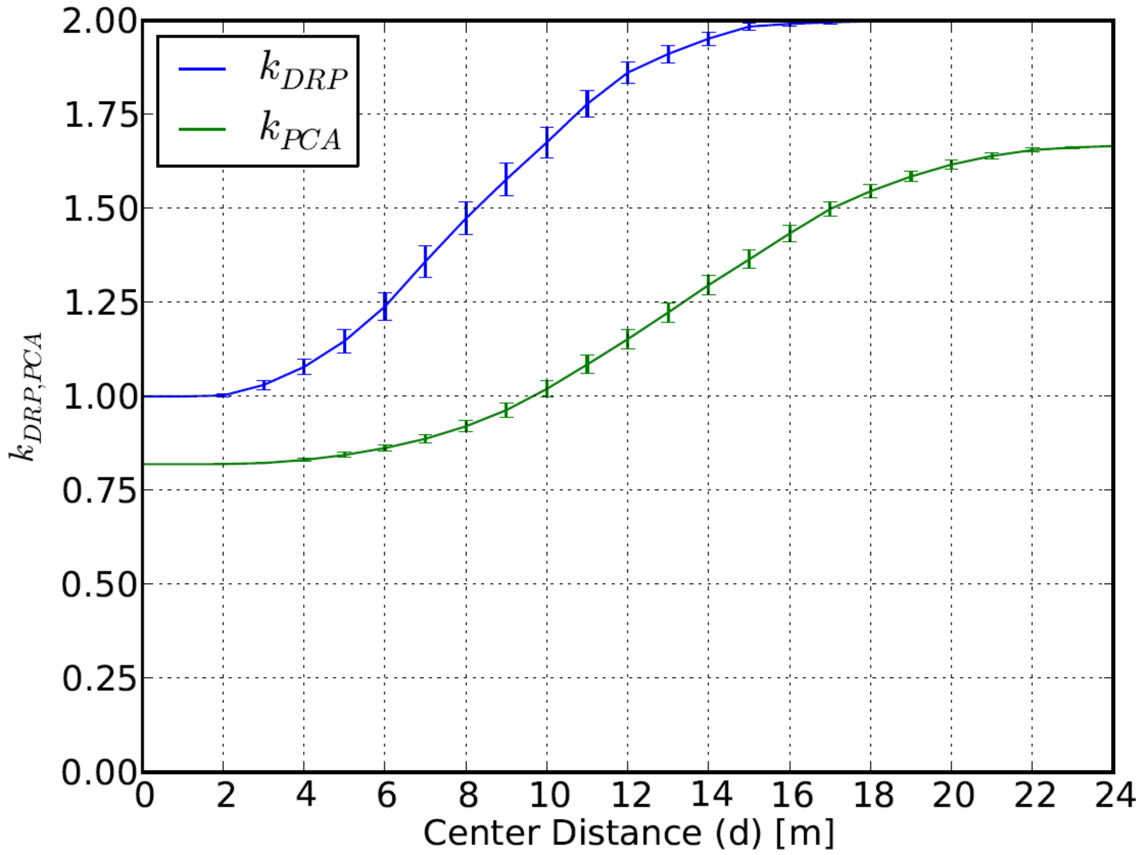


Results
Comparison of k_{PCA} & k_{DRP}

2 WPANs, 5 Stations per WPAN



- ➢ PCA: Channel access efficiency does not increase with decreasing number of contending stations

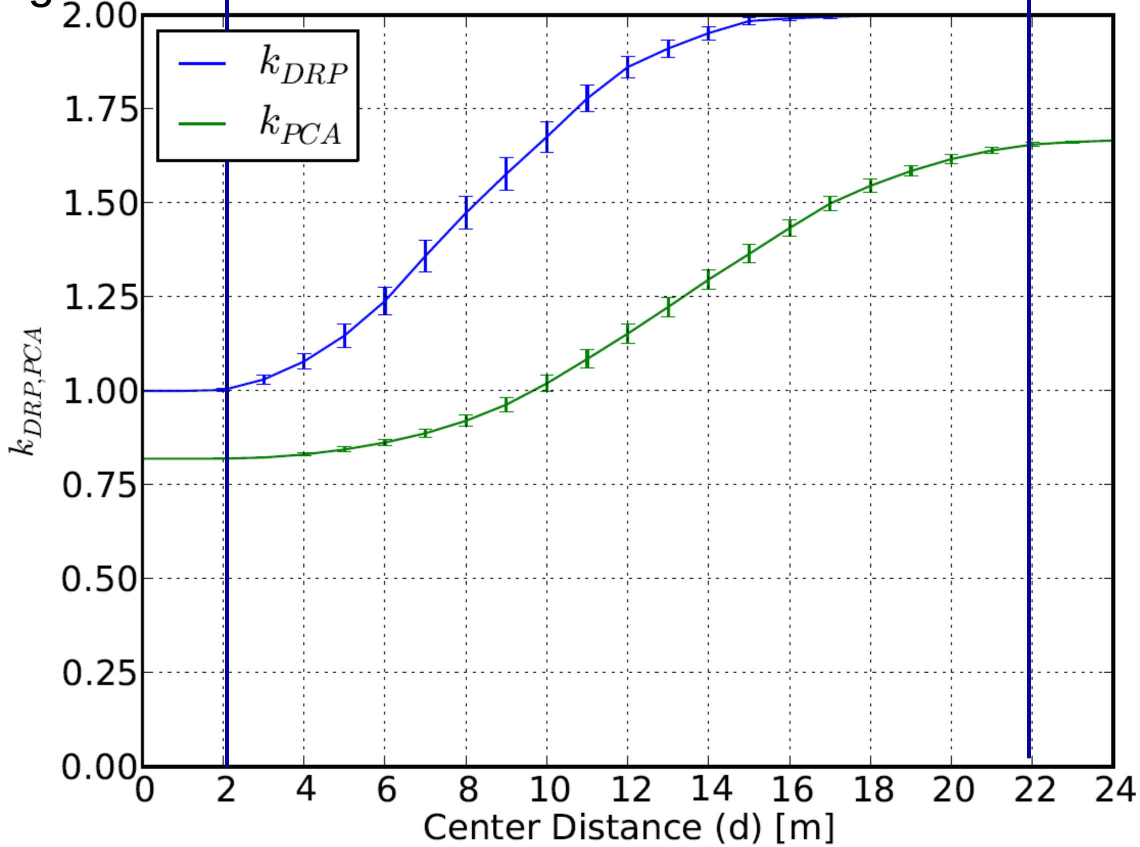
Results
Comparison of k_{PCA} & k_{DRP}

2 WPANs, 5 Stations per WPAN

Completely overlapping

Partially overlapping

Non-overlapping



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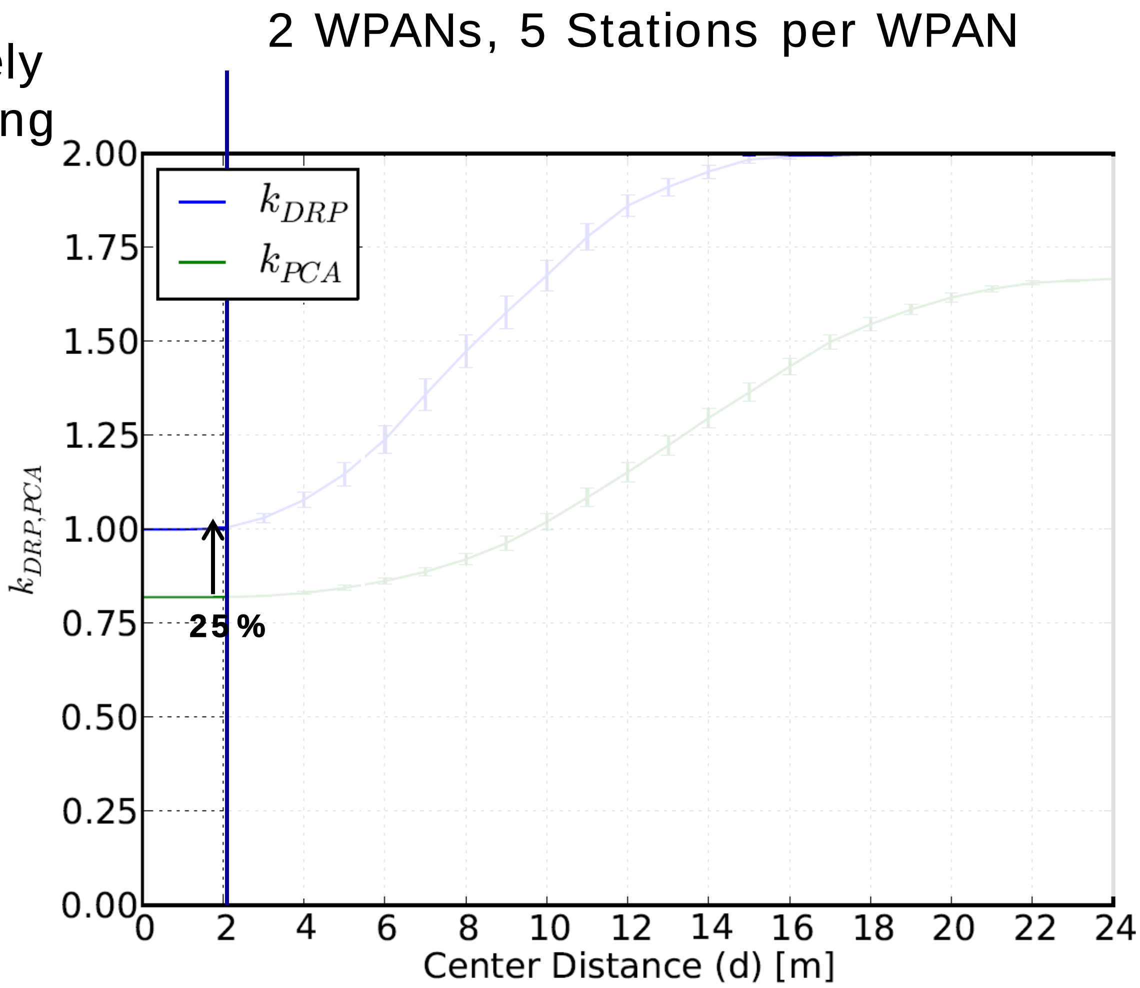

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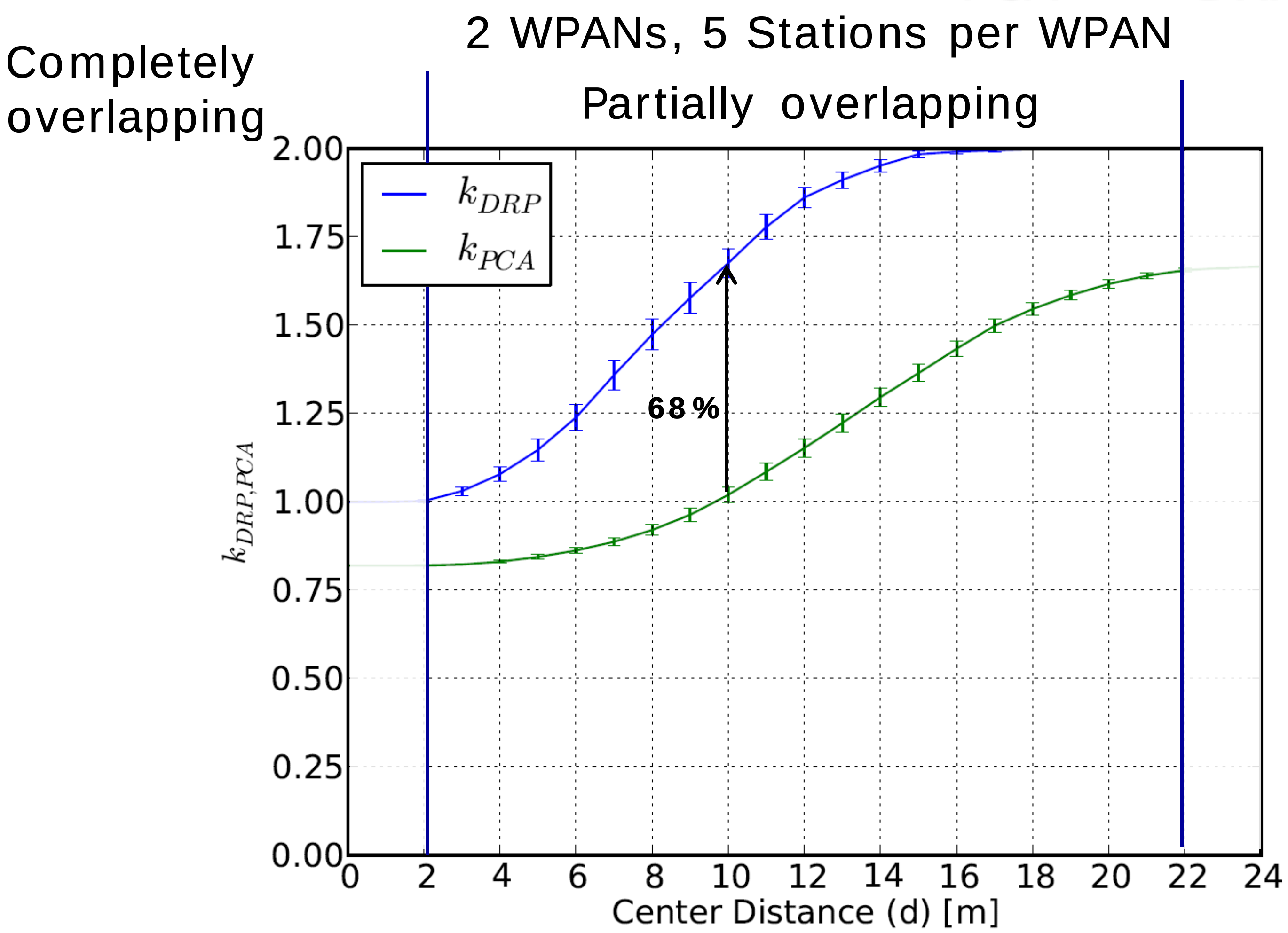

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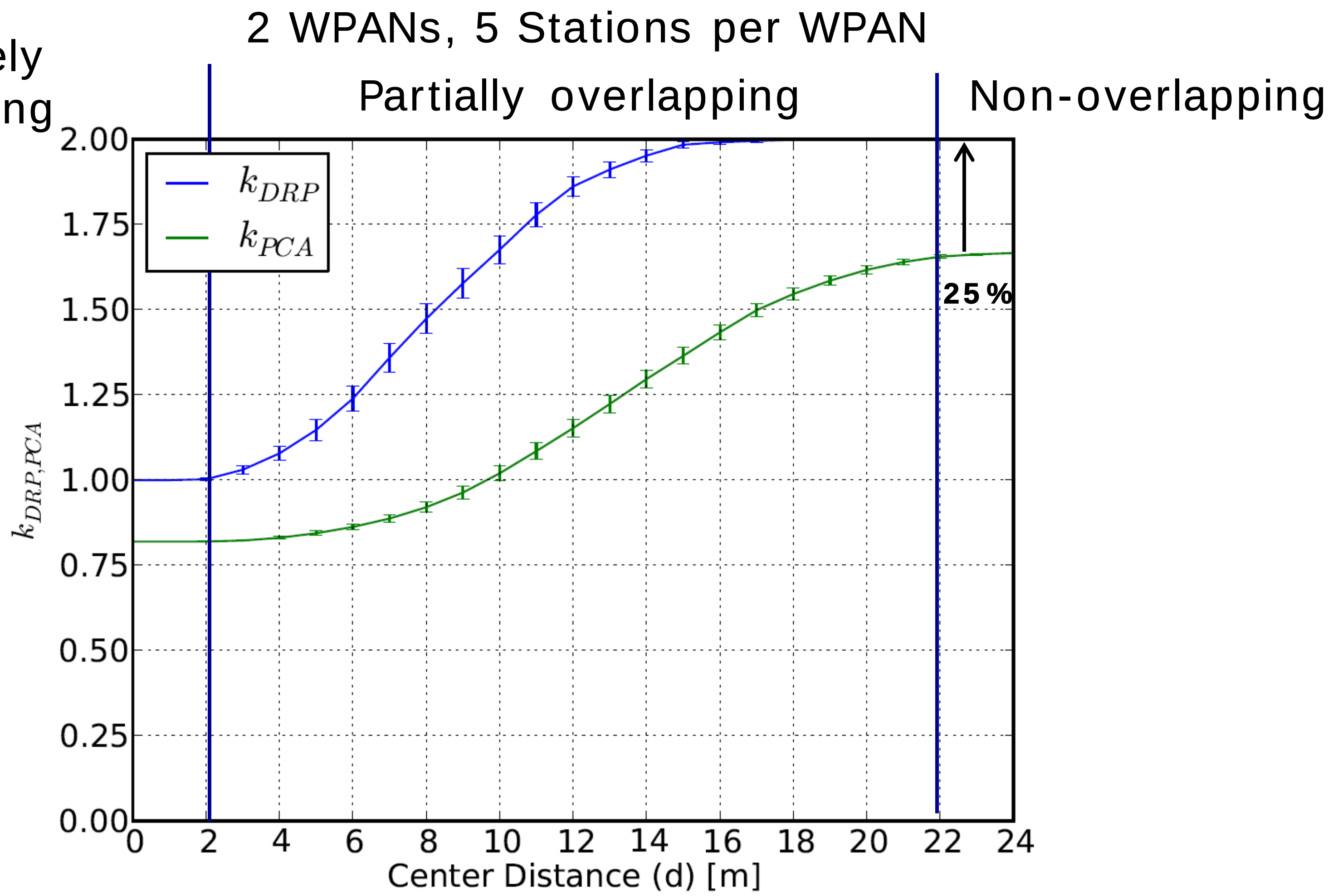

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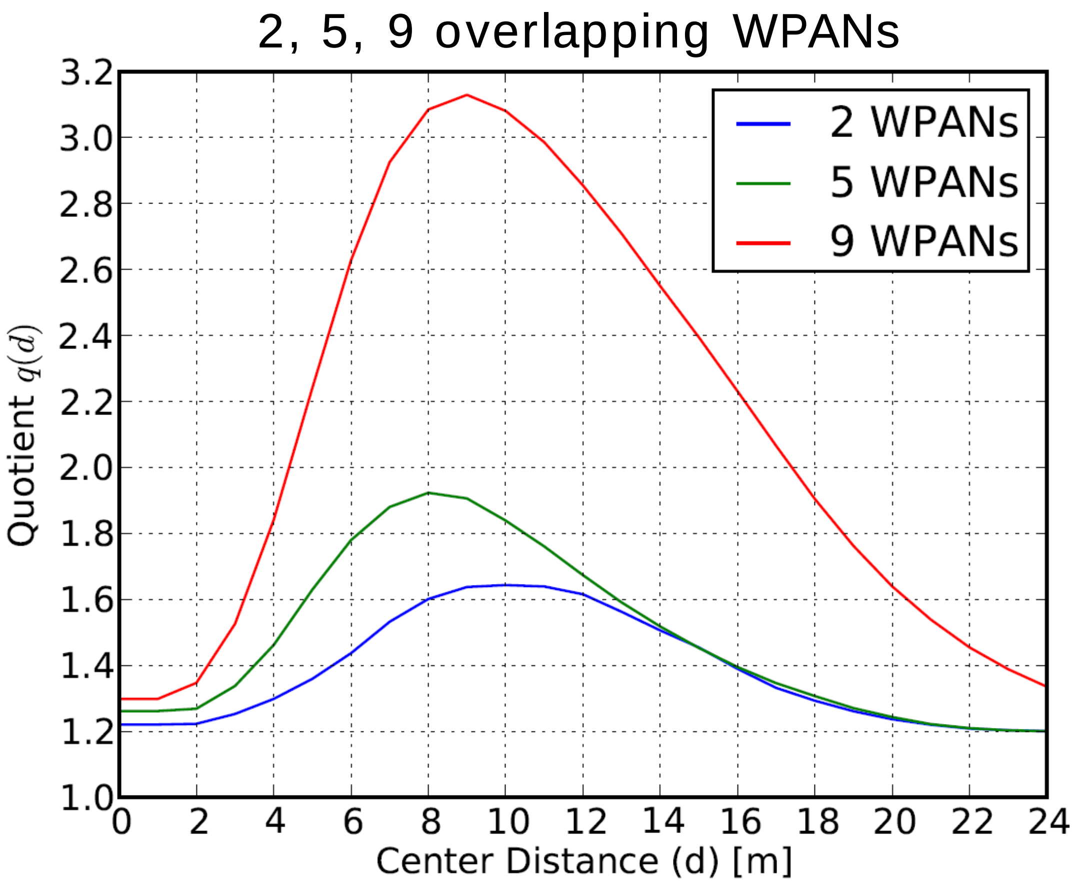
Results
DRP System Capacity Gain



$$q(d) = \frac{k_{DRP}}{k_{PCA}}$$

- PCA reuse depends on random process
- DRP benefits from higher channel (re-)use efficiency

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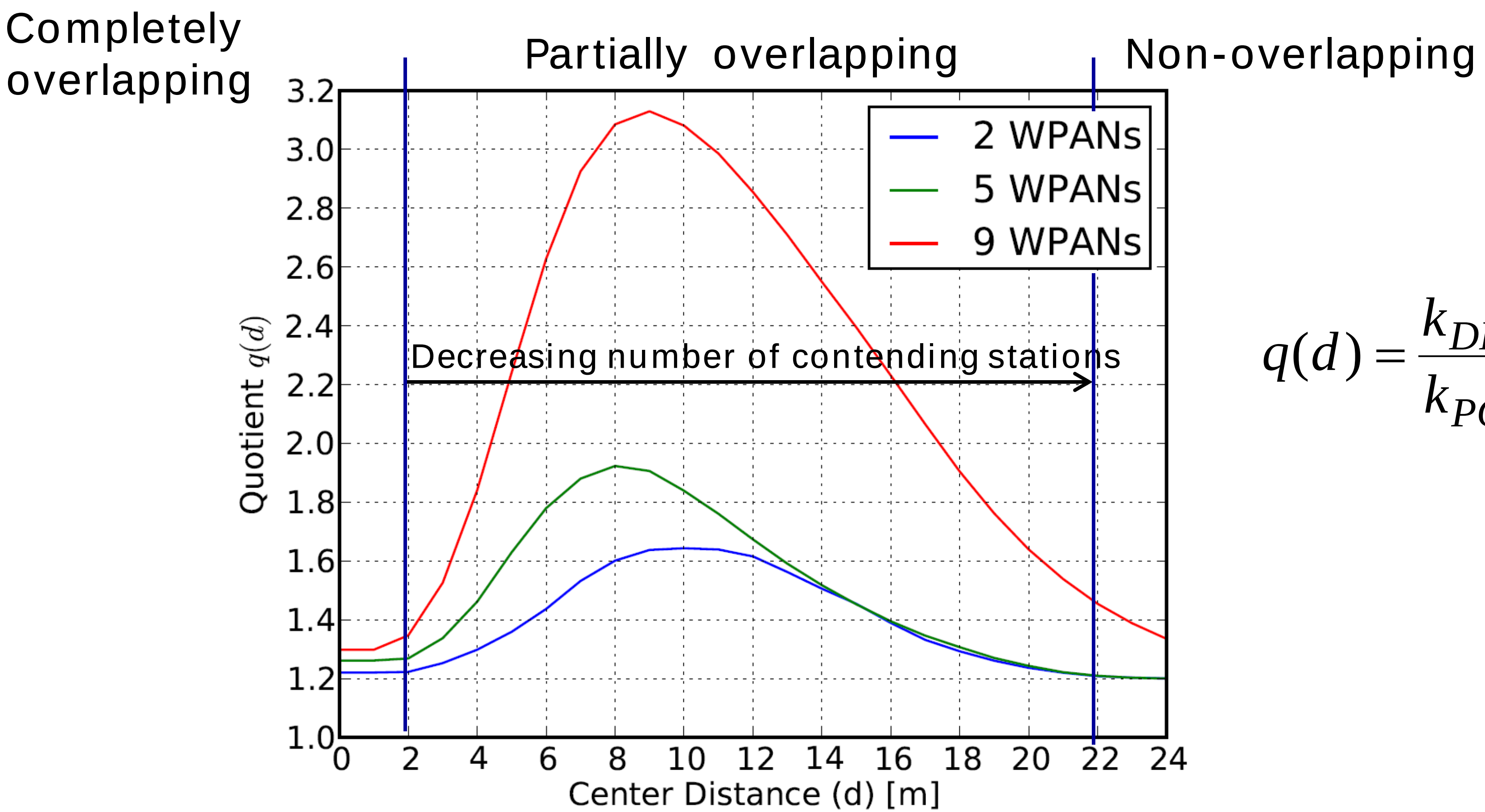

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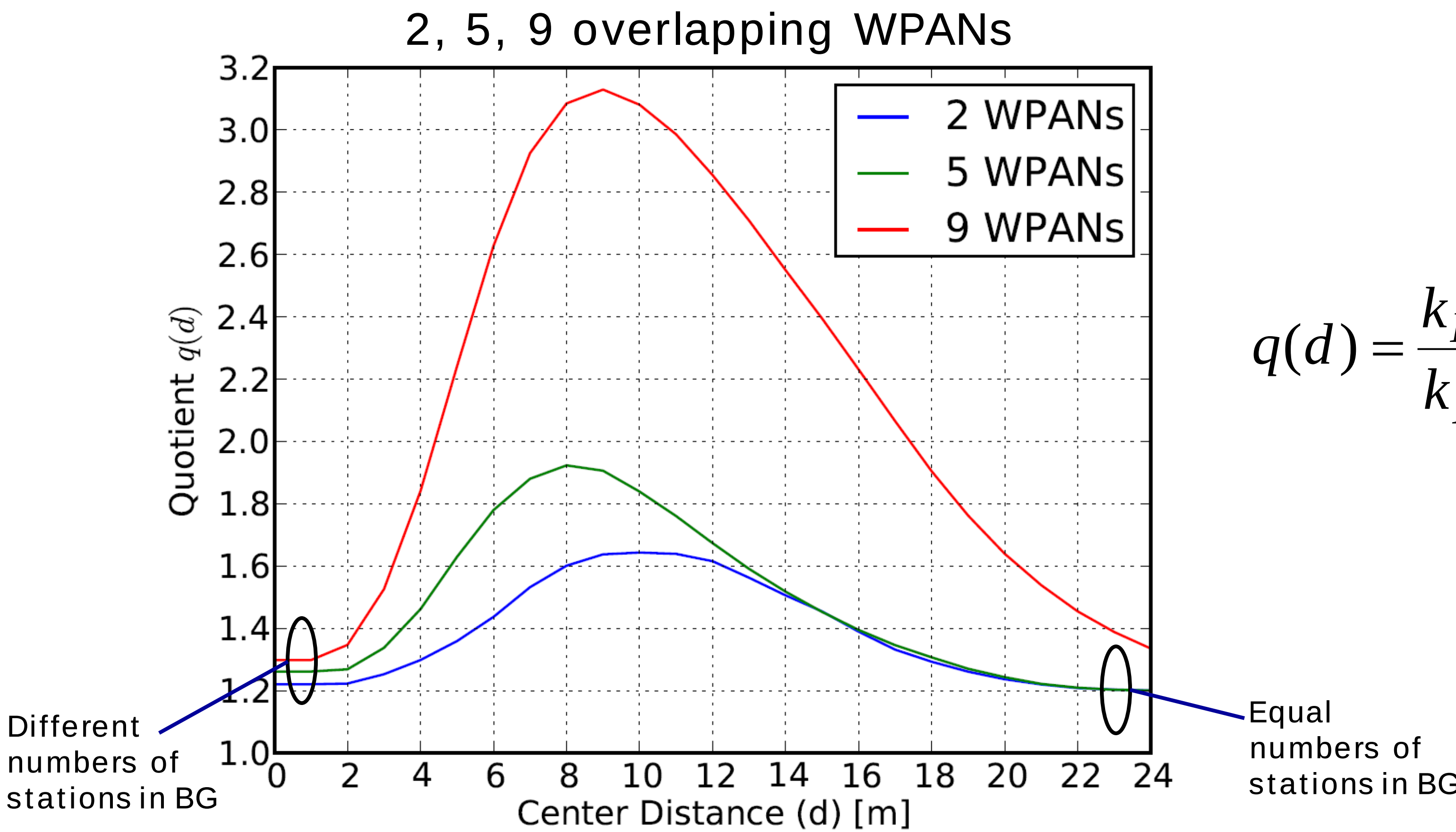
Results
DRP System Capacity Gain



$$q(d) = \frac{k_{DRP}}{k_{PCA}}$$

- PCA reuse depends on random process
- DRP benefits from higher channel (re-)use efficiency

Conclusion

- Limited radio resources require efficient MAC protocols
- Enhancement of an often used analytical model to examine PCA in partially overlapping networks
- Comparison shows:
  - PCA suffers from inefficient spatial channel reuse
  - DRP exploits channel reuse capabilities
- DRP exceeds PCA in partially overlapping network scenarios up to factor of 3

Thank you for your attention!

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