Performance Evaluation of DRPNext in ECMA-368 Wireless Personal Area Networks

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- Ultra-Wideband (UWB) ECMA-368 Standard
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Motivation

- Widespread use of wireless networks operating in license-exempt frequency bands
- Growing interest in distributed wireless networks for very high data rate communication in residential home environments

➡ Motivation to use UWB ECMA-368

- Nodes in not fully meshed network scenarios without central coordination suffer from hidden and exposed nodes reducing spectral efficiency

➡ Need for MAC protocols to use channel resources efficiently

Hidden & Exposed Nodes

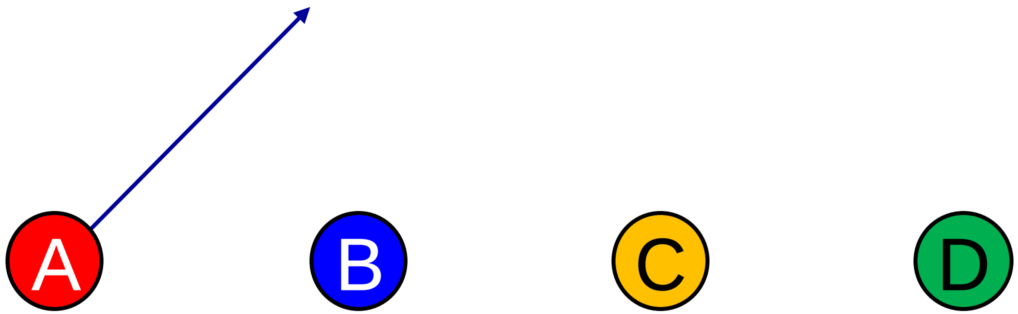
- Carrier sense for random channel access in not fully connected wireless network scenarios gives information on interference at transmitting node position

- Hidden Node:
  - Transmitting Node underestimates interference at receiving node position

- Exposed Node:
  - Transmitting Node overestimates Interference at receiving node position

Hidden & Exposed Nodes

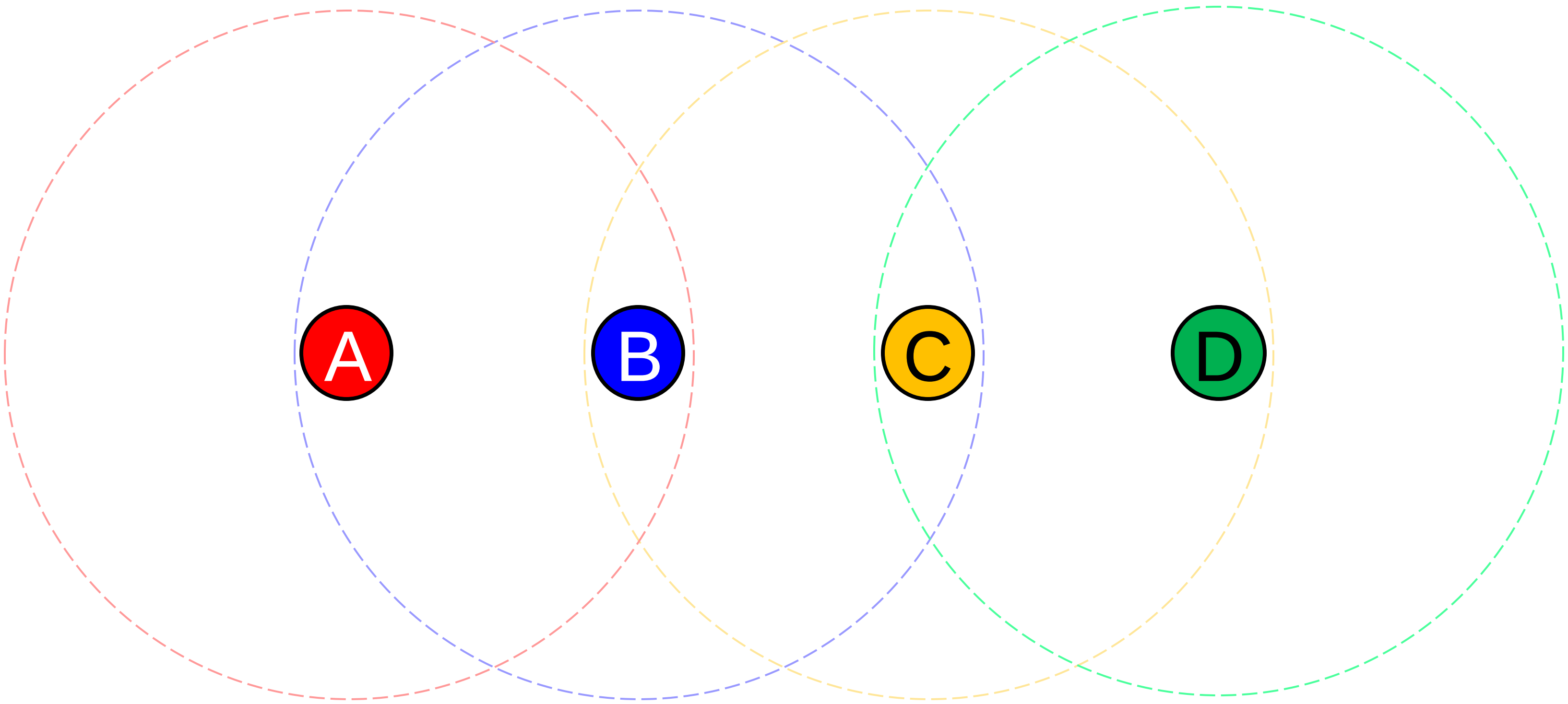
Hidden & Exposed Nodes



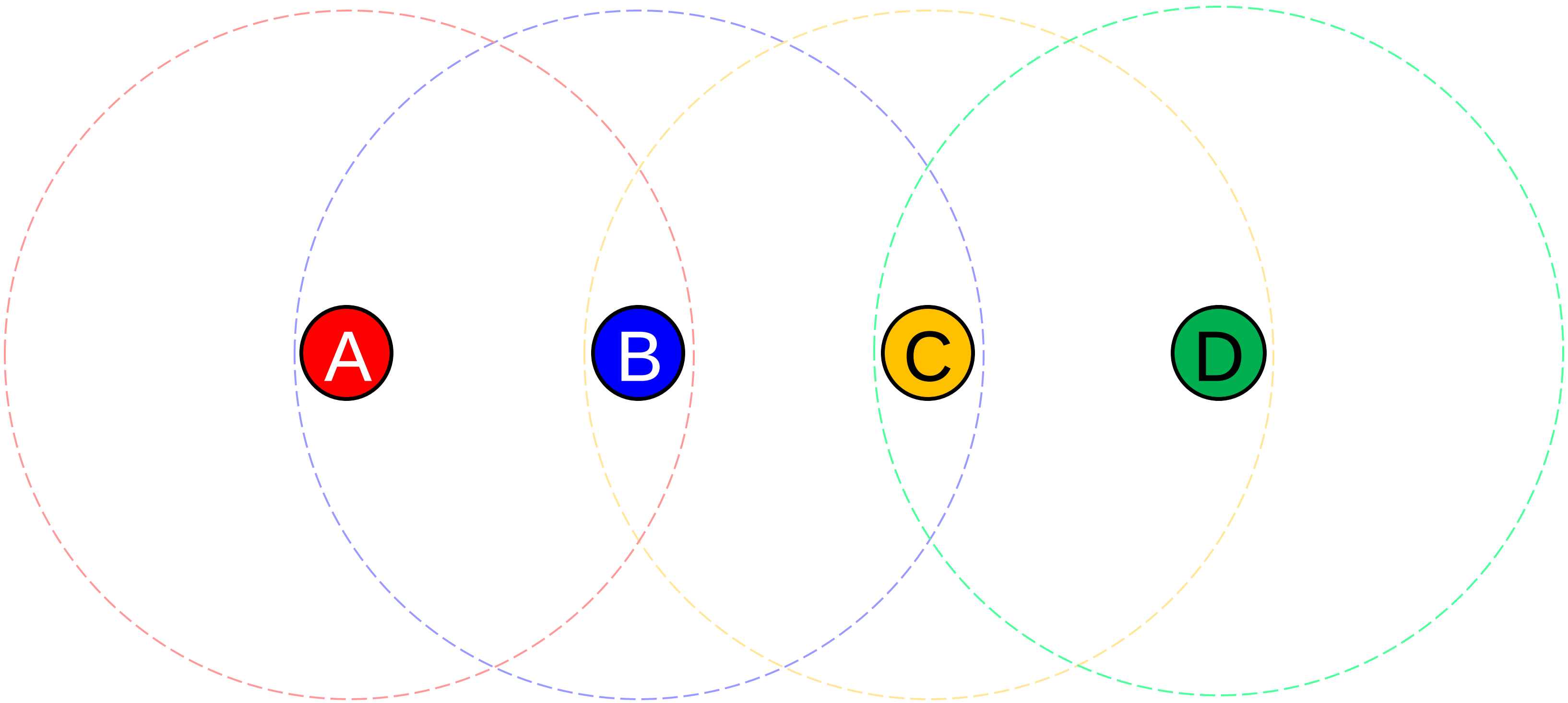
Detection Range

Node

Hidden & Exposed Nodes



Hidden node problem



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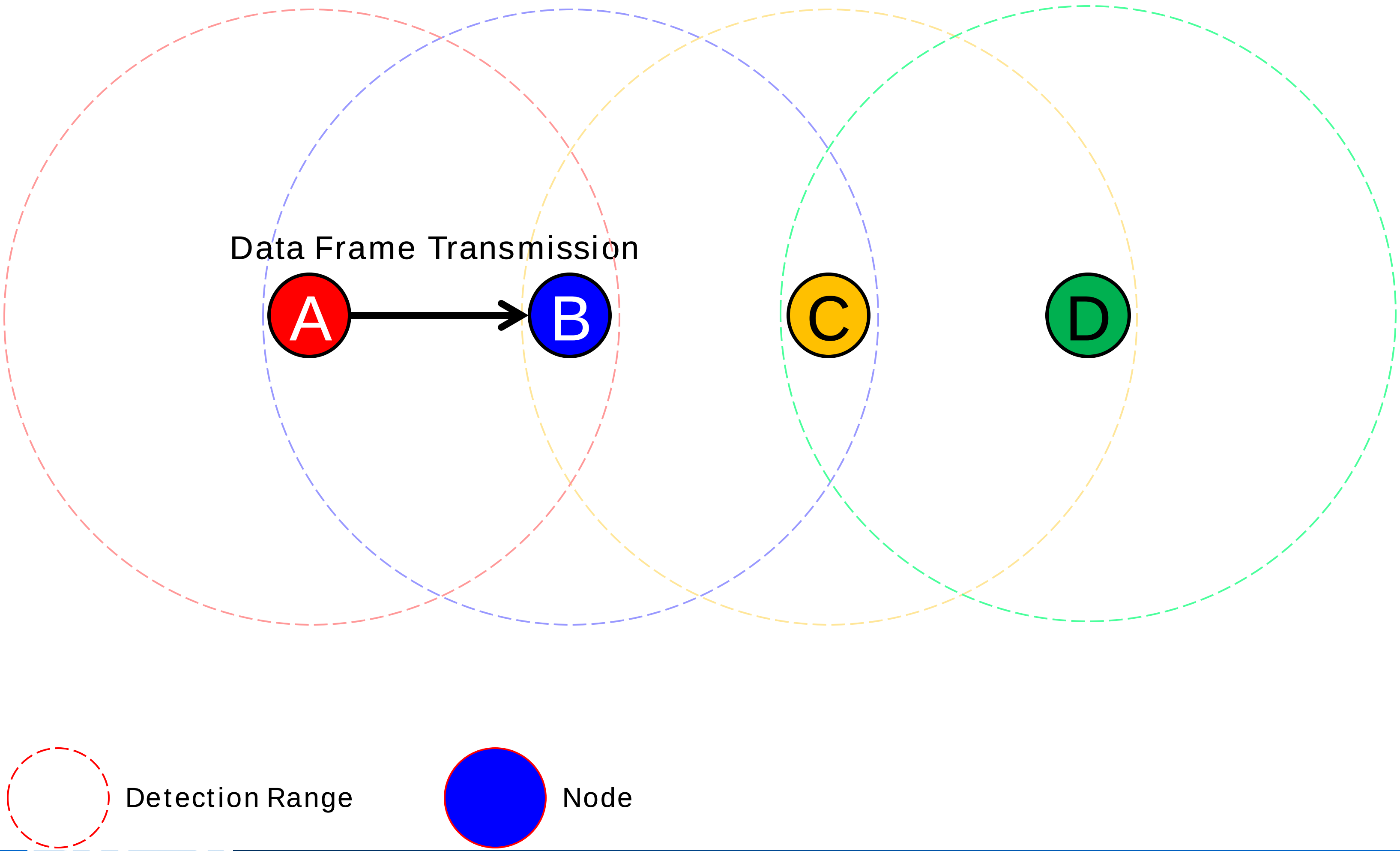

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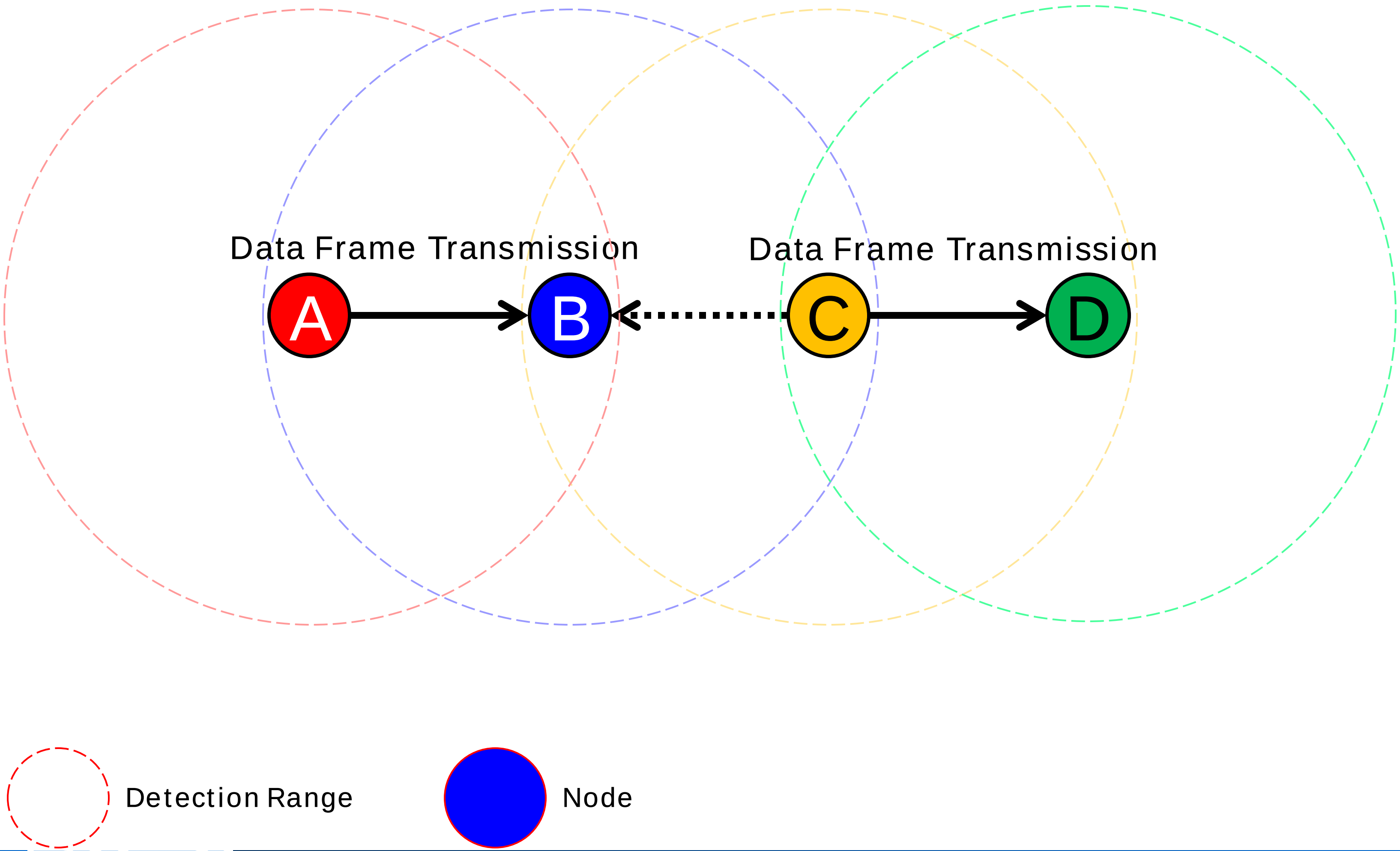

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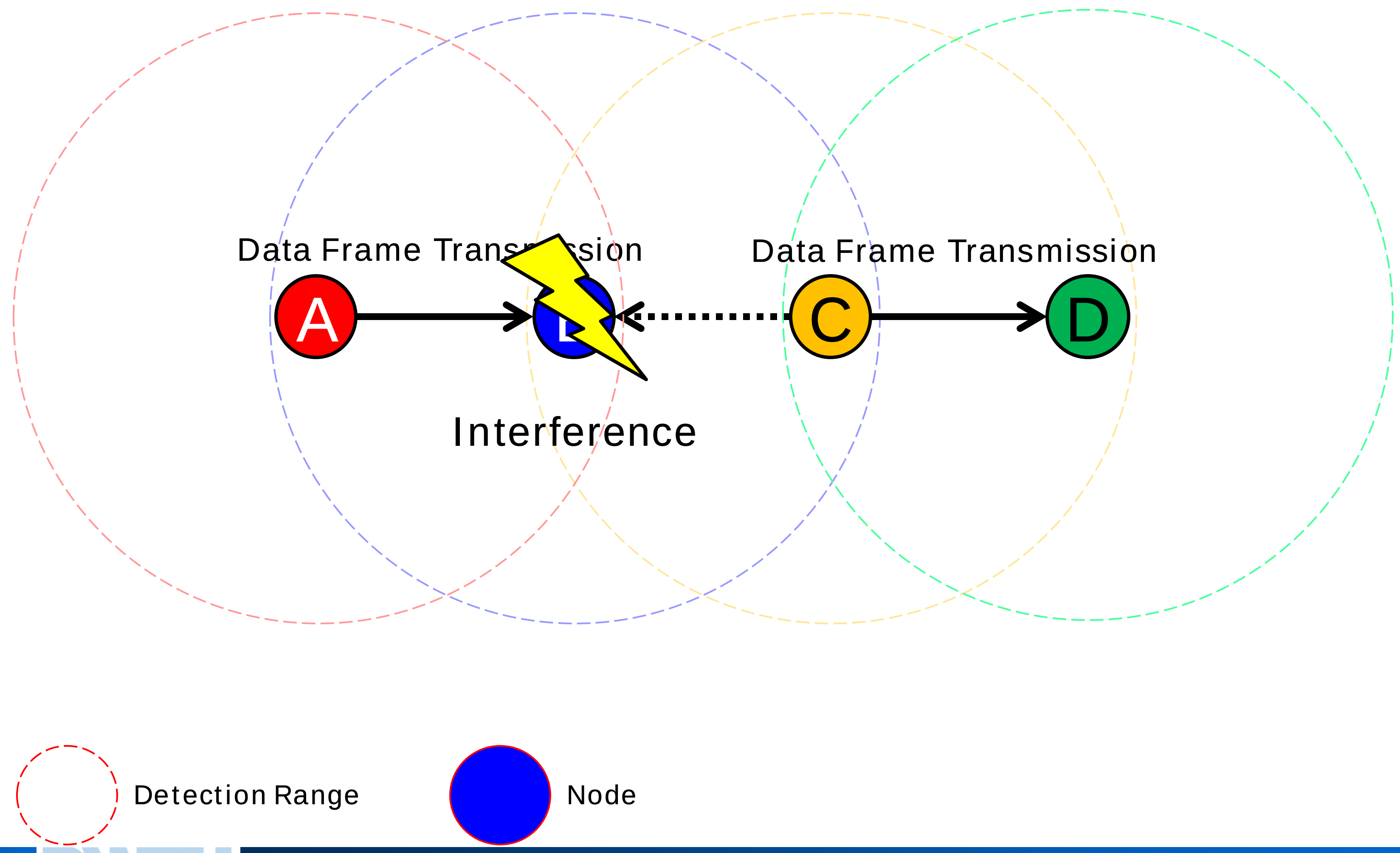
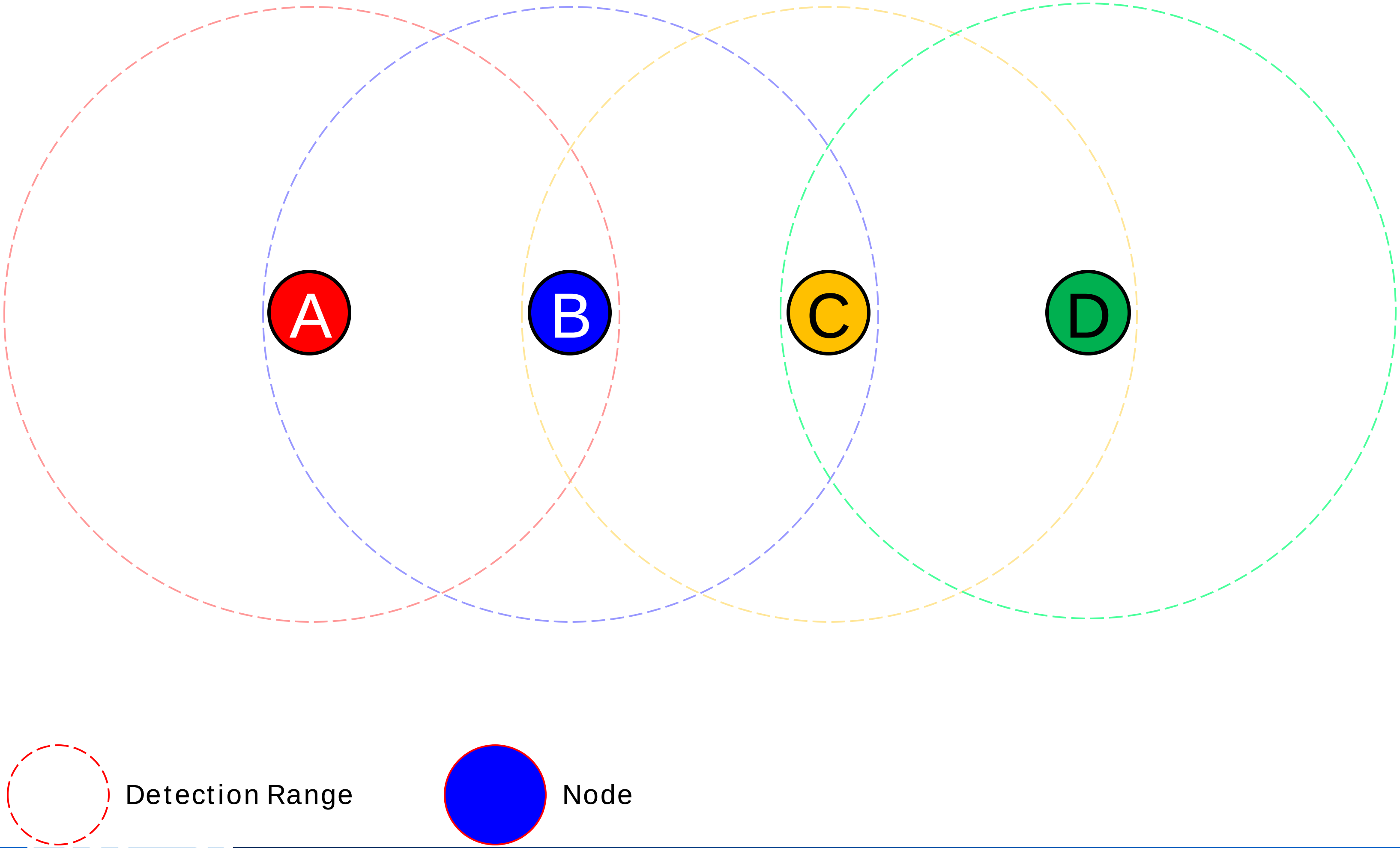


Exposed node



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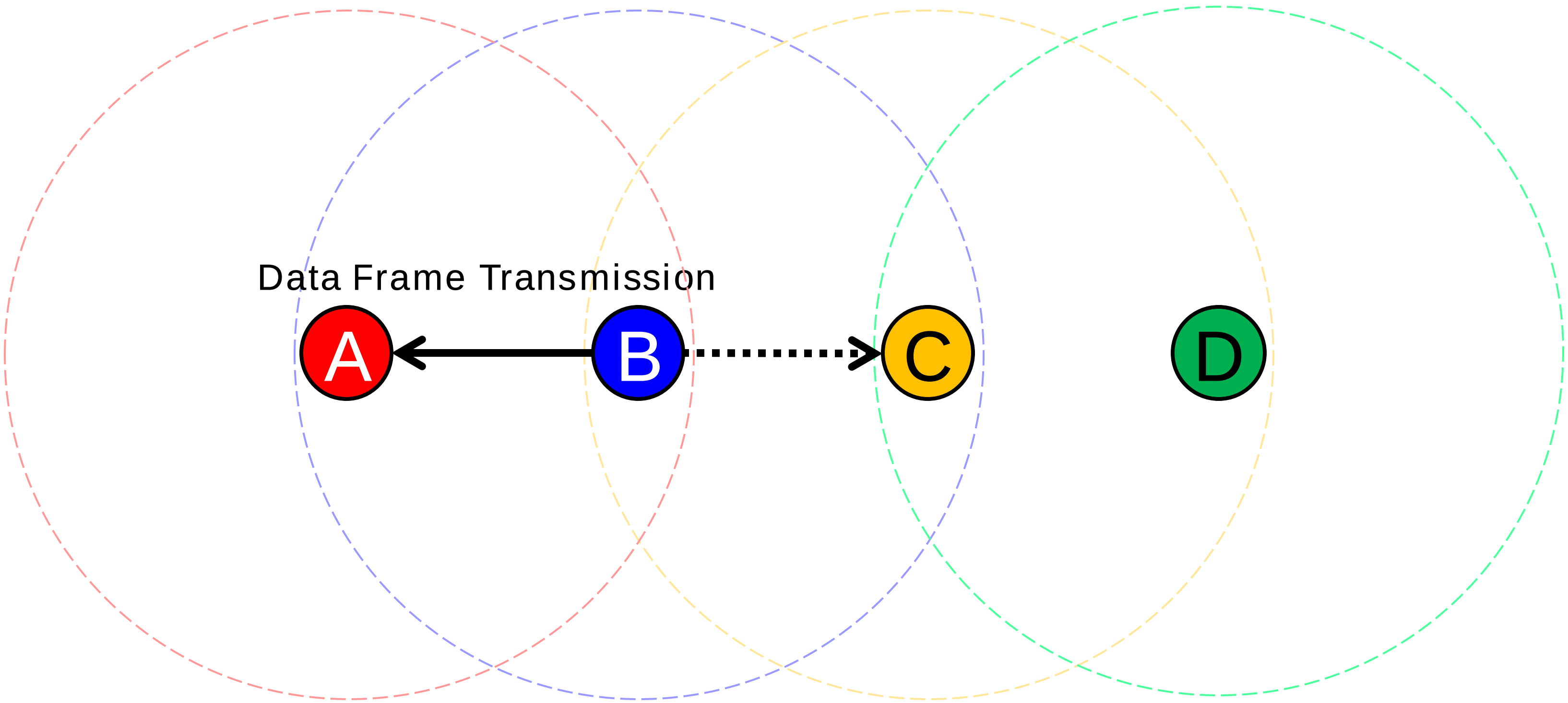

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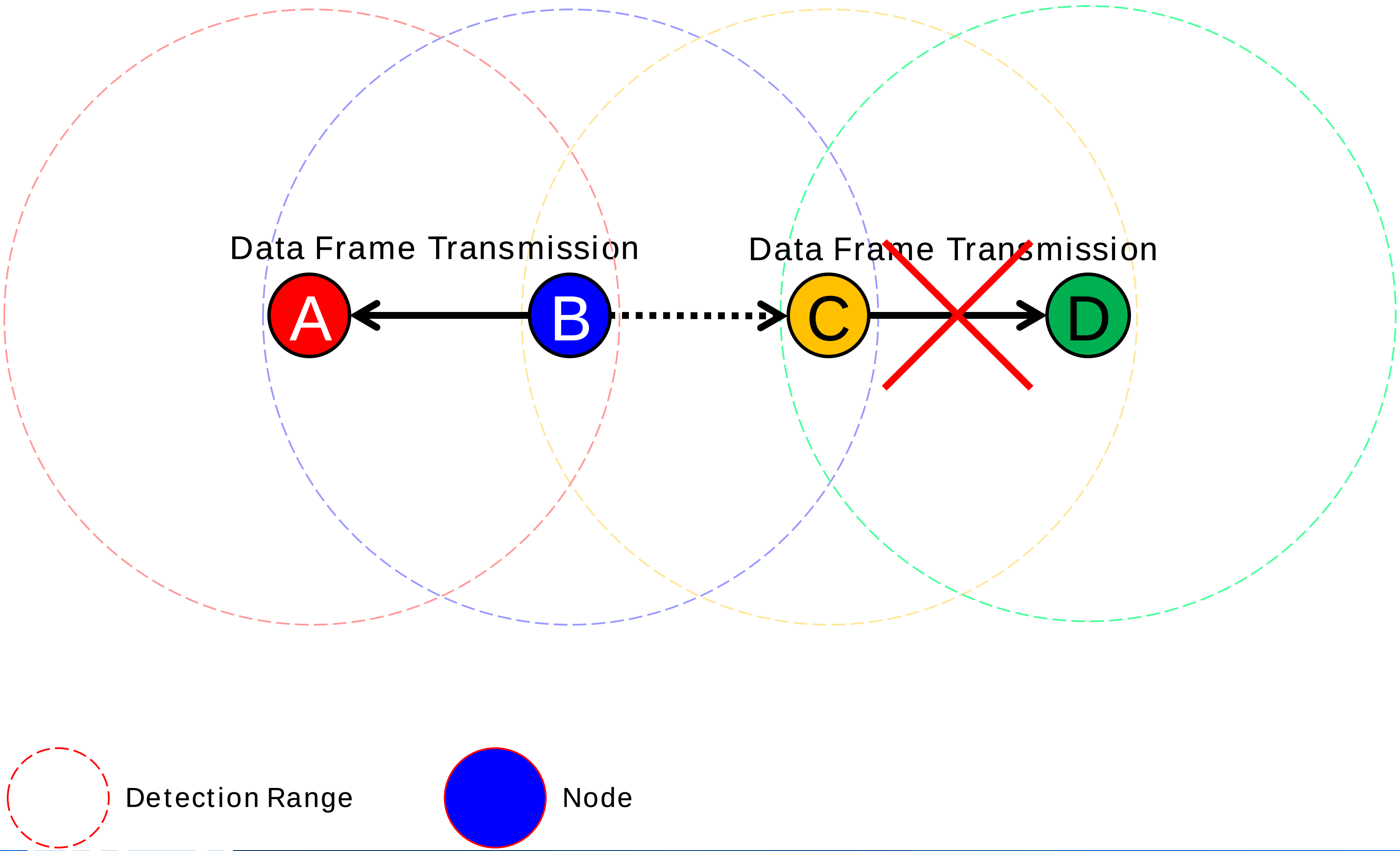

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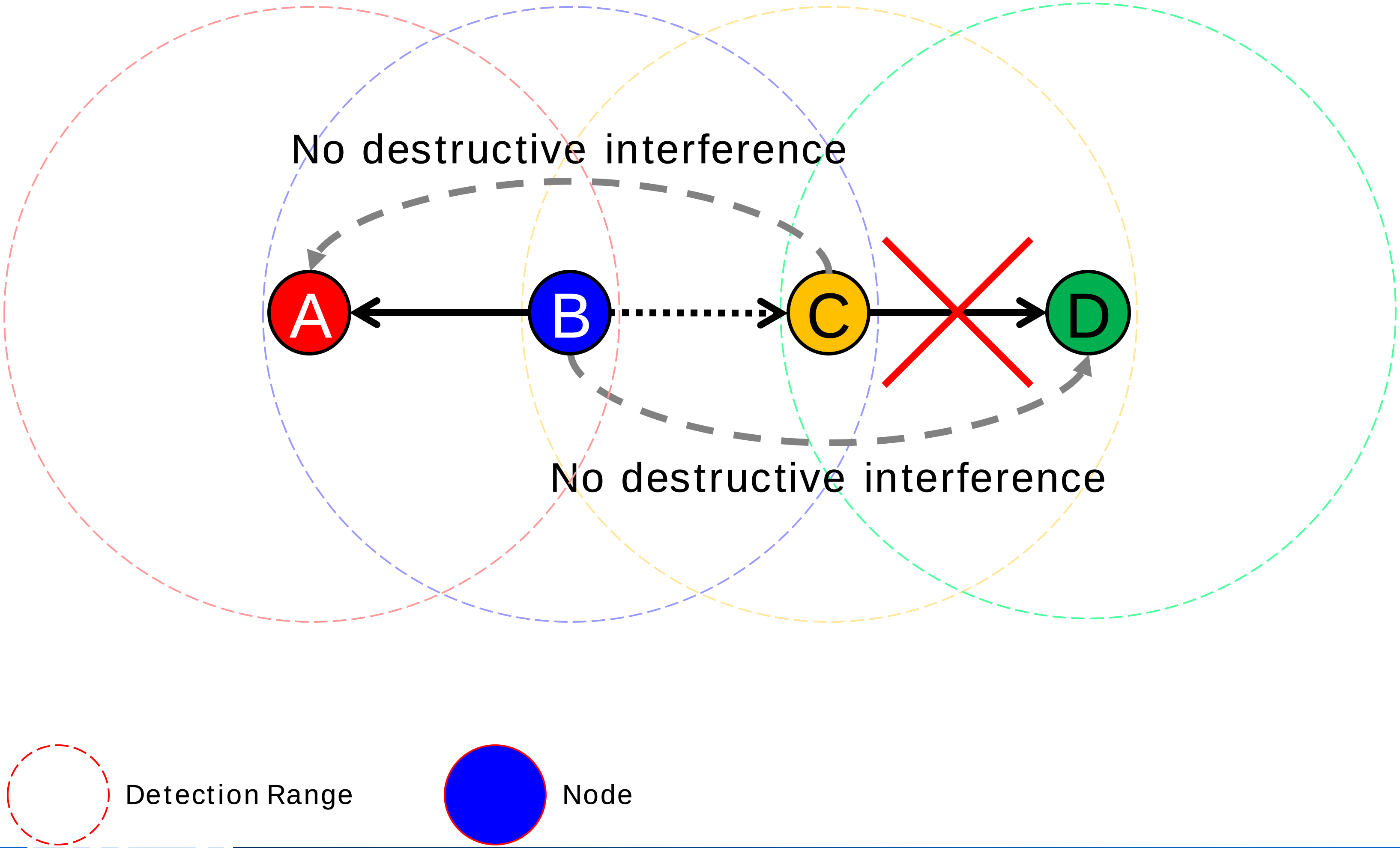

Hidden & Exposed Nodes

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- Hidden Node:
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- Exposed Node:
  - Transmitting Node overestimates Interference at receiving node position

- Distributed Reservation Protocol (DRP) inhibits transmissions from hidden nodes, exposed nodes still exist

Hidden & Exposed Nodes

Improvement to DRP:

Recognize exposed nodes

- Provide information on one-hop neighbourhood
- Gather information on two-hop neighbourhood

and

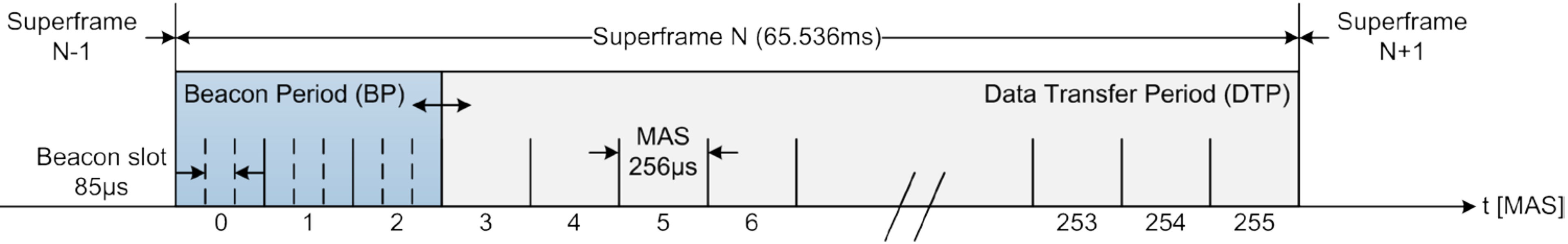
mitigate their impact on system capacity

- Combine gathered information
- Reuse channel resources

ECMA-368[1]: Medium Access Control (MAC) Overview

- Fully distributed MAC:
  - Coordination of nodes through beacons
  - No central coordinator

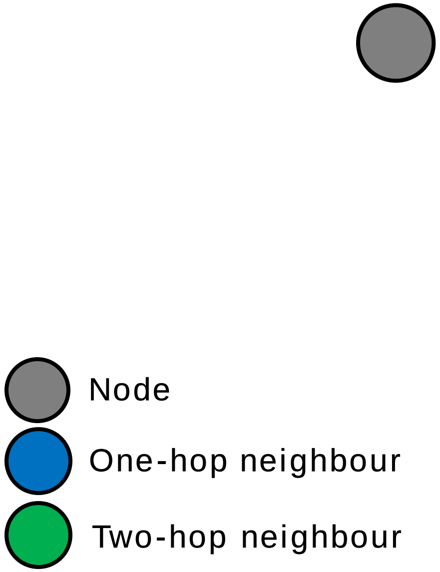
- Two multiple access protocols:
  - Prioritized Contention Access (PCA)
    - CSMA/CA protocol like IEEE 802.11e
  - **Distributed Reservation Protocol (DRP)**
    - Periodic reservation of Medium Access Slots (MAS) in Data Transfer Period (DTP)



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

ECMA-368: Medium Access Control Information Elements

- Information Elements (IE) are sent in Beacons
- A node receives Beacons from all one-hop neighbours



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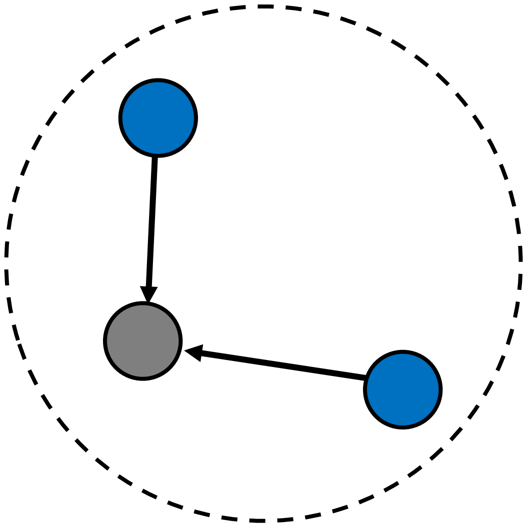

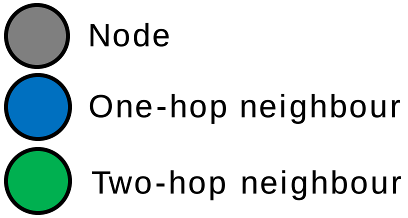

ECMA-368: Medium Access Control Information Elements

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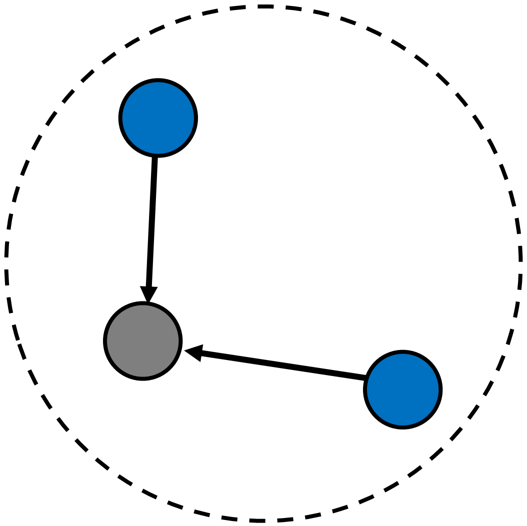
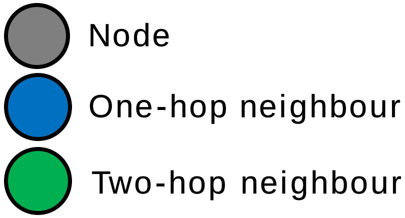
- Important information:
- Beacon Period Occupancy IE





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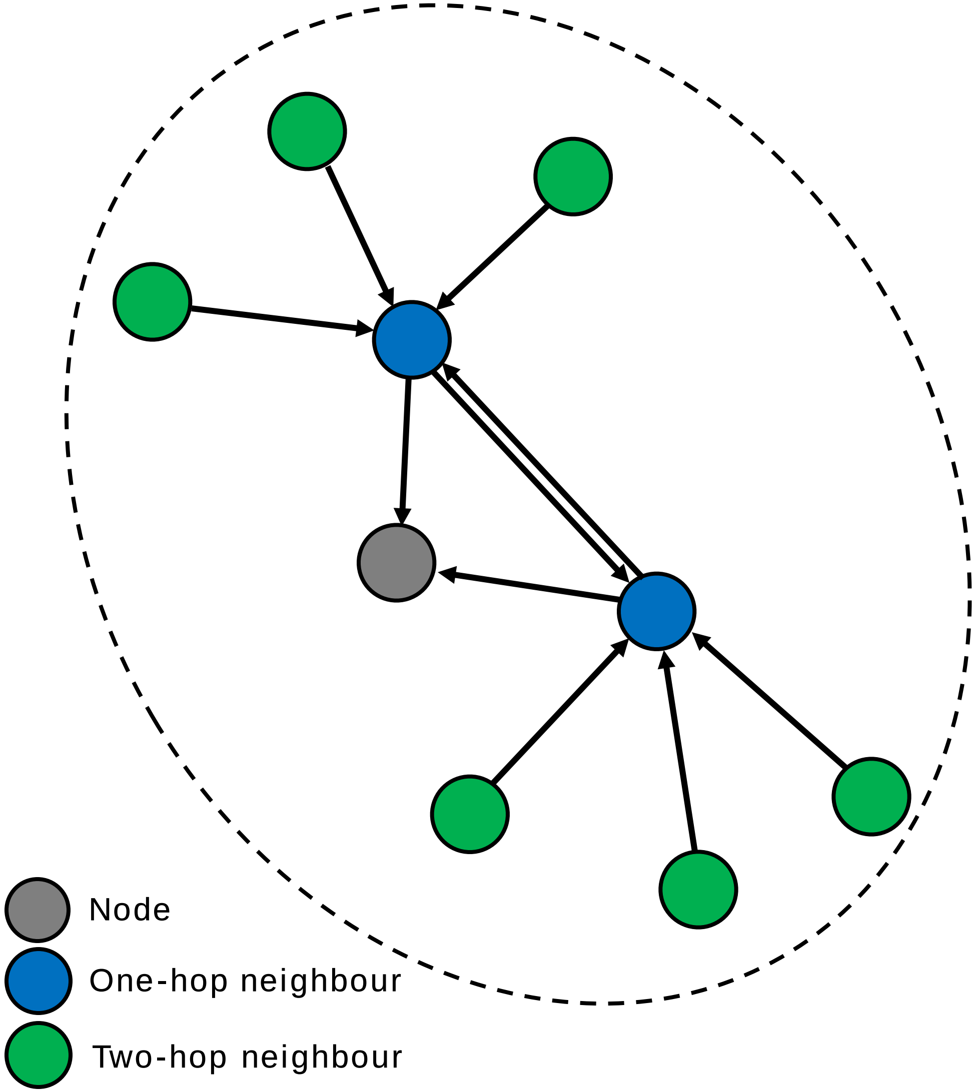
➡ Nodes get aware of two-hop neighbourhood



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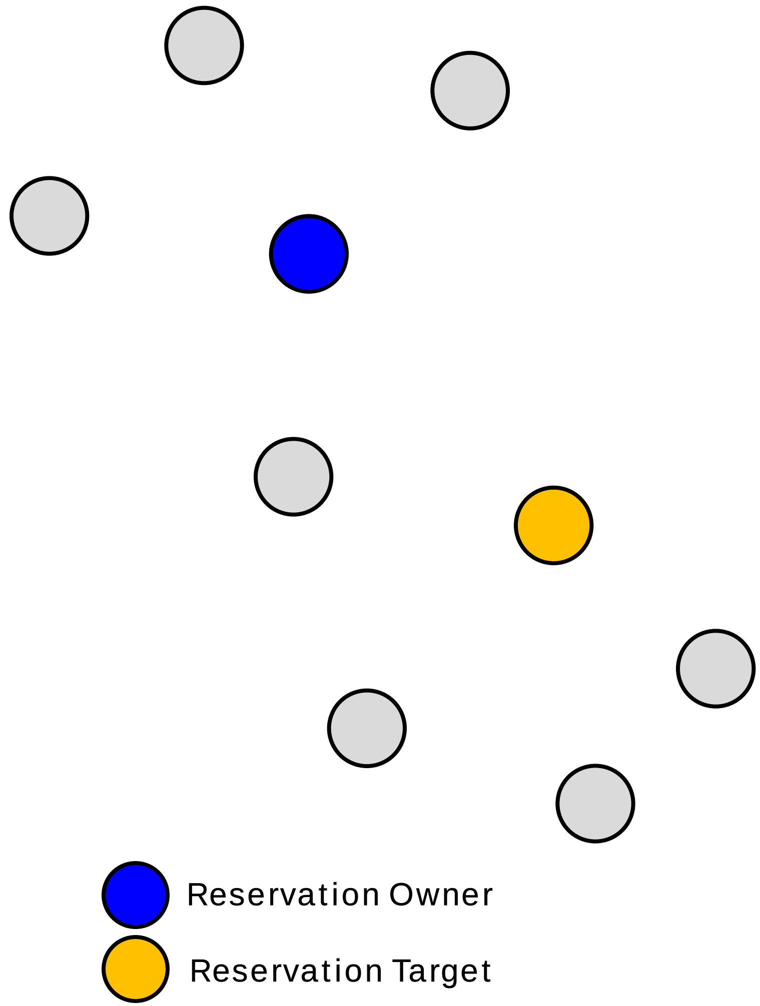
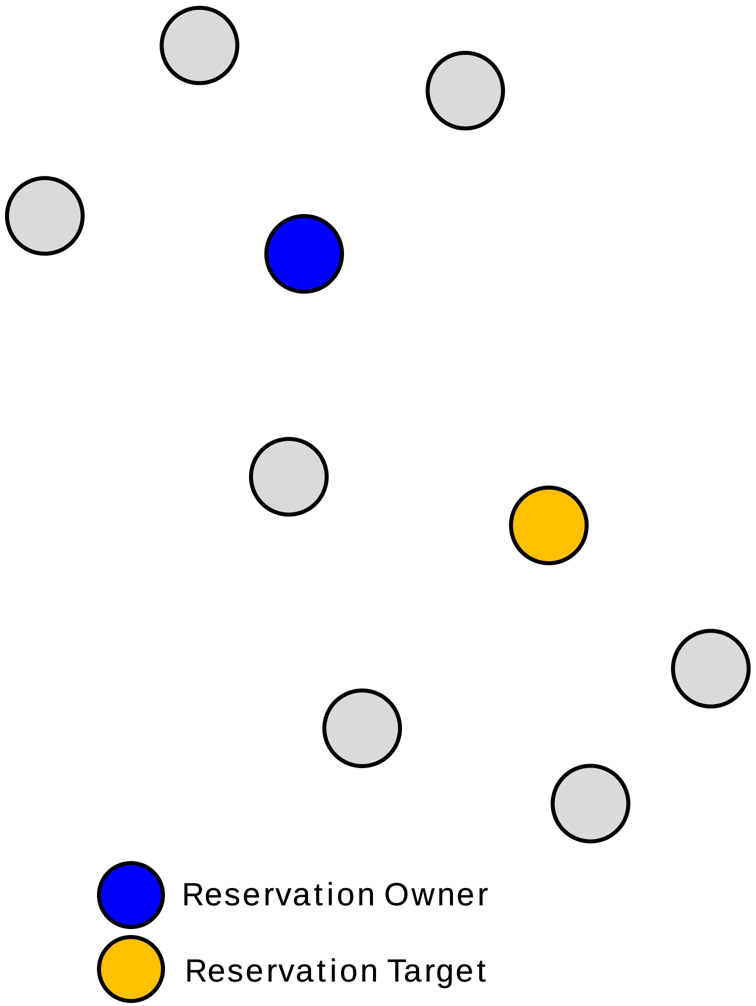


ECMA-368: Medium Access Control Information Elements

- Information Elements (IE) are sent in Beacons
- Important feature of DRP
- Distributed Reservation Protocol IE



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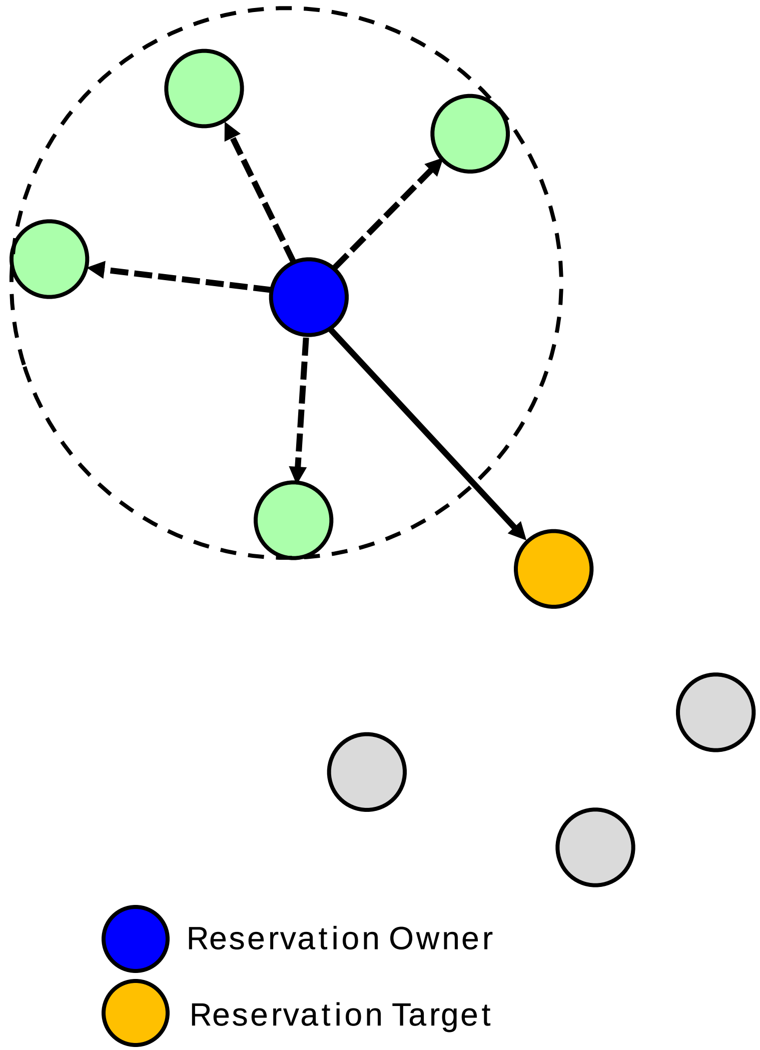
  - Reservation Owner sends DRP reservation request



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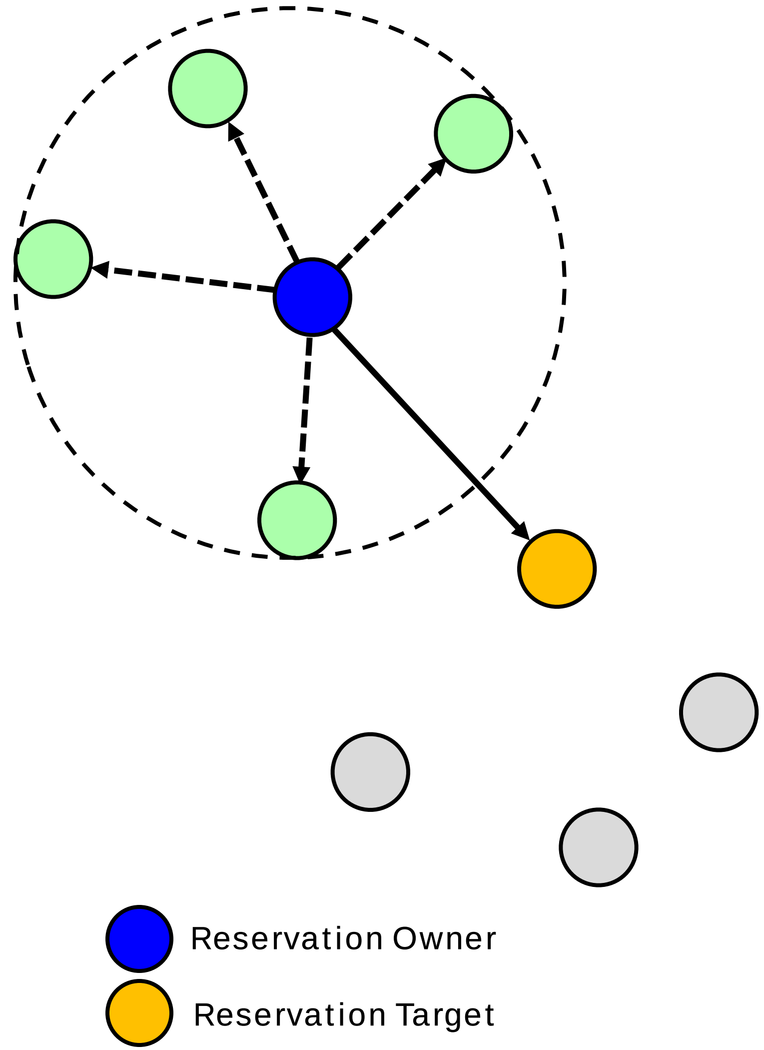

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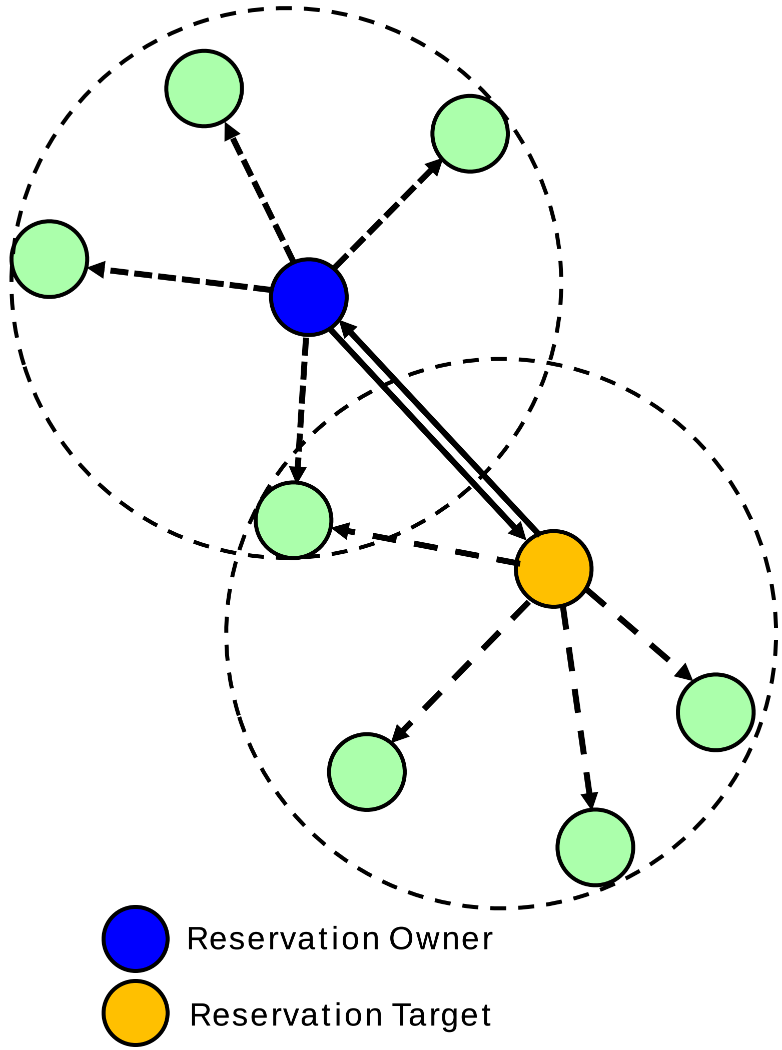
- Information Elements (IE) are sent in Beacons

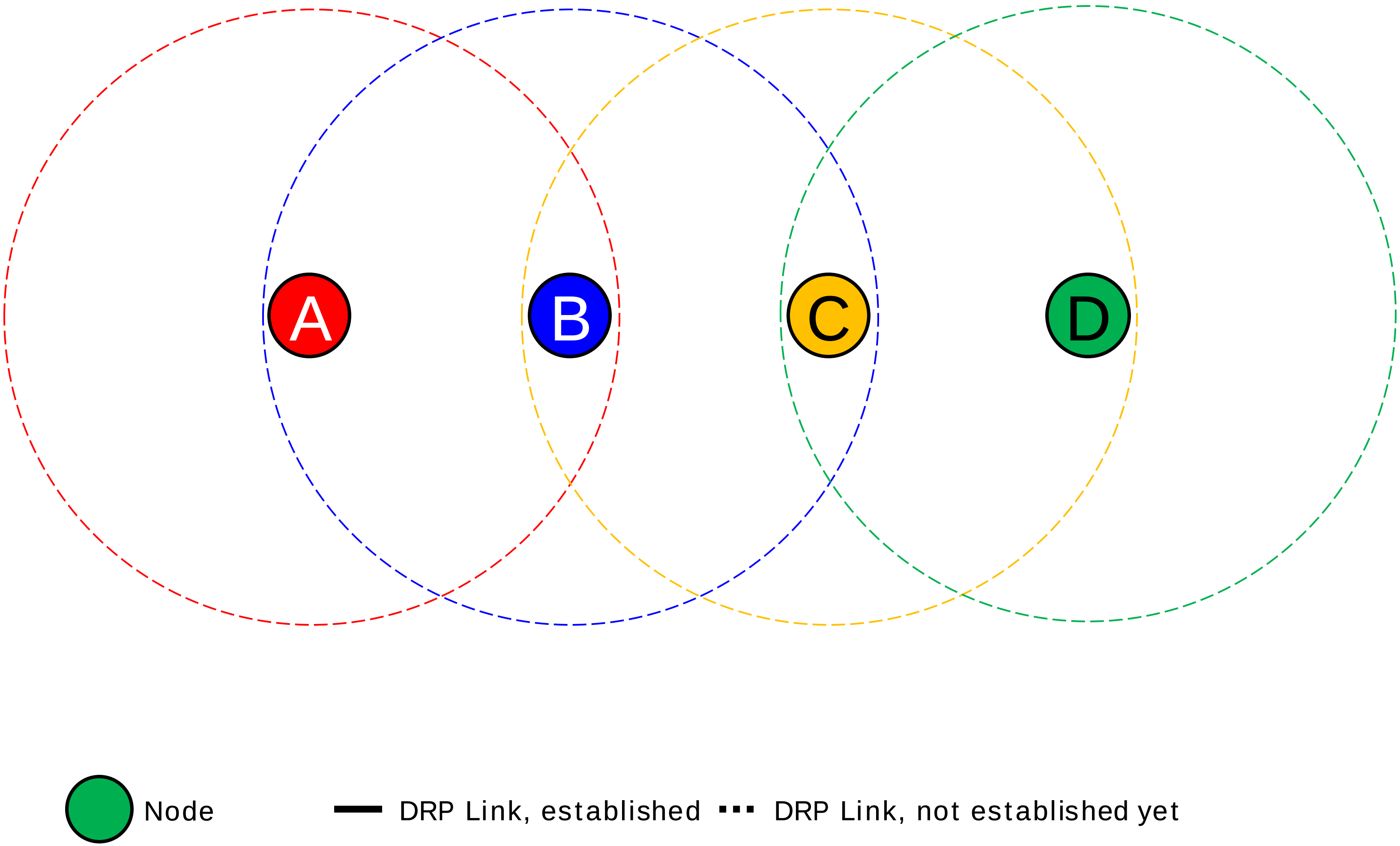
- Important feature of DRP

- Distributed Reservation Protocol IE
  - Reservation Owner sends DRP reservation request
  - Reservation Target sends DRP reservation response

➔ Nodes get aware of transmission direction



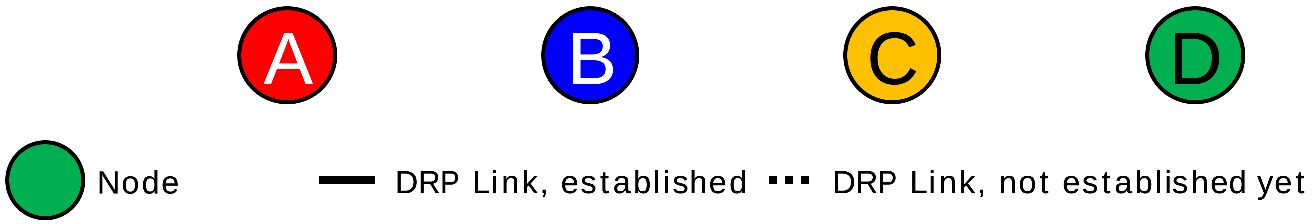
Identification & Exploitation of Exposed Nodes



Identification & Exploitation of Exposed Nodes

Nodes	Information from BPOIEs	Information from DRPIEs
A		
B		
C		
D		

▪



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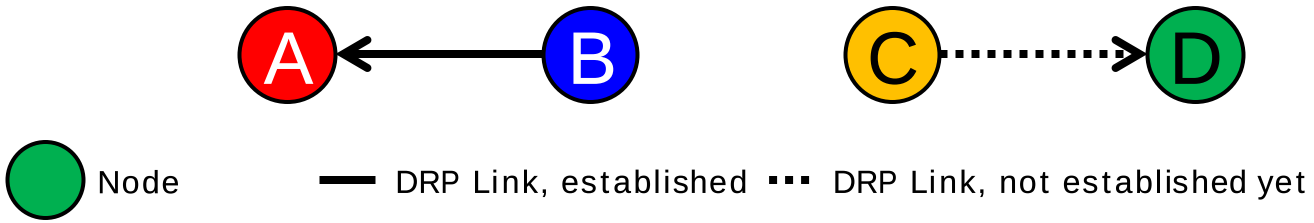

Identification & Exploitation of Exposed Nodes

- **Step 1:** Evaluation of beacon, BPOIE & DRPIE:

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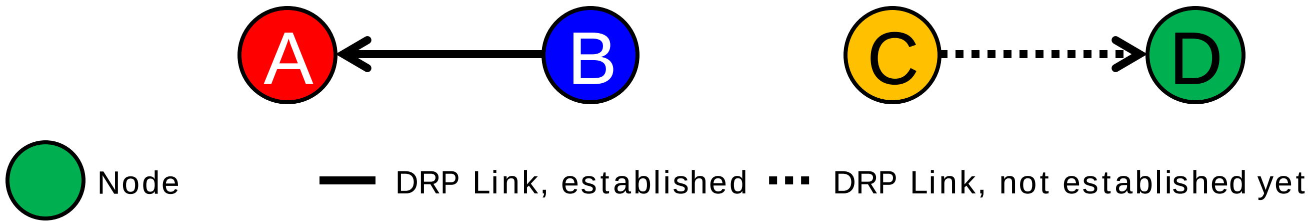

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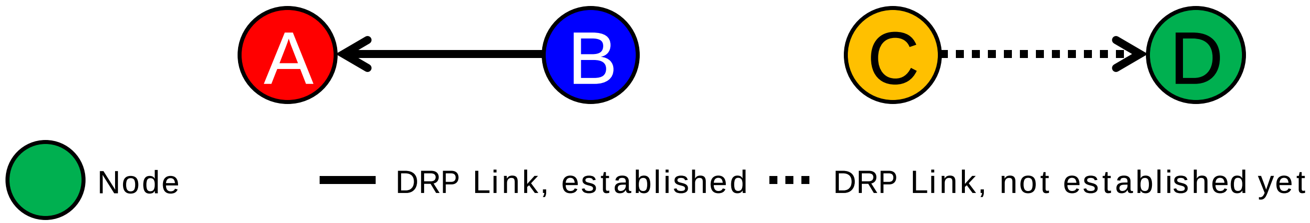

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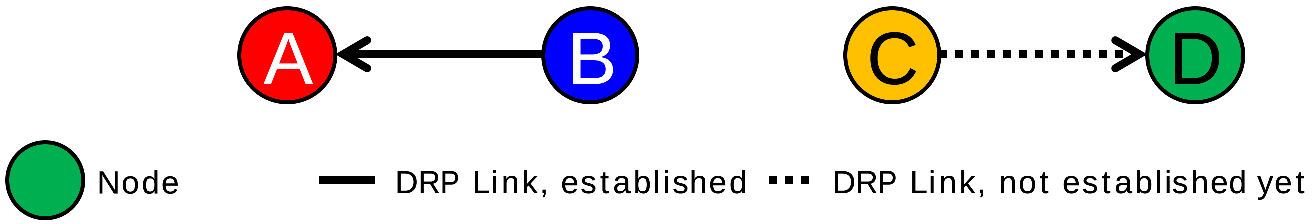

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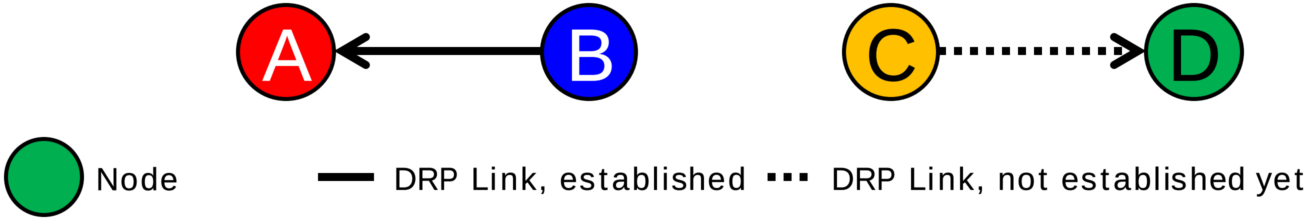

- **Step 2:** Combination of the information to identify exposed nodes

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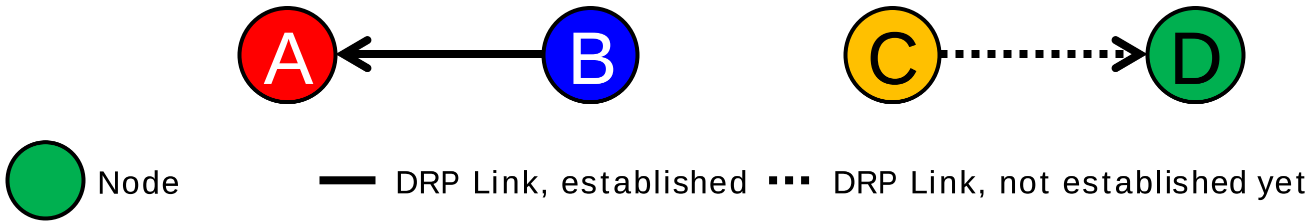

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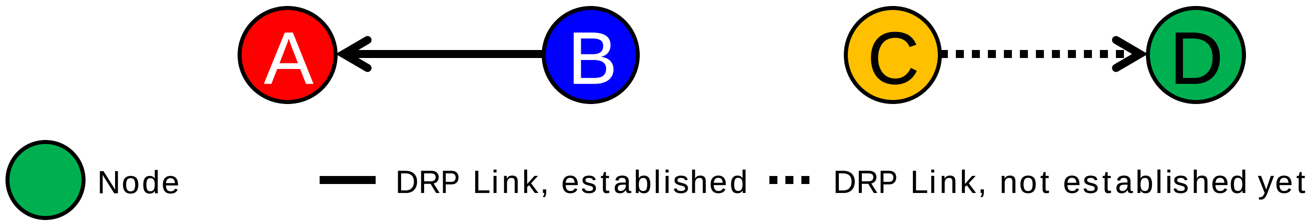
Node C checks: Owner B **not** in one-hop neighbourhood of D?



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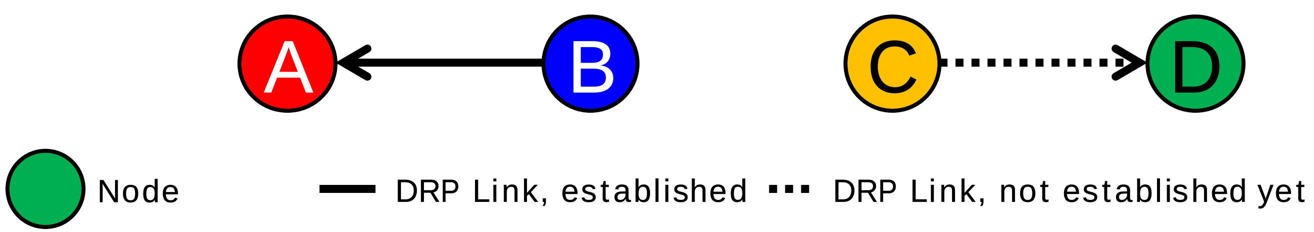

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Node C checks: Target A **not** in my own one-hop neighbourhood?

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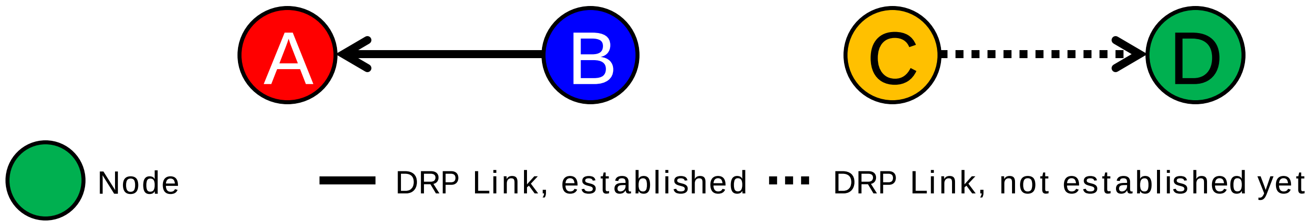

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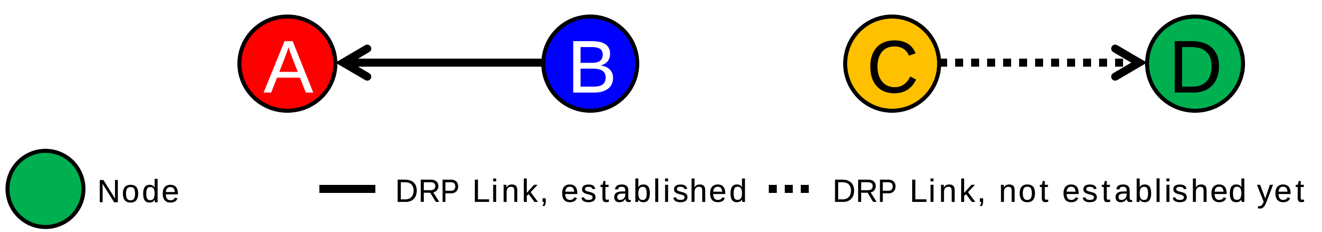

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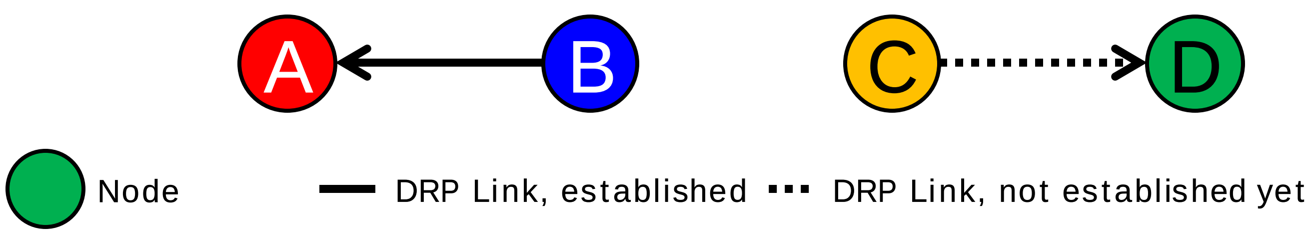
Node C checks: Target A **not** in my own one-hop neighbourhood? √

➢ **Exposed node identified, consider MASs from B reusable**



UWB for Digital Home Environments: Channel Model

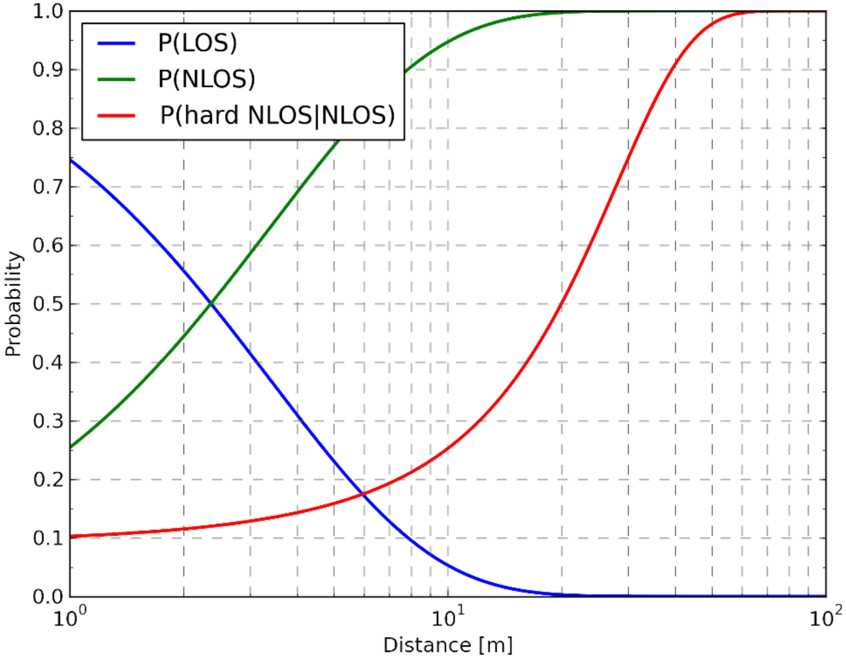
- UWB is most important for residential home environments
  - High throughput (max. 480Mb/s), short range (~ 14m), low transmission power (~ -14dBm)
- Indoor scenarios provide difficult surroundings
  - Signal attenuation through walls, furniture, doors
- Problem:
  - UWB currently lacks evaluation guidelines
  - There is no generally accepted channel model available
- Literature provides various UWB channel models for different environments with appropriate parameterization [4,5]
- Most UWB channel models distinguish Line of Sight (LOS) from (soft/hard) non LOS (NLOS), considering shadowing and frequency selectivity

[4] T. Zwick, C. Fischer, and W. Wiesbeck. A stochastic multipath channel model including path directions for indoor environments. Selected Areas in Communications, IEEE Journal on, 20(6):1178 – 1192, Aug. 2002.

[5] R.M. Buehrer, W.A. Davis, A. Safaai-Jazi, and D. Sweeney. Ultra-Wideband Propagation Measurements and Modeling. DARPA NETEX Program Final Report, Jan. 2004.

UWB for Digital Home Environments: Channel Model Parameters

- Distance dependent LOS and NLOS channel condition probability[4]



Path loss:	$PL = 20 * \log_{10}\left(\frac{4*\pi}{c_0}\right) + A * \log_{10}(d) + B * \log_{10}(f) + C$		c_0: $3*10^8$ m/s, d: Distance [m], f: Frequency [Hz]
Parameter	**LOS**	**Soft NLOS**	**Hard NLOS**
A (Distance dependency)	1.3	2.3	4.1
B (Frequency dependency)	0.8	0.8	0.8
C (Shadowing) (log-normal distributed)	$(\bar{\mu} = 0, \sigma = 2.6)$	$(\bar{\mu} = 0, \sigma = 2.4)$	$(\bar{\mu} = 0, \sigma = 1.8)$

[6] B. Gaffney. Combined LOS and NLOS UWB Channel Model, Jan. 2008. D0712003WP.

Scenario: Parameter

- Parameters:

Parameter	Value
Scenario Size	20m x 20m
Data Frame Size	1500 Byte
Load Generator	Constant Bit Rate
Offered Load	Variable
Number of Seeds	80
Comparison	DRPNext vs. standard DRP

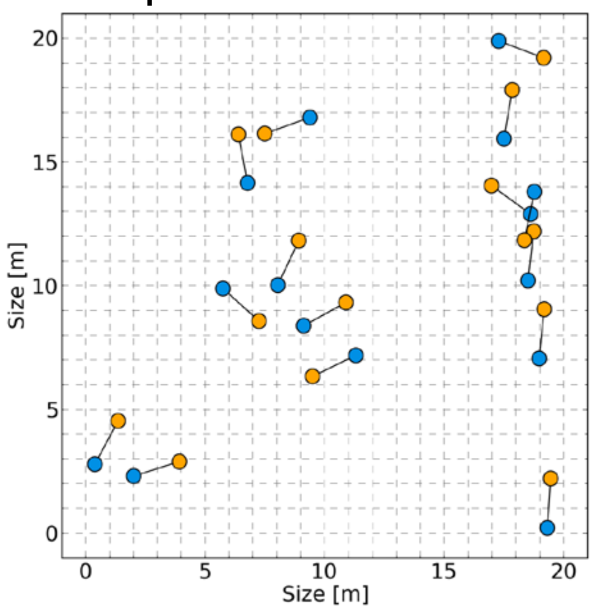
- Evaluation: System Capacity, throughput in system saturation:
  - All nodes shall be able to serve their offered load

$$\frac{throughput_i(offeredLoad)}{offeredLoad} \geq 1 - \varepsilon \;, \quad \forall i \in NodeIDs, \quad \varepsilon\text{: error tolerance}$$

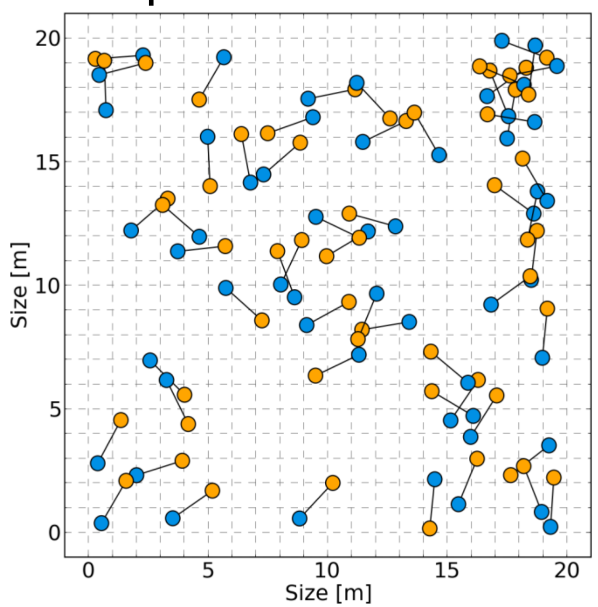
Scenario: Uniform Distributed Pairs of Nodes

Parameter	Value
Number of Owners	15, 40, 50
Number of Targets	+1 per Owner
Distance between Owner & Target	2m
Minimum SNR between Owner & Target	5dB

15 pairs of nodes

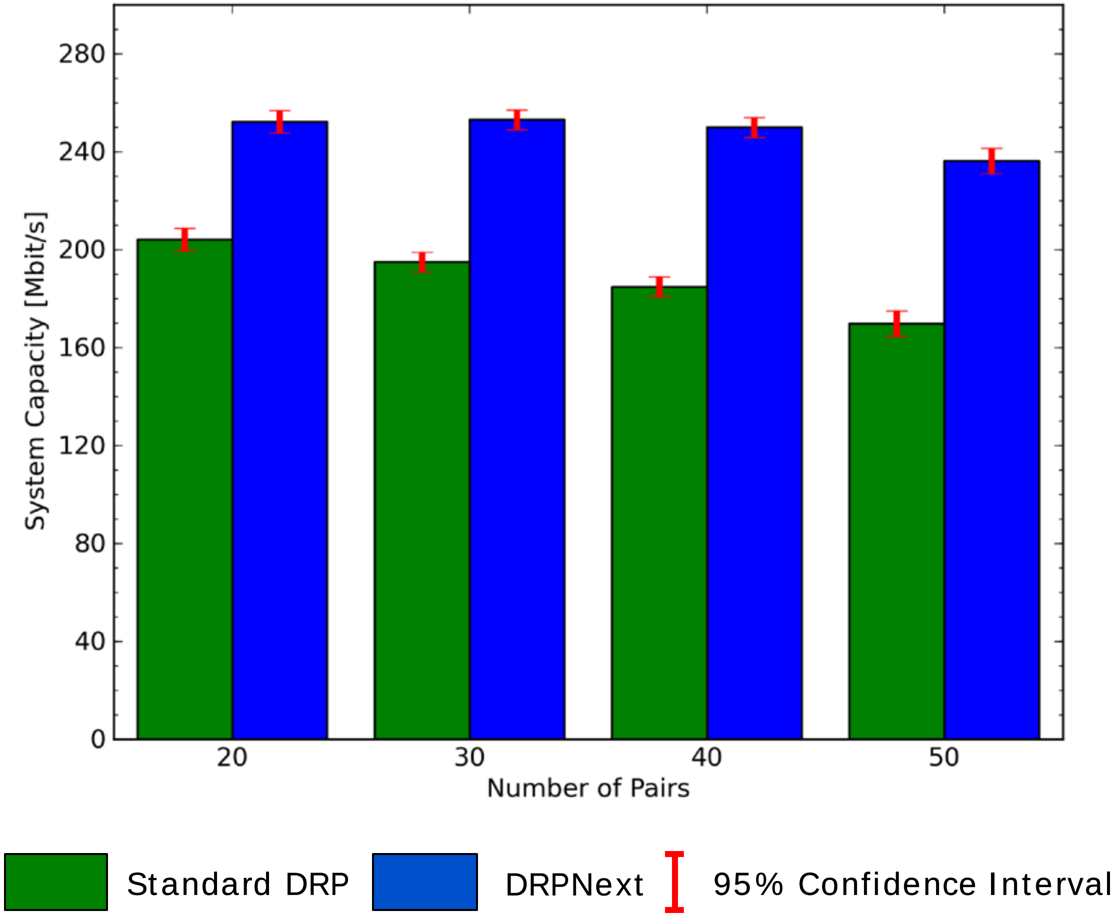


40 pairs of nodes



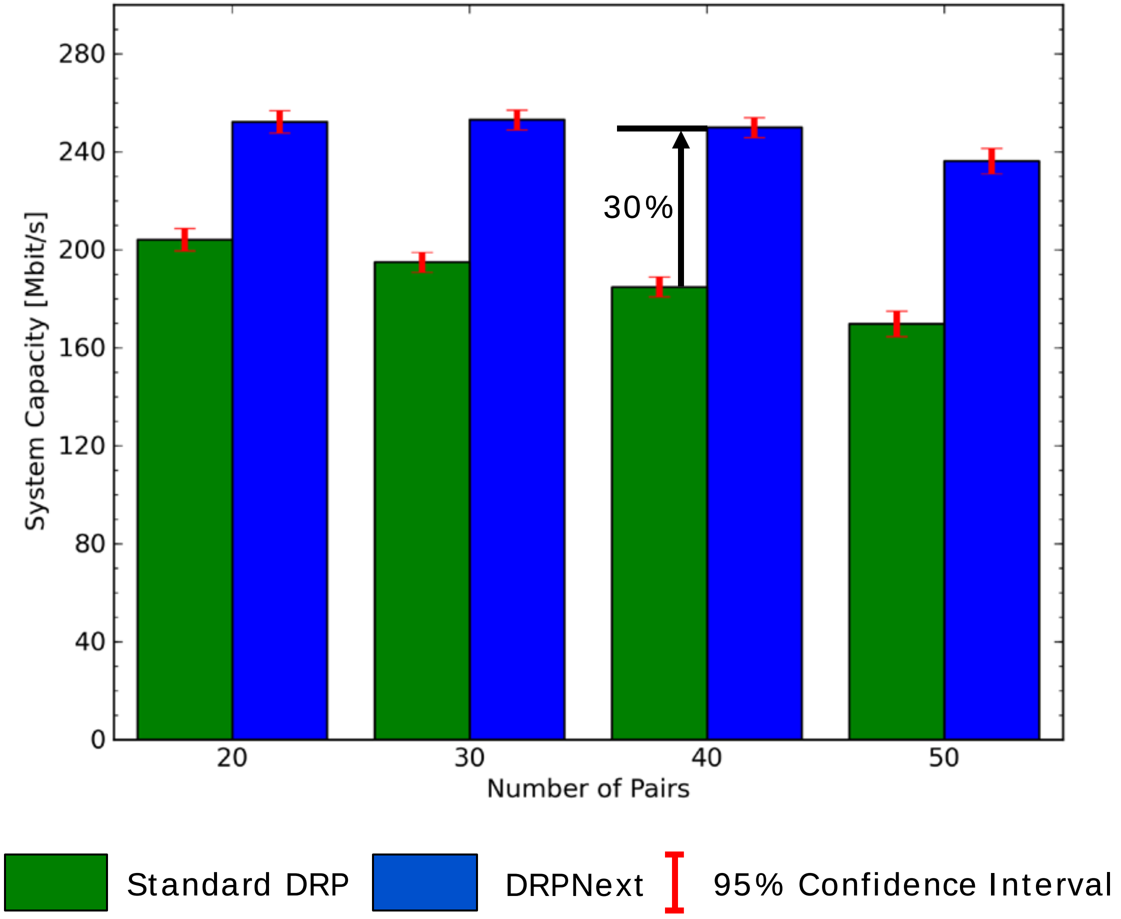
Owner Target DRP link

Results
System Capacity



- Probability of exposed Nodes increases with number of Nodes
- Beacon Period increases with number of Nodes at expense of MASs for User Data Frame transmission

Results
System Capacity



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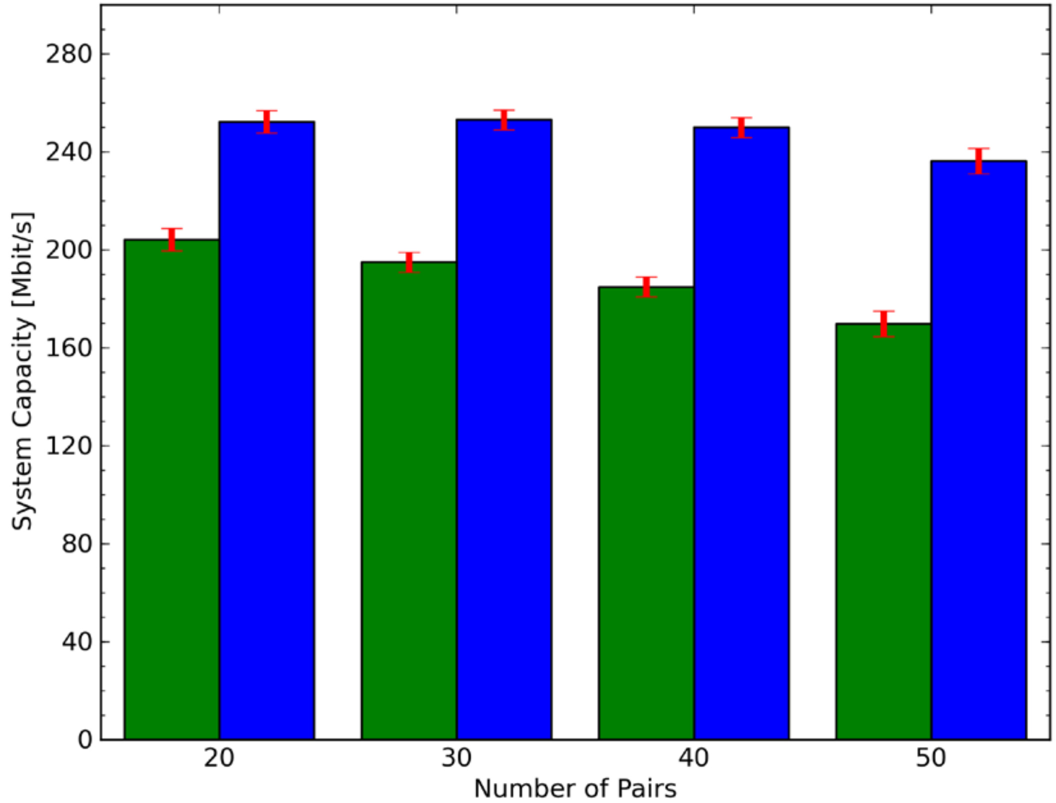

Standard DRP DRPNext 95% Confidence Interval

- Probability of exposed Nodes increases with number of Nodes
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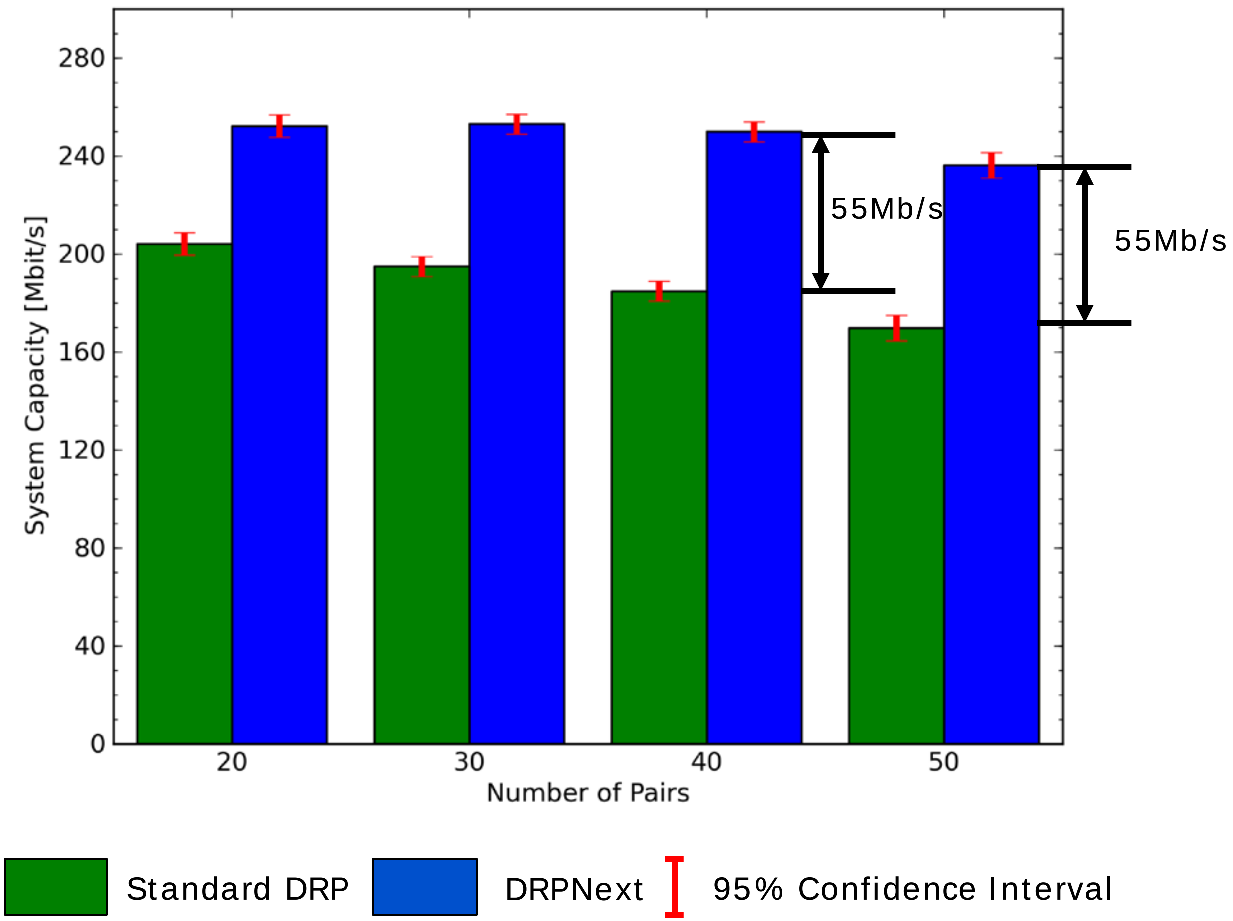
Results
System Capacity



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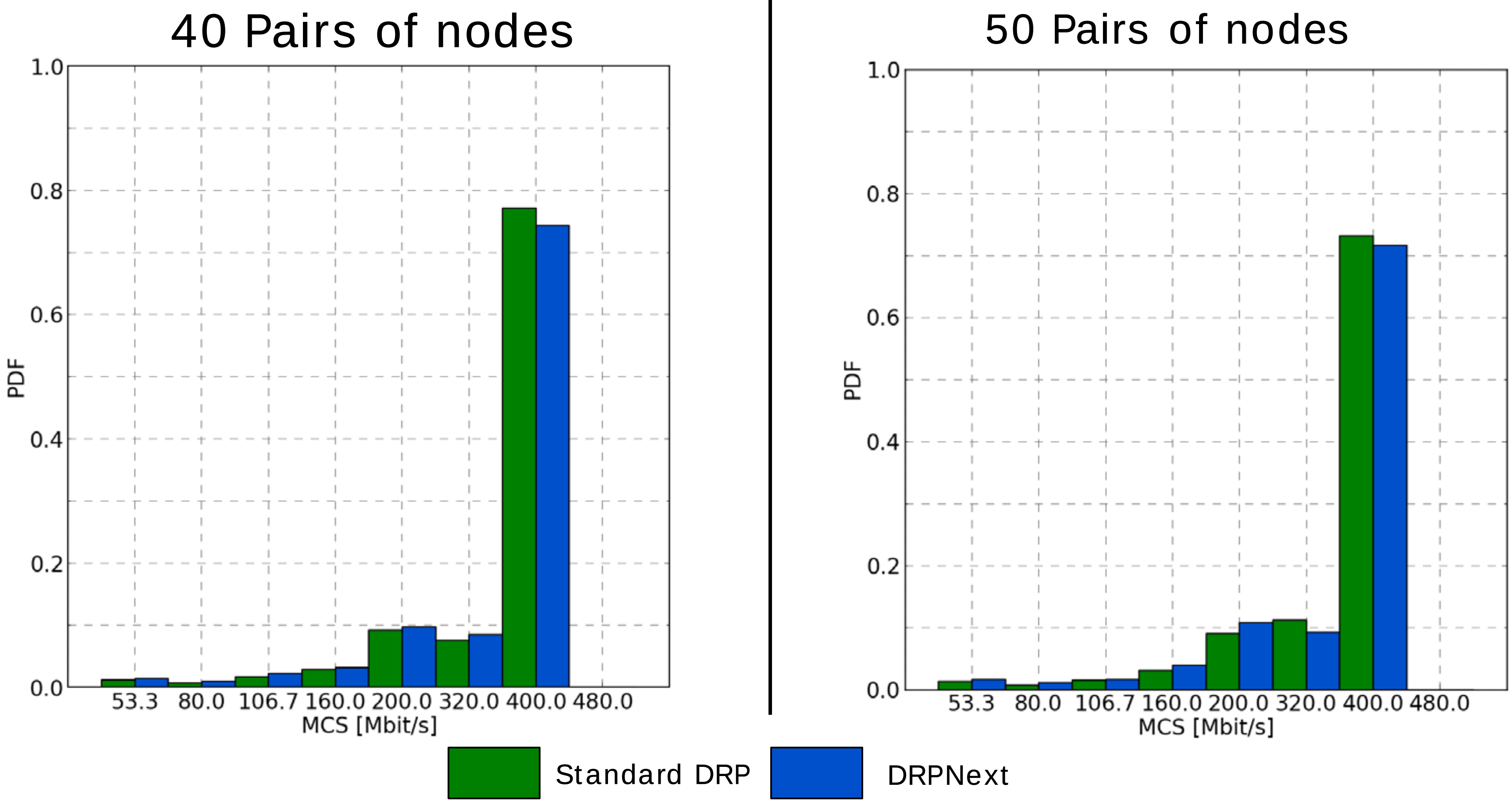
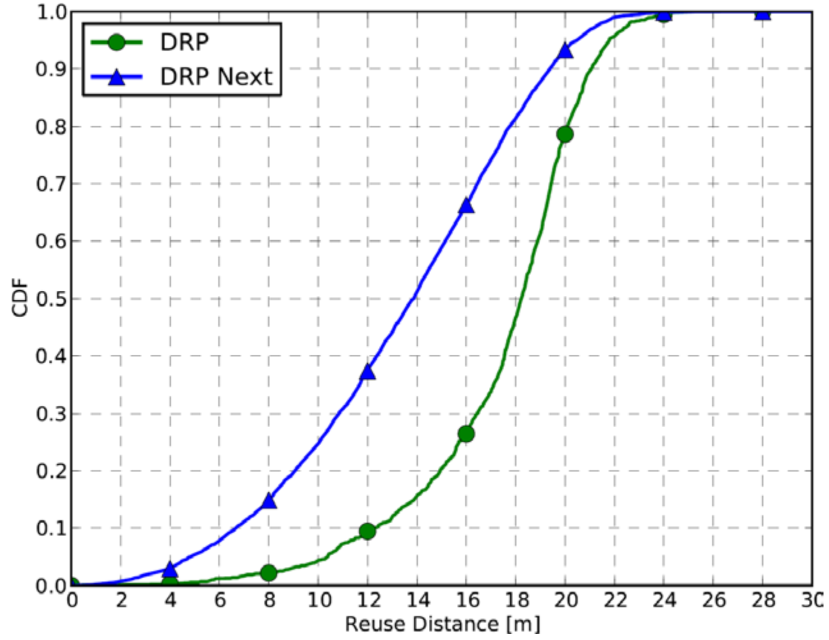
Results
Modulation and Coding Schemes (MCS)

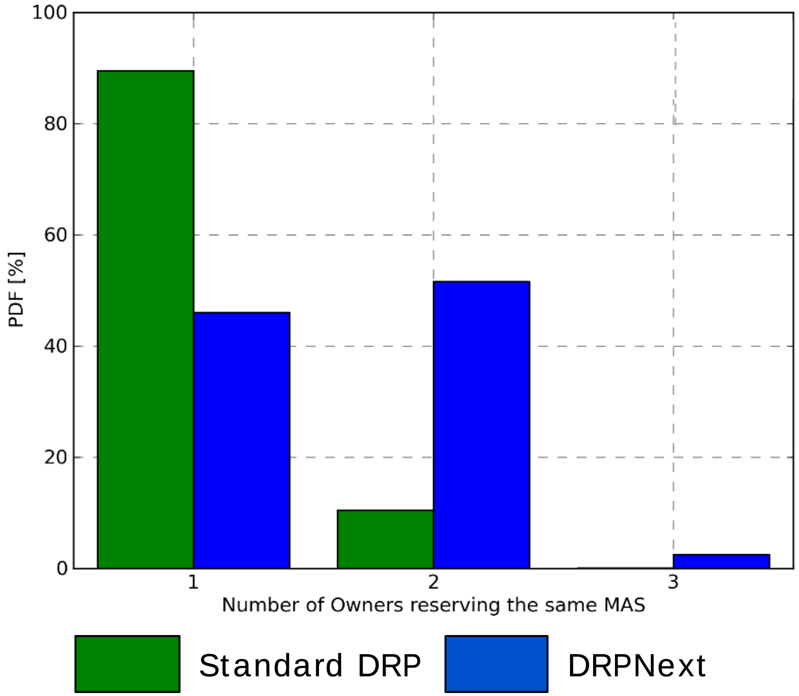


- DRPNext uses slightly more robust MCSs offering less Data Rates
- Increasing channel resource reuse probability forces Nodes to use more robust MCSs

Results
Reuse Distance & MAS Reuse

50 Pairs of Nodes





- Only 10% of MASs are reused for standard DRP, compared to 58% for DRPNext
- Mean Reuse Distance is decreased by factor 1.3
  - Standard DRP: 17.4m, DRPNext: 13.4 m

Conclusion & Outlook

Conclusion:

- DRPNext identifies and mitigates exposed nodes impact on system capacity, with only minor changes to ECMA-368
- DRPNext gains system capacity by more than 20% in residential home environment

Outlook:

- Ensure backwards compatibility to standard DRP
  - Nodes may refuse reuse of channel resources if SINR gets too low

Thank you for your attention!

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