Mesh networks: The benefits of interference awareness

Guido R. Hiertz
Yunpeng Zang
Rui Zhao
ComNets
Chair of Communication Networks
RWTH Aachen University
Aachen, Germany

Jörg Habetha
Philips Research
Aachen, Germany

Stefan Mangold
Philips Research
Briarcliff Manor, NY, USA

This version has been edited for publication as PDF file at ComNets, RWTH Aachen University.

Some animations may not be displayed correctly in PDF format.

Please see http://802wirelessworld.com for the original version in PowerPoint format.

Outline

- Path loss and antenna gains in wireless communication
- Damping factor
- Noise and interference
- PHY modes and ranges
- Clear channel assessment
- Interference awareness

We will show that interference awareness is a helpful concept for meshed networks

Free space attenuation in wireless communication

- Received (Rx) power (P_{Rx})
  - Transmitted power at isotropic (omni-directional) antenna ($P_{Isotrop}$)
- Attenuation
  - Distance (d)
  - Center Frequency (f_c)
  - Speed of light (c)

$$P_{Rx} = \frac{P_{Isotrop}}{d^2} * \left(\frac{c}{f_c * 4\pi} \right)^2$$

Non free space attenuation (α)

- α – parameter models, many effects:
  - Reflection
  - Diffraction
  - Scattering
  - Fading

$$P_{Rx} = \frac{P_{Isotrop} * \alpha}{d^2} * \left(\frac{c}{f_c * 4\pi} \right)^2$$

Antenna gains

- Rx antenna gain
  - Relative to isotropic antenna
  - g_{Rx}
- Tx antenna gain
  - Relative to isotropic antenna
  - g_{Tx}

$$P_{Rx} = \frac{P_{Isotrop} * g_{Tx} * g_{Rx} * \alpha}{d^2} * \left(\frac{c}{f_c * 4\pi} \right)^2$$

Simplified path loss model

- Let
  $P_{Tx} = \beta * P_{Isotrop}$
  - β, Antenna form factor
- Let
  $d^{2-\gamma} = \alpha * \beta * g_{Tx} * g_{Rx}$
  - γ, generalized damping factor

$$P_{Rx} = \frac{P_{Tx}}{d^{\gamma}} * \left(\frac{c}{f_c * 4\pi} \right)^2$$

Damping factor

- $\gamma=2$
  - Free space (outdoor)
  - Isotropic radiation
  - Theoretical value
  - Far distances (outside antenna near-field)
  - Line of Sight (LOS)
- $\gamma > 2$
  - More realistic
  - Depending on scenario and radio environment
  - Non LOS
  - Indoor
  - Valid for one location tuple (x,y,z) only

General assumption, here $\gamma = 3.5$

Noise

- Random process
  - Boltzmann constant, k_B
  - Temperature (here: 300K)
  - Bandwidth (.11a: 20MHz)

$$P_N = k_B T * \Delta f$$

- N ≈ -100dBm
  - Here: N = -95dBm
  - Increased value
    - Receiver noise figure N_f
    - More realistic

$$N(dBm) = 10 * \log_{10}\left(\frac{P_N}{10^{-3} W}\right) + \underbrace{N_f}_{\text{noise figure}}$$

Carrier over Interference ratio (CoI)

- Carrier (C) = $P_{Rx, wanted}$
- Interference (I) = $P_{Rx, unwanted, i}$
  - i interferer, $i \geq 0$
- Noise (N)

$$CoI = \frac{C}{N + \sum_i I}$$

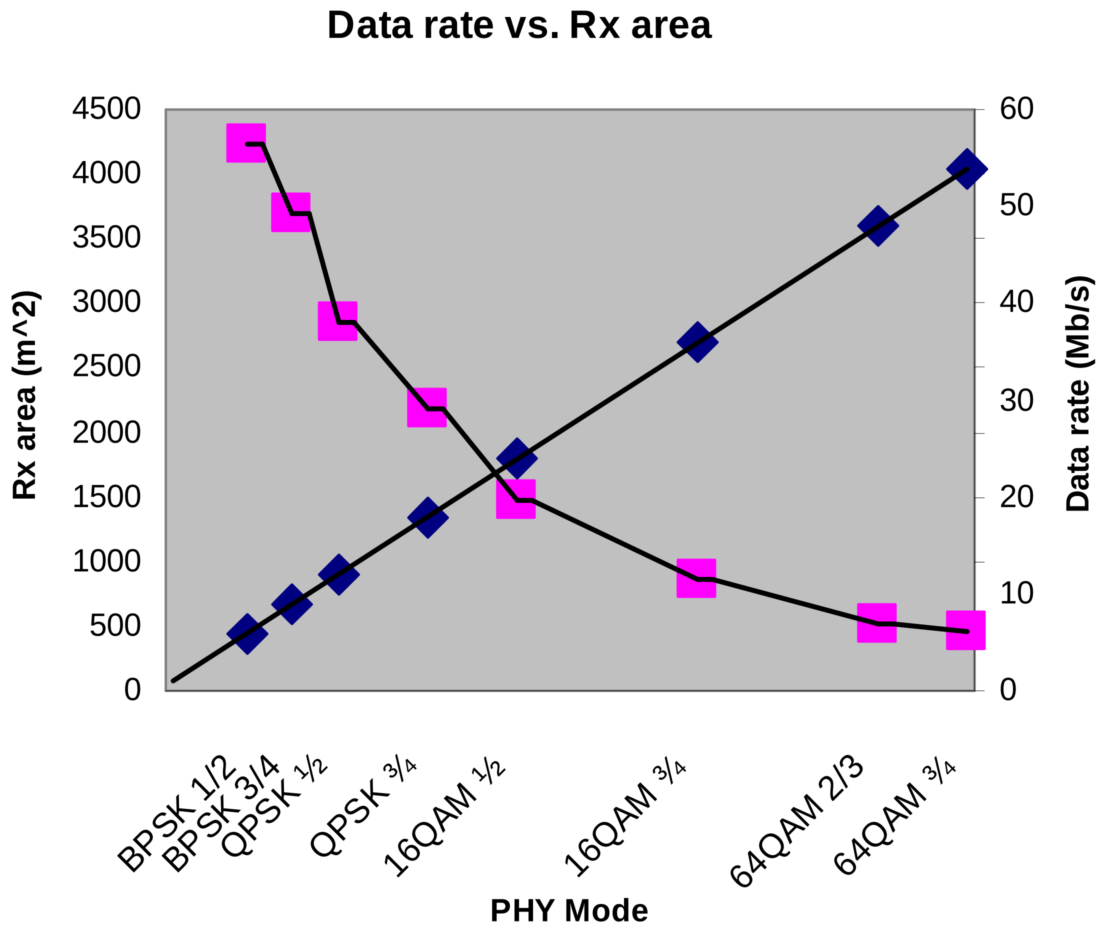
Minimal C & Minimal CoI

- 802.11a, OFDM
- Min. sensitivity
  - See .11a standard
  - 1000B
  - <10% Packet Error Ratio
- Min CoI (worst case)
  - 1000B
  - <10% Packet Error Ratio
- Robust PHY mode need
  - Less CoI
  - Less C

PHY mode	Minimum C (dBm)	Min. CoI (dB)
BPSK ½	-82	18
BPSK ¾	-81	21
QPSK ½	-79	22
QPSK ¾	-77	25
16QAM ½	-74	25
16QAM ¾	-70	32
64QAM 2/3	-66	34
64QAM ¾	-65	35

Min. C: Data rate vs. Rx area

- Tx, 20dBm
- Min. C @ Rx
- $\gamma = 3.5$
- →Rx area per PHY mode



Reception range

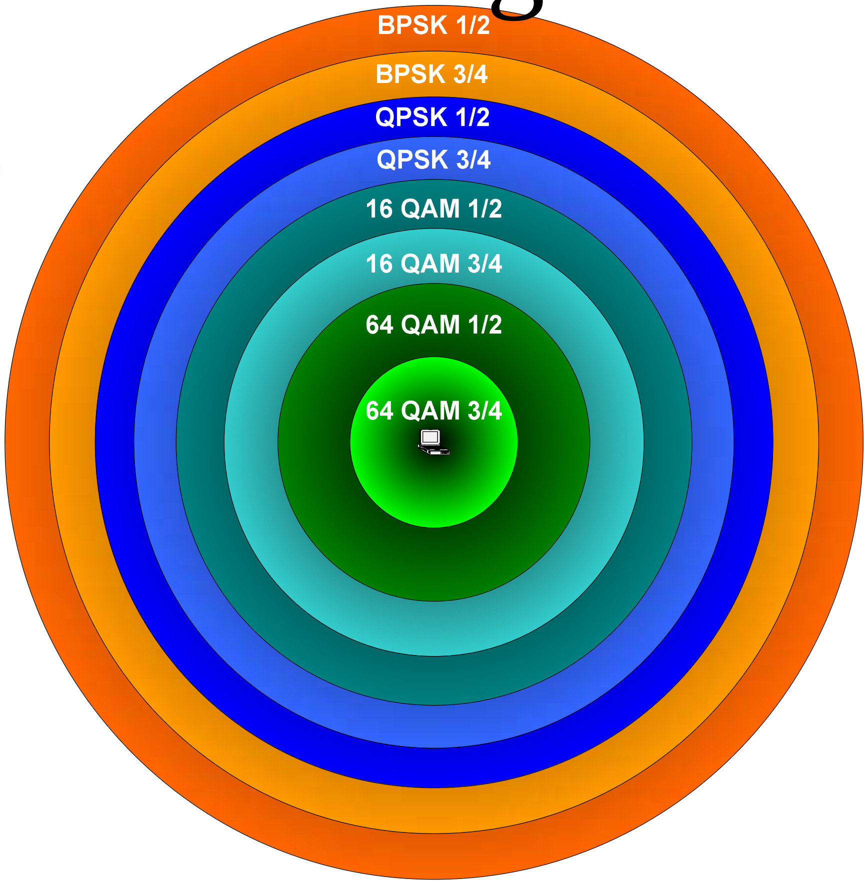
- PHY mode dependent
  - Modulation
  - Coding rate
  - C
    - Minimal energy for synchronization
  - CoI
- Packet Error Ratio (PER)
  - Probability distribution
  - Increasing CoI decreases PER
- Here, rx range

$$\Leftrightarrow$$

1000B, PER $\leq$ 10%

PHY modes: Rx Ranges

- Constant Tx power
  - Equal interference range
- Rx range limited
  - Attenuation
  - CoI
  - Etc.



Mandatory/Optional PHY modes

- Example: IEEE 802.11a, different PHY modes
- Mandatory
  - BPSK ½
  - QPSK ½
  - 16QAM ½
- Optional
  - BPSK ¾
  - QPSK ¾
  - 16QAM ¾
  - 64QAM 2/3
  - 64QAM ¾
- 802.11: “All Control frames shall be transmitted … so that they will be understood by all STAs in the BSS”

→ RTS, CTS, ACK … @ BPSK ½

802.11 Clear Channel Assessment

- 802.11a
  - OFDM PHY
  - 5.15GHz–5.25GHz
  - 5.25GHz–5.35GHz
  - 5.725GHz–5.825GHz
- Assumption, here
  $f_c = 5.5$GHz

- CCA busy if

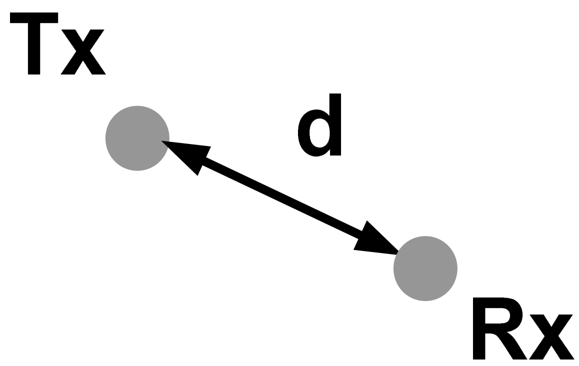
(1) >-62dBm for any signal

or

(2) Valid OFDM preamble,
Rx level ≥-82dBm
  - > 90% probability
  - within 4 μs

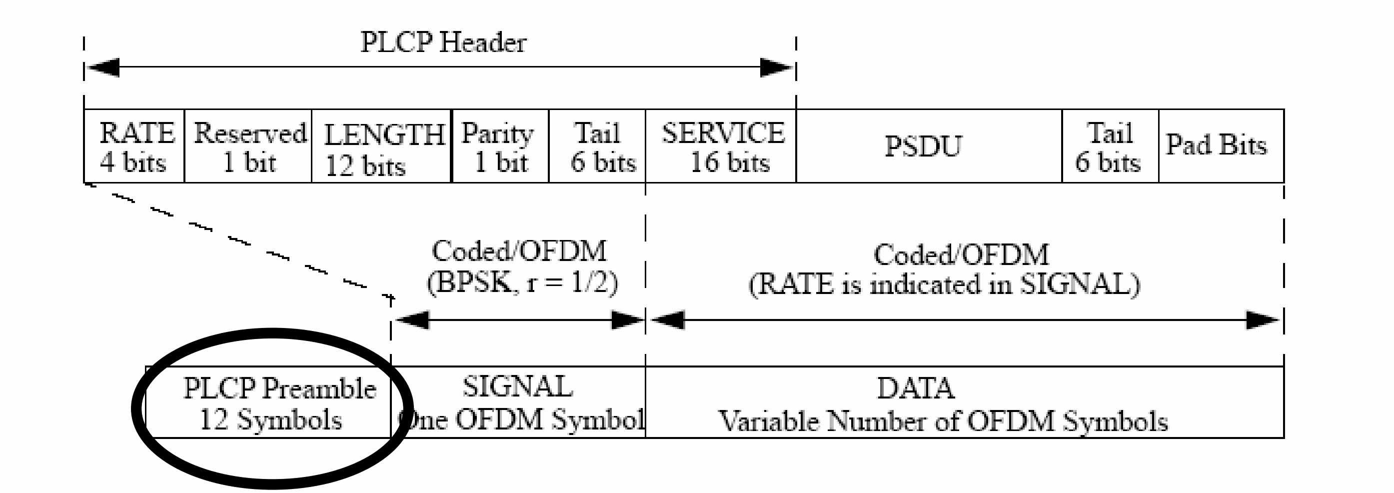
CCA busy detection (1)

- Rx: -62dBm, detect busy for any signal
  - Energy on wireless medium/busy tone
- Example
  - Tx: 100mW ≙ 20dBm
  - γ=2, free space
    - max. d = 54.6m
  - γ=3.5
    - max. d = 9.8m



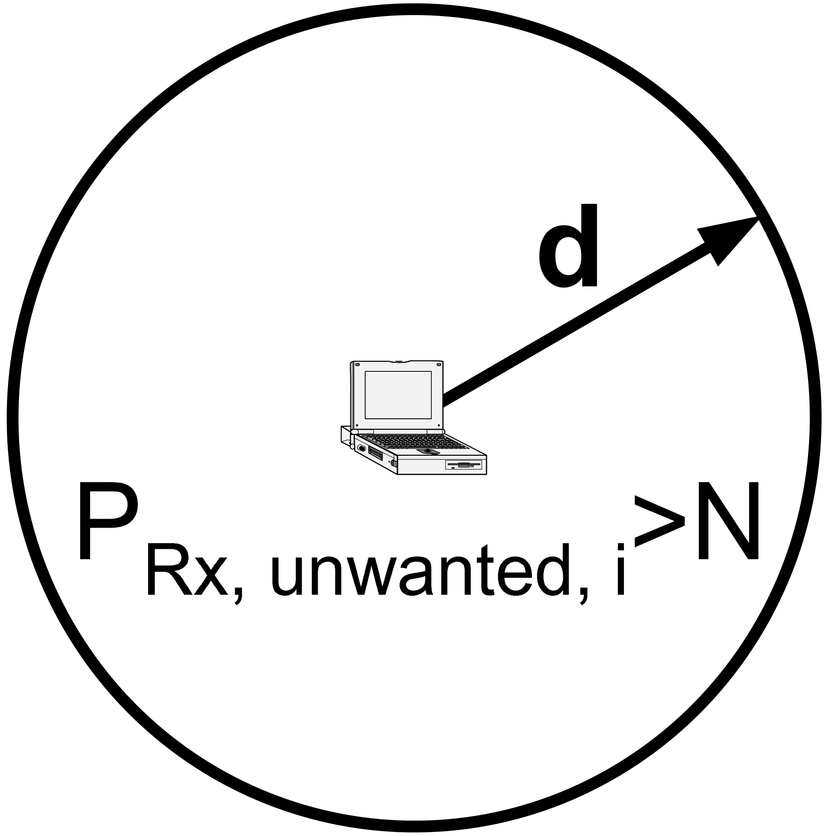
CCA busy detection (2)

- Valid start of OFDM transmission
  - C ≥ -82dBm
- Assumption
  - $\gamma = 3.5$
- →Preamble detection range
  - d = 58.1m



Interference range

- Assumption
  - N = -95dBm
  - Neglect interference if $P_{Rx,\ unwanted,\ i} \leq N$
- Example
  - Tx = 100mW $\hat{=}$ 20dBm
  - γ=2, free space
    - max. d = 2440.9m
  - γ=3.5
    - max. d = 105.1m

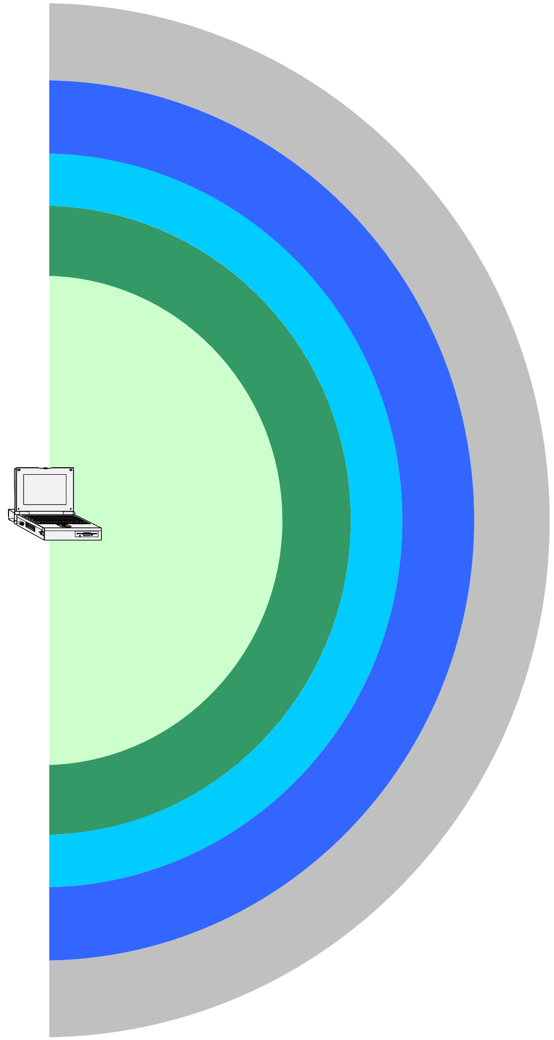


Range Comparison

1. Interference
2. CCA (1), OFDM preamble
3. CCA (2), busy detection
4. RTS,CTS, ACK … @BPSK ½
5. DATA reception

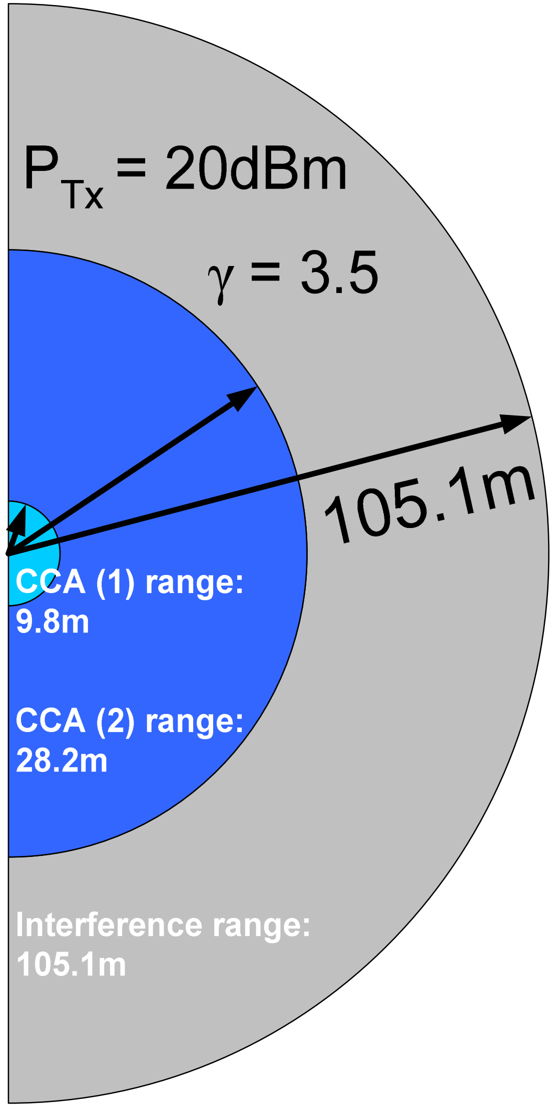
Ranges

Reception
RTS/CTS
CCA (1)
CCA (2)
Interference



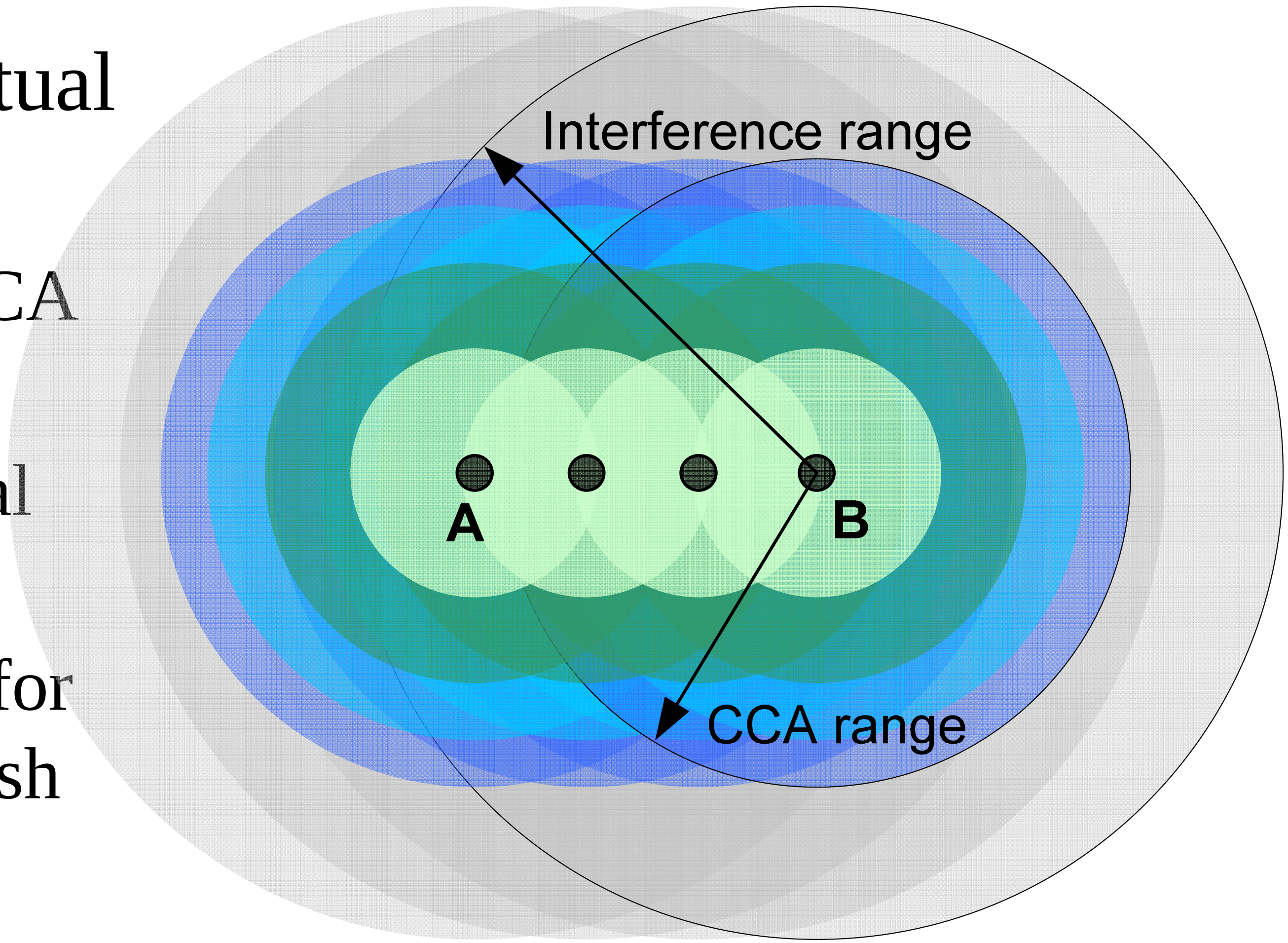
Range examples

- RTS/CTS handshake
  - Well known drawbacks
- CCA busy detection
  - Limited range
  - Cannot distinguish rx and tx STA
- Interference threatens rx STA



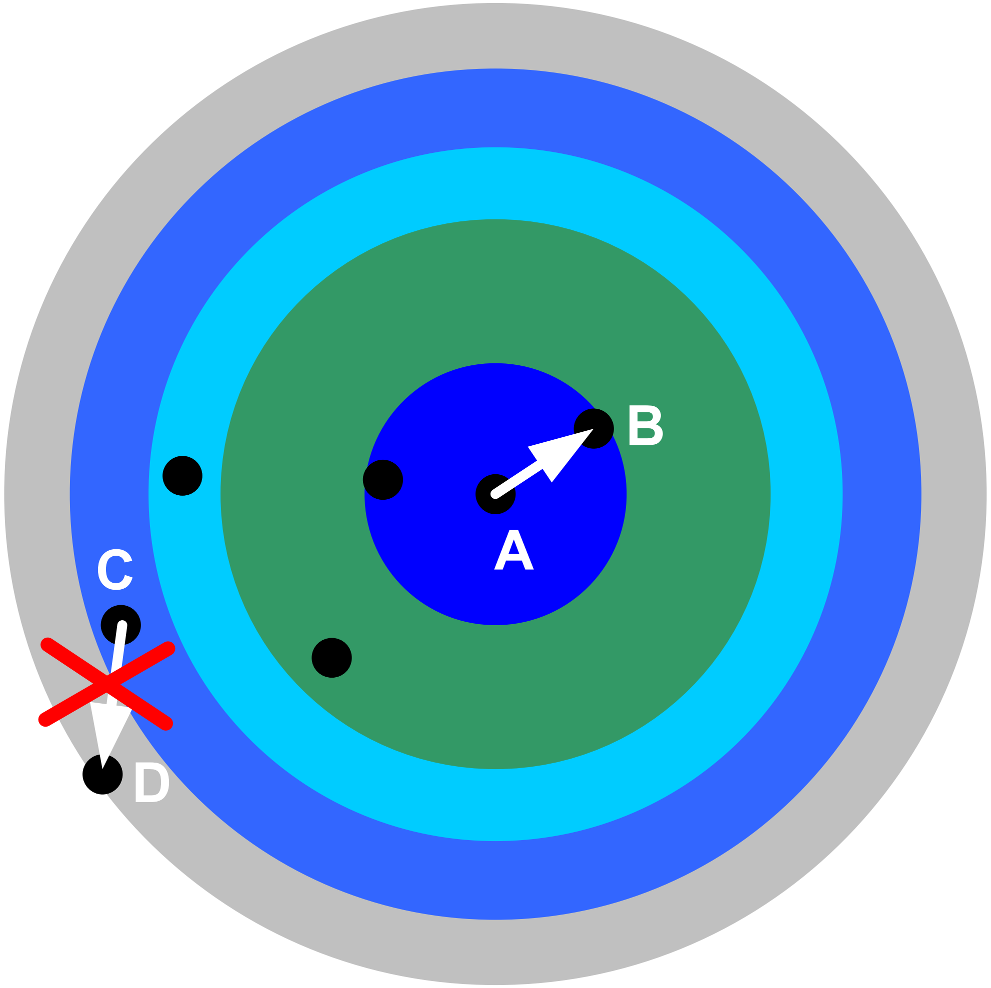
Multi hop interference

- A & B mutual interfere
  - Out of CCA range
  - No mutual detection
  - Problem for dense mesh



CCA limits capacity

- Contrary problem
  - CCA permits channel reuse (C→D)
  - CoI sufficient
  - CCA range too wide
  - Single tx per BSS only



Summary

- RTS/CTS handshake insufficient (11-04/760r1, 11-04/732r1)
  - Cannot avoid interference
  - Hidden & exposed node problems not solved
- Rx STA threatened by interference
- CCA very sensitive
  - Limits capacity
- Mesh network capacity shared by all Mesh Points
  - Spatial frequency reuse important
    - Especially for single frequency solutions
  - Important to distinguish between rx and tx STA
- No mechanism to distinguish between different ranges (rx, CCA etc.)

Conclusion

- Large scale mesh networks limited by interference
- CCA and RTS/CTS not sufficient
  - Capacity limited
  - Mutual interference decreases CoI for all STAs

Mesh networks need support for interference awareness

Thank you for your attention

hiertz@ieee.org
zangyp@ieee.org
rui@comnets.rwth-aachen.de
joerg.habetha@philips.com
stefan.mangold@philips.com

http://www.comnets.rwth-aachen.de
http://www.research.philips.com