

# The Impact of Channel Bonding on 802.11n Network Management

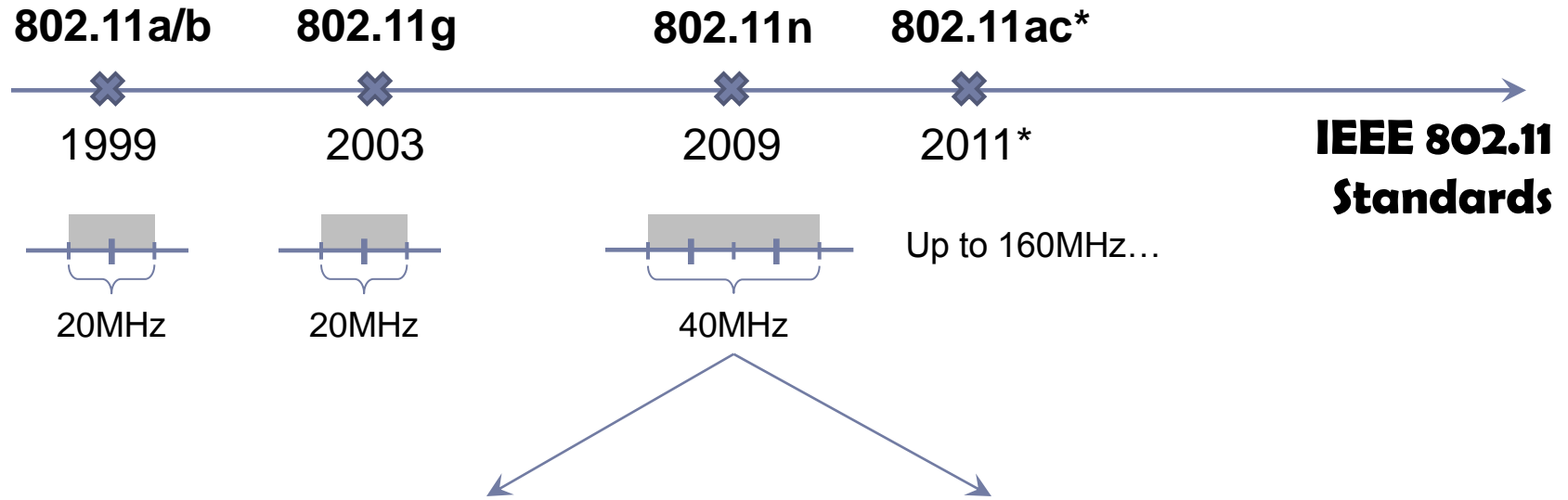


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UC Santa Barbara §, UPC-Barcelona TECH ‡,  
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# Channel Bonding (40MHz)



**+ Higher transmission rates**

- Reduction in number of non-overlapping channels**
- Greater susceptibility to interference**
- Degradation in transmission range**

# Context

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## Related Work

- ▶ Operation on 2.4GHz range  
[Shrivastava08] [Pelechrinis10]  
[Chandra08]
  - ▶ Limited opportunities for channel bonding
- ▶ Insight into characteristics of channel bonding  
[Arslan10] [Pelechrinis10] [Chandra08]

## Our Work

- Operation on 5GHz range
  - Significant opportunities to exploit channel bonding
- Extensive study of channel bonding in real-world network settings
  - Compare 20MHz vs. 40MHz
  - Identify network settings that impact channel bonding decisions
    - Signal quality
    - Strength and transmission rates of neighboring links

# Empirical Study of Channel Bonding

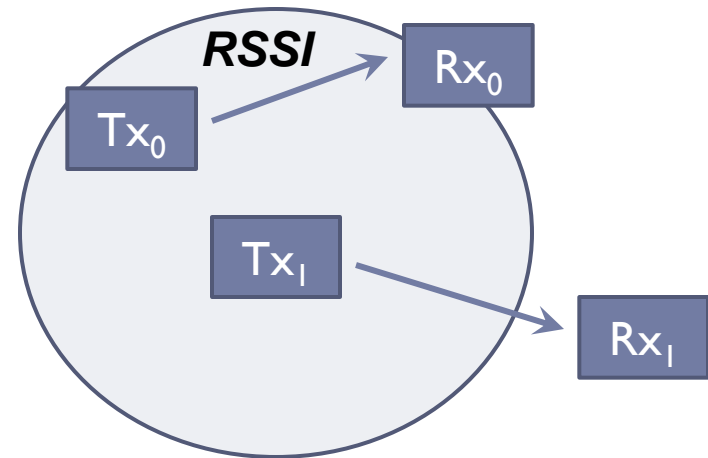
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- ▶ What is the impact of \_\_\_\_\_ on performance?
  - ▶ Receiver Signal Strength (RSSI)
  - ▶ Rich Scattering Environment
  - ▶ Modulation and Coding Scheme (MCS)
  - ▶ Neighboring nodes
    - ▶ Interference from Channel Leakage
    - ▶ Channel Sharing

# Empirical Study of Channel Bonding

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- ▶ What is the impact of \_\_\_\_\_ on performance?
  - ▶ Receiver Signal Strength (RSSI)
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  - ▶ Modulation and Coding Scheme (MCS)
  - ▶ Neighboring nodes
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# Testbed Environment

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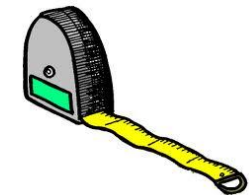
## ▶ Node configuration

- ▶ Laptops running Ubuntu 10.04 LTS
- ▶ 802.11n, 2x3 MIMO PC cards with Atheros chipset
- ▶ Ath9k driver



## ▶ Measurement environment

- ▶ Semi-open office environment at UCSB
- ▶ 5GHz operation
- ▶ Controlled environment
- ▶ Packet aggregation and retransmission disabled
- ▶ Rate adaptation disabled



## ▶ Performance metrics

- ▶ *Best UDP Goodput*
  - ▶ Measured at best transmission rate using exhaustive search
  - ▶ Averaged over multiple runs

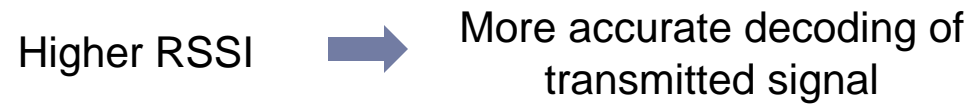


# RSSI

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- ▶ What is the impact of RSSI?

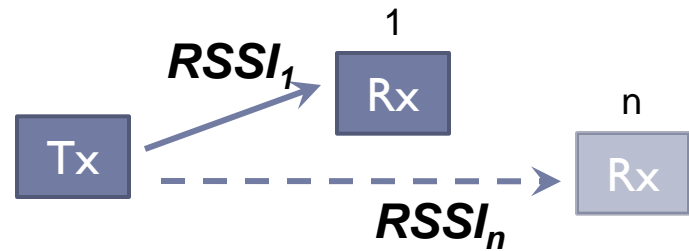
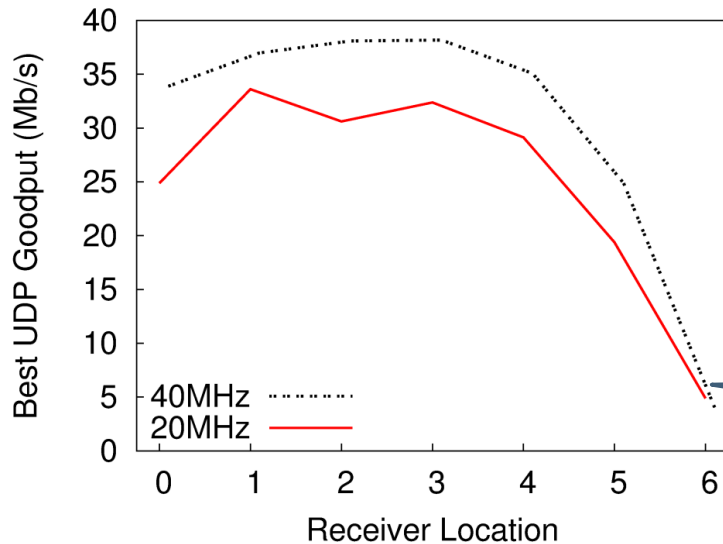


# RSSI



- ▶ What is the impact of RSSI?

**Lesson 1:**  
Channel Bonding degrades throughput when  
RSSI is close to minimum input sensitivity.



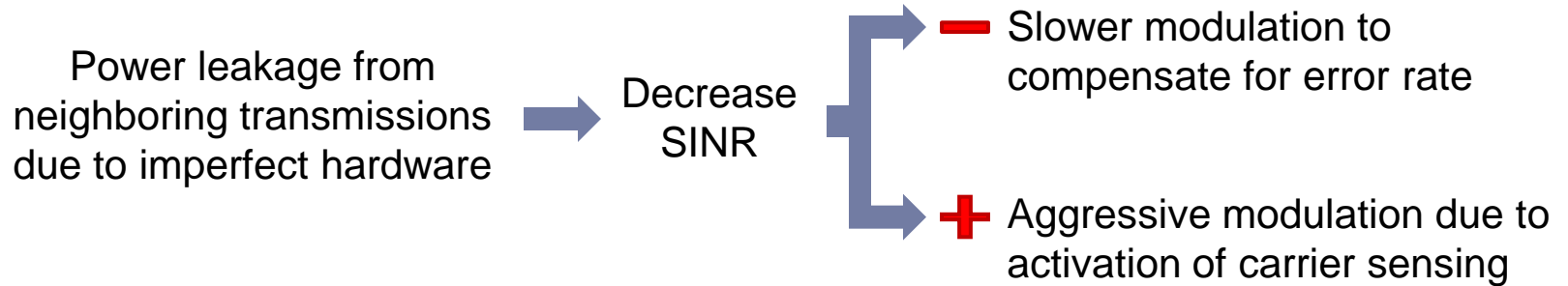
RSSI < Receiver Minimum  
Input Sensitivity



# Neighboring Nodes: Channel Leakage

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- ▶ What is the impact of channel leakage?



# Neighboring Nodes: Channel Leakage

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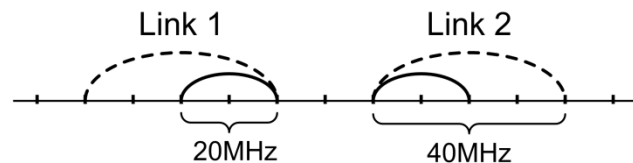
- ▶ What is the impact of channel leakage?

## Lesson 2:

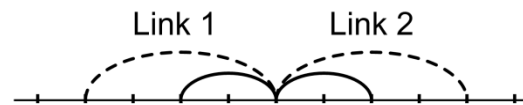
Signal strengths between adjacent transmitters affect channel bonding decisions.

- ▶ Evaluate impact of channel leakage configurations:

1. 20MHz channel separation



2. Adjacent channels



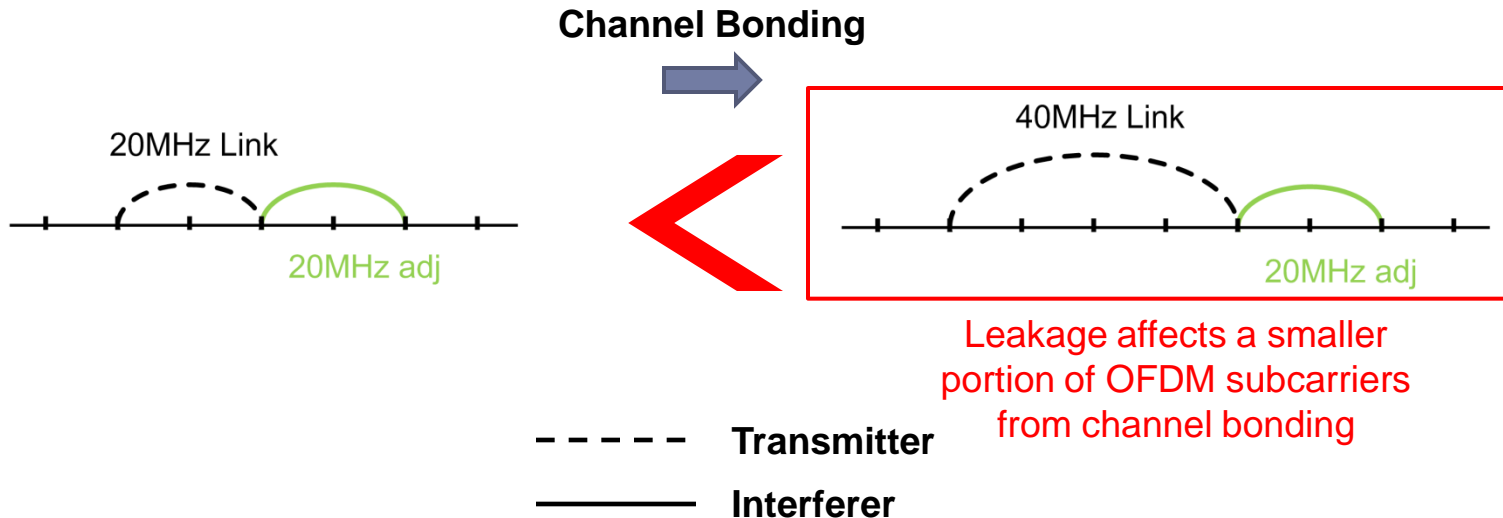
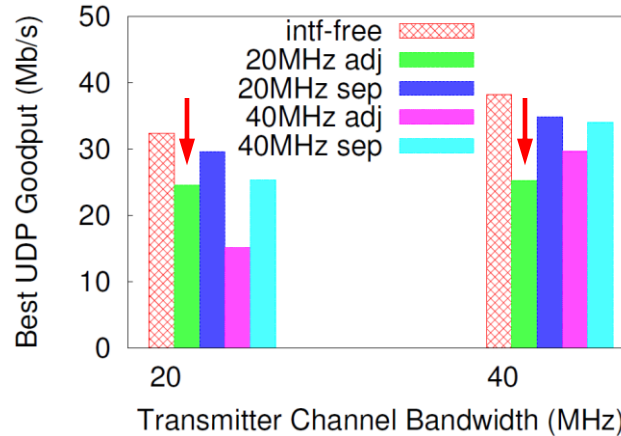
3.  $\geq 40$ MHz channel separation

- ▶ *Transmitter*: Link where performance is evaluated
- ▶ *Interferer*: Neighboring link causing interference at the *Transmitter* link

# Neighboring Nodes: Channel Leakage

- For the same *Interferer* configuration, is channel bonding a favorable option?

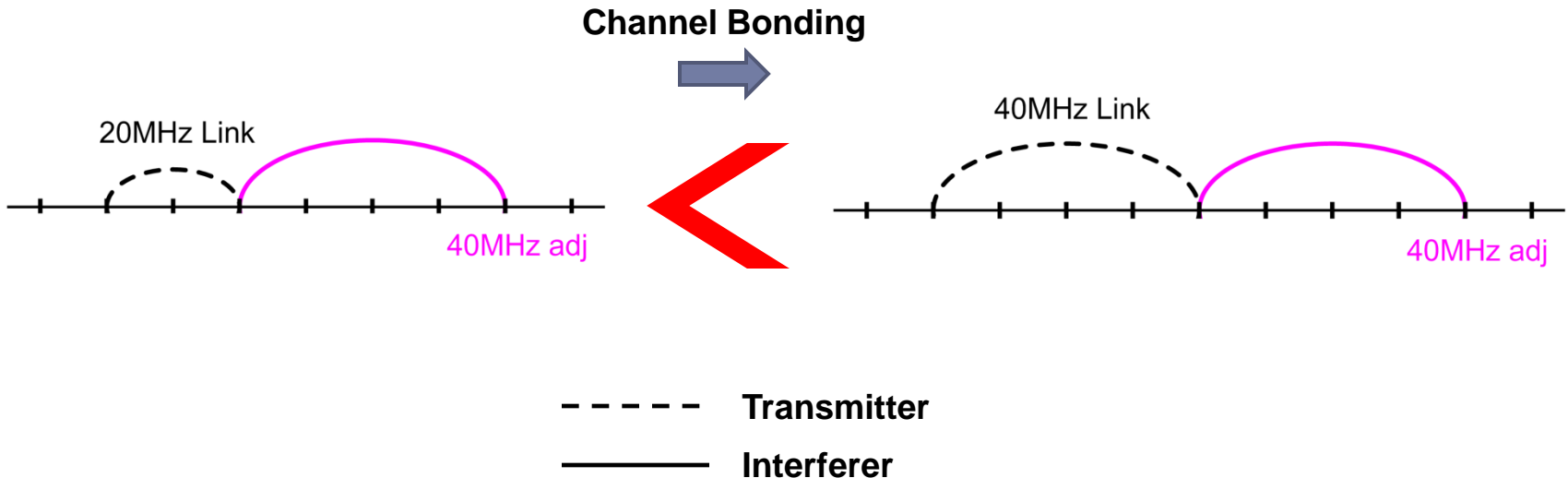
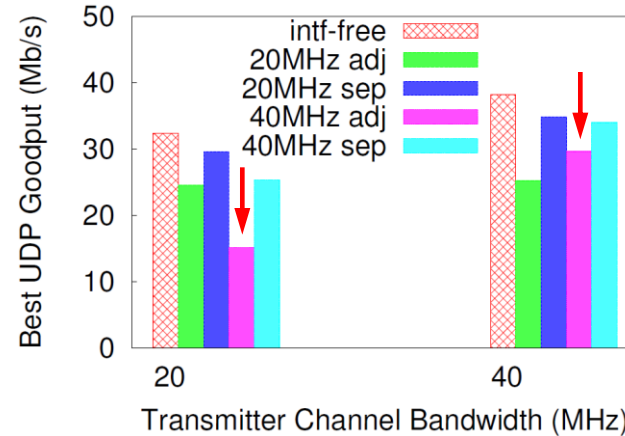
- Yes



# Neighboring Nodes: Channel Leakage

1. For the same *Interferer* configuration, is channel bonding a favorable option?

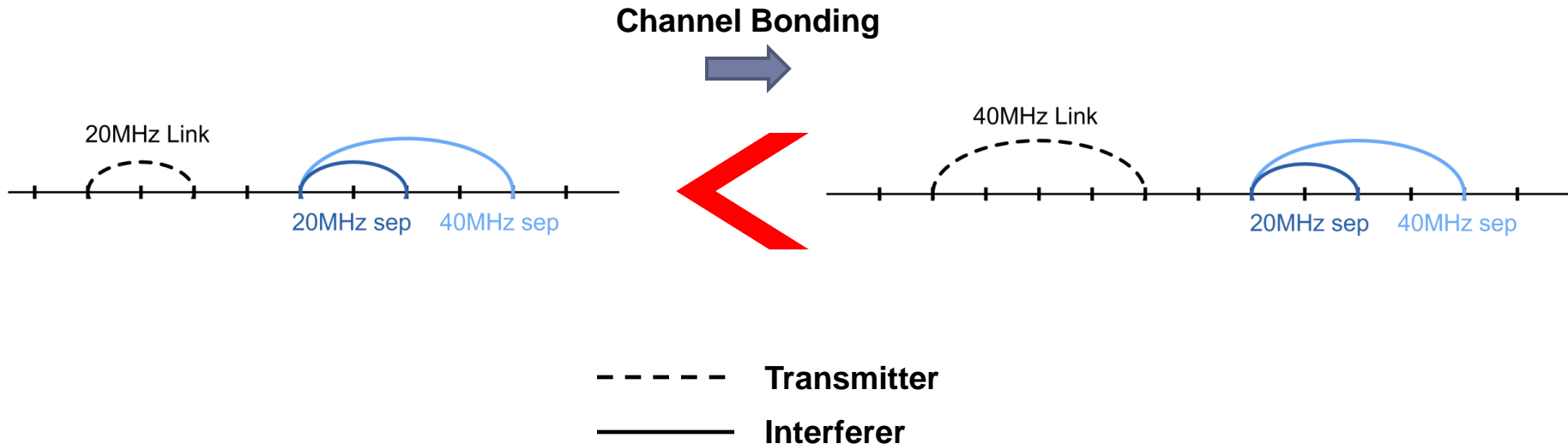
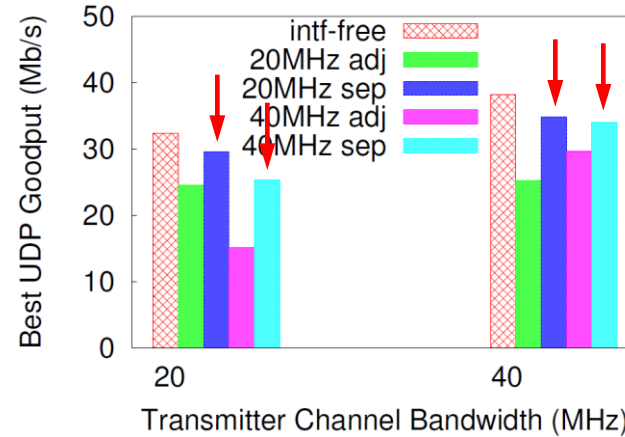
- Yes



# Neighboring Nodes: Channel Leakage

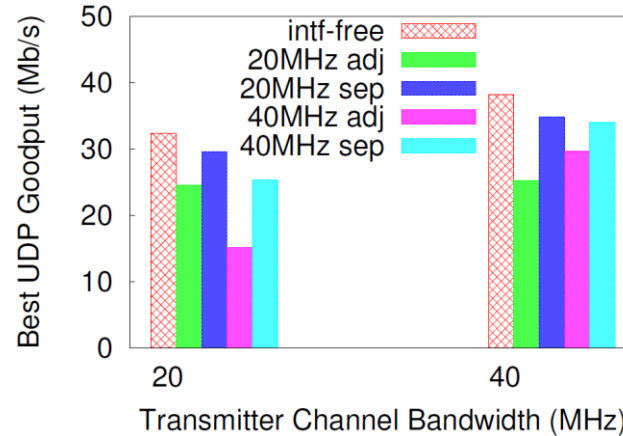
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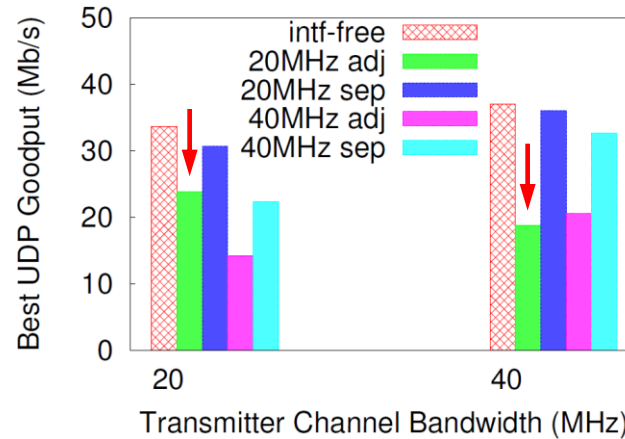
# Neighboring Nodes: Channel Leakage

1. For the same *Interferer* configuration, is channel bonding a favorable option?
  - Yes
2. What affects the benefits of channel bonding?
  - *Interferer RSSI at Transmitter*

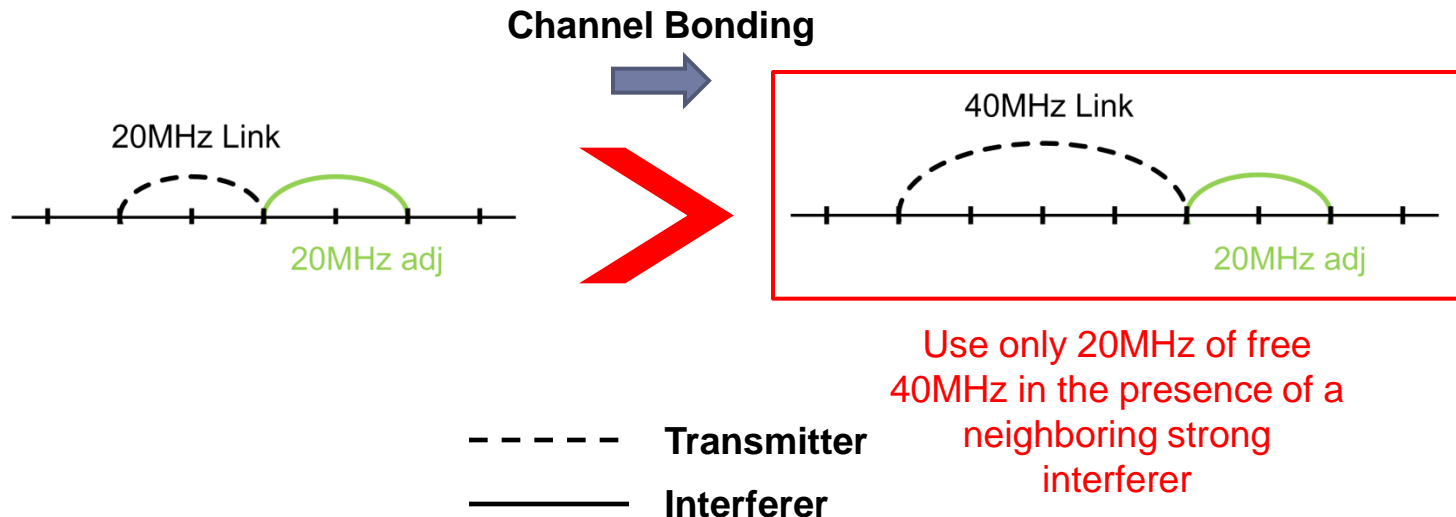


# Neighboring Nodes: Channel Leakage

- For the same *Interferer* configuration, is channel bonding a favorable option?
  - Yes
- What affects the benefits of channel bonding?
  - Interferer RSSI at Transmitter*



**Strong Transmitter**  
**Strong Interferer**



# Neighboring Nodes: Channel Sharing

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- ▶ What is the impact of channel sharing?

Multi-rate CSMA nodes  
sharing the medium



Weak/slow nodes  
penalizing fast stations

# Neighboring Nodes: Channel Sharing

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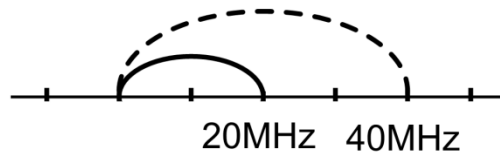
- ▶ What is the impact of channel sharing?

## Lesson 3:

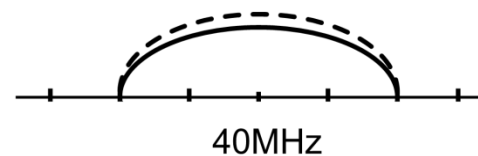
Knowledge of the transmission rate of neighboring links affects channel bonding decisions.

- ▶ Evaluate impact of channel sharing configurations:

1. Partial overlap



2. Complete overlap

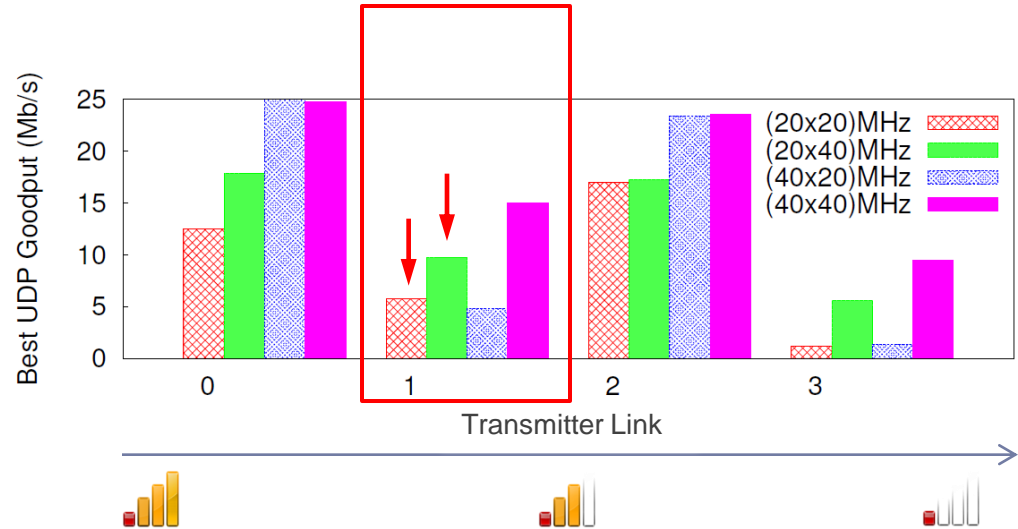


- ▶ *Transmitter*: Link where performance is evaluated
- ▶ *Interferer*: Neighboring link causing interference at the *Transmitter* link
  1. **Strong** Interferer, **fast** transmission rates
  2. **Weak** Interferer, **slow** transmission rates

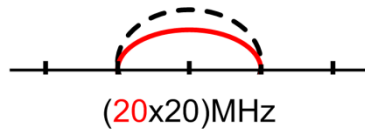
# Neighboring Nodes: Channel Sharing

1. Which bandwidth do we prefer to compete with?

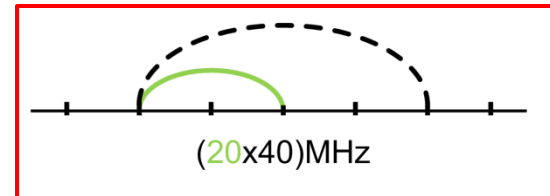
- 40MHz



Competing with a 20MHz interferer



Competing with a 40MHz interferer



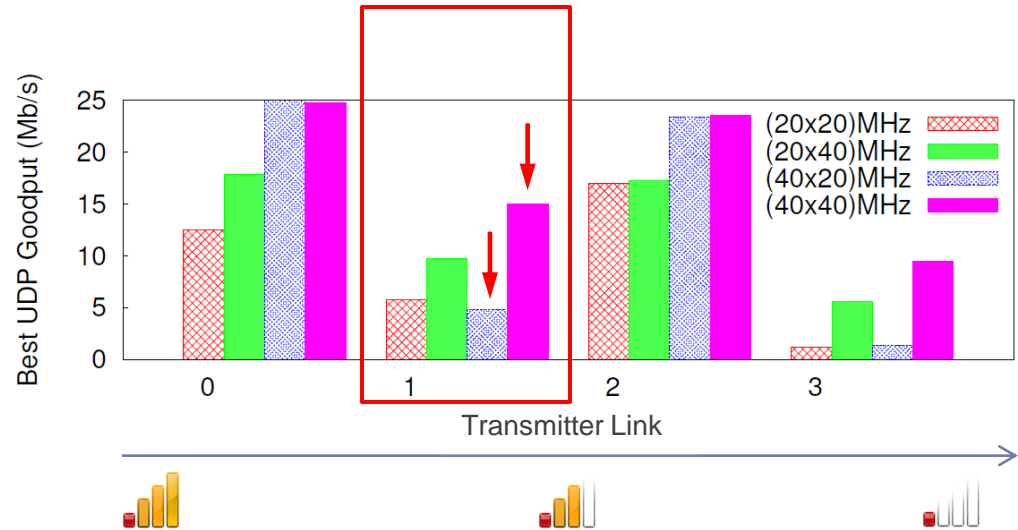
40MHz achieves higher rates thus alleviating fairness issues

----- Interferer  
 \_\_\_\_\_ Transmitter

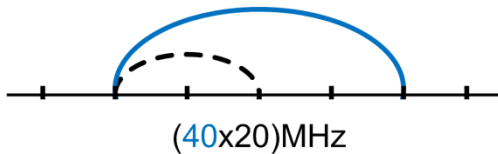
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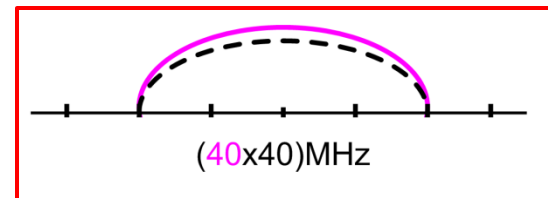
- 40MHz



Competing with a 20MHz interferer



Competing with a 40MHz interferer



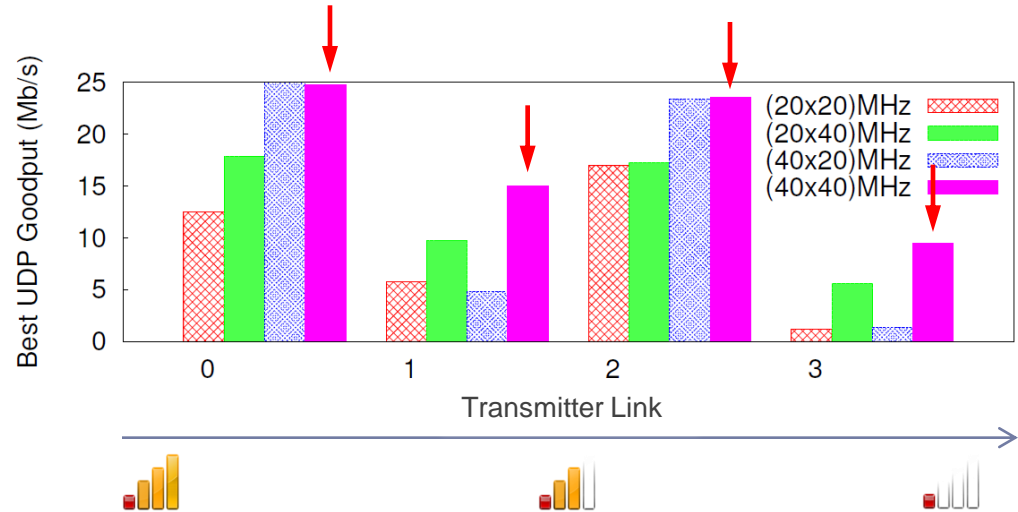
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----- Interferer  
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# Neighboring Nodes: Channel Sharing

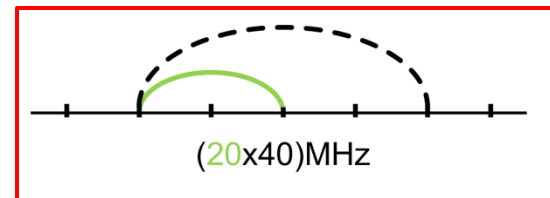
1. Which bandwidth do we prefer to compete with?

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## Competing with a **40MHz** interferer

Best performance

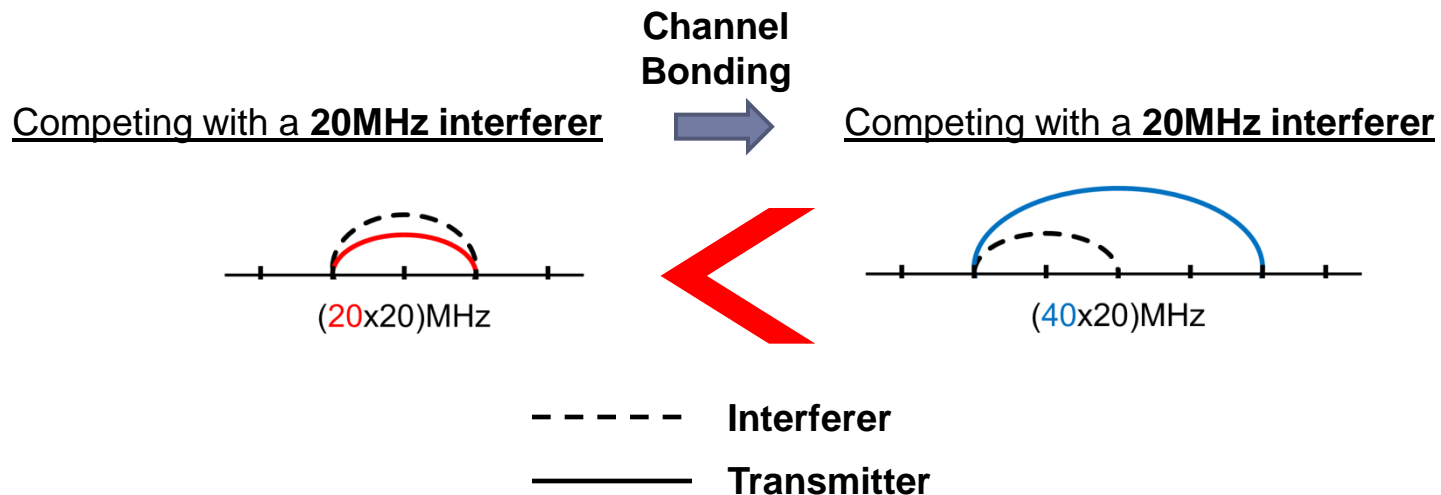
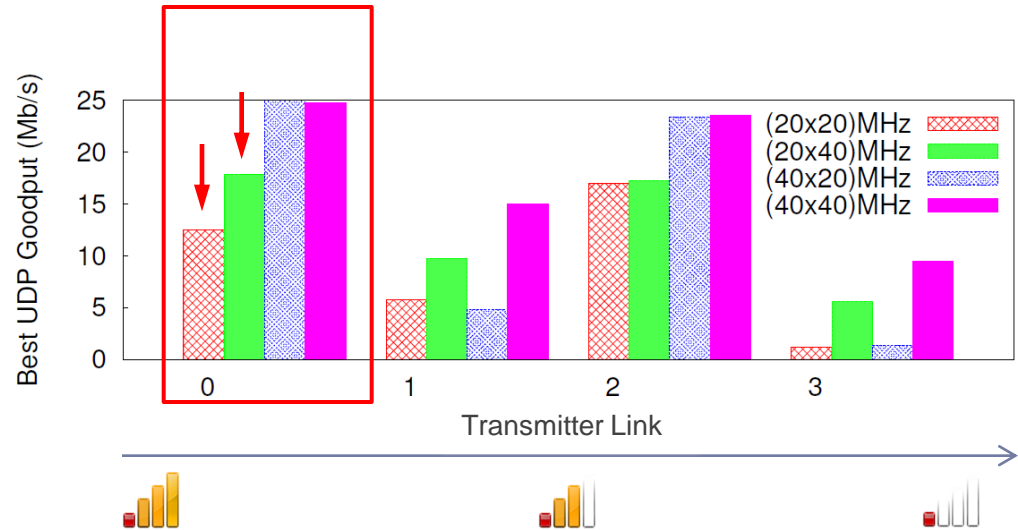


40MHz achieves higher rates thus alleviating fairness issues

----- Interferer  
 \_\_\_\_\_ Transmitter

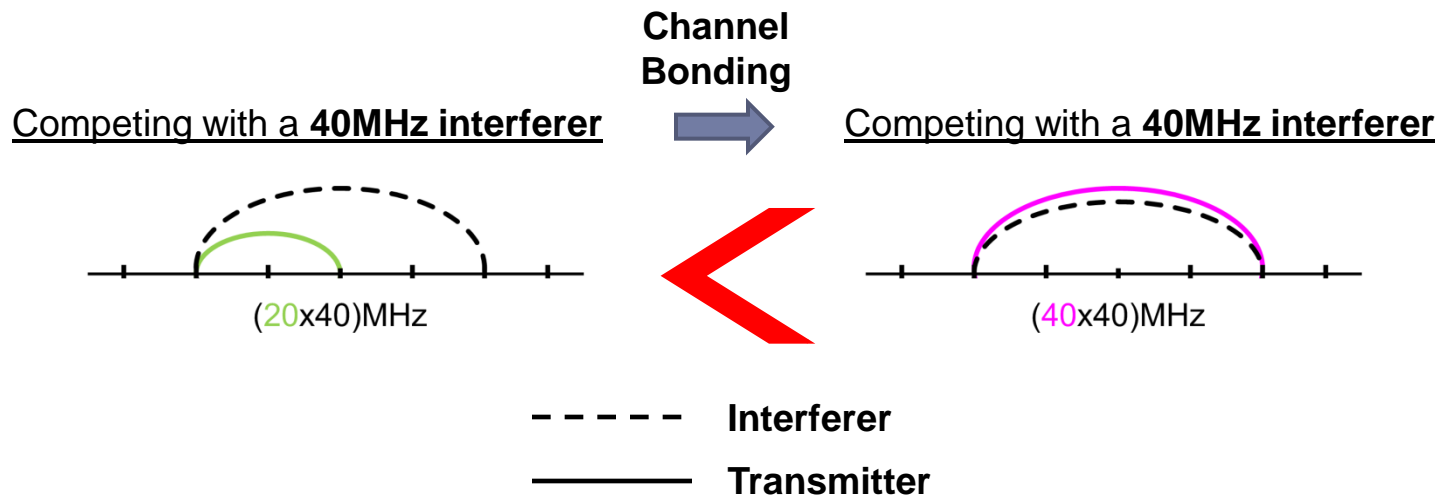
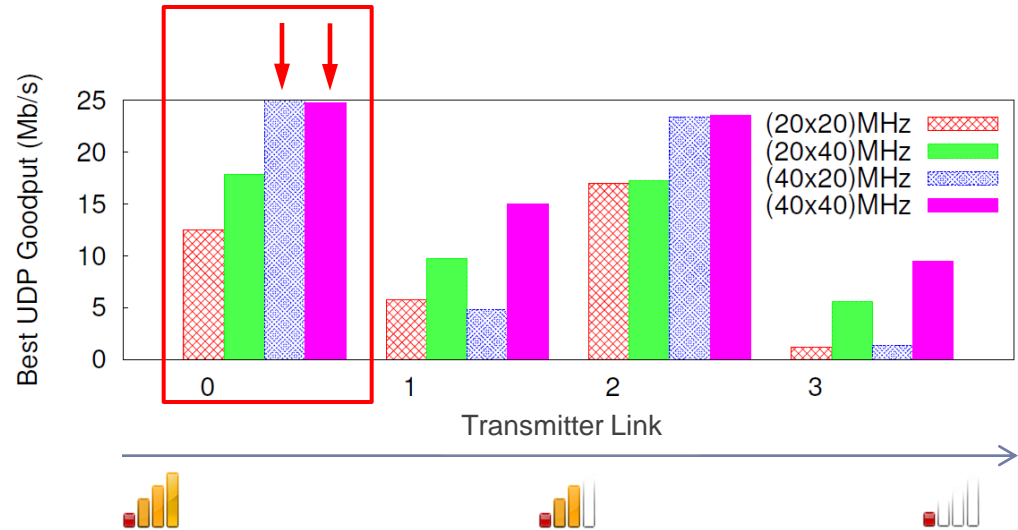
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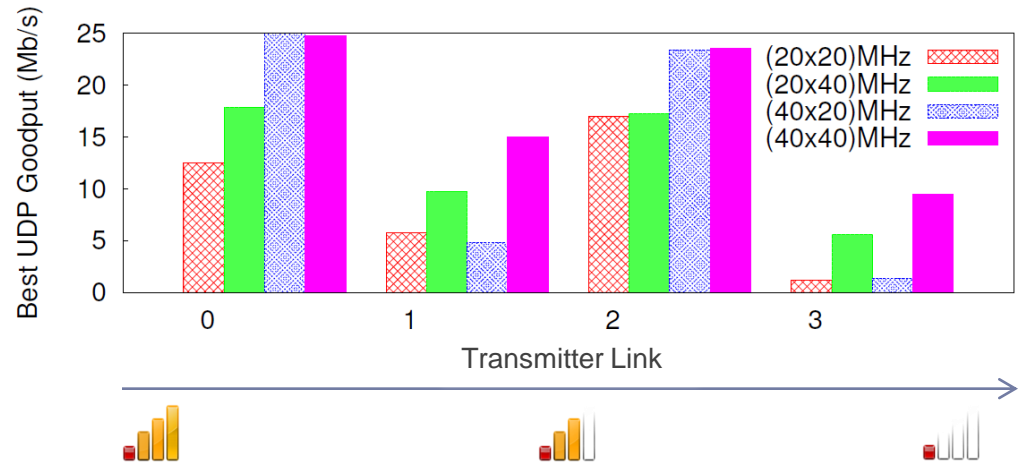
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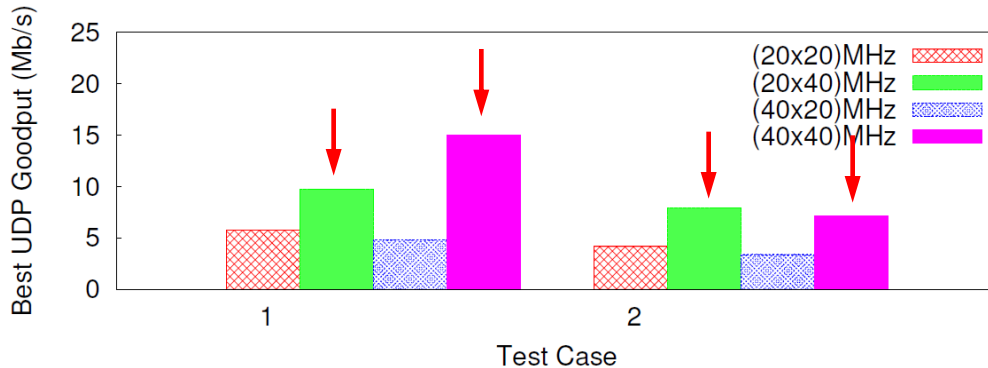


# Neighboring Nodes: Channel Sharing

1. Which bandwidth do we prefer to compete with?
  - 40MHz
2. For the same *Interferer* configuration, is channel bonding a favorable option?
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3. What affects the benefits of channel bonding?
  - *Interferer* transmission rate

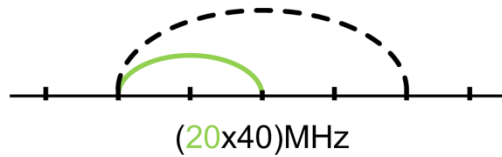


# Neighboring Nodes: Channel Sharing



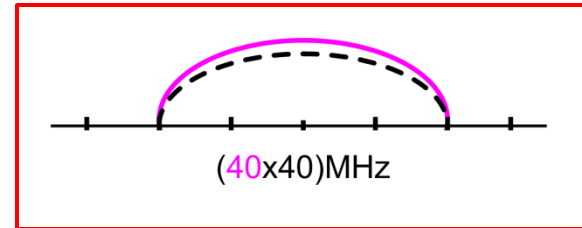
**For the same Transmitter,**  
Test Case 1: Interferer good link quality  
 (fast transmission rate)  
Test Case 2: Interferer poor link quality  
 (slow transmission rate)

Competing with a 40MHz interferer



Channel Bonding  
 →

Competing with a 40MHz interferer



Test Case 1: Performance improves

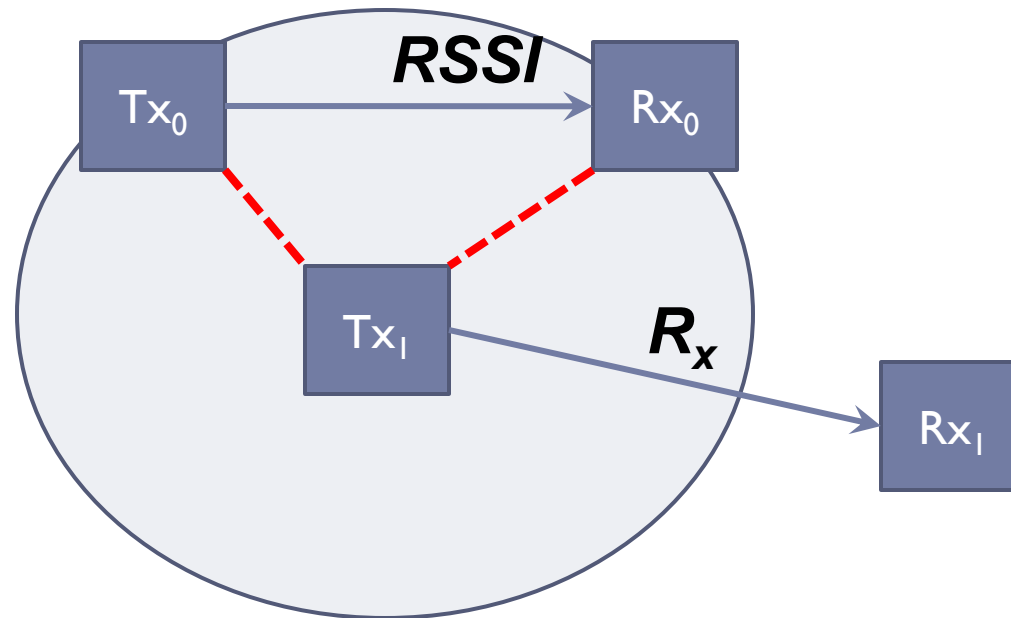
Test Case 2: Performance benefits diminish due to lower rates at the *Interferer*

----- Interferer  
 \_\_\_\_\_ Transmitter

# Summary of Lessons Learned

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- ▶ **Lesson 1:** Signal strength at receiver (RSSI)
- ▶ **Lesson 2:** Strength of interfering transmissions
- ▶ **Lesson 3:** Transmission rates of links in CS range



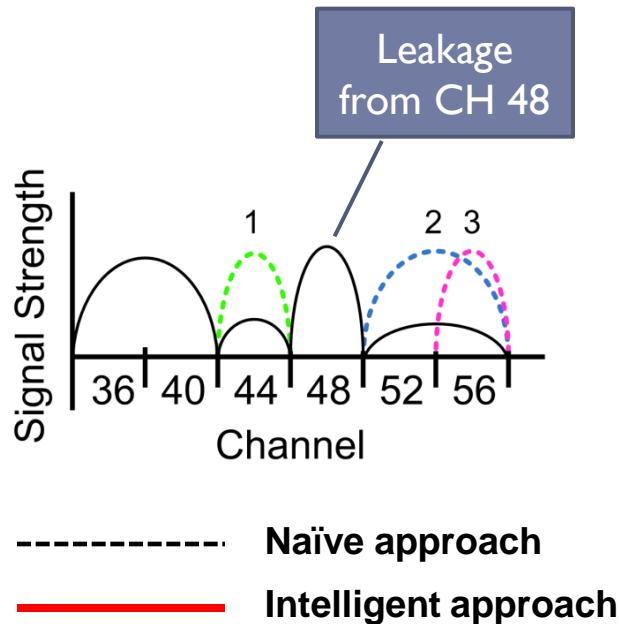
# Evaluation of Lessons Learned

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- ▶ Create network scenarios and compare the impact of:
  - ▶ Naïve decisions
    - ▶ Assign channel with weakest interfering signal
  - ▶ Intelligent decisions
    - ▶ Rely on lessons learned to assign channel
  
- ▶ Evaluation environment
  - ▶ Limit available channels to recreate contention for bandwidth
  - ▶ Replicate off-the-shelf wireless devices
    - ▶ Enable frame aggregation
    - ▶ Enable automatic rate selection

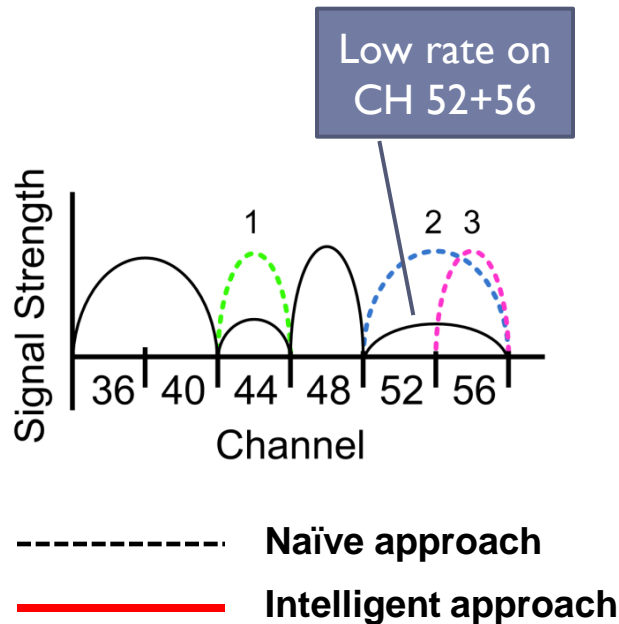
# Evaluation of Lessons Learned (cont'd)

- ▶ Transmitter “T” requesting bandwidth:



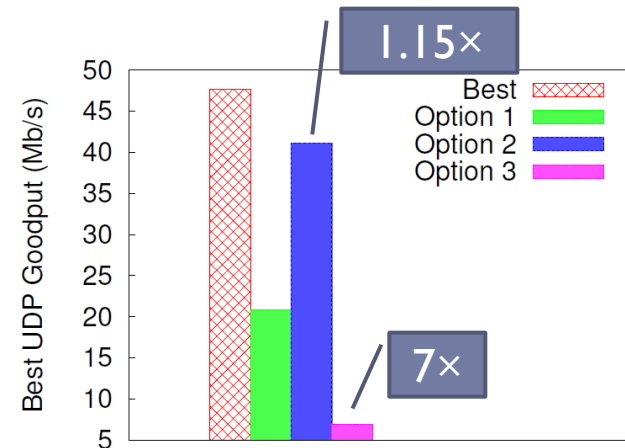
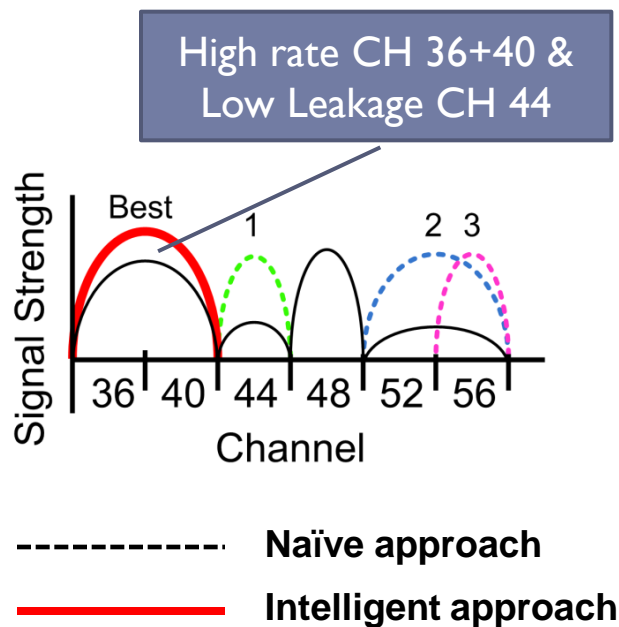
# Evaluation of Lessons Learned (cont'd)

- ▶ Transmitter “T” requesting bandwidth:



# Evaluation of Lessons Learned (cont'd)

- ▶ Transmitter "T" requesting bandwidth:



**Lessons allow for intelligent decisions that leverage the benefits of channel bonding in typical 802.11n environments**

# Conclusion

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- ▶ Provide an extensive study of the behavior of channel bonding in real-world network settings
- ▶ Identify usage terms for intelligently incorporating channel bonding in network deployments
  - ▶ **Lesson 1:** Receiver RSSI
  - ▶ **Lesson 2:** Strength of interfering transmissions
  - ▶ **Lesson 3:** Transmission rate of links in CS range
- ▶ Channel bonding provides the benefits it was touted for if applied correctly
- ▶ Lessons learned can be applied to design intelligent network management and rate adaptation solutions for 802.11n networks



# Thank you



**ANY QUESTIONS?**

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