Glia: A Practical Solution for Effective High Datarate Wifi-Arrays

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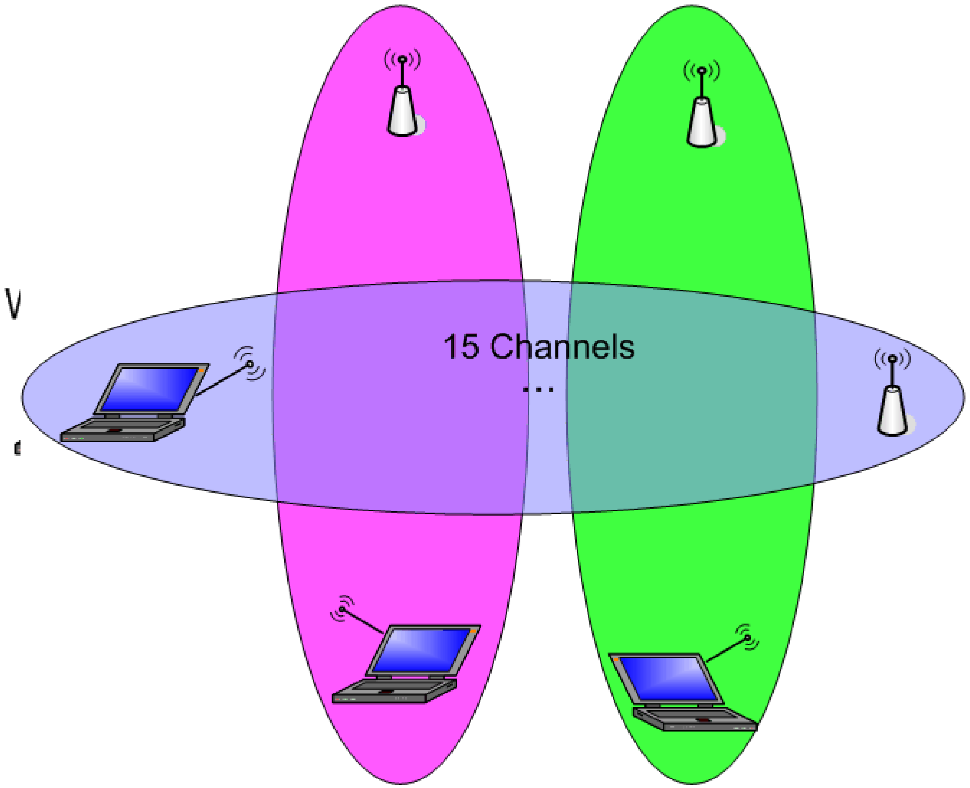
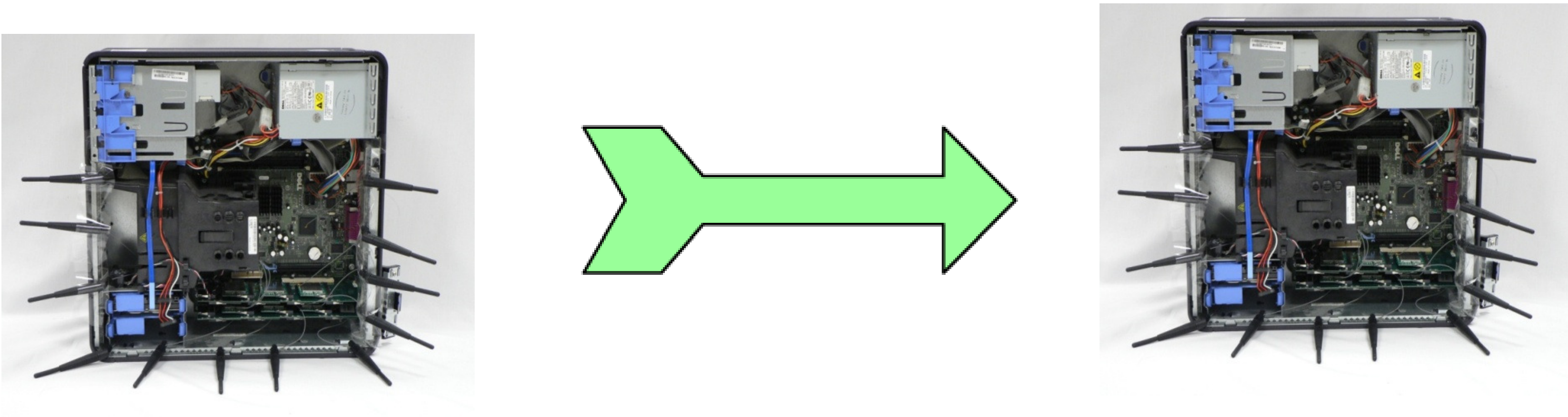
Introduction

- 3 orthogonal channels in 802.11g and 12 channels in 802.11a.
- Channels used by different networks in the same vicinity.
- Can two devices with 15 radios each use all channels to realize a single high data-rate wireless link ?
- We term such a system with multiple off-the shelf (OTS) radios as a wifi-array.



Does Throughput Scale with Radios?

- Wifi-array Setup: Microtik R52 miniPCI 802.11 a cards mounted on Routerboard IA/MP8 miniPCI-PCI adapters.
- Two identical 12 radio wifi-arrays used for source and destination of traffic.
- 12 channels in 802.11a are used.
- Iperf traffic generator is run as separate instance on each radio, to generate UDP traffic.

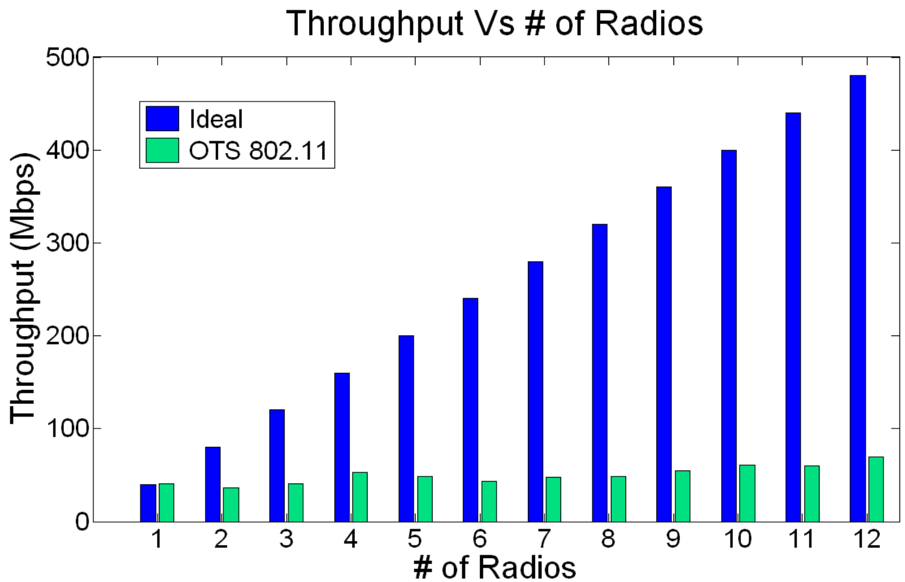


Does Throughput Scale with Radios?

- Individual per-channel application throughput is 40Mbps.
- Ideal throughput = 480 Mbps for 12 radios.

  ➢ Observed throughput = 70 Mbps !

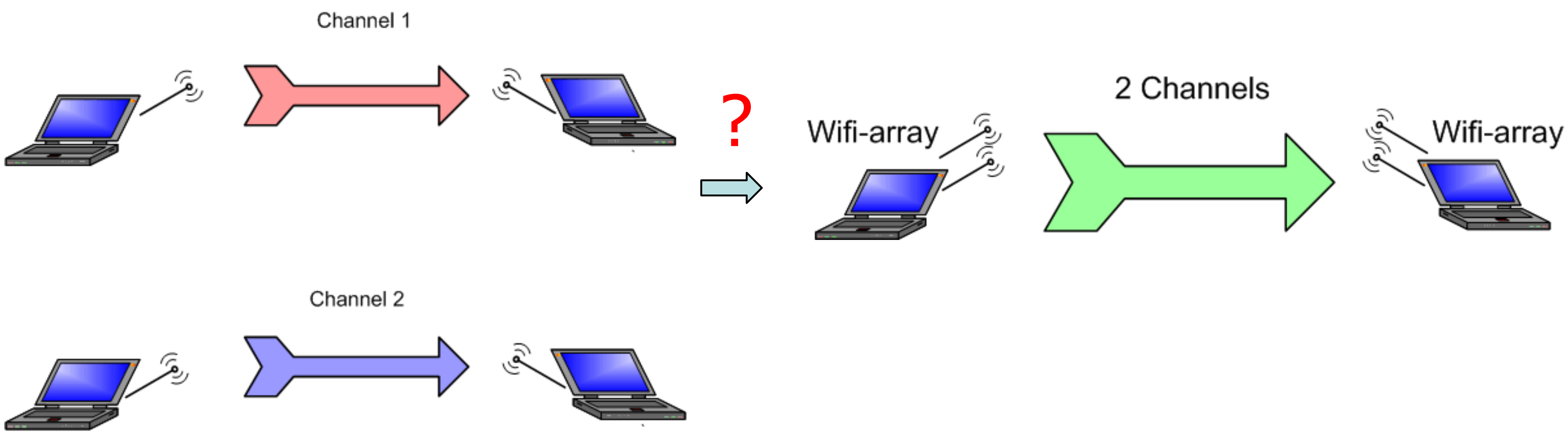
- Why is there such a disparity ?



Analyzing the Disparity

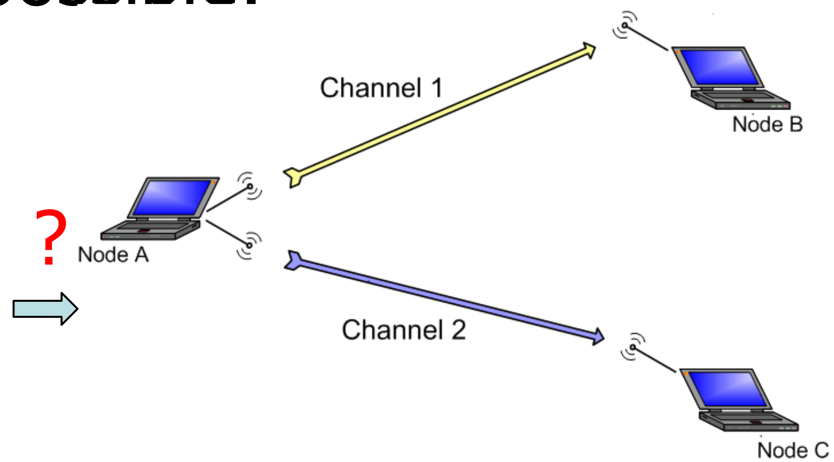
- A simpler 2 radio wifi-array setup.

80 Mbps 40 Mbps



Analyzing the Disparity

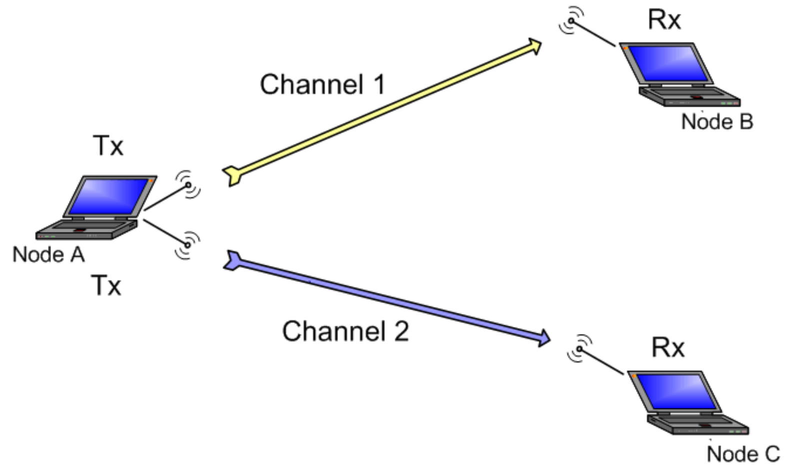
- A simpler 2 radio wifi-array setup.
- Depending on whether the 2 radios of a wifi-array are transmitting (Tx) or receiving (Rx), three scenarios are possible:
  - Tx-Tx
  - Rx-Rx
  - Tx-Rx

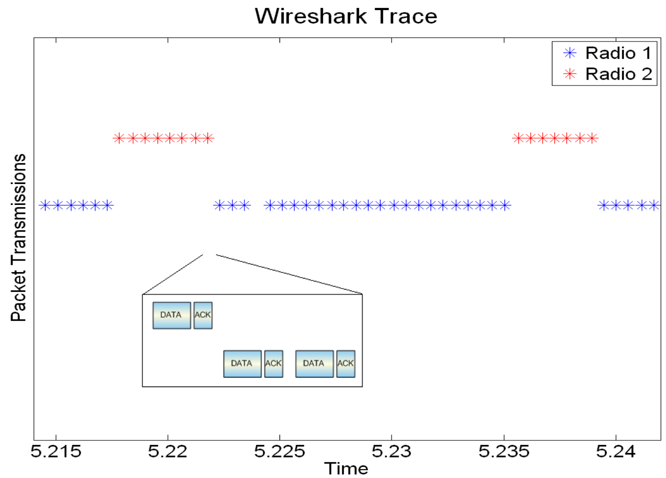


- To isolate the three scenarios, a 3 node setup is used

Co-located Tx/Tx

- Both radios of node A are Tx.
- While expected aggregate throughput is 80Mbps, observed aggregate is only 44Mbps.
- In-spite of two orthogonal channels, only single channel throughput is observed.
- Wireshark analysis on node A shows that at any given time, only one radio of node A is transmitting DATA packets.



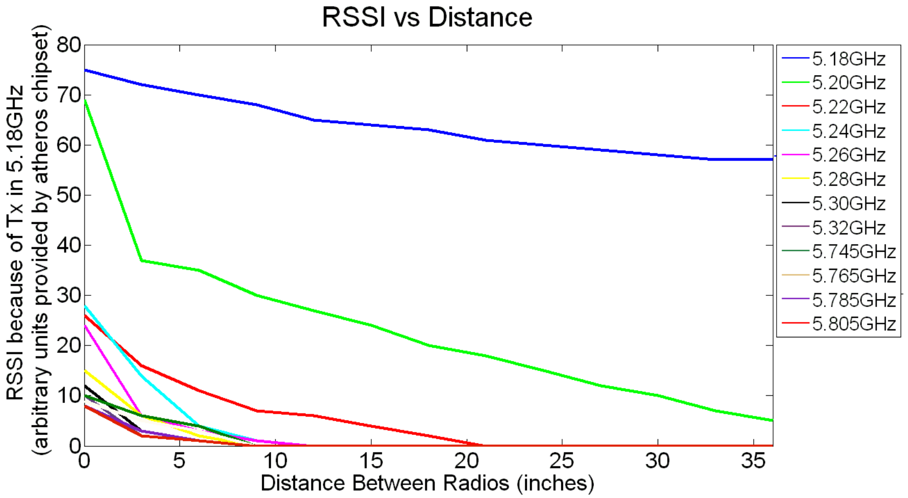


Investigating RSSI

Problems in wifi-arrays

• OOB triggers Carrier Sense

- Setup: Transmit DATA on 5.18GHz from one radio. Measure RSSI (Receive Signal Strength Indicator) using a separate radio on different channels and at different distance from first radio.



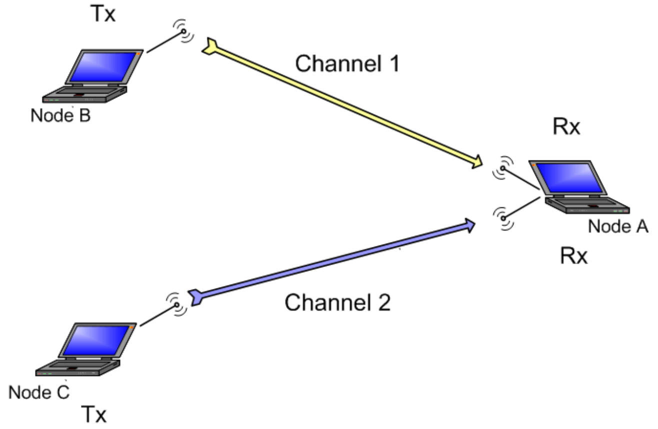
- Observation:
  - At distances greater than 20 inches, RSSI for other channels is 0.
  - However at short distances significant RSSI on all channels.
- Inference:
  - Power leaks from one radio to another at small distances.
  - Leakage power triggers carrier sense and prevents co-located radios to transmit DATA simultaneously.
  - Leakage power is known as Out-of-Band emission [Adya'04, Robinson'05, Liese'06, Liu'06].

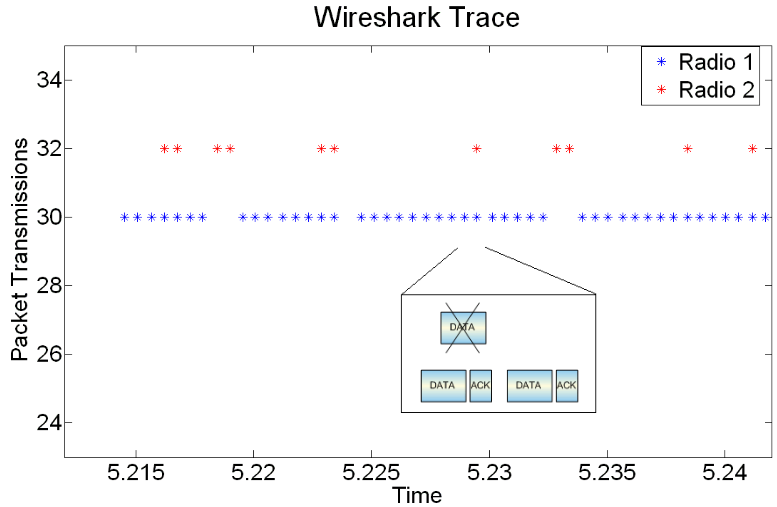
Co-located Rx/Rx

- Both radios of node A are Rx.
- Observed aggregate throughput is 45Mbps. Single-radio throughput is observed again in-spite of two orthogonal channels.
- Wireshark on node A shows some of the DATA packets received are corrupted.
- Closer inspection shows that DATA packets are corrupted when ACKs are sent on other radio.
- ACK transmission on one radio corrupts DATA reception on other radio because of OOB.

Problems in wifi-arrays

- OOB triggers Carrier Sense
- ACKs corrupt DATA reception



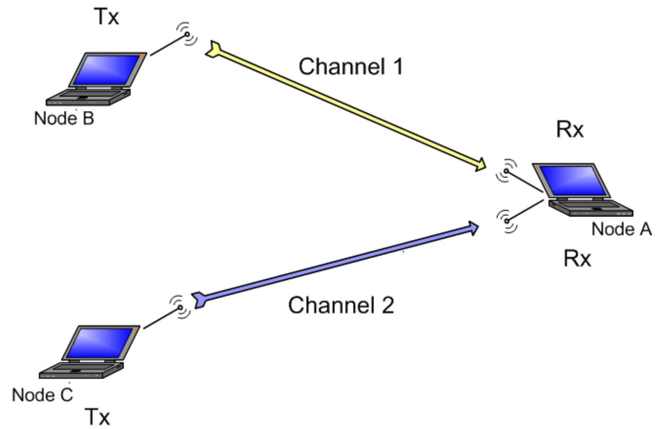


Co-located Rx/Rx

Problems in wifi-arrays

- OOB triggers Carrier Sense
- ACKs corrupt DATA reception
- Imperfect filters affect reception

- More experiments with Rx/Rx and ACK turned OFF.
- Non-adjacent channels allow proper aggregation
- When adjacent channels are used for the two links (ex 5.18 GHz and 5.20GHz). Aggregate throughput depends on
  - pair of adjacent channels used.
  - Location of Node A
- Lower throughput caused because of packet errors
- Packet errors occur because of imperfect receive filters [TI Report].



Channels/ Location	PER	Thrpt (Mbps)
5.18,5.20 / I	0.01,0.1	75.6
5.18,5.20 / II	0.32,0.24	56.7
5.24,5.26 / I	0.5,0.1	58.0
5.24,5.26 / II	0.2,0.21	62.8

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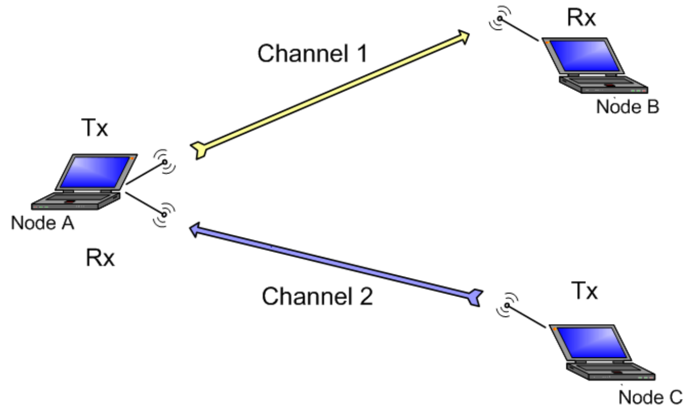
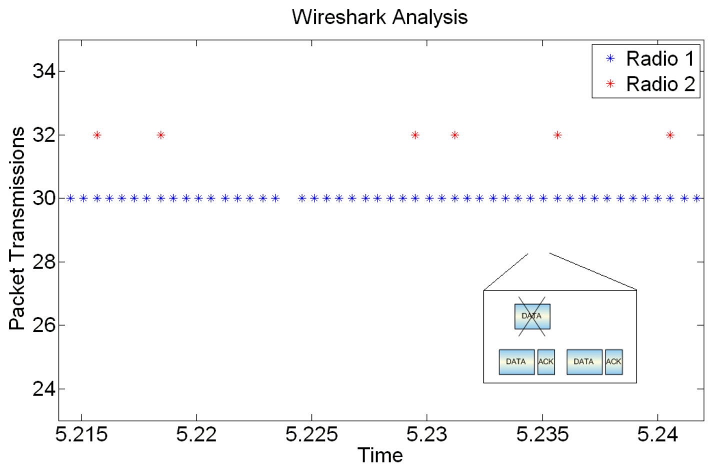
Co-located Tx/Rx

Problems in wifi-arrays

- OOB triggers Carrier Sense
- ACKs corrupt DATA reception
- Imperfect filters affect reception

- One radio at node A is Tx, while other radio is Rx.
- Observed aggregate throughput is 39 Mbps. Throughput of Tx flow is 38 Mbps while throughput of Rx flow is only 1 Mbps.
- Wireshark analysis, at node A, shows that almost all packets received by the Rx radio are corrupted. This is because of the OOB emission from Tx radio.
- DATA transmission on one radio corrupts DATA reception on a co-located radio.



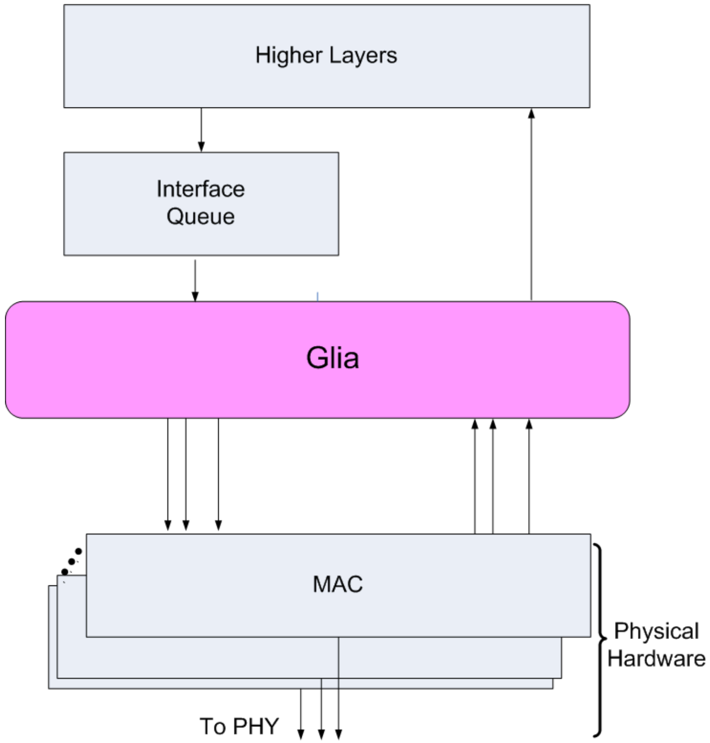


Problems in Wifi-arrays

- OOB triggers Carrier Sense
- ACKs corrupt DATA reception
- Imperfect filters affect reception
- DATA transmission corrupts DATA reception

Glia: A Software-only Solution for High Datarate Wifi-arrays

- Based on insights from analysis.
- Two-ended solution (source and destination wifi-arrays).
- 2.5 Layer operation.
- Centralized control of the individual medium access layers (MACs) of each radio.
- Two broad design elements
  - I. Act-as-One: multiple physical radios coordinate their communication to act as one logical radio.
  - II. Exploit-the-Many: the multiplicity of radios is exploited to combat channel diversity.



I.1 Mutually exclusive Tx/Rx

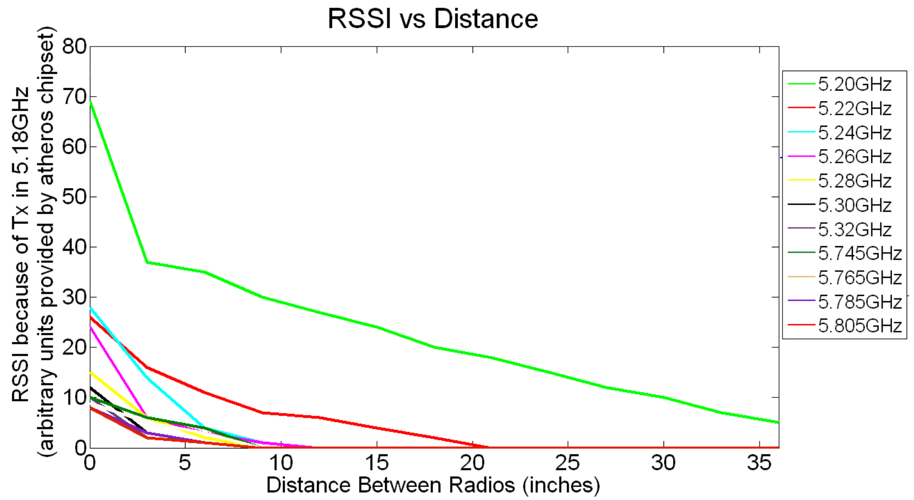
- Principle
  - Prevent transmission on one radio affecting reception on other radios.
  - All radios in an array must either transmit or receive only.

- Algorithm
  - Achieved using a centralized scheduler for all radios in the wifi-array.
  - A wifi-array interacts only with one other wifi-array at a time.
  - Scheduler avoids transmission on one radio if any other radio is receiving.

I.2 Adaptive Carrier Sense

- Principle
  - Prevent OOB of one radio from triggering carrier sense on other radios.
  - Estimate and remove the leakage power component.
- Algorithm
  - Estimate leakage powers L(1),L(2)…L(R)
  - Run-time operation:

    For each radio r from 1 to R
    - Measure current receive powers of active radios l
    - E' = E- L'
    - If E' > Th, Channel not c
    - Else, Clear channel



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I.3 Coarse Synchronization and Framing

- Principle
  - Efficiently use all channels without wasting bandwidth.
  - Coarsely synchronize packets in epochs:
    - Vary sizes of packets to reduce wastage of bandwidth
    - Use delayed ACKs.
- Algorithm
  - Input: alpha – fixed system delay, beta – variable delay estimate, rate(r) - data-rate of radio r, epoch – time slot.
  - For each radio r from 1 to R {

    frame size = frame size – alpha*rate(r)

    Send packet on radio r }
  - At receiver, wait for a timeout after the last bit of first packet
  - Transmit ACK on each radio
  - Lost packets are scheduled for retransmission in the next epoch,
  - Single back-off

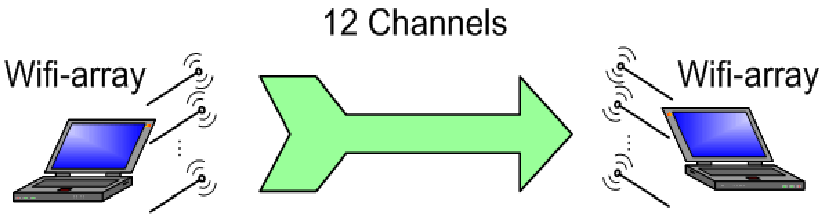
II. Exploit-the-Many

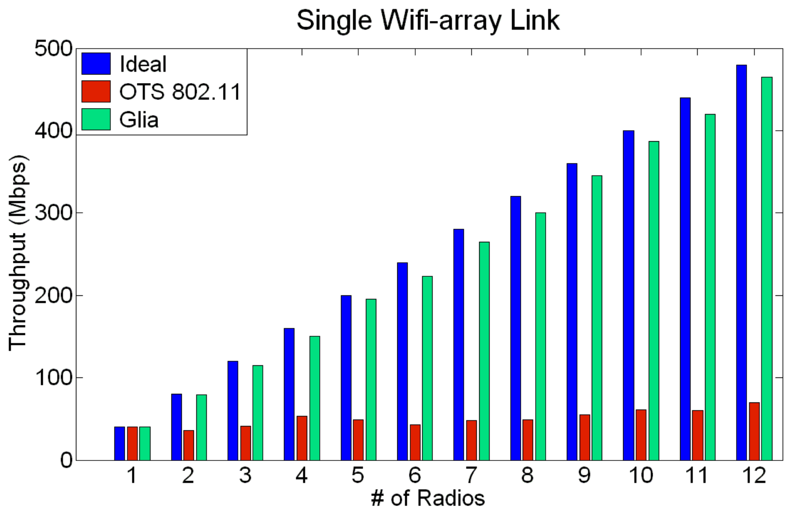
- Principle
  - Use the multiple radios efficiently to exploit channel diversity.
  - Select the best radio-channel combination such that the expected throughput is maximized.
- Algorithm
  - Number of possible radio-channel combinations increases with the number of radios and channels.
  - Brute-force search for best radio-channel association.
  - Approximation
    - Receive RSSI is correlated to throughput.
    - Measure RSSI for different excitations
    - Number of RSSI measurements required are reduced by measuring RSSI in all radios on receive node at the same time.

Performance Evaluation

- Implementation details:
  - Glia is implemented on the wifi-array testbed as a software application.
  - Open source madwifi driver is modified to provide hooks for Glia.
  - The hooks allow Glia to read current RSSI values from hardware registers.
  - Default carrier sense is disabled.
  - Radio-channel association is performed as an offline process.
- Experimentation:
  - UDP datagrams, using sockets, serve as traffic.
  - All experiments are performed in an urban office environment.
  - No other users in 802.11a.
  - Experiments in 802.11g are performed at night when there is no other background traffic.

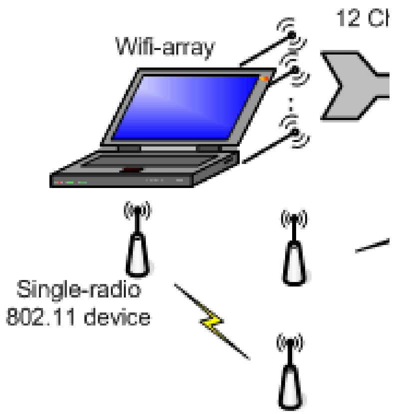
Results: Single Wifi-Array Link

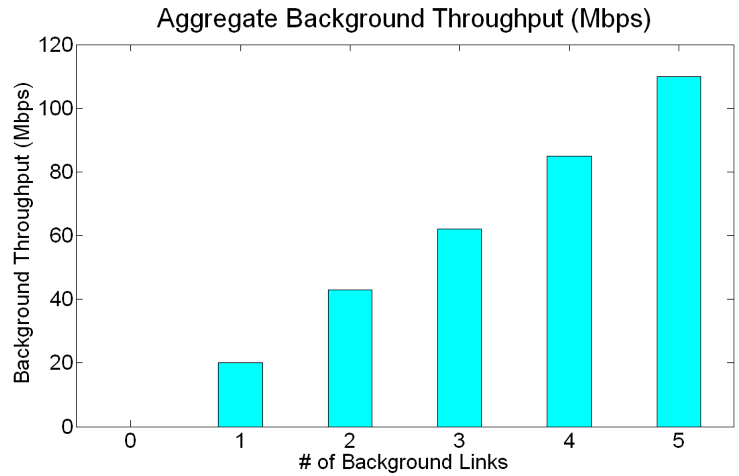




- Single 12 radios wifi-array link on 12 channels in 802.11a.
- Ideal throughput for 12 radios is 480Mbps.
- Off-the-Shelf (OTS) 802.11 shows throughput of 70Mbps for all radios.
- Glia shows a linear increase in throughput with number of radios.
- Aggregate throughput with all 12 radios is 465Mbps. Very close to ideal.

Results: Co-existence with 802.11

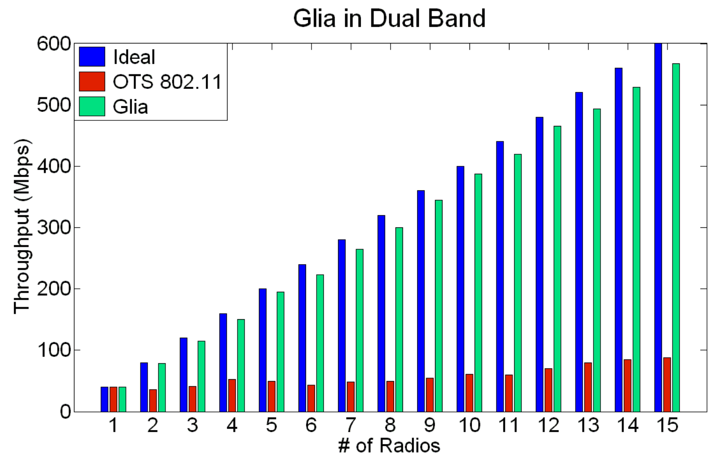




- Glia on 12 channels.
- Introduce background single-radio 802.11 links on different channels.
- With increasing number of background links, throughput of wifi-array link reduces, while aggregate background throughput increases.
- Background 802.11 links do not starve. They share channel with Glia.

Results: Glia in Other Contexts

- Glia in two bands (802.11g and 802.11a) at the same time:
  - 15 channels.
  - OTS 802.11 throughput of 91 Mbps while Glia throughput of 567 Mbps.



- Glia in 802.11n context:
  - 2 radio wifi-array.
  - OTS 802.11 throughput of 81 Mbps as opposed to ideal of 192 Mbps.
  - OOB is still an issue.
  - Carrier Sense turned OFF. Throughput observed is 132 Mbps.

Scenario	Aggregate (Mbps)
Ideal two-radio	192
Default two-radio	81
Partial Glia	132

Related Work

- Out-of-Band emission
  - [Adya'04, Robinson'05, Liese'06, Liu'06]
- Multiple channel usage
  - Channel bonding [802.11n, Linksys dual band]
  - Wideband wireless spectrum usage [802.11vht, Rahul'08]
- Directional antennas
  - Multi-radio wifi AP [Xirrus Inc].
  - Directional antennas for long-distance wifi [Raman'05, Patra'07].

Conclusion

- Default throughput performance of a wifi-array is much less than expected.
- We identify and characterize the reasons for poor performance.
- We present Glia, a software-only solution, that achieves near ideal throughput performance.
- The principles developed for Glia are relevant for all types of 802.11 networks (a/g/n).
- There are several open issues including: impact of Glia on TCP, 802.11n wifi-arrays, and wifi-arrays with other technologies like Wimax.

Thank You

Questions and Comments?

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