Considerations for In-Band Simultaneous Transmit and Receive (STR) feature in HEW

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Abstract

Self-Interference cancellation technology for enabling in-band simultaneous transmit and receive (STR) , often referred as full-duplexing, is advancing.

Adoption of STR technology is expected to provide gains in WLAN MAC efficiency. However, it will necessarily involve modifications to the current WLAN MAC.

We present a summary of the state of the STR technology, and ask (straw poll) whether the group is willing to consider the MAC changes to accommodate in-band STR

In-Band Simultaneous Transmit and Receive (STR)

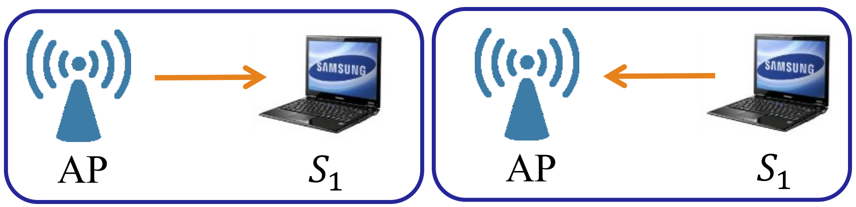
The ability of a station S_1 to successfully decode the transmissions received from station S_2 *while* transmitting to station S_2 or an other station S_3 on the *same* frequency resource.

Requirements to support In-Band STR in WLAN:

- **Sufficient suppression of the Tx signal at STR node (referred here as self-interference cancellation (SIC)).**
- **Protocol (MAC) support for STR**
- **Co-existence considerations**

Motivation for considering In-Band STR

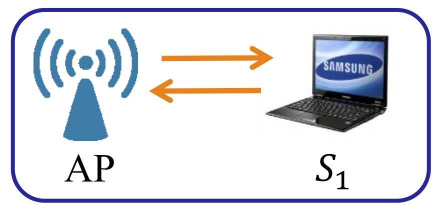
Present: Either Tx or RX

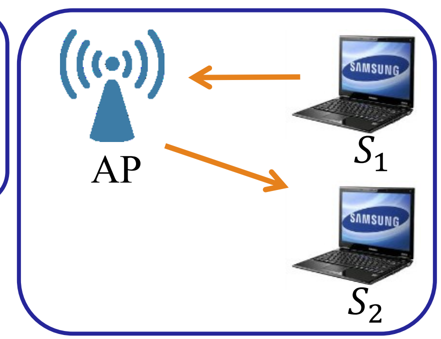


Wireless devices either transmit or receive, but not both

Inefficient Spectral Utilization!

What if: Simultaneous Tx & Rx





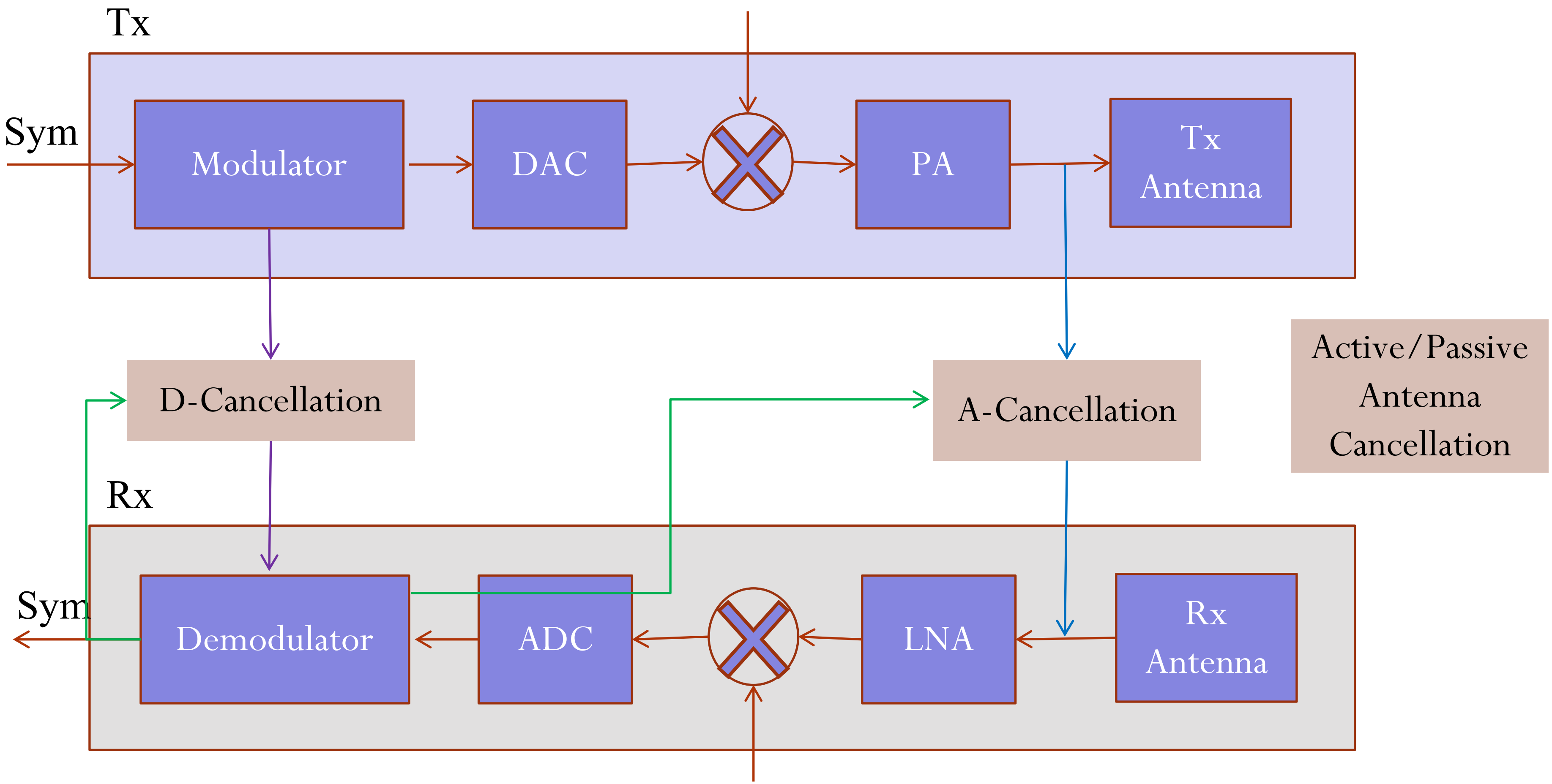
On the same time and frequency resource

Up to 2x throughput improvements!

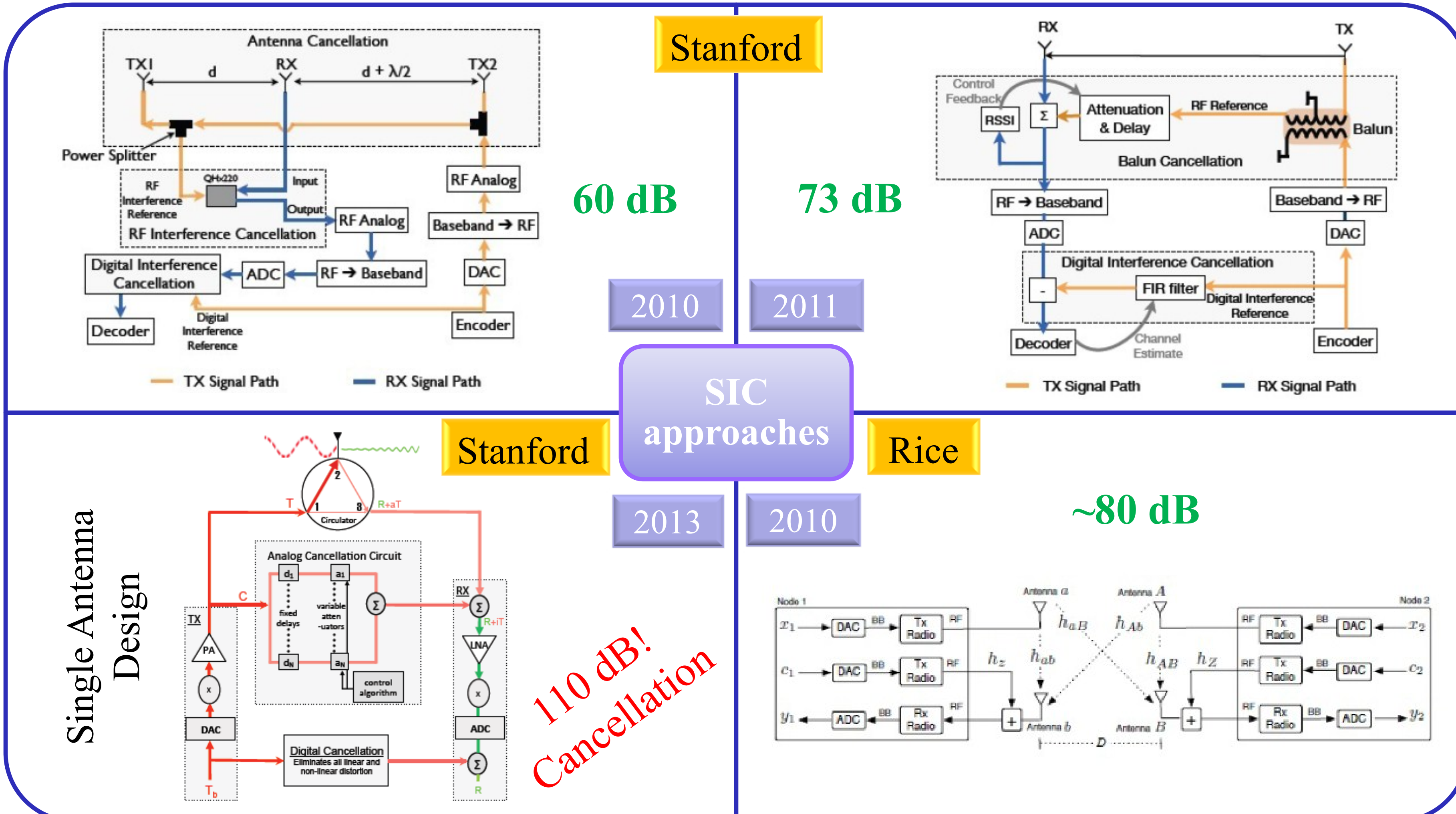
First, hardware must be capable of providing sufficient Self-Interference cancellation!

Status of BB/RF self-interference Cancellation technologies to enable STR

Self-Interference Cancellation Approach



Advances in Self-Interference Cancellation



Self Interference Cancellation Designs

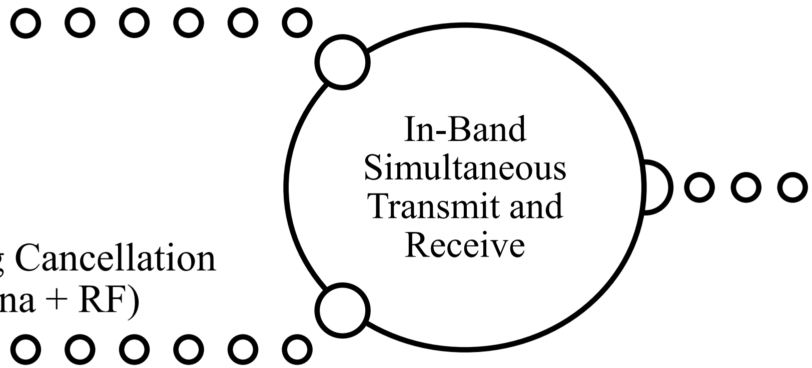
Reference	Band	Bandwidth	# Antenna	# RF	Cancellation			Total
					Antenna	Analog	Digital	
MSR [8]	530MHz		2	2	25~30 dB	30 dB		55~60 dB
Rice [9]	2.4GHz	625KHz	2	3	39~45 dB	31~33 dB		78~80 dB
Stanford [10]	2.4GHz	5MHz 802.15.4	3	2	30 dB	20 dB	10 dB	60 dB
Stanford [4]	2.4GHz	10MHz 802.11n	2	2		45 dB	28 dB	73 dB
Stanford [7]	2.4GHz	80MHz 802.11ac	1	2		60 dB	50 dB	110 dB
NEC [11]	5GHz	10MHz WiMAX	4	2	10(polar)+ 45 dB		20 dB	75 dB
Princeton [12]	2.4GHz	625KHz	$2M + 2N$	$M + N$	37 dB			
NYU [13]	914MHz	26MHz	1	2	40~45 dB	14 dB		59 dB

Cancellation Requirements and Tech Status

SIC Requirements

Digital Cancellation

Analog Cancellation (Antenna + RF)



Requires **about 110 dB** self-interference cancellation for WLAN operation.

SIC Feasibility

State of the art (Stanford Design 2013):

- 110 dB self-cancellation for
- 80MHz signal bandwidth
- 20dBm Tx Power
- 2.4 GHz band

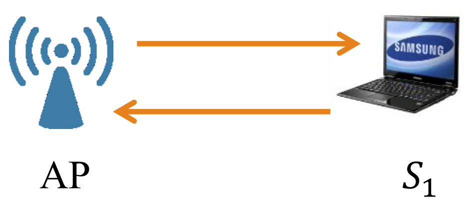
How to utilize advances in SIC technology to improve WLAN **MAC efficiency?**

MAC Issues in In-band STR

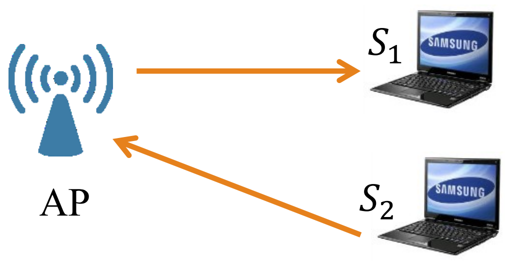
Scenarios for STR in WLAN

Two Basic Constructs for STR in WLAN

- Pair-Wise STR:
  - Example: AP Transmits to S_1; S_1 transmits to AP
  - AP/S_1 cancel own outgoing transmissions while receiving the transmissions from S_1/AP.
- Unrestricted STR
  - Example: AP Transmits to Station S_1; AP receives from Station S_2
  - S_1 needs to cancel the transmission from S_2 to decode the AP transmission correctly



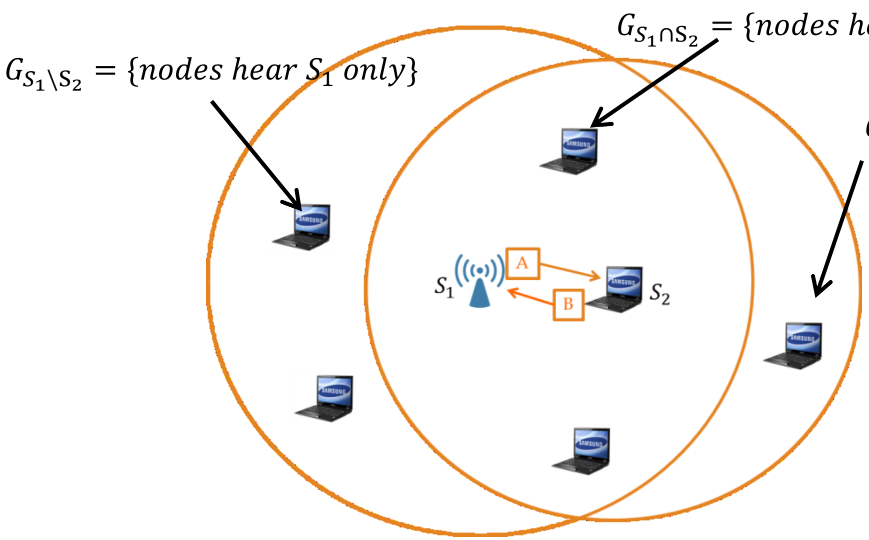
AP transmits to Station S_1 while receiving data from S_1

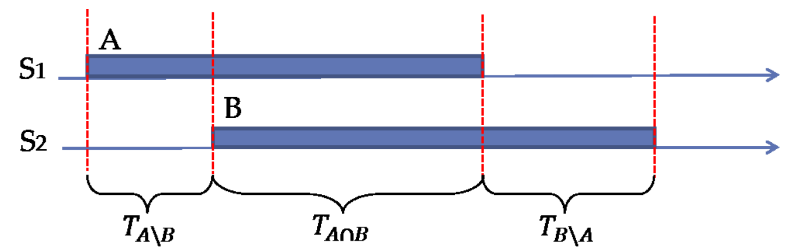


AP transmits to Station S_1 while receiving data from S_2

More challenging problem!

STR MAC Issues: Basic Overhearing Issues





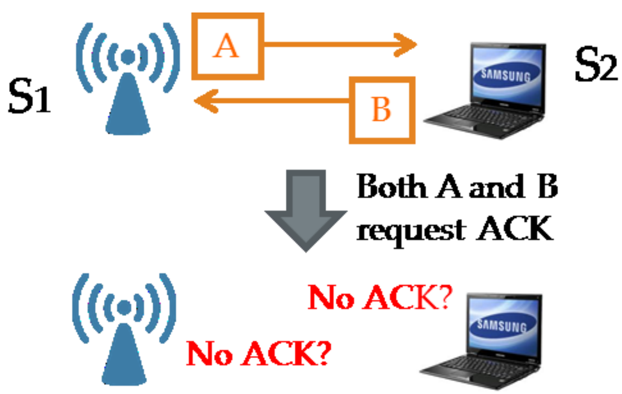
Three basic overhearing issues in STR

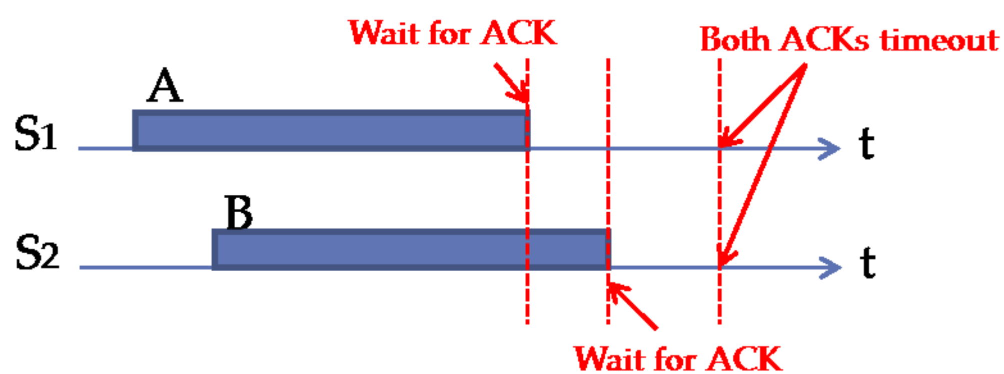
- During $T_{B \setminus A}$, the nodes in $G_{S_1 \setminus S_2}$ may send packets to S_1 as they sense the completion of transmission from S_1, and that may result in **corrupted reception of packet *B*** at S_1
- During $T_{A \cap B}$, the nodes in $G_{S_1 \cap S_2}$ **always receive corrupted packets** even if the transmissions succeed.
- During $T_{A \setminus B}$, the nodes in $G_{S_2 \setminus S_1}$ might send packets to S_2 since they cannot overhear packet A which is sent by S_1, and hence corrupt packet A (**hidden terminal problem**).

STR MAC issues: ACK mechanism

ACK mechanism in STR

- In a 2-node scenario (node S_1 and node S_2) with pair-wise symmetric STR:
    - S_1 sends packet A to S_2 and S_2 sends packet B to S_1 **with overlapping TX duration**.
    - **Both A and B request/expect ACK**.
- **Waiting for ACK after transmission is the highest priority** in current 802.11ac MAC
    - S_2 cannot send ACK to S_1 even after it has received packet A correctly because S_2 is still transmitting packet B to S_1.
    - How long should S_1 wait for ACK before resending packet A and when should S_1 transmit an ACK for successfully receiving packet B
    - S_1 and S_2 may get stuck in retransmissions and ACK timeouts.

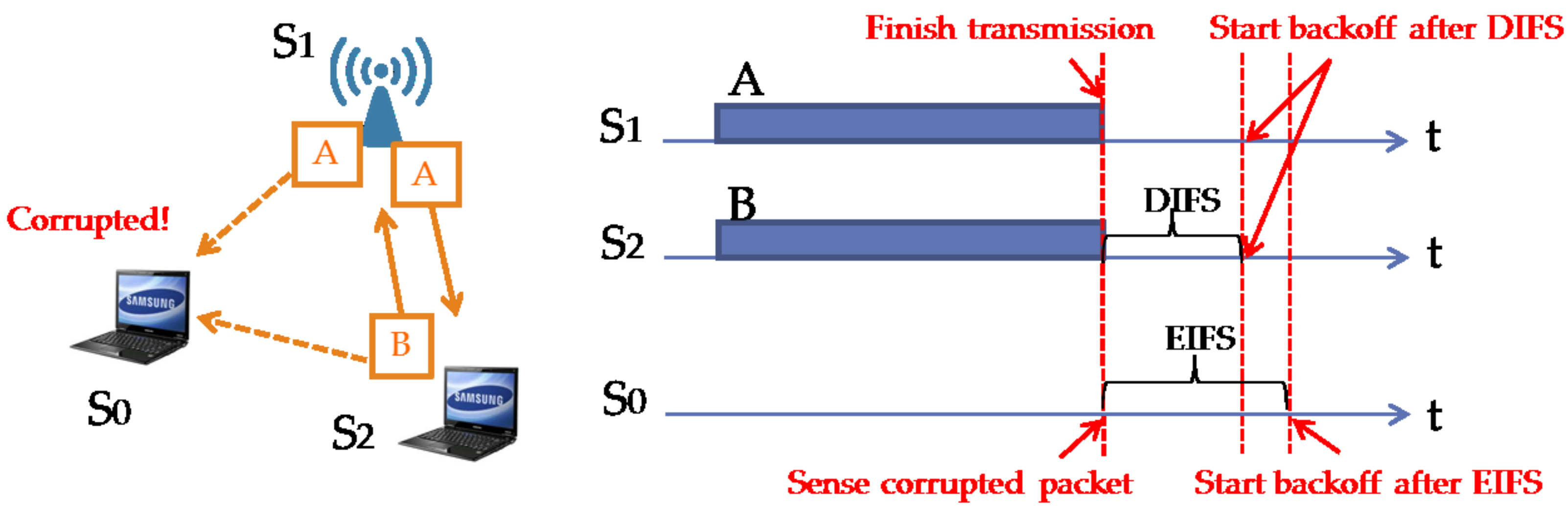




STR MAC issues: Contention Fairness

Contention fairness for the overhearing nodes

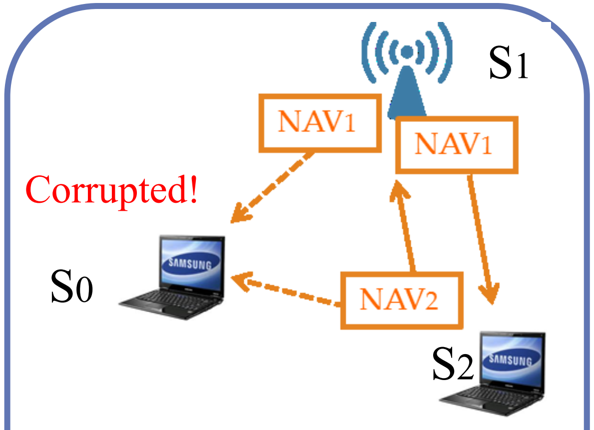
- Suppose node S_0 is **in the radio ranges of all the nodes** involved in STR transmission.
  - S_1 receives packet B successfully and S_2 receives packet A successfully.
  - S_0 receives a **corrupted packet**.
- Upon corrupted packet reception, S_0 waits for **EIFS** for next contention while S_1 and S_2 wait for **DIFS** for next contention. **Unfair Contention**!



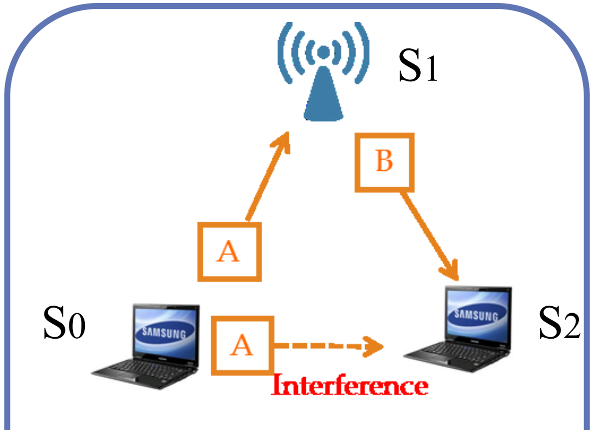
… + several backward compatibility issues

Coexistence will pose several challenges

- Should STR be a separate mode or a feature with sufficient co-existence built-in?
- In case of Co-existence
  - How to **set/broadcast NAVs** correctly?
  - How to avoid/alleviate the **interference** from Primary Transmitter (S_0 in the right figure) to Secondary Receiver (S_2 in the right figure) in unrestricted STR?
- Are we willing to even consider the option that legacy stations performance may degrade?



Node S_0 has problems setting NAV_1 and/or NAV_2



Node S_2 has problems decoding packet B due to interference

Summary of STR MAC issues

STR Scenarios

- Two Scenarios: **Pair-Wise and Unrestricted STR**.

ACK mechanism

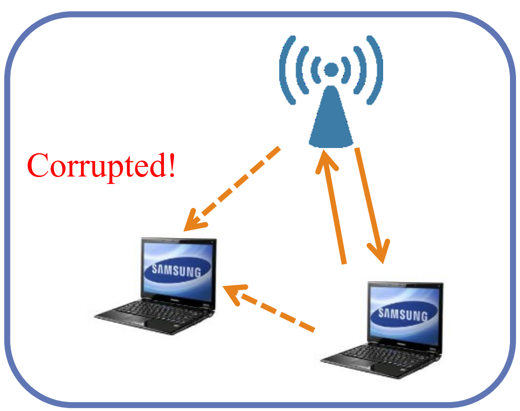
- Modifications necessary to the ACK mechanism

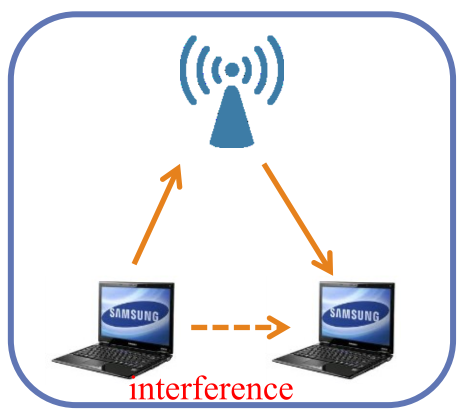
Overhearing behavior

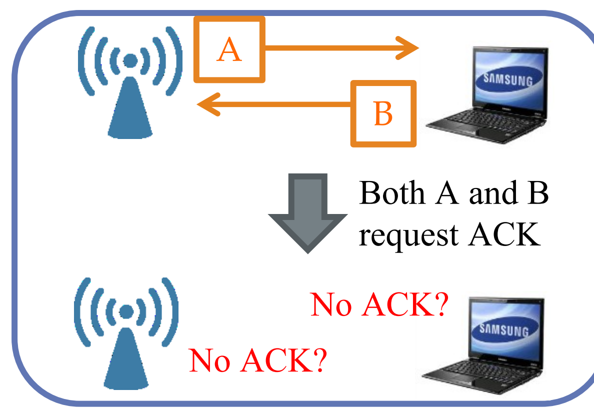
- Behavior of the overhearing nodes need to be taken in to account when defining/incorprating the STR MAC protocol.

Backward compatibility

- How to **co-exist with** legacy 802.11 devices?
- How to minimize **throughput degradation** of legacy devices?







A Summary of Published Approaches

ContraFlow[1]

Algorithm

- CSMA/CA-based algorithm;
- Supports pair-wise and unrestricted STR scenarios.

Changes to Specification

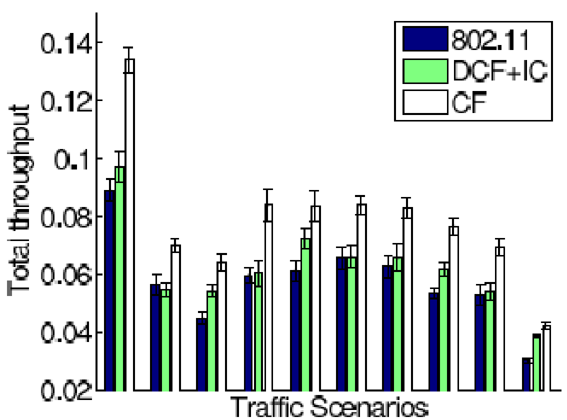
- **Requires Modification** of current ACK:
  - Specify the order of sending ACKs after full duplex transmission.
- **Adds a new feature** – Secondary Transmission:
  - Determine the destination of secondary transmission based on history-based interfering table.
- **Adds a new feature** – Primary Collision mechanism:
  - Use Secondary Transmission as an *implicit* ACK.

Backward Compatibility

- Require all nodes to be **STR-aware**.
- Cannot support legacy 802.11 devices.

Performance

- Claim **30%-50%** throughput improvement over CSMA/CA for
  - 3 network topologies with 5- 6 stations
  - Random traffic with fixed arrival rate.



PT: Primary Transmitter; PR: Primary Receiver; SR: Secondary Receiver

FD MAC[2]

Algorithm

- Support existing 802.11 devices;
- Focus only on pair-wise STR scenario

Changes to Specification

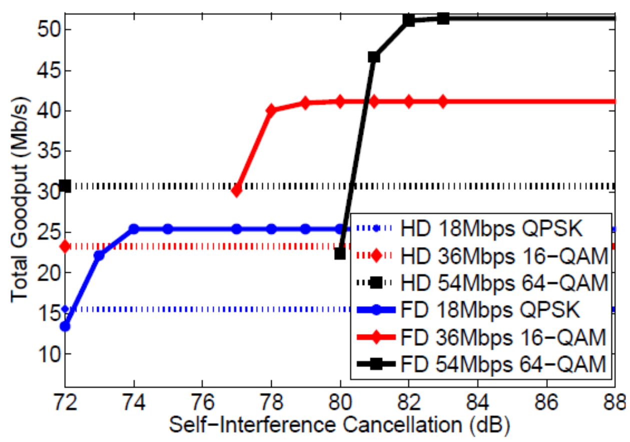
- **Requires Modification** of current ACK:
  - Modify the priority of sending ACKs to be higher than waiting for ACKs.
- **Requires modification** of current overhearing behavior:
  - After one successful full-duplex transmission, every node waits for EIFS to start next contention.
- **Adds a new feature** – Pairwise secondary transmission:
  - Embed the initiation of secondary transmission in RTS-CTS exchange.

Backward Compatibility

- Compatible with existing 802.11 devices with higher contention overhead (EIFS).

Performance

- Claims **45%-72%** throughput improvement over CSMA/CA under
  - 3 network topologies with 2 to 8 stations;
  - Saturated arrival traffic.



Janus[3]

Algorithm

- AP-centralized algorithm;
- Supports pair-wise and unrestricted STR scenarios.

Changes to Specification

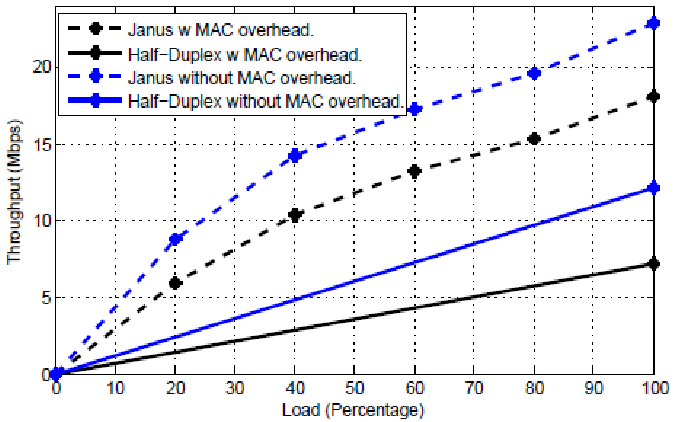
- **Requires a new centralized medium access mechanism**.
  - Controlled by AP and operated in a 3-step cycle;
  - AP collects information about data-length and interference relationship from STAs;
  - AP broadcasts the scheduling decision packet and initiates data transmissions;
  - Send ACKs in the predefined order embedded in the scheduling decision packet.

Backward Compatibility

- Require all nodes to be **STR-aware**.
- Cannot support legacy 802.11 devices.

Performance

- Claim maximum **150%** throughput improvement over CSMA/CA under
  - 3 interfering topologies with 1 AP; 3 STAs;
  - 3 traffic types with varying packet sizes.



Summary of other STR MAC approaches

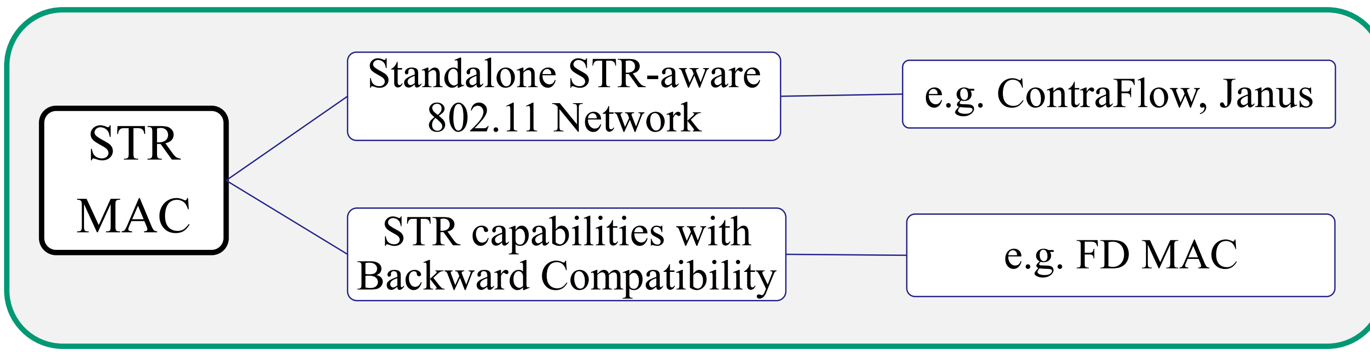
Other References	Attributes
Practical, Real-time, Full Duplex Wireless[4]	Require modifications of CSMA/CA: 1) Primary Receiver initiates the secondary transmission (restricted to pairwise STR); 2) Primary Receiver sends busy tone whenever there is no packet for secondary transmission.
Node Architecture and MAC Protocol for Full Duplex Wireless and Directional Antennas[5]	Require modifications of CSMA/CA: 1) Primary Receiver initiates the secondary transmission (can be unrestricted STR); 2) Remove ACK mechanism; 3) Remove contention window.
Performance of Medium Access Control Protocols for Full-Duplex Wireless LAN[6]	Require modifications of CSMA/CA: 1) Primary Receiver initiates the secondary transmission (restricted to pairwise STR); 2) AP adopts dynamic contention window size to balance the uplink/downlink load.

Concluding remarks

Concluding Remarks

Summarized the status of technologies needed for supporting In-Band STR

- It is well understood that introducing STR will result in increased MAC efficiency.
- Inadequate and insufficient suppression of self-interference was a major obstacle to STR adoption.
- Self-Interference techniques have advanced significantly and initial results claiming sufficient SIC are beginning to emerge ➔ Time to consider system/protocol aspects to accommodate STR
- We also surveyed the System/Protocol changes to accommodate In-Band STR operation and summarized it in this presentation.



It is very likely that changes to the existing MAC mechanisms will be needed to accommodate In-band STR

Is this group willing to consider those changes in HEW?

HEW SG Straw poll

Straw Poll

In-band simultaneous transmit and receive (STR) feature should be considered for inclusion in HEW even if fundamental changes to the MAC are incurred

In Favour: 44

Opposed: 20

Abstain: 48

Acknowledgment: Many thanks to Sean Coffey (Realtek) and Brian Hart (Cisco) for their comments and contributions to the wordings of this straw poll

Thank you!

References

[1] Singh, N.; Gunawardena, D.; Proutiere, A.; Radunovic, B.; Balan, H.V.; Key, P., "Efficient and fair MAC for wireless networks with self-interference cancellation," *Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks (WiOpt), 2011 International Symposium on* , vol., no., pp.94,101, 9-13 May 2011

[2] Melissa Duarte, A. Sabharwal, V. Aggarwal, R. Jana, K. K. Ramakrishnan, C. W. Rice, N.K. Shankaranaravana, “Design and Characterization of a Full-duplex Multi-antenna System for WiFi networks,” CoRR abs/ 1210.1639 2012

[3] J. Y. Kim, O. Mashayekhi, H. Qu, M. Kazadiieva, P. Levis, “Janus: A Novel MAC Protocol for Full Duplex Radio,” CSTR 2013-02 7/23/13 2013

[4] M. Jain, J.I. Choi, T. Kim, D. Bharadia, S. Seth, K. Srinivasan, P. Levis, S. Katti, P. Sinha, “Practical , real-time, full-duplex wireless,” *Proceeding of the 17th annual international conference on Mobile computing and networking* (MobiCom), page 301—312, 2011

[5] Miura, K.; Bandai, M., "Node architecture and MAC protocol for full duplex wireless and directional antennas," *Personal Indoor and Mobile Radio Communications (PIMRC), 2012 IEEE 23rd International Symposium on* , vol., no., pp.369,374, 9-12 Sept. 2012

[6] Oashi, S.; Bandai, M., "Performance of Medium Access Control Protocols for Full-Duplex Wireless LANs," *Information and Telecommunication Technologies (APSITT), 2012 9th Asia-Pacific Symposium on* , vol., no., pp.1,4, 5-9 Nov. 2012

References

[7]D. Bharadia, E. McMilin, S. Katti, “Full duplex radios,” *Preceeding of ACM SIGCOMM 2013*, page 375—386,

[8] Radunovic, B.; Gunawardena, D.; Key, P.; Proutiere, A.; Singh, N.; Balan, V.; DeJean, G., "Rethinking Indoor Wireless Mesh Design: Low Power, Low Frequency, Full-Duplex," *Wireless Mesh Networks (WIMESH 2010), 2010 5th IEEE Workshop on* , vol., no., pp.1,6, 21-21 June 2010

[9] Duarte, M.; Sabharwal, A., "Full-duplex wireless communications using off-the-shelf radios: Feasibility and first results," *Signals, Systems and Computers (ASILOMAR), 2010 Conference Record of the Forty Fourth Asilomar Conference on* , vol., no., pp.1558,1562, 7-10 Nov. 2010

[10] J. I. Choi, M. Jain, K. Srinivasan, P. Levis, and S. Katti, “Achieving single channel, full duplex wireless communication,” in *Proc. 16th Int. Conf on Mobile Computing and Networking*, 2010, pp. 1—12

[11] M. A. Khojastepour, et. al., “The case for antenna cancellation for scalable full-duplex wireless communications,” in *Proceedings of the 10th ACM Workshop on Hot Topics in Networks*, ser. HotNets-X, 2011, pp. 17:1—17:6

[12] E. Aryafar, et. al., “MIDU: enabling MIMO full duplex,” in *Proceedings of the 18th annual Int. Conf on Mobile computing and networking*, 2012, pp. 257—268

[13] M. Knox, “Single antenna full duplex communication using a common carrier,” in *2012 IEEE 13th Annual Wireless and Microwave Technology Conference* (WAMICON), 2012, pp. 1—6