SourceSync

Exploiting Sender Diversity

Why Develop SourceSync?

- Wireless diversity is intrinsic to wireless networks
- Many distributed protocols exploit receiver diversity
- Sender diversity is a largely unexplored topic
- Simultaneously forwarding packets ensures that no frequency is deeply faded and allows senders to combine transmission power

What’s the problem?

- Synchronising senders for simultaneous transmission
  - Requires a high level of accuracy
- Received signal is a combination of different signals
  - Different channels between sender-receiver pairs
  - Different operating frequencies
- Signals can combine constructively or destructively

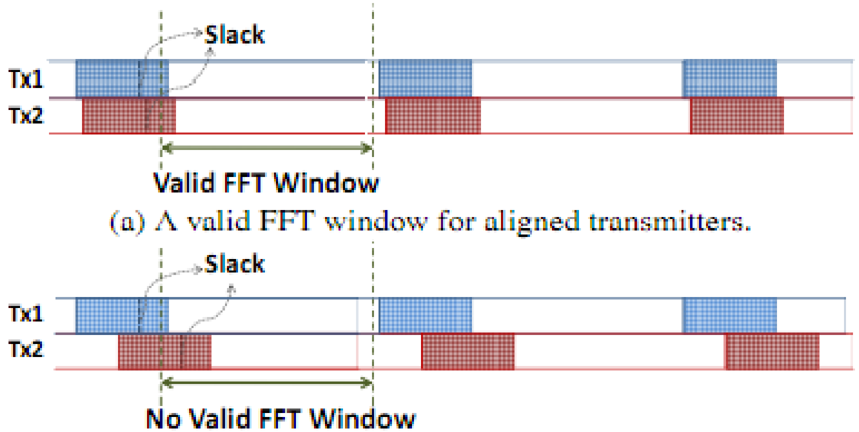
Main Contributions

- Demonstrates that simultaneous transmission is both practical and beneficial
- Presents a distributed algorithm and protocol for sender synchronisation at the symbol level
- Demonstrates benefits of combining sender diversity with receiver diversity schemes like opportunistic routing

Design of SourceSync

- Symbol Level synchroniser (SLS)
  - synchronise arrival at receiver
- Joint Channel Estimation (JCE)
  - Decodes the combined signal
- Smart Combiner
  - Encodes data so that transmitted codewords do not combine destructively

SLS : Why Synchronise?

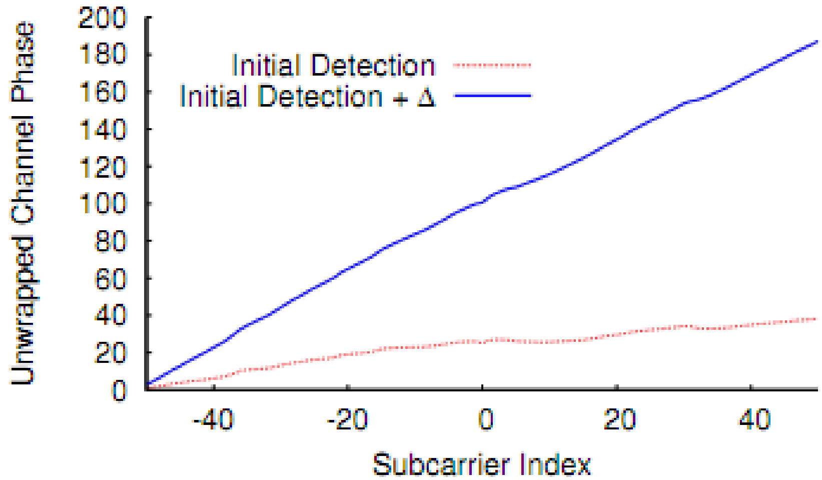


- Multipath effect causes copies of signal
  - Corrupts next symbol
  - Guard interval (cyclic prefix)
- Analogous to misaligned transmission
- Increasing CP isn't the solution

Synchronise by delays

- Lead sender acquires medium then transmits
- Co-senders hear transmission then join
- Transmissions must arrive aligned
- Problems:
  - Packet detection delay
  - Different hardware turnaround times
  - Different transmitter-receiver propagation times

Estimating Packet Detection Delay



- Delay between arrival of sample and detection
- Delay in time will manifest as a phase shift in frequency
- Treating packet as though detected Δ samples later, shifts graph to solid line
- Additional slope is

$$\xi = \frac{2\pi\Delta}{N_s}$$

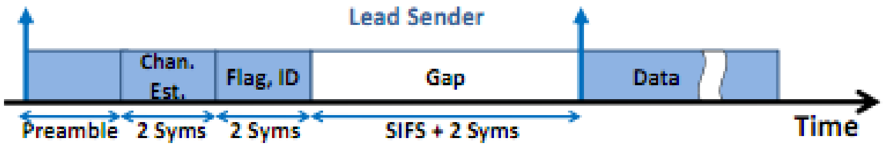
- Use this to obtain Δ, the detection delay offset

More Delays

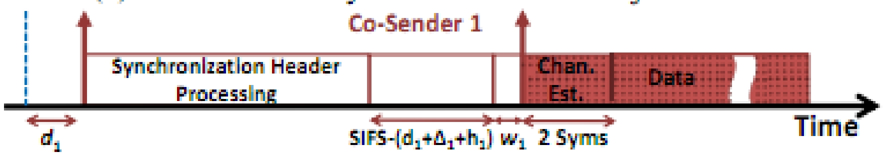
- Hardware turnaround
  - Time between receiving and sending
  - Must be less than SIFS
- Propagation Delay
  - Estimate RTT for transmitter-receiver pair
  - Probe networks
  - $Delay_{Probe\text{-}Response}$ = Prop delay Tx – Rx
    + Packet detection delay at Rx
    + Turnaround at Rx
    + Prop delay Rx – Tx
    + Packet detection delay at Tx
  - Include delay values in response
- Senders have differing wait times
  - $w_i = T_0 - t_i$

Synchronisation Protocol

- Synchronisation header
  - Preamble
  - channel estimation
- Silent for SIFS + 2 symbols
- More than 2 senders?



(a) Transmission by lead sender for the joint frame.



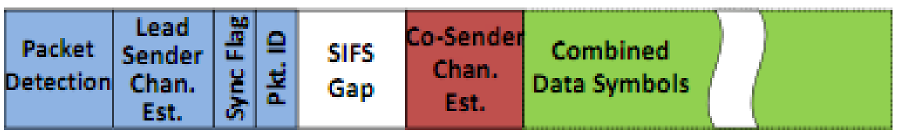


Figure 7: Format of joint frame seen by the receiver.

Moving nodes and Multiple Receivers

- Moving Nodes
  - Receiver calculates time offset between senders and lead sender
  - Includes misalignment in ACK
  - Co-senders change wait time appropriately
- Multiple Receivers
  - Synchronization isn't always feasible
  - Can increase Cyclic Prefix to account
  - Pick wait times to minimise the max misalignment
  - Linear optimization to minimise the max wait time

    $|(w_i + t_{ik}) - T_k|$ and $|(w_i + t_{ik}) - (w_j + t_{jk})|$

Joint Channel Estimation

- Receiver gets symbol $y_i = H_i x_i$ + noise
- H_i is the effect of the composite channel
  - Channels traversed by x_i are different
  - Senders have different frequency offsets
- $H_i(t) = H_{i,1}e^{j2\pi\Delta f1t} + H_{i,2}e^{j2\pi\Delta f2t}$
- Δf is relatively stable over time – can calculate and correct by sending $x_i \times e^{-j2\pi\Delta fit}$
- Insufficient
  - Small residual error in frequency estimate
- OFDM phase tracking – pilot subcarriers

Smart Combine

- Residual frequency error and random initial phase at sender
- Signals can combine constructively of destructively
  - Cannot track channel and phases before transmission
- Encode data using space time block codes at each sender
  - Eliminates deep fades from destructive combinations
  - Only requires a subset of codes to decode

Combining SourceSync with Last Hop Diversity

- SourceSync complements uplink receiver diversity schemes
  - by enabling sender diversity on the downlink
  - e.g. MRD and SOFT
- A SourceSync controller on the wired network
  - forward packets arriving from the wired uplink to all the APs in a neighbourhood

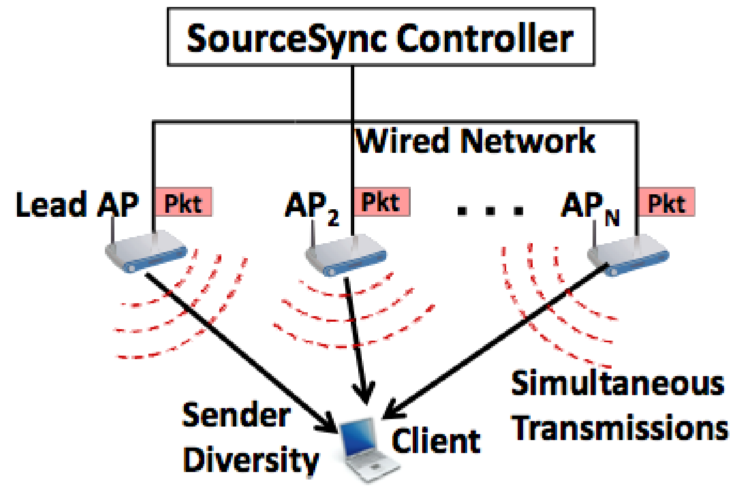


Figure 9: SourceSync for the last hop. SourceSync can harness sender diversity using concurrent transmissions from many APs.

Combining SourceSync with Opportunistic Routing

- Multiple routers hearing same packet
  - Chances increases with the size and density of the network.
  - Existing protocols cannot exploit this property
- SourceSync can make these routers transmit the packet simultaneously
- Increases the effective transmission power, enabling the packet to make longer jumps
- Overall loss rate is reduced

Test Evaluation

- Overview: the settings of the tests
- Symbol Level Synchronisation
- Power and Diversity Gains
- Last Hop Diversity
- Opportunistic Routing with SourceSync

The Setting of the Test

- Transmit board connect to normal PCI bus on PCs
- 802.1a: 20 MHz bandwidth and 1symbol time of 1 μs
- SourceSync in the FPGA, using a combination of Verilog and Simulink

Figure 11: Testbed map. Node locations are highlighted.

SourceSync Provides Tight Synchronisation

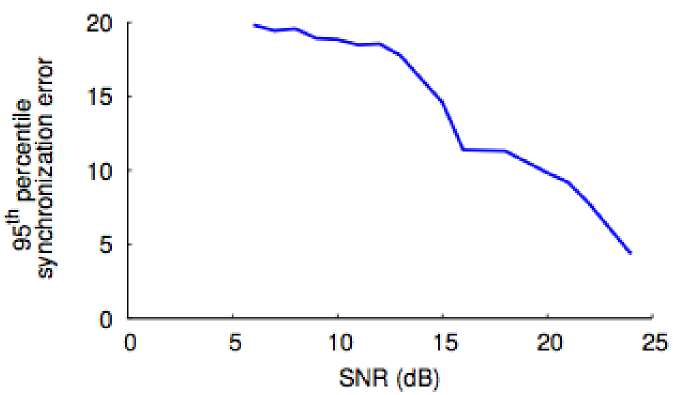


Figure 12: 95^{th} **percentile synchronization error.** SourceSync ensures that the synchronization error is less than 20 *ns* across the operational range of 802.11 SNRs.

- Goal: whether SourceSync provides accurate symbol- level synchronisation across transmitters
- Method: Use another overhead error estimate algorithm to evaluate the error rate of SourceSync
- Results: SourceSync's synchronisation algorithm is robust across a wide range of SNRs.

The Need for Accurate Synchronisation

- Goal: evaluate the consequences of loose vs. tight synchronisation
- Method: for different schemes, calculate the average receiver SNR of a joint transmission, and perform this calculation for various values of the cyclic prefix (CP)
- Results: SourceSync requires a far lower CP to achieve the peak SNR of the combined transmission

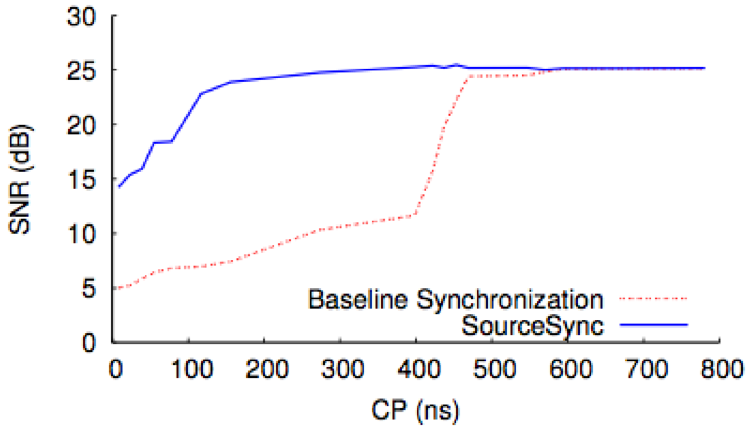


Figure 13: CP reduction with SourceSync. SourceSync enables concurrent transmissions to achieve high SNR with a significantly lower CP than an unsynchronized baseline that does not compensate for delay differences.

Power and Diversity Gains

- Goal: Verify that SourceSync actually provides these gains
- Method: Compare average SNR for different groups of locations
- Results: SourceSync improves the average SNR by 2–3 dB for all SNR ranges

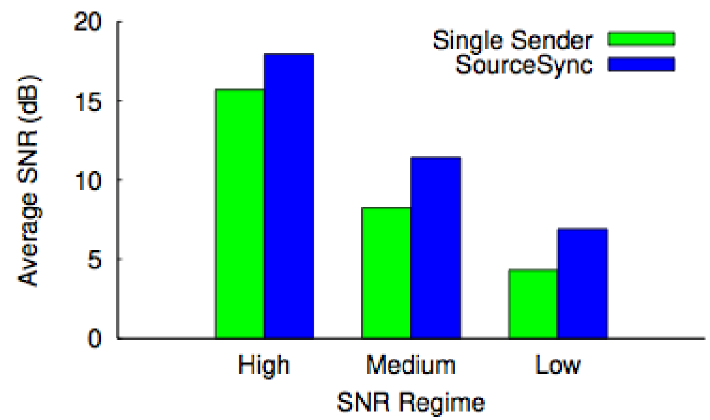


Figure 15: Power gains. SourceSync achieves a 2–3 dB gain over a single sender across the range of SNRs.

Last Hop Diversity

- Goal: examine the gains from using SourceSync in a last-hop scenario to harness sender diversity gains
- Method: compute the throughput at different location and settings: with and without SourceSync
- Results: benefits over selective diversity at all client throughputs, with a median throughput gain of 1.57×

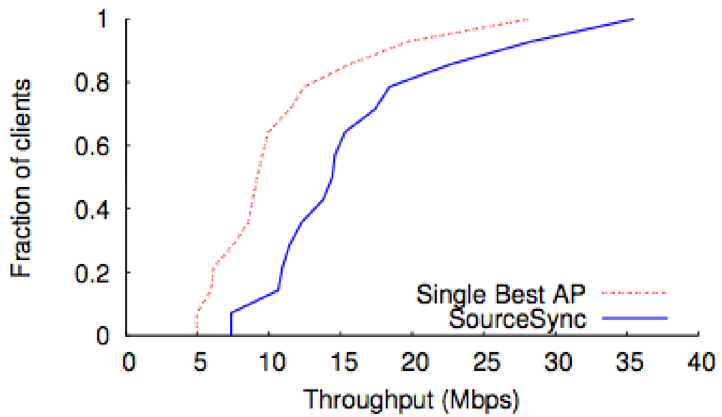
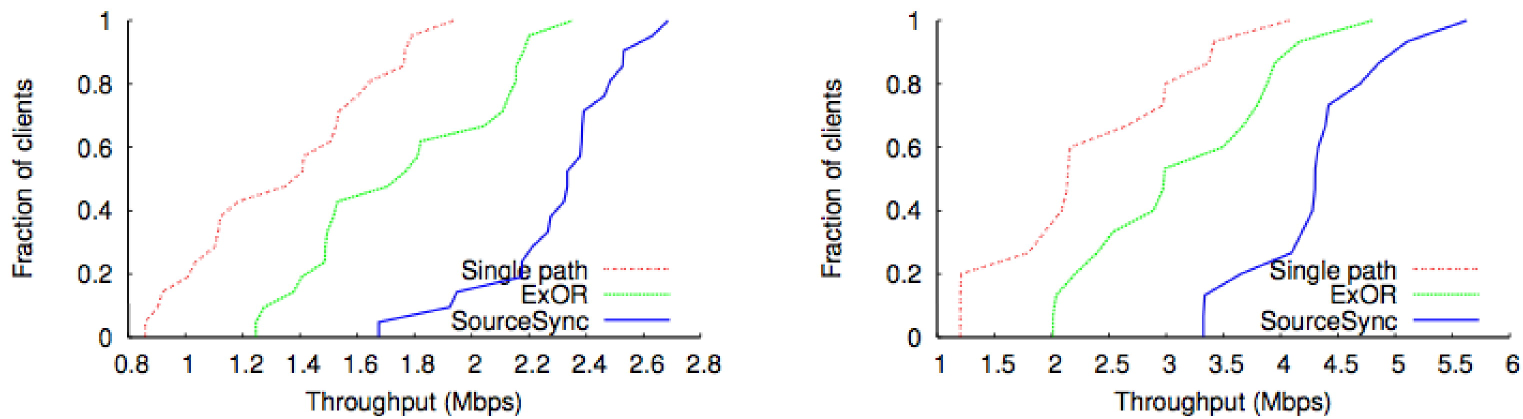


Figure 17: SourceSync at the last hop. The red dotted line is the CDF of throughput using selective diversity (*i.e.* single best AP). The blue solid line is the CDF of throughput using sender diversity across both APs with SourceSync. The CDFs show that sender diversity produces a median gain of 1.57× over selective diversity.

Opportunistic Routing with SourceSync

- Goal: measure pairwise loss rates between the nodes, compute the ETX metric for each link, and evaluate three schemes
- Results: single path routing, ExOR, and ExOR combine with Sync,1.7–2× over single path routing



(a) Bitrate of 6 Mbps (b) Bitrate of 12 Mbps

Figure 18: SourceSync with opportunistic routing. SourceSync together with ExOR provides gains both over ExOR alone, and over traditional single path routing. The median gains are 1.26-1.4× over single path routing, and 1.35-1.45× over ExOR, depending on the bitrate.

Related and Future Work

- Previous Researches
- Recent Work
- Other Similar Algorithm
- Future Work

Previous Researches

- Laneman and Wornell's
  - work on cooperative diversity
  - theoretically demonstrated the gains of spatially diverse senders cooperating to relay information
- Analysis on sender spatial diversity focusing on signal processing and coding algorithms at the relays
- Focus on theoretical gains, ignore practical issues

Recent Work

- Cellular networks
  - to exploit sender diversity using Distributed Antenna Systems (DAS)
- WiMax multi-hop relay standard
  - simultaneous transmissions from multiple relays as an optional feature
- Expensive and inflexible, too many constraints
- No practical design and implementation of simultaneous transmissions

Other Diversity work in this field (1)

- Solution for 802.11 networks in exploiting sender diversity
  - Restrict to only one best sender transmitting at a time
  - Neither exploit frequency diversity across senders, nor the power gain from combining multiple senders.
- Implementation of cooperative diversity with nodes connected to a single shared clock.
  - Need shared clocks, not practical; no synergy of sender diversity with opportunistic routing

Other Diversity work in this field (2)

- Systems that exploit concurrent transmissions from multiple senders
  - e.g. SMACK, Message-in-Message, ZigZag, ANC
  - Cannot provide any sender diversity gains since they do not synchronise transmissions at the symbol level.
- Space-time block codes could be improved by SourceSync
  - to be implemented in a distributed manner

Future Work

- Apply SourceSync to improve existed practical systems
- A more accurate simultaneous algorithm to improve the performance
- Throughput could be improved by techniques such as distributed beam forming and lattice codes
- More sophisticated implementation

Conclusion

- SourceSync, a distributed architecture for harnessing sender diversity
  - Symbol Level Synchroniser
  - Joint Channel Estimator
  - Smart Combiner
- Integrates sender diversity with last-hop diversity and opportunistic routing
- Significantly improve throughput.