
From Theory to Practice: A PHY/ MAC for Wireless Ad-hoc Networks

Sanjay Shakkottai
ECE Dept, UT Austin

Joint work with A. Jovicic, R. Laroia, J. Li, T.
Richardson, X. Wu, S. Tavildar, [Qualcomm](#)

FlashLinQ – Direct Device-to-Device PHY/MAC Communication Technology over Licensed Spectrum

Requirements for a Proximate Internet

- **Peer Discovery** – Establishing the need to communicate
 - Discovery range about 1 km
 - Discover few thousand devices
 - Discover only authorized devices
- **Paging** – Initiate communications
- **Scheduling** – Efficient spatial packing
 - Distributed signaling
 - Rate/power scheduling

Main Challenges

- **Half-Duplex**: When to listen and when to transmit?
- **Power and rate selection**: Which connections and at what rates?
 - Problems well understood in general
- **Signaling**: How to enable distributed decision making with low overhead?
 - Practical signaling schemes lacking
 - **The key bottleneck in transitioning ideas from theory to practice**

Problems with 802.11

- SNR based spatial reuse
 - Threshold for carrier sense
 - Orthogonalizes links irrespective of link lengths
 - Poor spatial reuse of spectrum



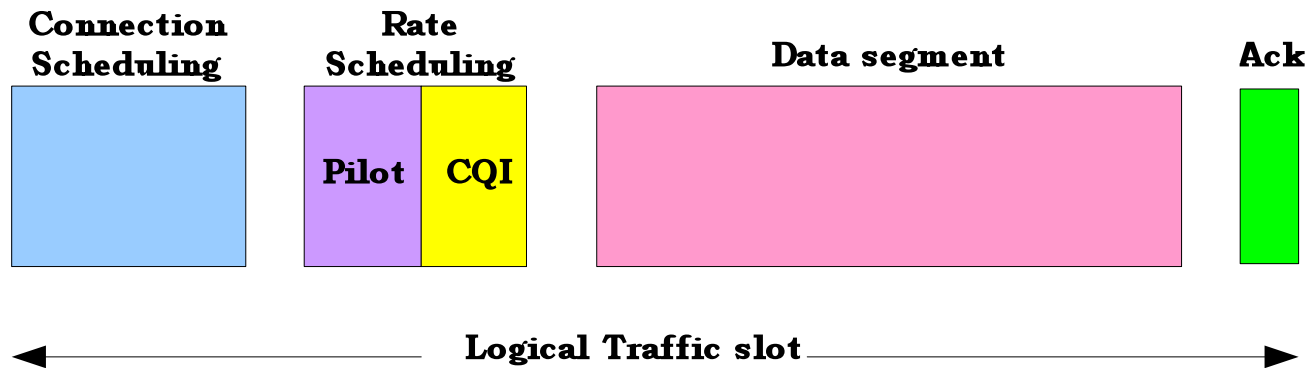
FlashLinQ Summary



- OFDM based **analog** signaling framework
 - Synchronous system over licensed spectrum
 - Timing derived from cellular system
 - Time-slot of about 2 msec
 - Enables device discovery of up to ~ km, few thousand devices
 - Enables distributed rate/power allocation
 - Prototype using custom FPGA/DSP platform
 - ASIC developed for large-scale field testing

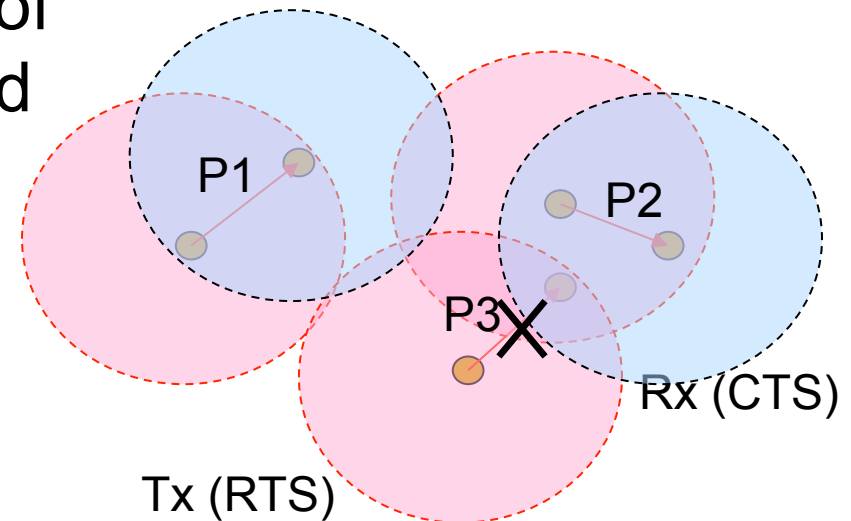
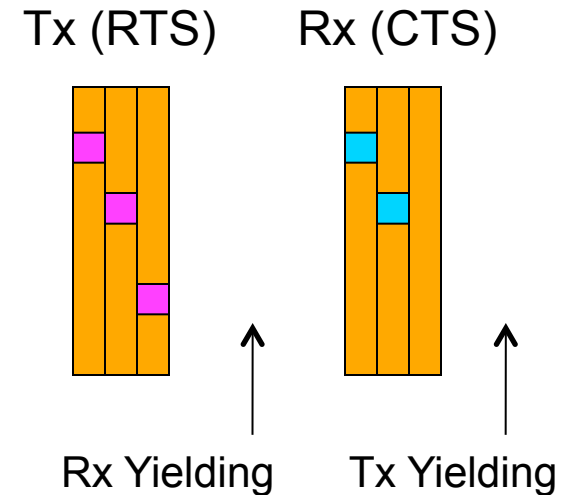
FlashLinQ Signaling Structure

- Synchronous system
- Scheduling every timeslot
 - Enables channel-aware spatial packing



Connection Scheduling

- SINR based scheduling difficulty:
 - Need to know other Tx and Rx before I can decide whether to transmit/receive
 - **Circular problem** – each of the other Tx/Rx also need to know my decision
- **Our Solution**: A parallel tone matrix

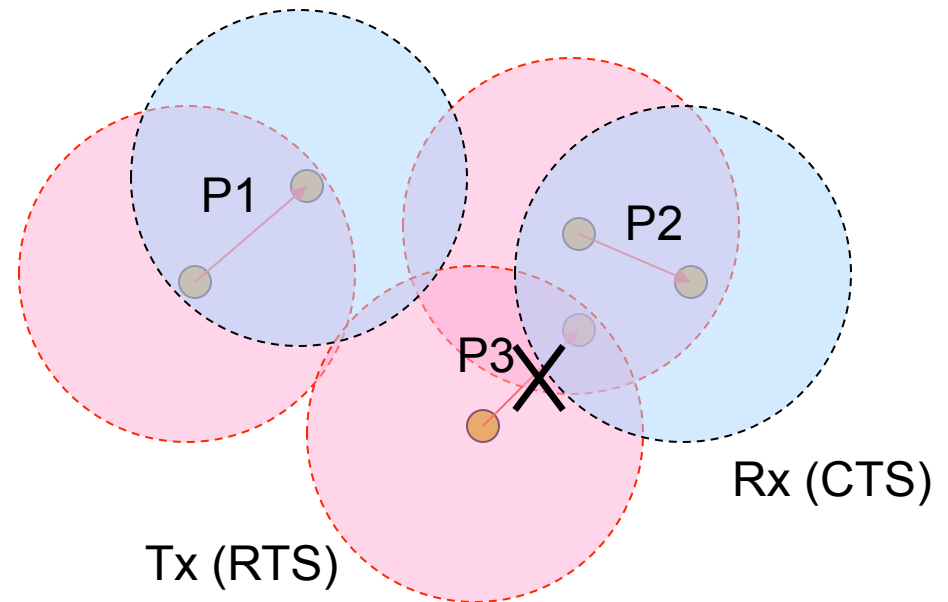
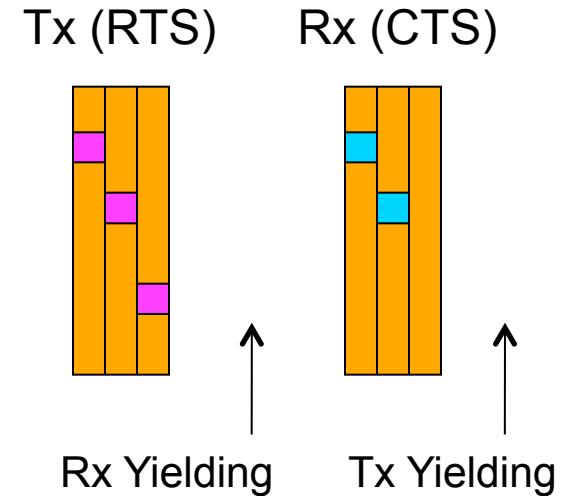


... contd. Connection Scheduling

- Synchronous parallel signaling
 - Removes need for carrier sense
 - Parallel signaling enables node to learn **potential** interferers
- Each Tx sends single tone (RTS)
 - Rx decides CTS based on **entire** tone matrix
- Either Tx or Rx can decide to **yield**
 - Yield = Remove link from schedule as it would cause “too much” interference

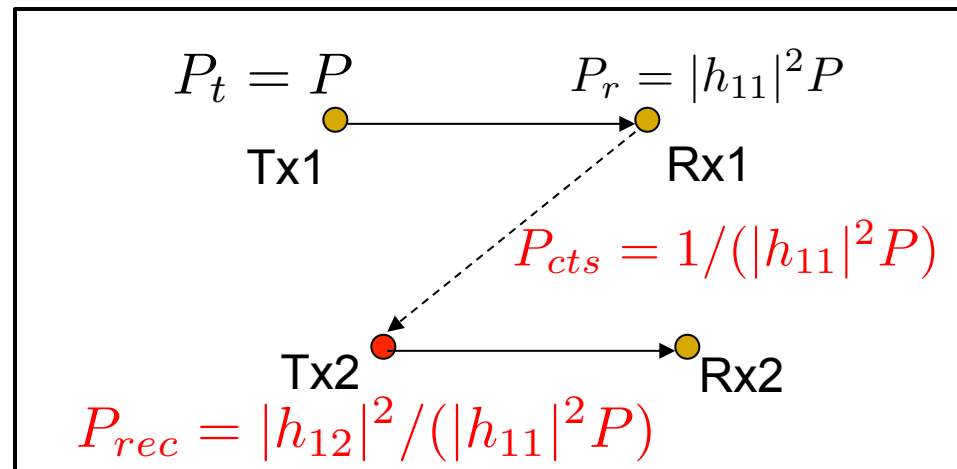
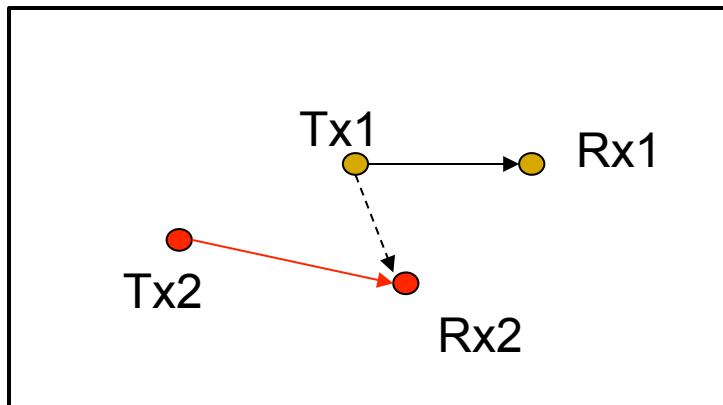
Tone Matrix

- OFDM single tones
- Priority embedded in location of tone
- Tone location pre-allocated (paging)
 - Tone locations globally “rotates” over time for fairness



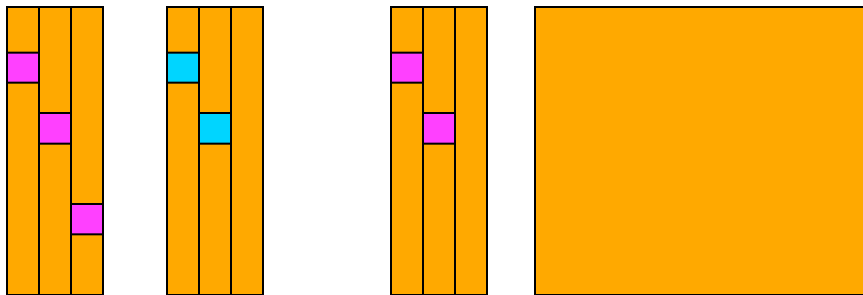
Analog Tone Signaling

- Power level in each tone conveys information
- Rx Yield: Compare signal strength from intended Tx to that by interferer
- Tx Yield: Rx sends **inverse power CTS**
 - Tx estimates SINR using this signal



Rate Scheduling

- Multiple rounds of tone signaling
 - Leads towards a maximal matching
- **Last Round**: All “winning” transmitters send single tone
 - Enables all receivers to estimate **actual** interference environment
 - Rate scheduling based on common information



FlashLinQ vs 802.11: Summary

802.11	FlashLinQ
Asynchronous	Synchronous
CSMA/CA with RTS/CTS	Parallel analog signaling
Signal power does not convey information	Power level used for estimating SINR
No distributed rate scheduling	Explicit rate scheduling of all users using common information

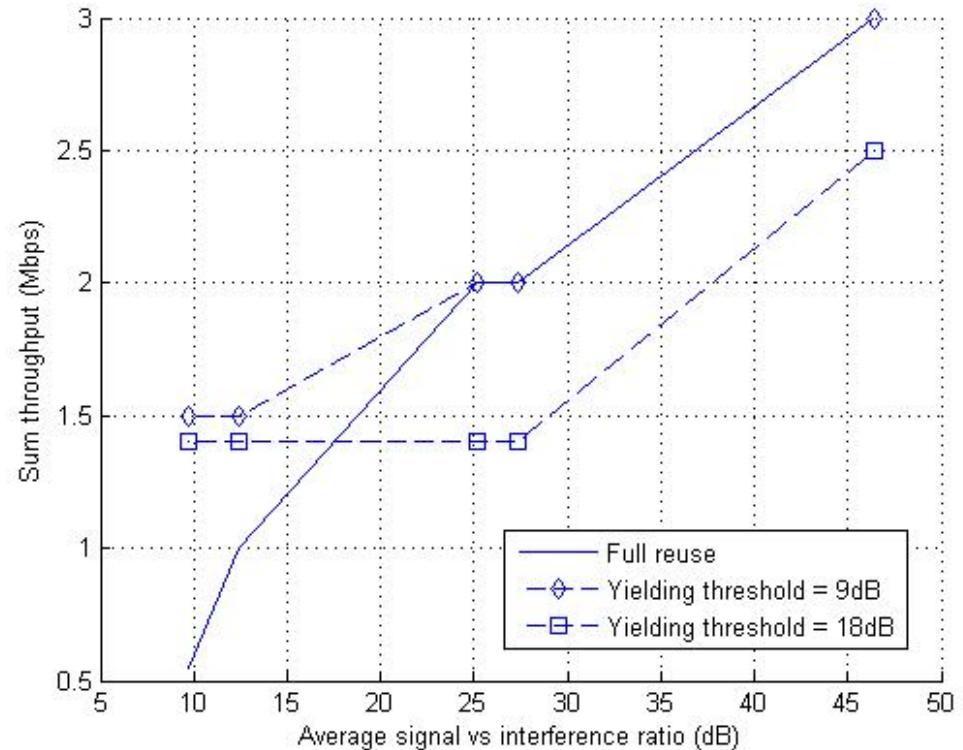
Prototype

- Implemented on a FPGA/DSP Platform
 - TMS-6482 DSP, Xilinx Virtex 4 FPGA
 - 2.586 GHz carrier frequency, 5 MHz bandwidth
- ASIC for large-scale field trials has been developed
 - Chip currently undergoing testing



Measurements

- Test orthogonalization vs. reuse
 - Nodes within carrier sense range
 - 802.11 will always orthogonalize



Tx1 (TS)



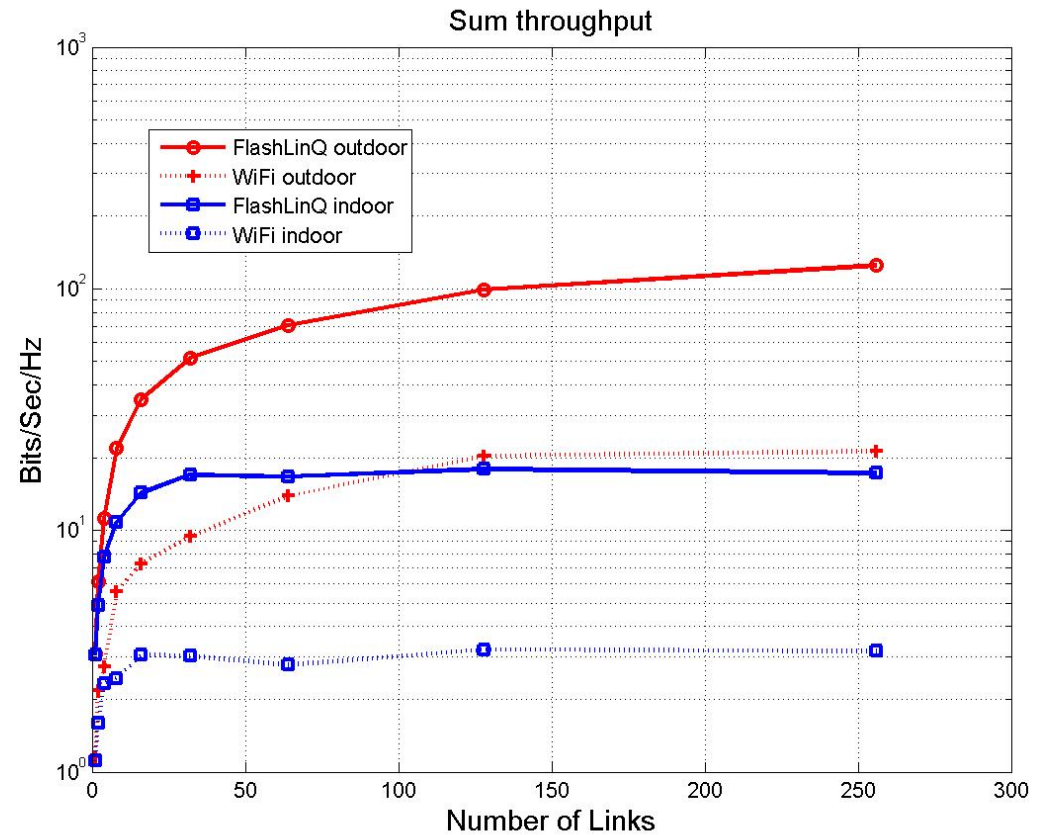
Rx1 (PP) Rx2 (MB)



Tx2 (AT)

Simulations

- Outdoor Model
 - 1000m x 1000m
 - 20m links
 - ITU-1411 LOS
- Indoor Model
 - 50m x 100m x 20m
 - 5 floors
 - Keenan-Motley model



450% Sum Throughput increase with 256 links

Conclusion

- A synchronous MAC/PHY for device-to-device communications
 - Leverages **parallel, analog** signaling with OFDM
- Licensed spectrum operation over 5 MHz
- Complete solution including peer discovery, paging and scheduling
- ASIC for field trials undergoing testing