Cross-layer Transport Protocol Approaches for wireless networks

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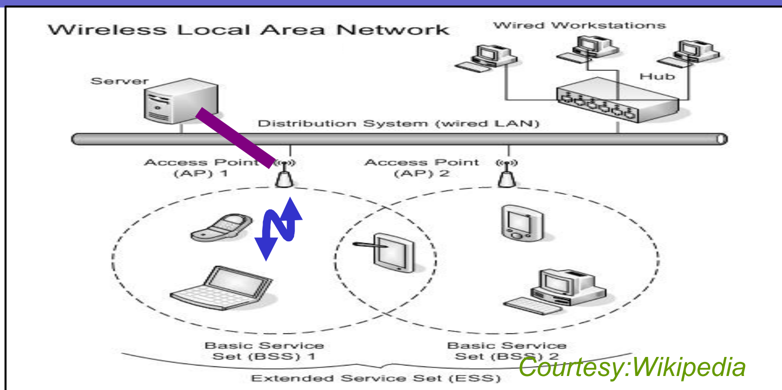
WIRELESS INFORMATION NETWORK LABORATORY

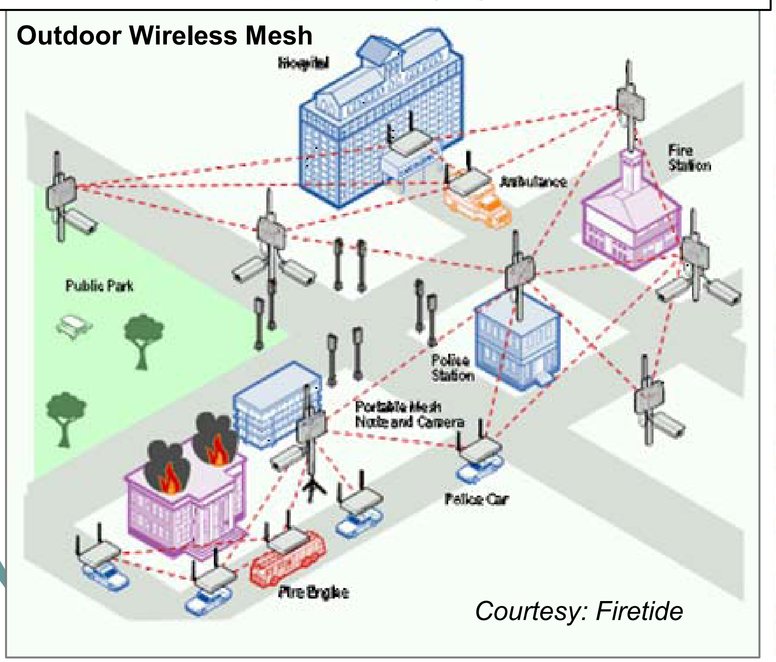
Talk Outline

- Overview of WINLAB's research in wireless networks
- WINLAB's experimental methodologies
- The fundamental wireless problem for transport protocols
- A novel approach to transport over wireless networks with *CLAP*
- Performance of CLAP in single-hop and multi-hop networks
- Conclusion and future work

WLANs, Mesh, Vehicular …



Courtesy:Wikipedia



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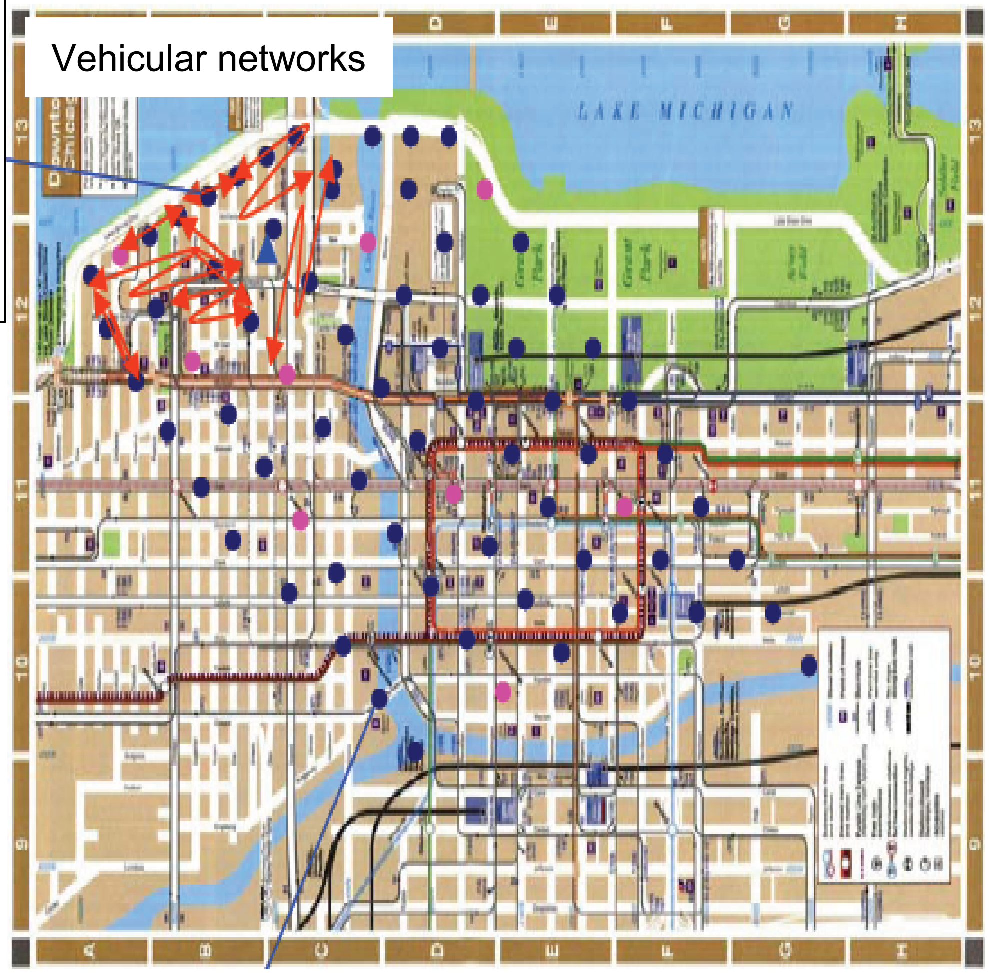
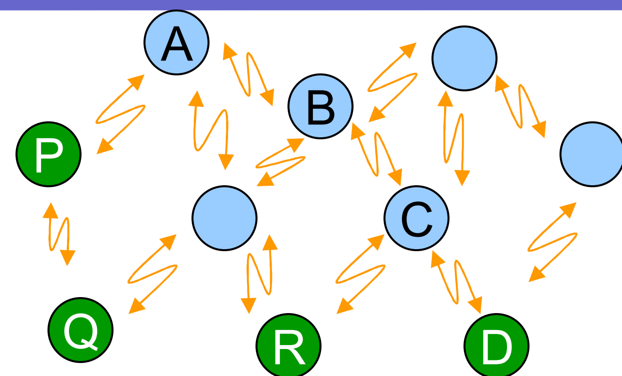


Related Research at WINLAB



Technical challenges	WINLAB Research
Adhoc network scalability issues	Hierarchical architecture (Zhao) [6] [7]
Poor spatial reuse due to MAC interference	D-LSMA, IRMA (Wu, Ganu) [8], [9]
Routing performance problems due to Phy/MAC effects	Cross Layer Routing methods such as PARMA, DCMA+ (Ganu, Wu, Zhao) [10]
High control overhead	Global Control Plane (GCP) and Zero-MAC (Wu, Ganu) [11], [12]
Transport layer performance problems with TCP	Cross layer TP approaches, CLAP (Gopal) [1],[2],[3],[4]

Experimental Methodologies in WINLAB

The ORBIT Test-bed

- **World's largest** state-of-the-art wireless test-bed - 400 dual-radio nodes located at WINLAB
- Dynamic interconnectivity into specific topologies
- with reproducible wireless channel models
- Used by a broad cross-section of experimenters

WINLAB WIRELESS INFORMATION NETWORK LABORATORY

Experimental methodologies in WINLAB

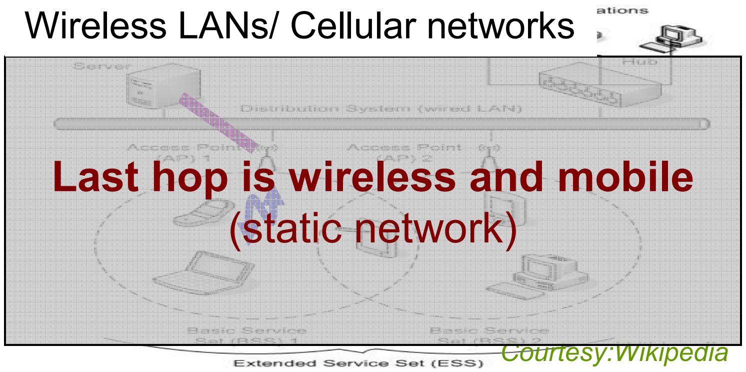
- Analysis, Protocol development and evaluation NS2 simulations
- Emulation in the ORBIT test-bed
- Real world experimentation
  - Outdoor vehicular experiments with 802.11 network cards
  - Wireless LAN experiments in office environments for video multicast
  - others ….

Cross Layer Transport protocols for wireless networks

A novel top-down approach

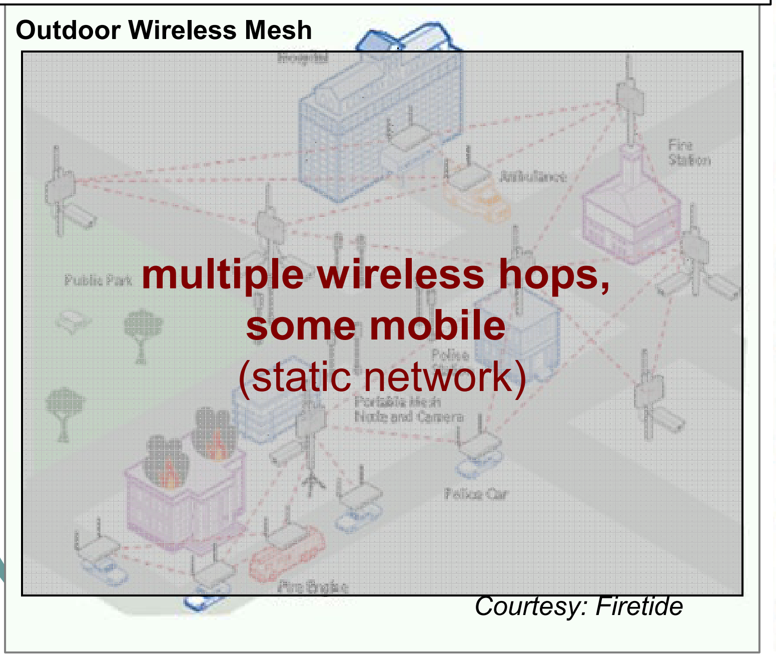
Wireless Networks

Wireless LANs/ Cellular networks



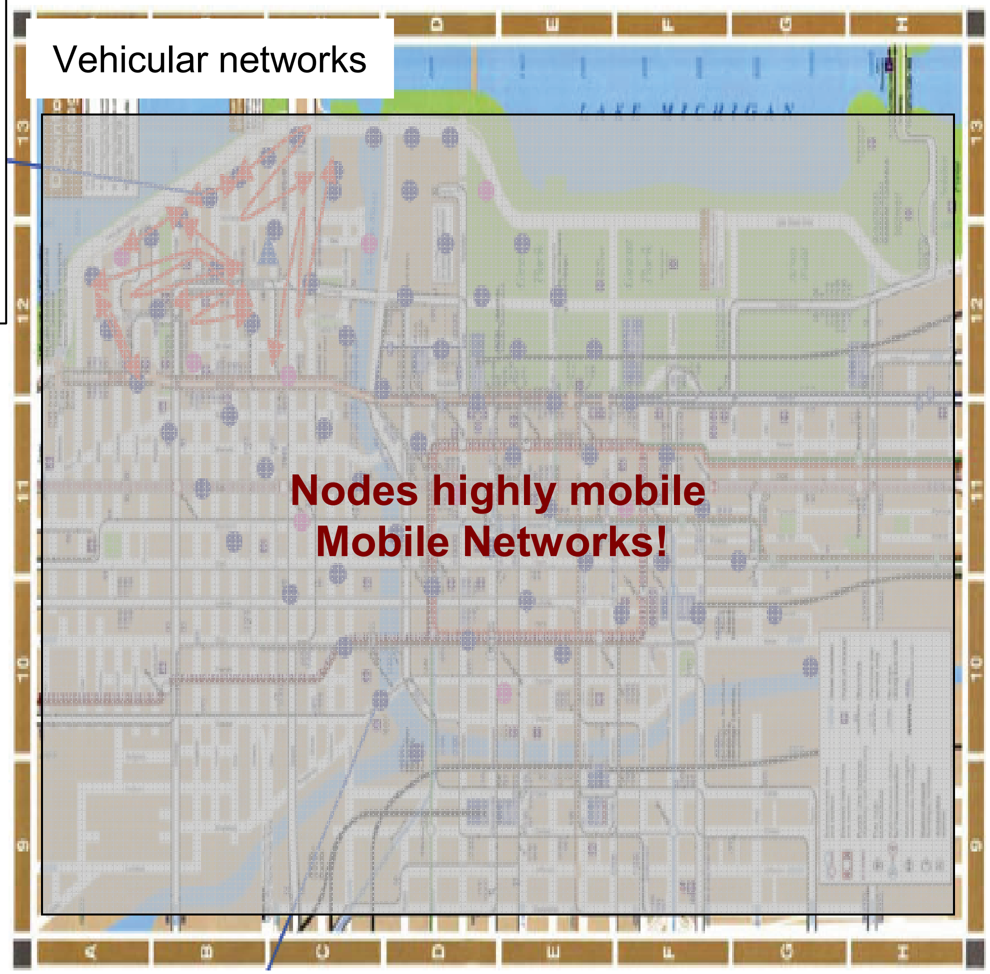
Courtesy:Wikipedia

Outdoor Wireless Mesh



Courtesy: Firetide

Vehicular networks



Cross-layer awareness in wireless networks

- Cross-layer status has been applied several times to transport protocols
  - Snoop-TCP, TCP-ELFN, Ack-Regulator, ATP, TCP-BEAD etc
- We ask the basic question:

What is the best transport performance that can be achieved with cross-layer awareness in wireless networks ?

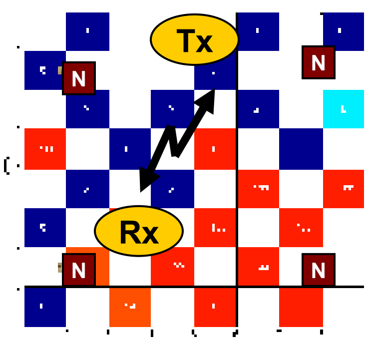
The fundamental wireless problem

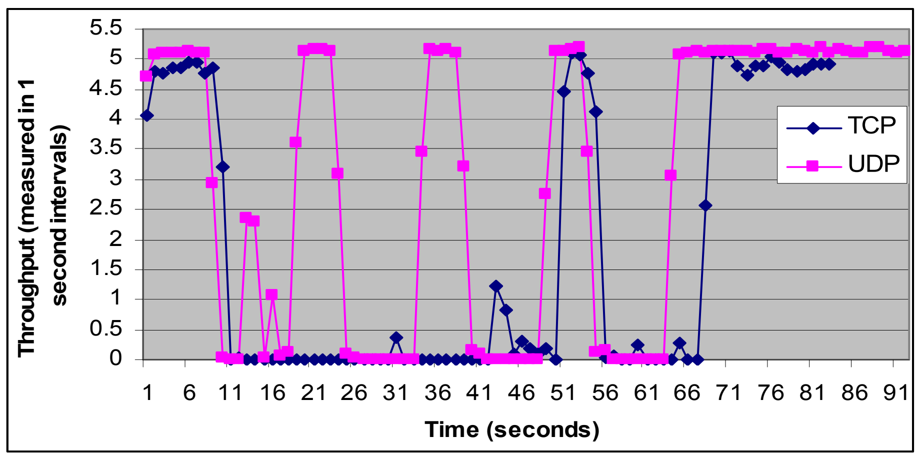
Interference, mobility, DTN, vehicular networks….

Time varying error characteristics, time-varying bandwidth

Time-varying

TCP performance over time-varying links in the ORBIT test-bed with *noise injection*





TCP poorly utilizes fluctuating link bandwidth

Learning from TCP's poor performance

Core reason: *Combined error and flow control*

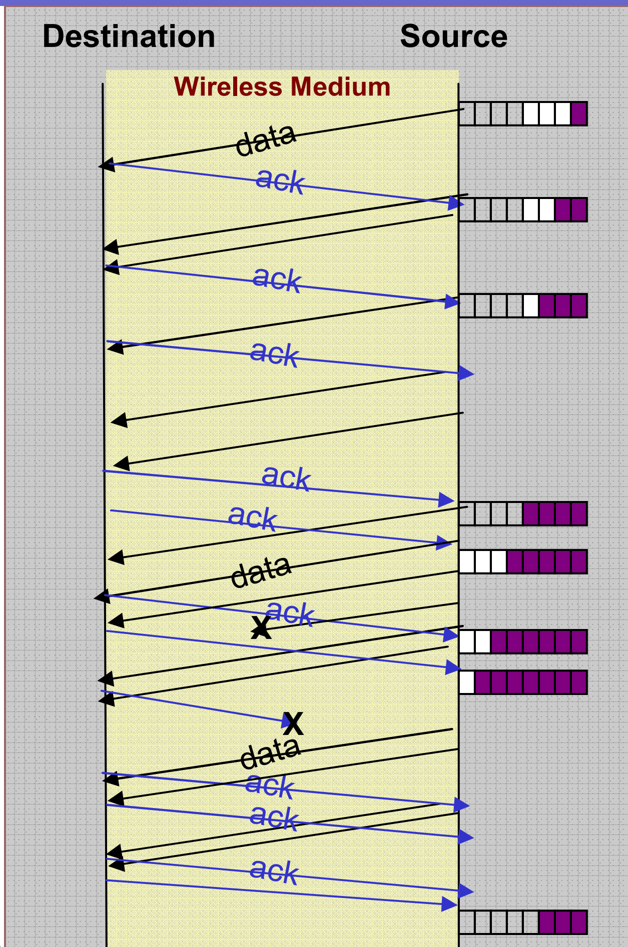
- TCP sees errors and backs off the sending rate
- The tight dependence on timely ACKs during transmission causes -
  - incorrect estimation of link bandwidth
  - incorrect estimation of the round-trip time

Hence **TCP incorrectly estimates the delay-bandwidth product** in a time-varying wireless link

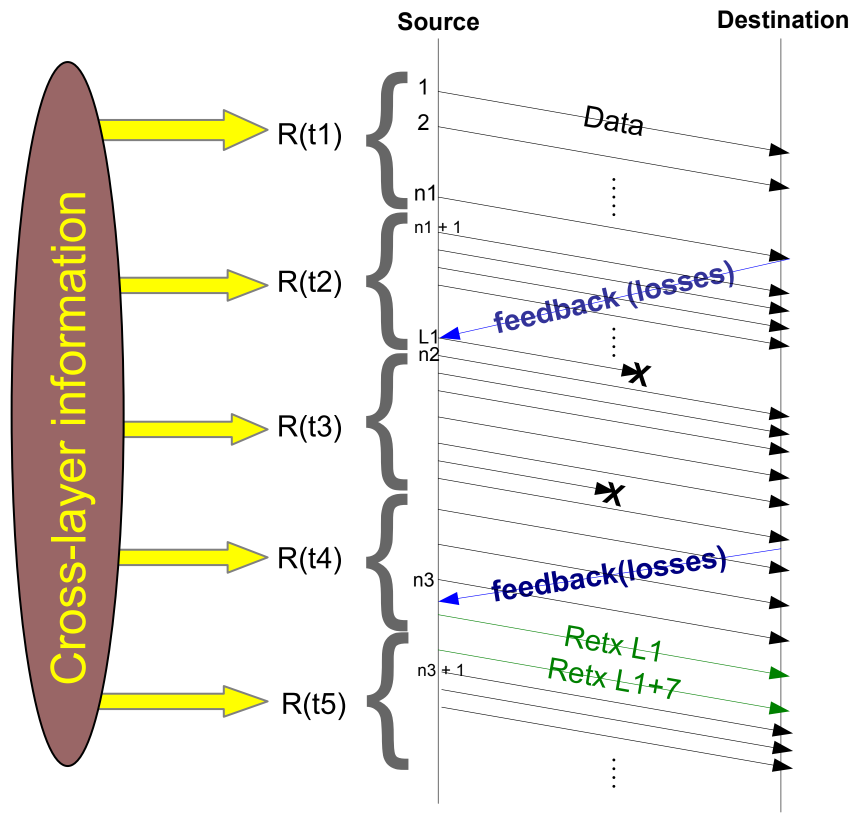
Opportunity in wireless networks

- Lower layers – Phy and MAC *know the exact status of the wireless link*
- These layers can provide direct knowledge of parameters that TCP tries to estimate with its channel independent design

Decoupling+ cross-layer = Simpler TP

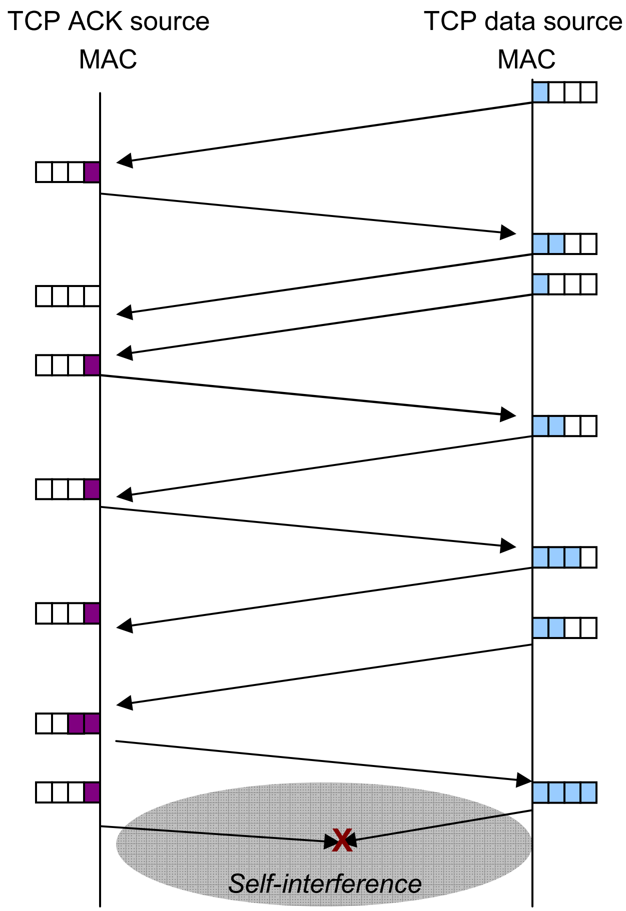


Conceptual Timing Diagram of TCP



Far simpler TP with Decoupling + Cross Layer

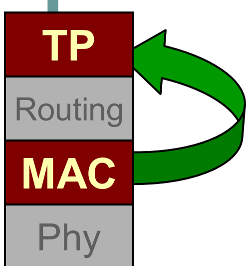
Additional wireless characteristics



- *Self-interference:* Collision between data and ACK packets of the same flow
- Fuctuations in round trip time

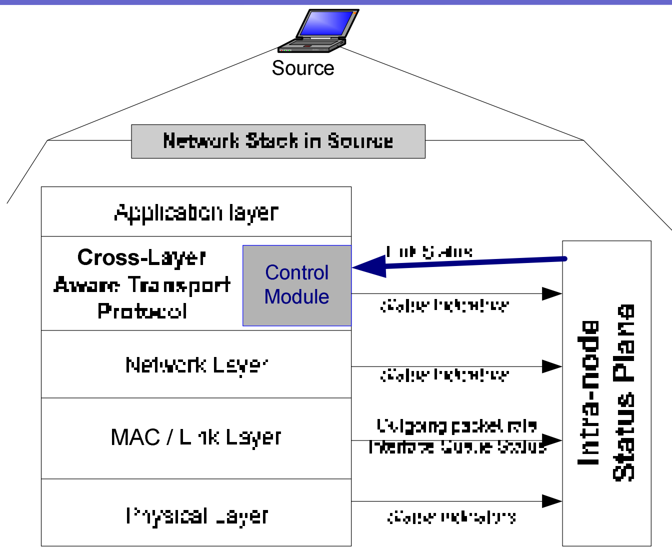
Publications: SIGCOMM-E-WIND'05 [3], ICC'05 [4]

Cross Layer Aware transport Protocol (CLAP)



- Near-real-time reliable file transfer
  - Designed for robustness in wireless networks
- Decouples error and flow control
- Rate-based flow control algorithm leverages MAC information
  - Simple Params: <MAC sending rate, MAC underflow> ;
  - MAC captures “net” status of the wireless link
- *Aggregate* NACKs for error control
  - Seqno and Bitmap fields
  - Variable length Bitmap
  - bitmap indicates receipt status of variable number of packets- 8 -> FileSize.

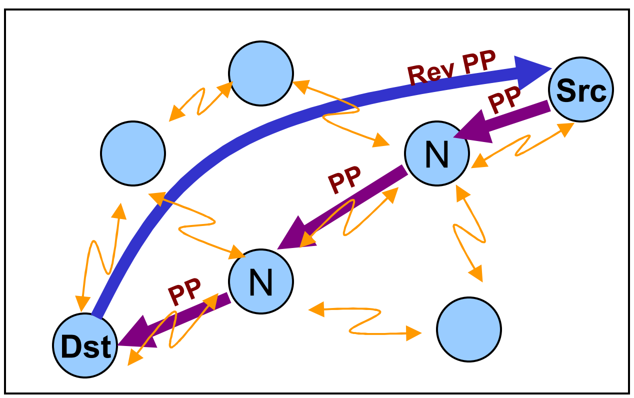
Software framework for cross-layer status information



Generic Register and Pull Architecture for Intra-node

- Standard API for network entities
- Abstraction of Parameters
- Scalable w.r.t both parameters and layers

Necessary to avoid *spaghetti code* [11



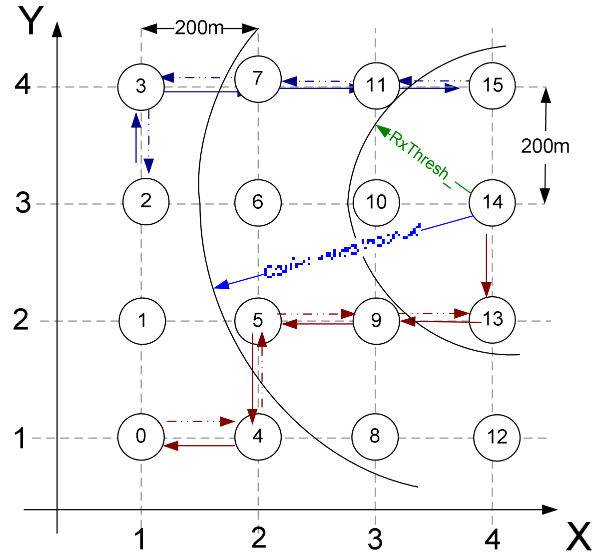
Probe Packets (PP) for inter-node status collection; At node N: min (PPrate, Nrate)

Simulations and Results

Simulations in NS2

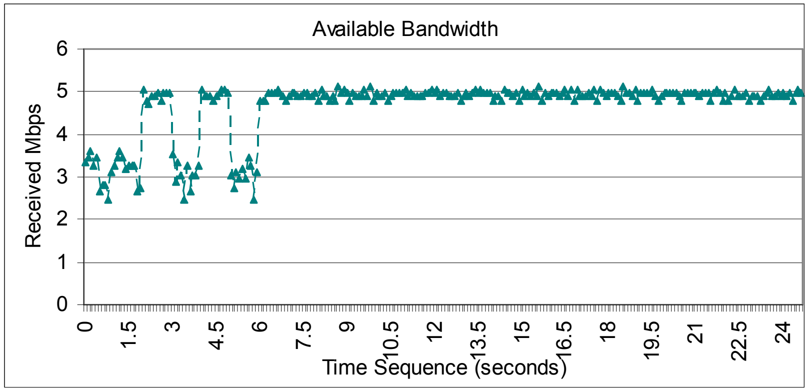
ORBIT-like time-varying links in NS2 simulations

- On-off Additive Noise with gaussian distribution.
- Saturating UDP flow to measure available bandwidth

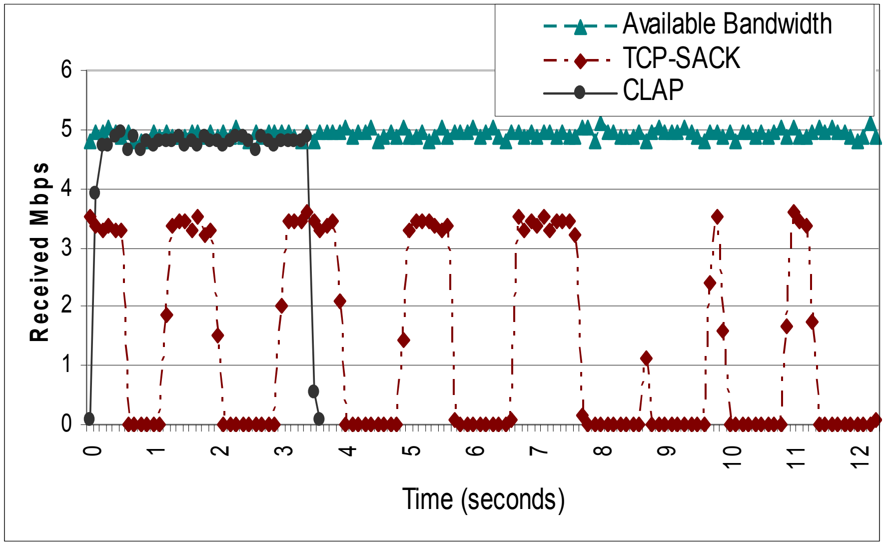


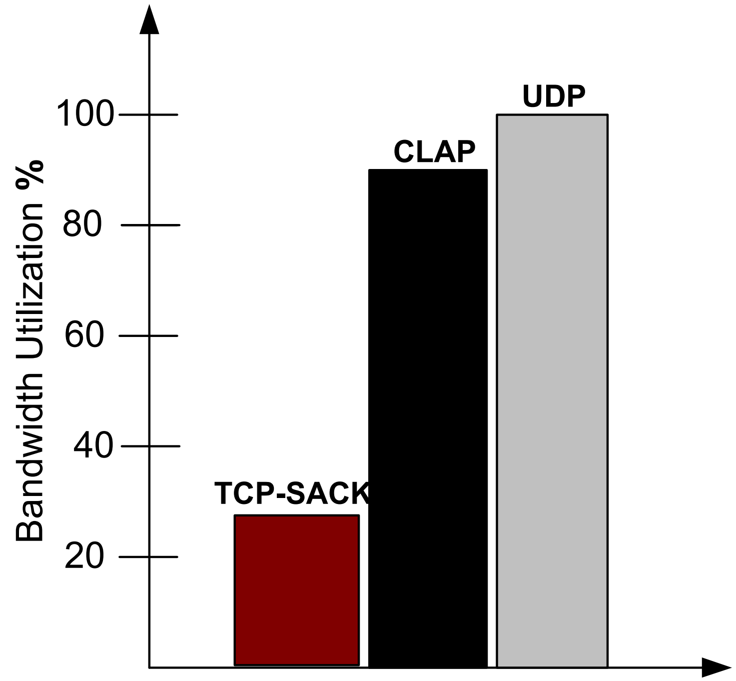
Other parameters

- 802.11 with 11 Mbps channel rate, Disabled MAC retries
- Noise power : 9.3 X 10-8 W, Phy parameters from Orinoco card specs
- Noise pulses of 1 second duration
- TCP-SACK with 1MB file transfer; UDP data rate of 8 Mbps



Single hop, single flow – no noise





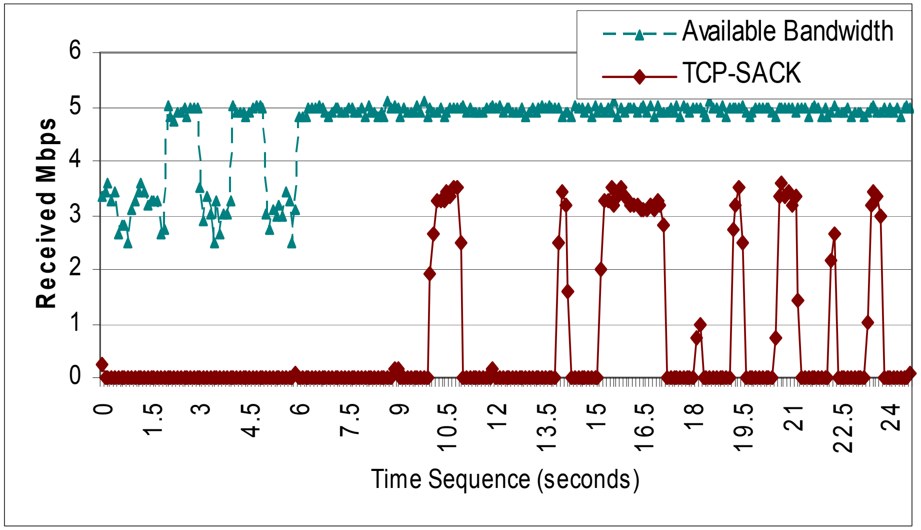
When no errors TCP suffers timeouts due to *self-interference*.

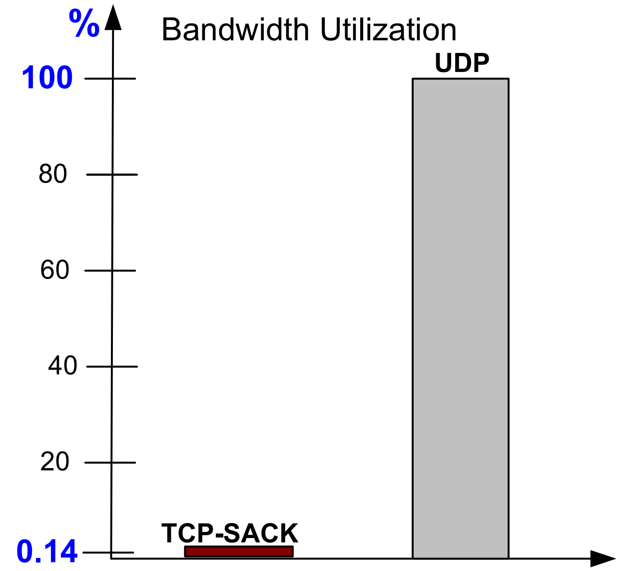
Diminished peak throughput due to bandwidth sharing with TCP-ACKs

CLAP gains 300% over TCP-SACK, making far better utilization of link bandwidth

Publications: ICC'07 [2], SIGCOMM-E-WIND'05 [3], ICC'05 [4]

Single-hop, single flow – time-varying



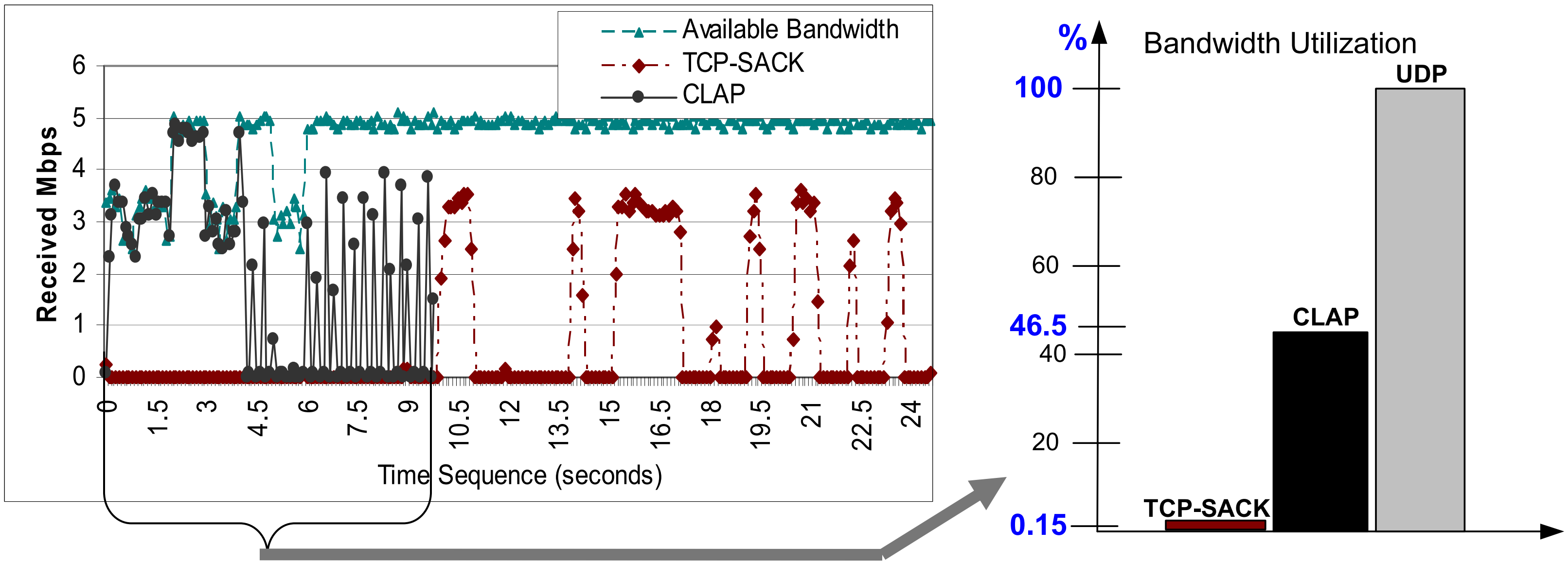


TCP shuts down operation in the presence of link errors.

TCP is slow to adapt good bandwidth due to exponential backoff

Publications: COMSWARE-WILLOPAN Jan 2007 [1], ICC'07 [2], SIGCOMM-E-WIND'05 [3], ICC'05 [4], *several ongoing*

Single-hop, single flow – time-varying

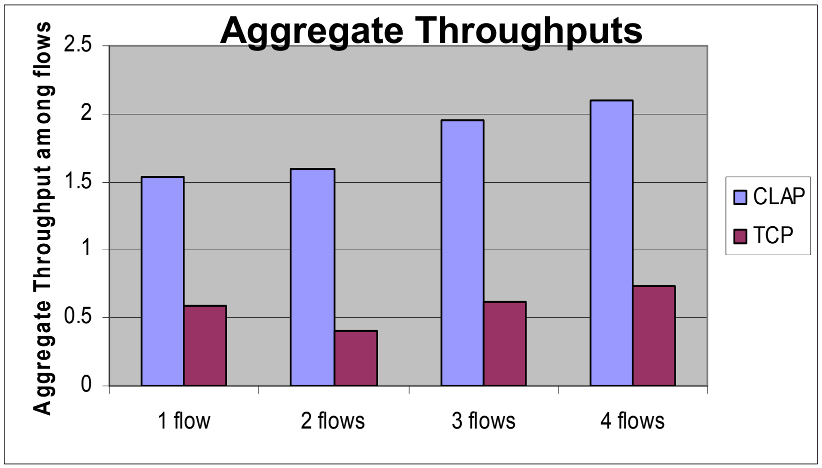


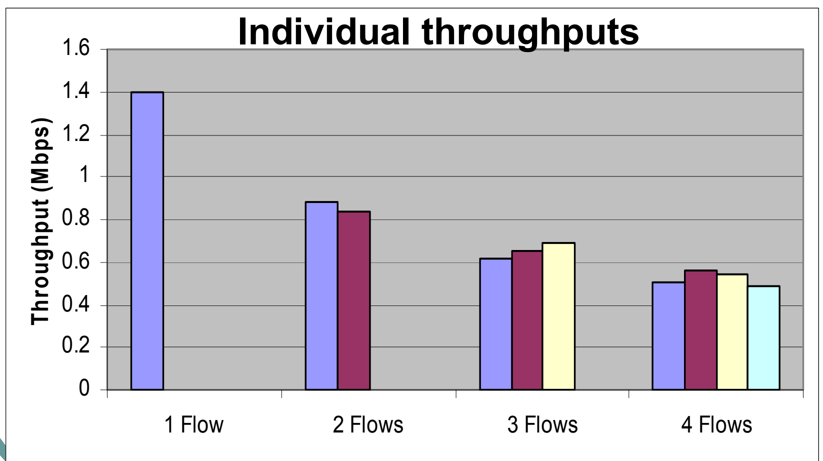
CLAP adapts its rate quickly enough to utilize available link bandwidth in wireless links with time-varying link characteristics

CLAP operates despite errors and bandwidth fluctuations; achieves significant (4500%) **performance gains over TCP-SACK**

Some results at: IEEE COMSWARE-WILLOPAN Jan 2007 [1]

Single hop, multiple flows – no noise



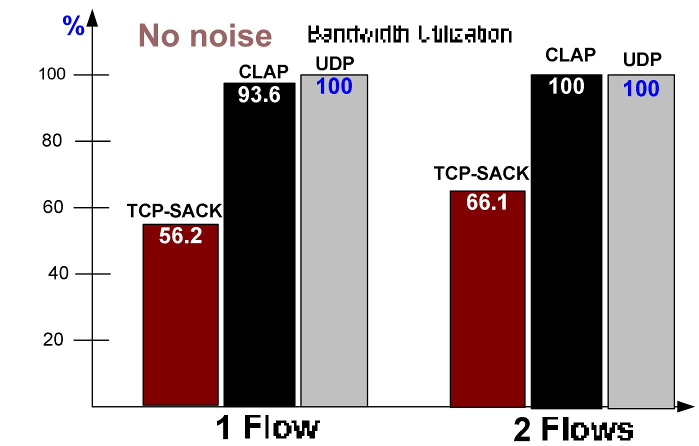


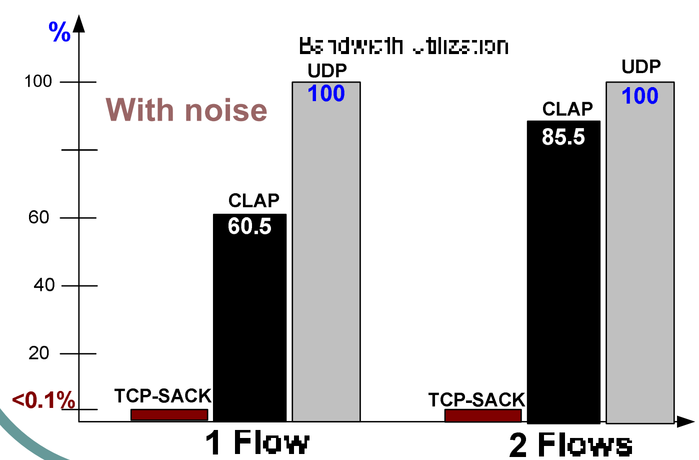
CLAP outperforms TCP **3:1** for aggregate throughput for multiple flows

CLAP achieves fair bandwidth sharing among multiple flows despite opportunistic rate adaptation

Ongoing work…

Multi-hop, multi-flow prelim results





- CLAP performance consistent in multi-hop noise-free and noise-prone wireless scenarios.
- Near perfect bandwidth utilization in no-noise scenario.

probe packet overhead = 80 kbps/flow

Expression to calculate overhead: 16*p/f(2t+d)* * number of flows*

p: pkt size bytes; f: seconds between PPs;
t: transmission delay (secs);
d- processing delay in each intermediate hop

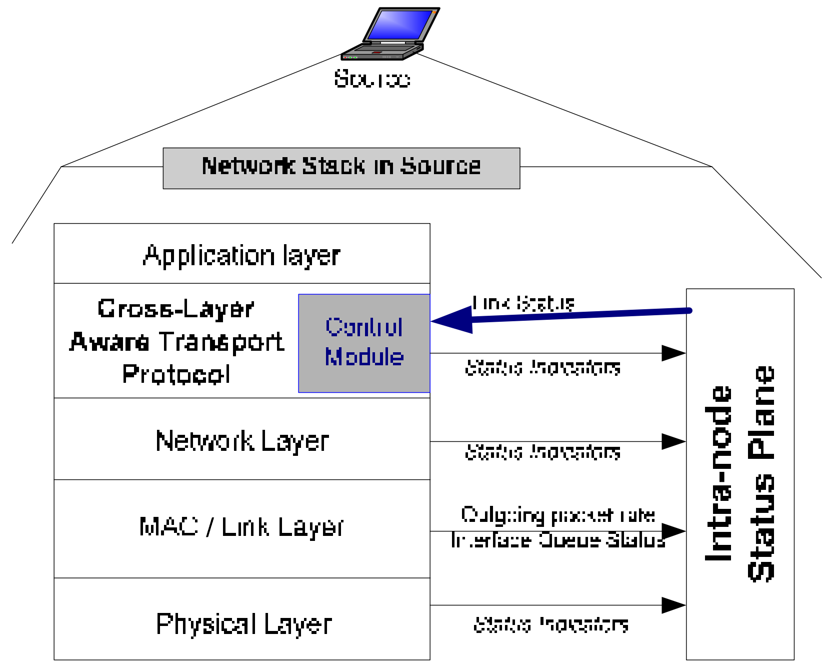
Publications: *writing; ongoing work*

Conclusion

- Immense advantages of (Decoupling + Cross Layer info) for transport over wireless links
- New *CLAP* protocol for reliable file transfer over wireless networks
- A software framework for status extraction in network stack
  - layer-independent,
  - Parameter independent
  - easily extensible and hence scalable
- Magnitudes of gain achieved over TCP in typical (time-varying) wireless scenarios

Future Work

- This work is the *tip of an iceberg*
- Several status parameters can be used to improve end-to-end performance
  - *Cross-layer error avoidance*
  - Reduce redundancies in the stack (retransmissions in MAC and TP)
- opportunity for a “synergistic” approach to data transport over wireless networks



References

[1] Sumathi Gopal, Sanjoy Paul, Dipankar Raychaudhuri "Leveraging MAC-layer information for single-hop wireless transport in the Cache and Forward Architecture of the Future Internet", The Second International Workshop on Wireless Personal and Local Area Networks (WILLOPAN) held in conjunction with COMSWARE 2007, Bangalore, INDIA, January 12th, 2007

[2] Sumathi Gopal, Sanjoy Paul, "TCP Dynamics in 802.11 Wireless Local Area Networks", *To appear in* IEEE Computer and Communications Conference (ICC) 2007, to be held in Glasgow, Scotland, UK, June 25-28th 2007.

[3] Sumathi Gopal, Dipankar Raychaudhuri, "Experimental Evaluation of the TCP Simultaneous-Send problem in 802.11 Wireless Local Area Networks", ACM SIGCOMM Workshop on Experimental Approaches to Wireless Network Design and Analysis (E-WIND), Conference held in Philadelphia, USA in August 2005.

[4] Sumathi Gopal, Sanjoy Paul, Dipankar Raychaudhuri, "Investigation of the TCP Simultaneous-Send problem in 802.11 Wireless Local Area Networks", Proceedings of the IEEE Computer and Communications Conference (ICC) 2005, Volume 5, page(s):3594 - 3598. Conference held in Seoul, South Korea. 16-20th May 2005.

[5] Suli Zhao and Dipankar Raychaudhuri, "On the Salability of Hierarchical Hybrid Wireless Networks," *Conference on Information Sciences and Systems (CISS 2006),* March 2006

[6] Suli Zhao, Zhibin Wu, Arup Acharya, and Dipankar Raychaudhuri, "PARMA: A PHY/MAC Aware Routing Metric for Ad-Hoc Wireless Networks with Multi-Rate Radios", *IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks (WoWMoM 2005)*, June 2005.

[7] Zhibin Wu, Dipankar Raychaudhuri, "D-LSMA: Distributed Link Scheduling Multiple Access Protocol for QoS in Ad-hoc Networks", in Proceedings of IEEE GLOBECOM '04, November 2004.

[8] A. Acharya, S. Ganu, A. Misra, "DCMA: A Label Switching MAC for Efficient Packet Forwarding in Multihop Wireless Networks", IEEE JSAC Special Issue on Wireless Mesh Networks, November 2006

[9] Z. Wu, S. Ganu and D. Raychaudhuri, "IRMA: Integrated Routing and MAC Scheduling in Wireless Mesh Networks", Proceedings of the Second IEEE Workshop on Wireless Mesh Networks, (WiMesh), Reston, 2006

More in the works…

Thank You!

Questions ?

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ORBIT noise injection

Packet error rate (PER) observed at nodes across 64-node ORBIT grid for -5 dBm noise

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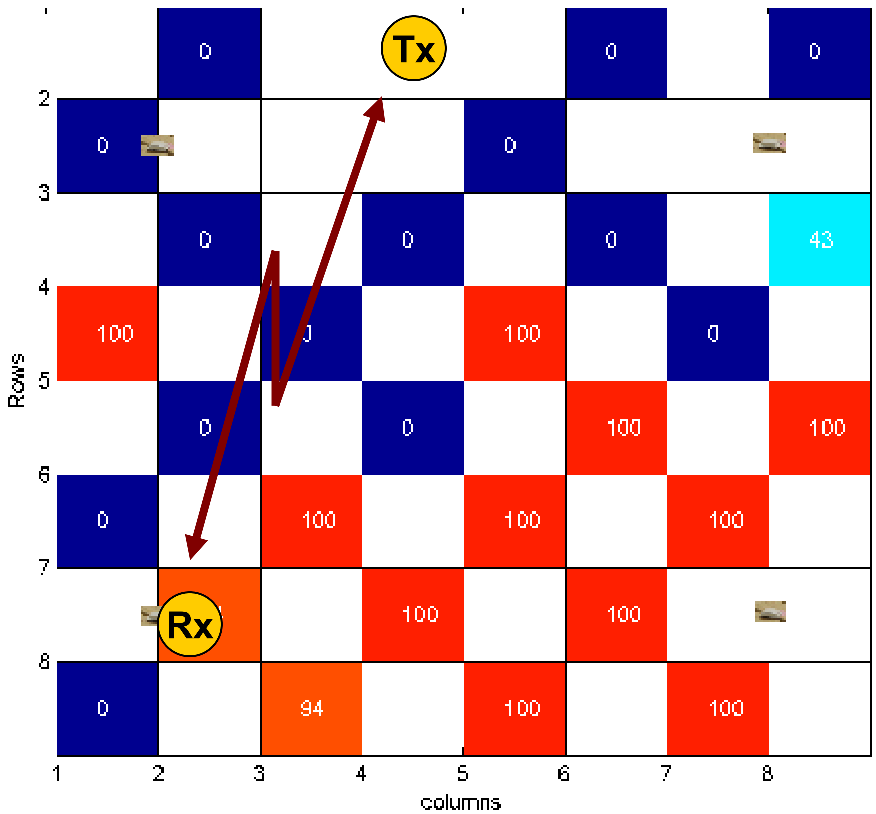

Reference: Creating Wireless Multi-hop Topologies on Space-Constrained Indoor Testbeds Through Noise Injection
Sanjit Krishnan Kaul, Marco Gruteser, and Ivan Seskar, WINLAB, Rutgers University, USA