Evaluation of 802.11a for Streaming Data in Ad-hoc Networks

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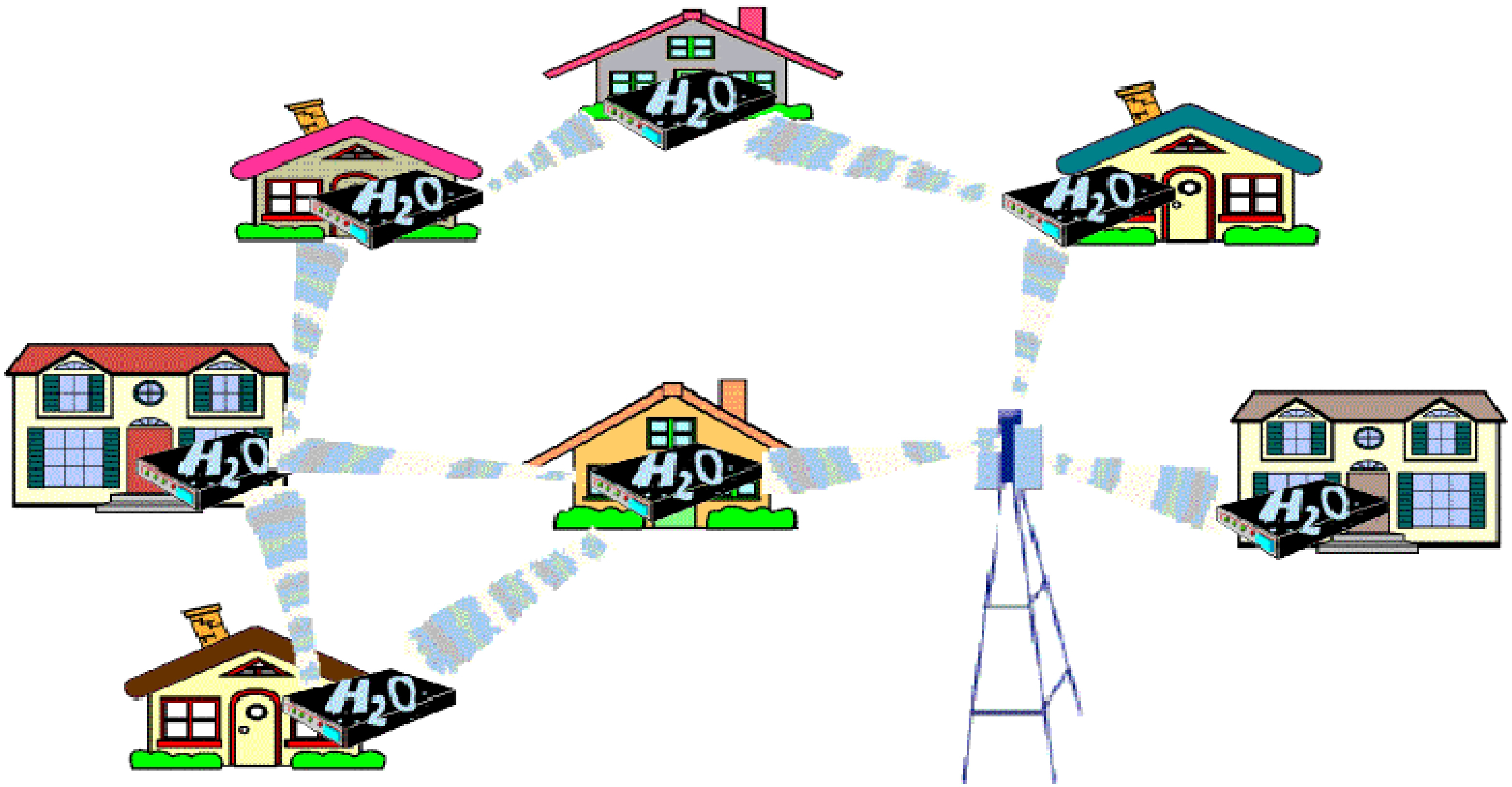
H20 Application class: An example deployment



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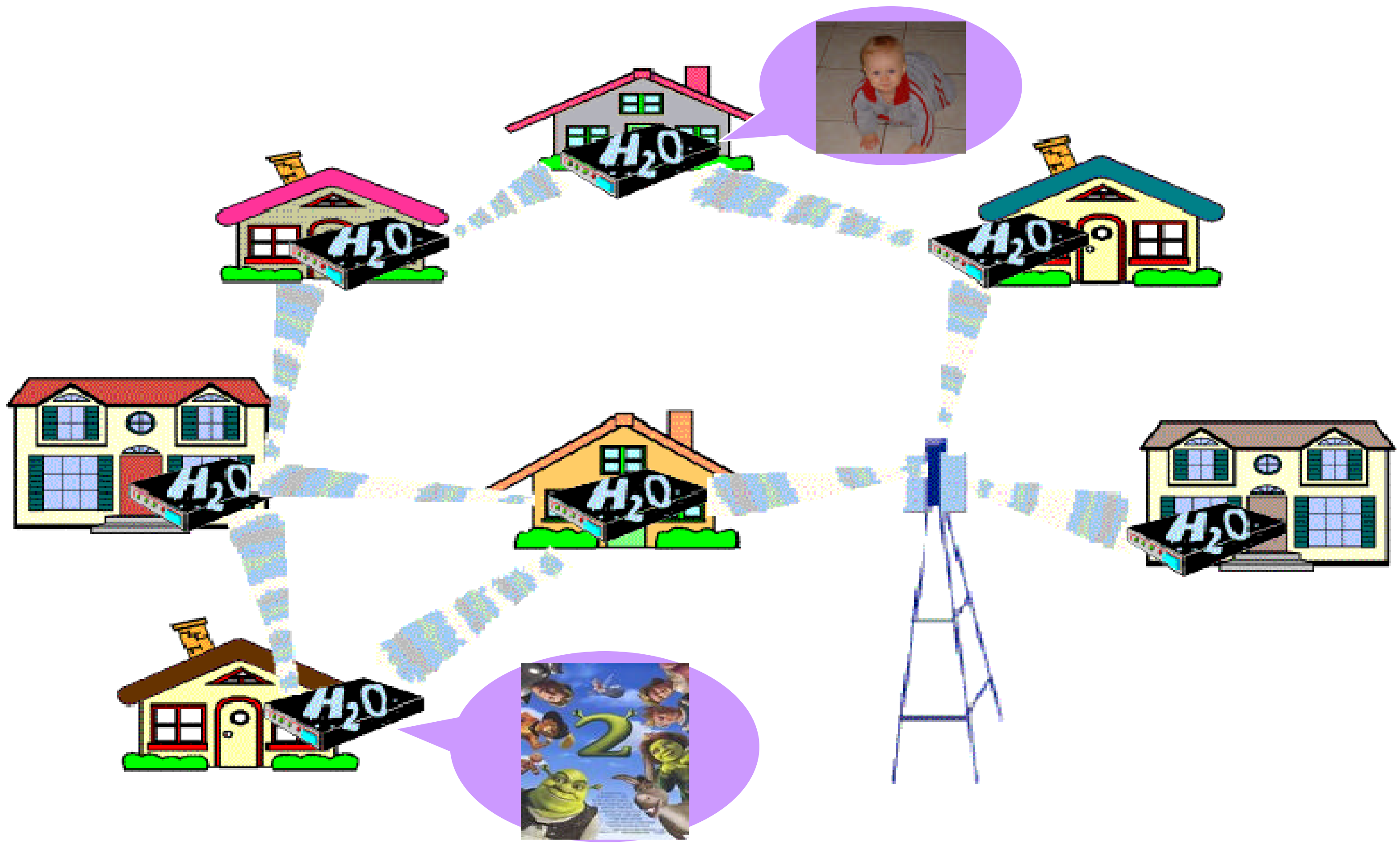


H2O device roles:

Data producer (source), Data forwarder (router), Data consumer (sink)

Candidate wireless technologies

Technology	Frequency band	Spec B/W	Typical B/W	Radio-range(indoor)
Bluetooth	2.4Ghz	1Mbps	700Kbps	30 feet
802.11b	2.4-2.48Ghz	11Mbps	4-5Mbps	300 feet
802.11a	5.725-5.85Ghz	54Mbps	20-25Mbps	40 feet

Note:

(1) 802.11a turbo provides bandwidths upto 75Mbps (raw) but not supported by all manufacturers (not a IEEE std)

(2) Bandwidth required for display of a DVD-quality (MPEG-2) video clip is 4Mbps.

Hypothesis: IEEE 802.11a may be a feasible option for the H20 application class.

Dimensions of the empirical study

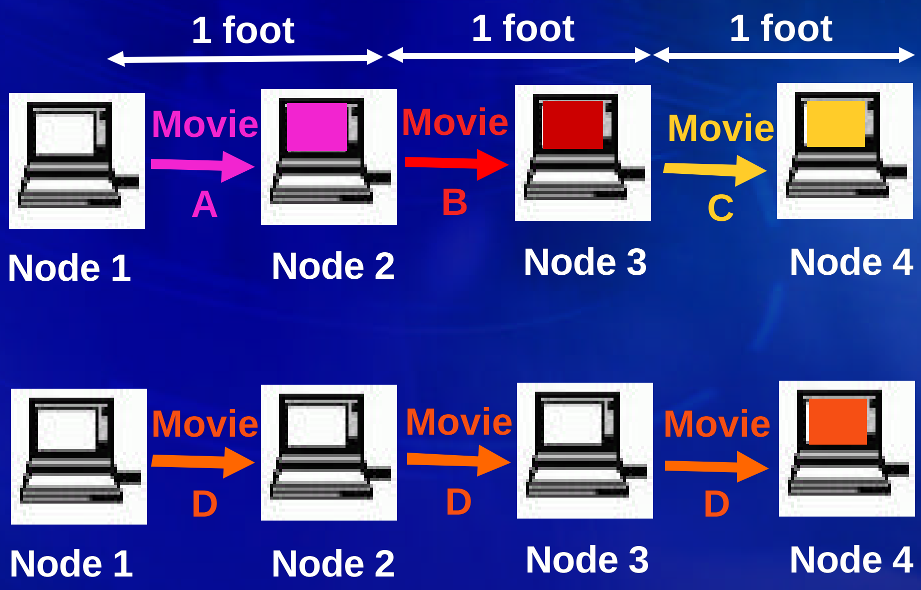
- Distance between participating devices
- Number of intermediate H20 devices used to route a stream from a producing H20 device to a consuming H20 device
- Number of simultaneous senders in the same radio range
- Operating system level versus application level routing

Note: Used INTEL PRO/Wireless 5000 LAN Cardbus adapter 802.11a cards at 54Mbps (Auto data rate control disabled)

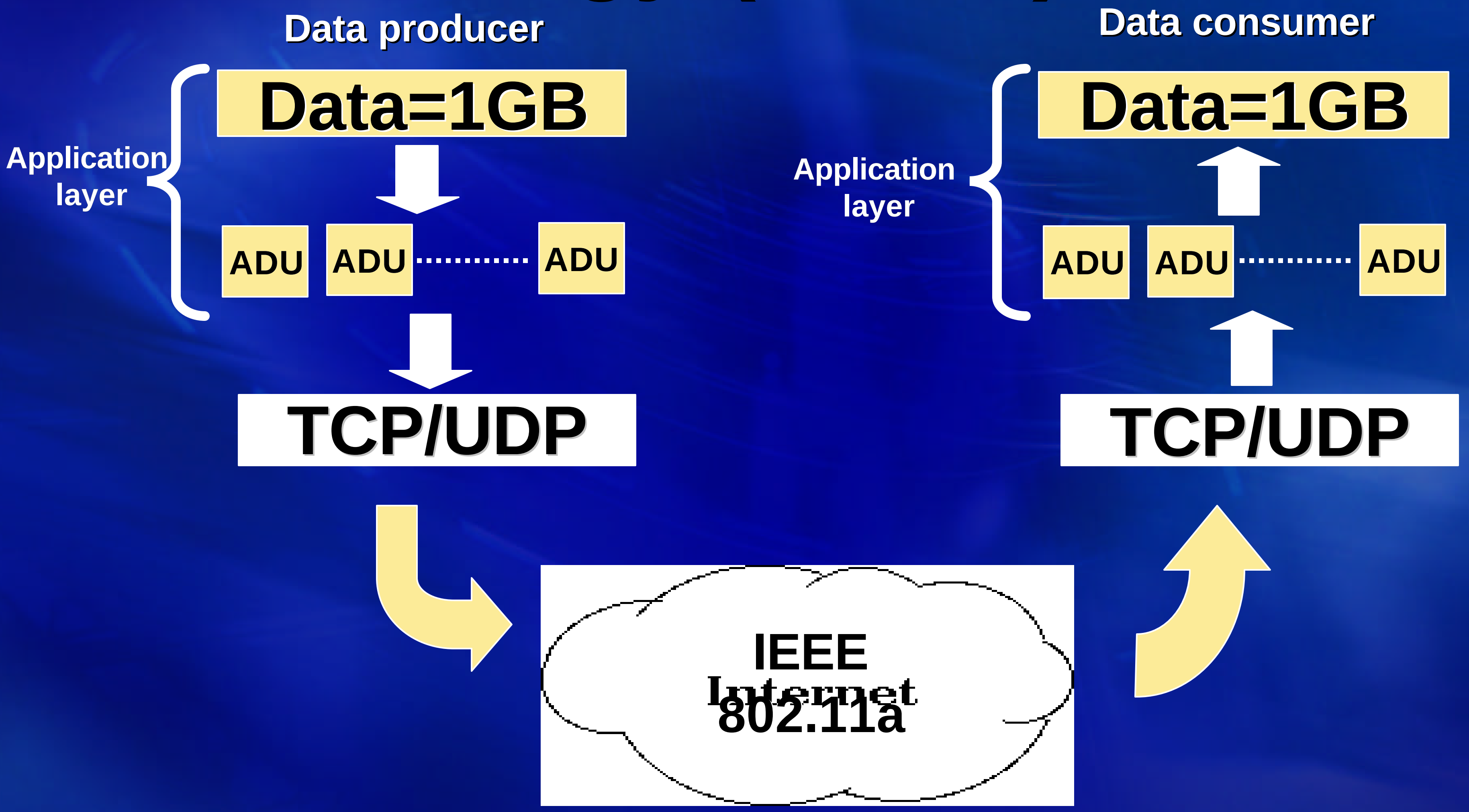
Terminology

- In general, any scenario is m transmissions k hops each
  - Denoted as m:k, m,k>=1

- For e.g.
  - (a) 3:1 hop transmission
  - (b) 1:3 hop transmission

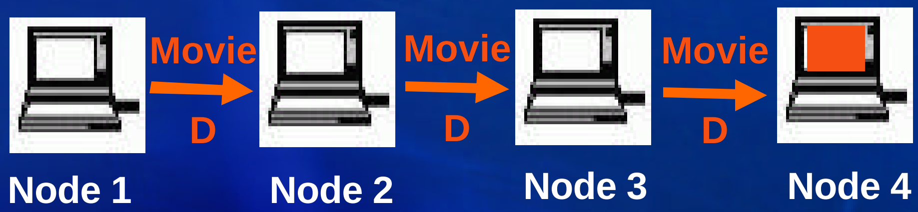


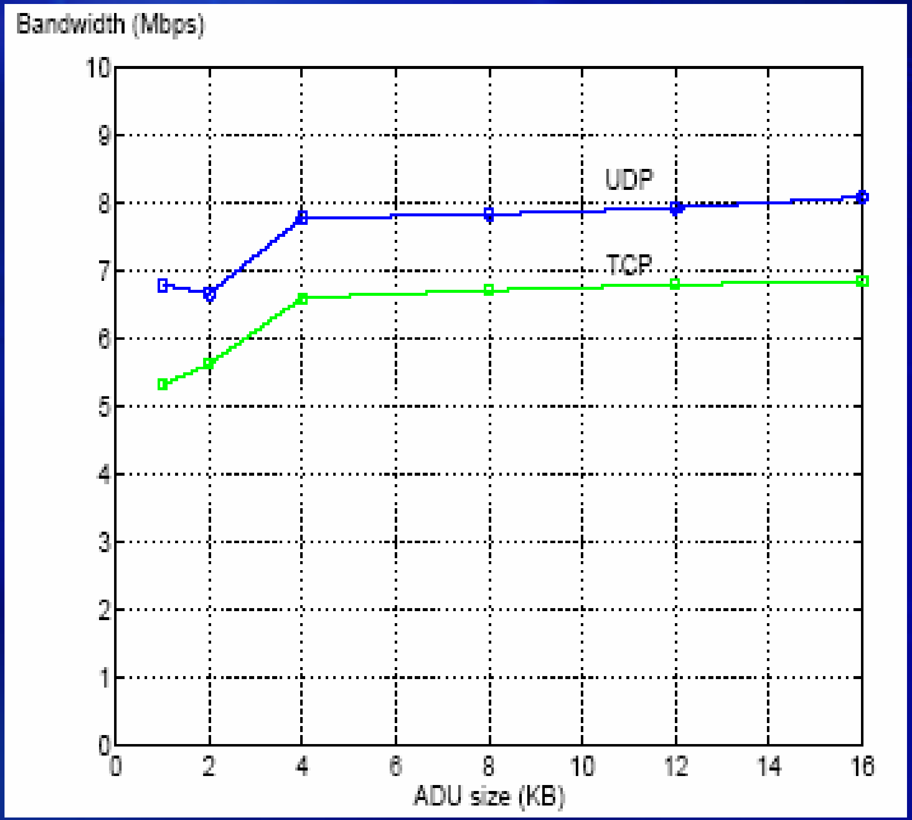
Terminology (contd)

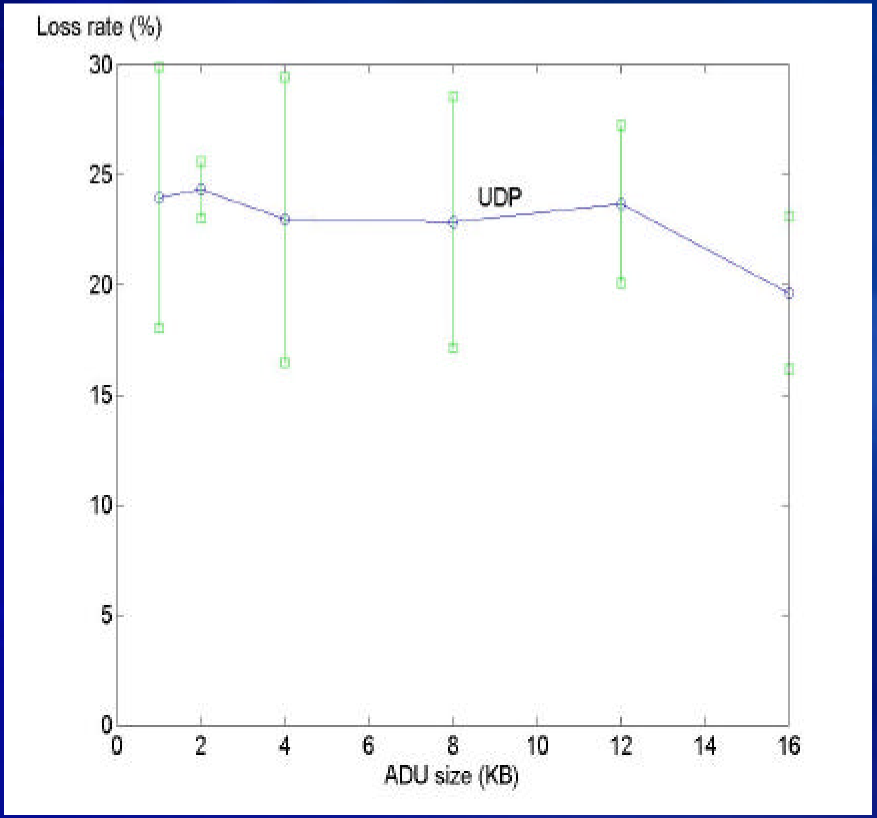


Note: ADU – Application Data Unit

TCP and UDP performance for a 1:3 hop connection





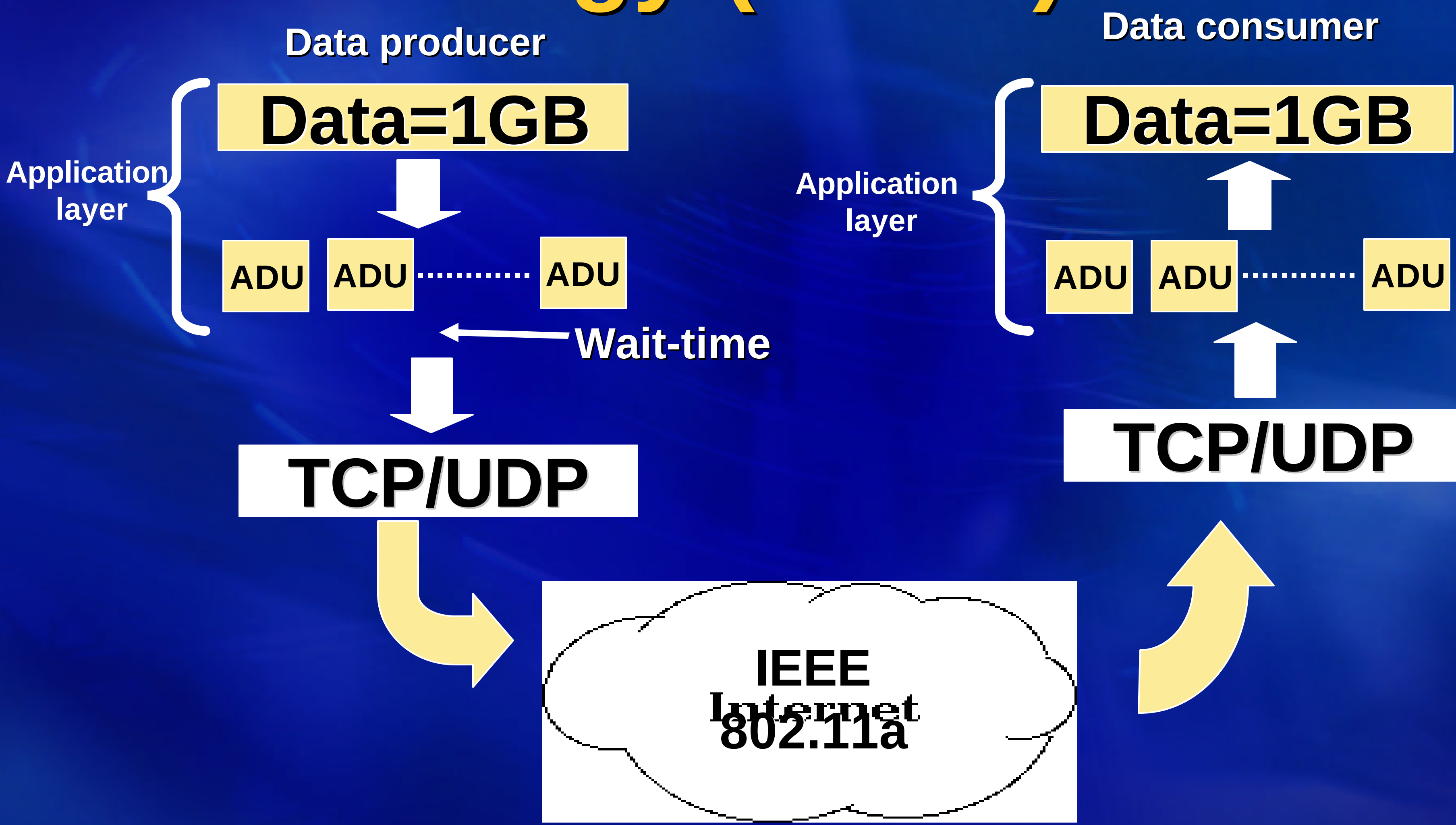


Bandwidth (Goodput) and loss rate for a 1:3 hop connection.

Observations

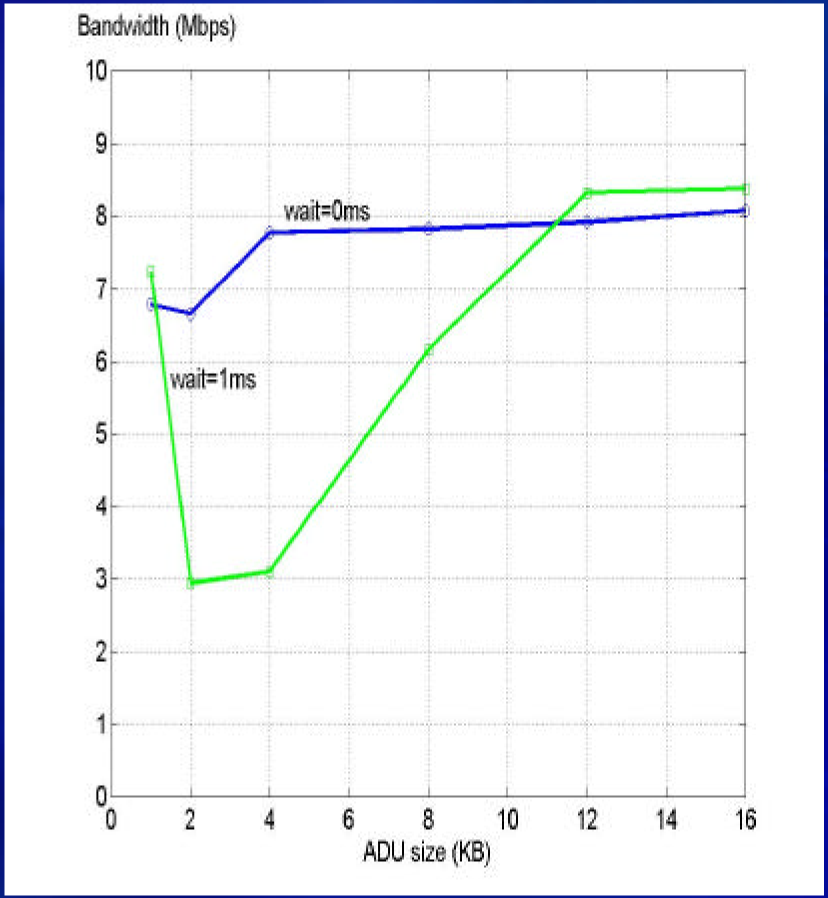
- UDP Loss rate between 15-30% with a large variance
  - Losses occur due to transient bottlenecks at intermediate routers
  - k participants competing for the channel
  - Due to randomness intermediate router is flooded occasionally and drops data
- TCP performs well even though there is the ACK overhead
  - **A protocol with flow control and congestion control does well in case multiple senders in the same radio range**
- System may produce data at a slower rate than available network bandwidth
  - Introduce a delay between successive ADUs

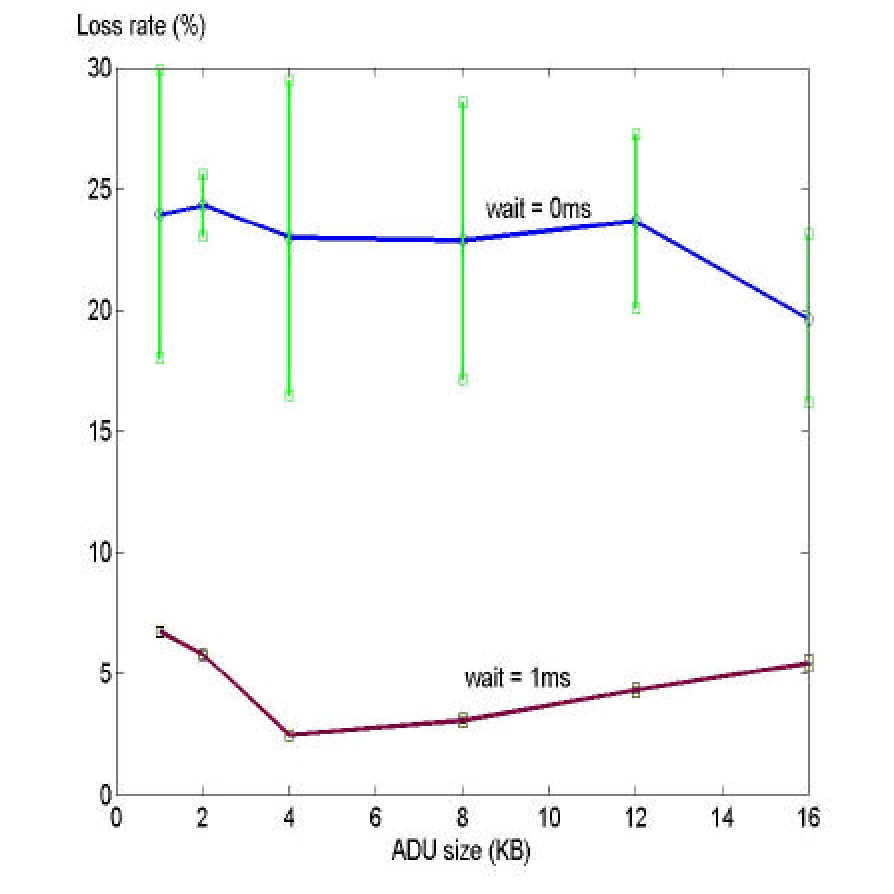
Terminology (contd)



Note: ADU – Application Data Unit

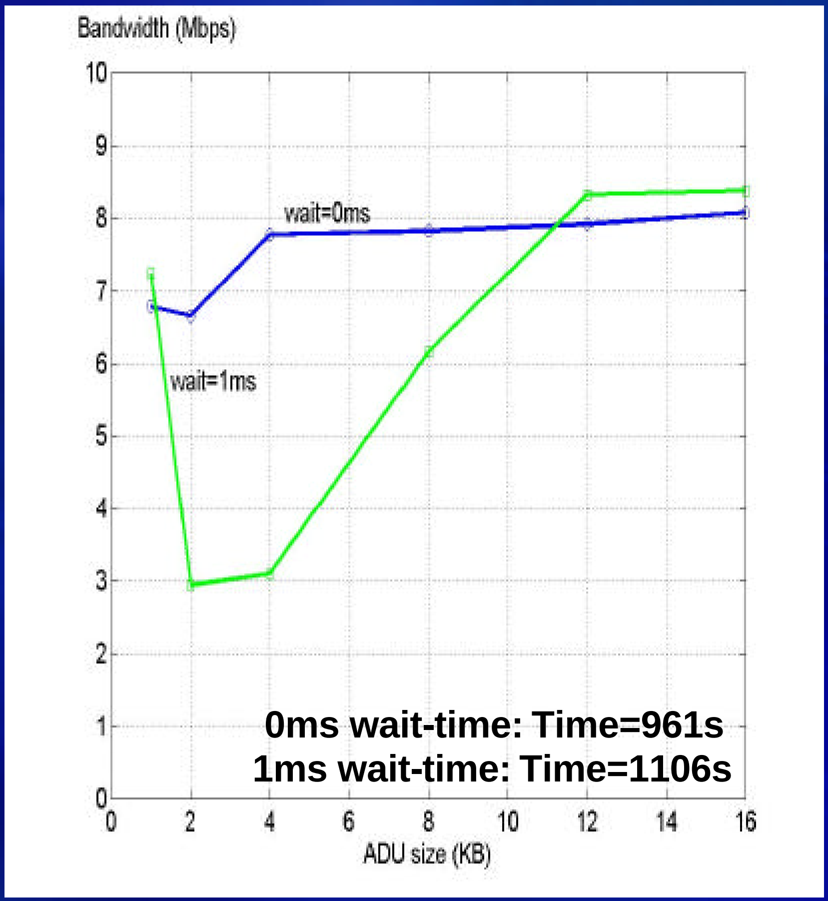
Data Flow Control

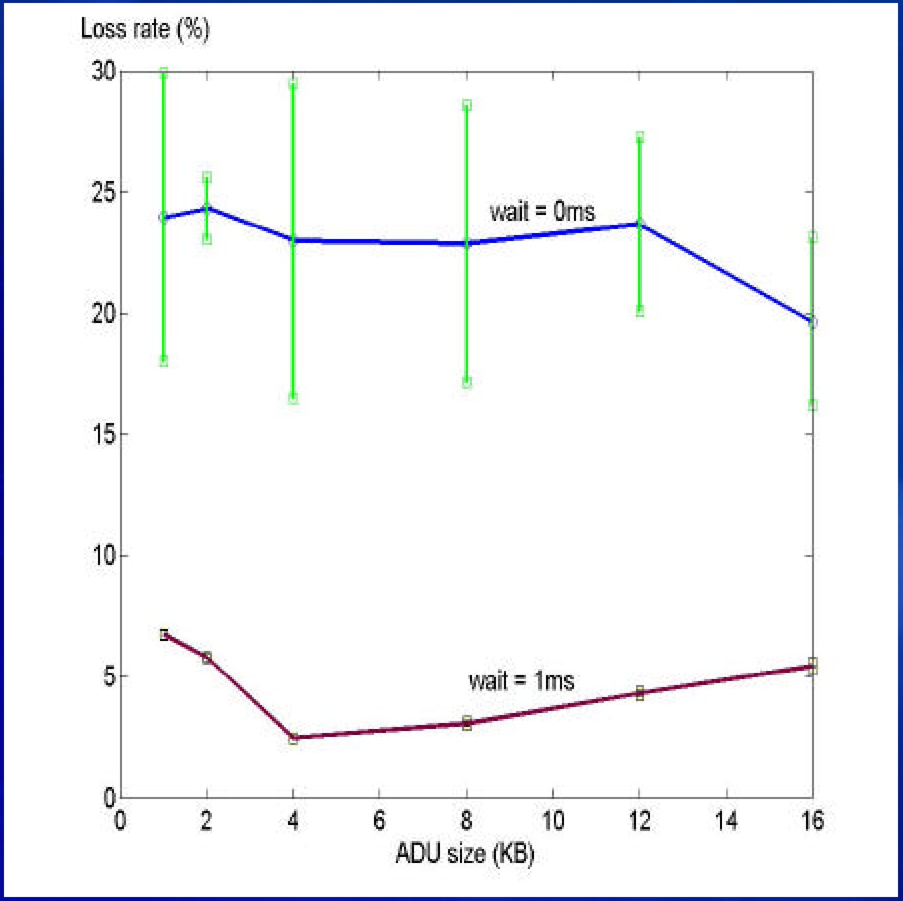




Bandwidth and loss rate with UDP for a 1:3 hop connection with wait-time.

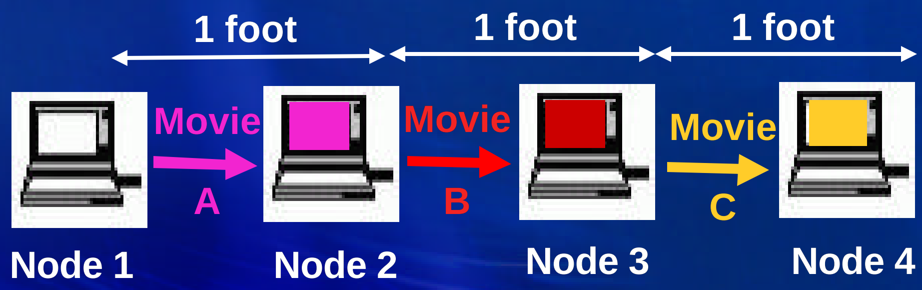
Data Flow Control

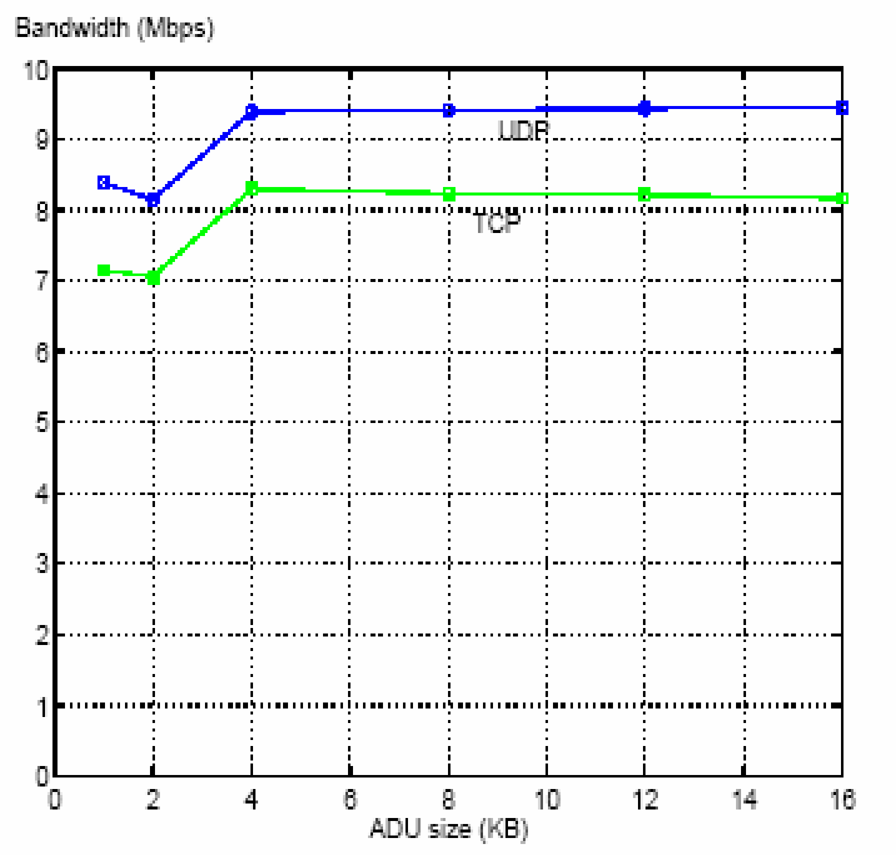


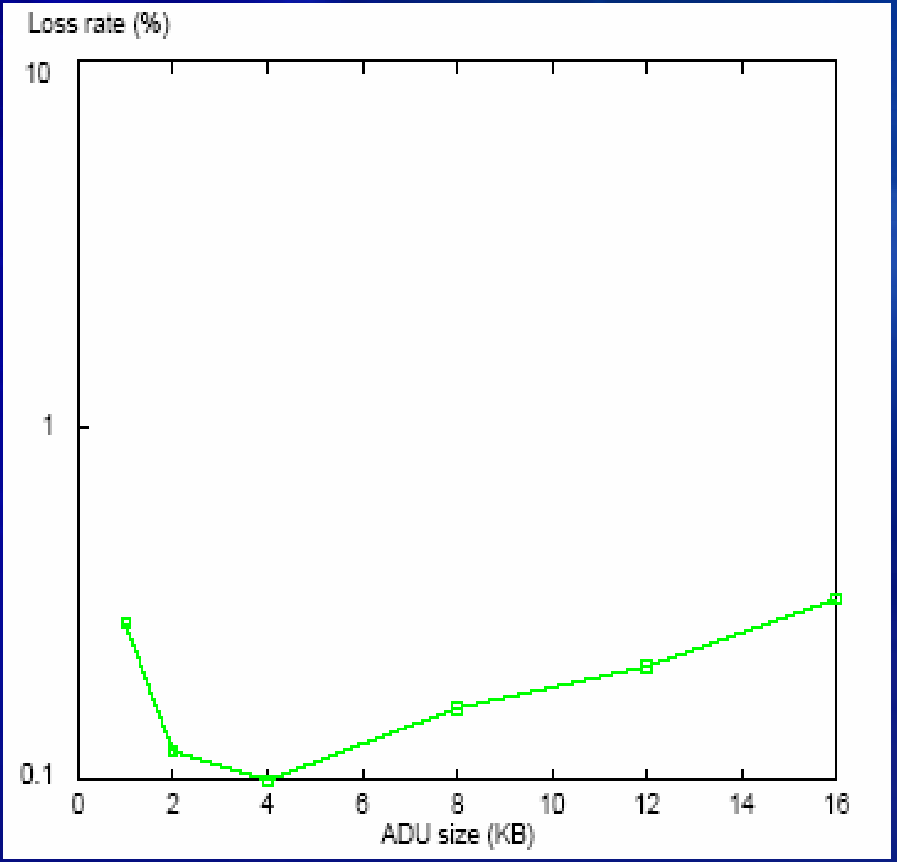


Bandwidth and loss rate with UDP for a 1:3 hop connection with wait-time.

TCP and UDP performance for 3:1 hop connection

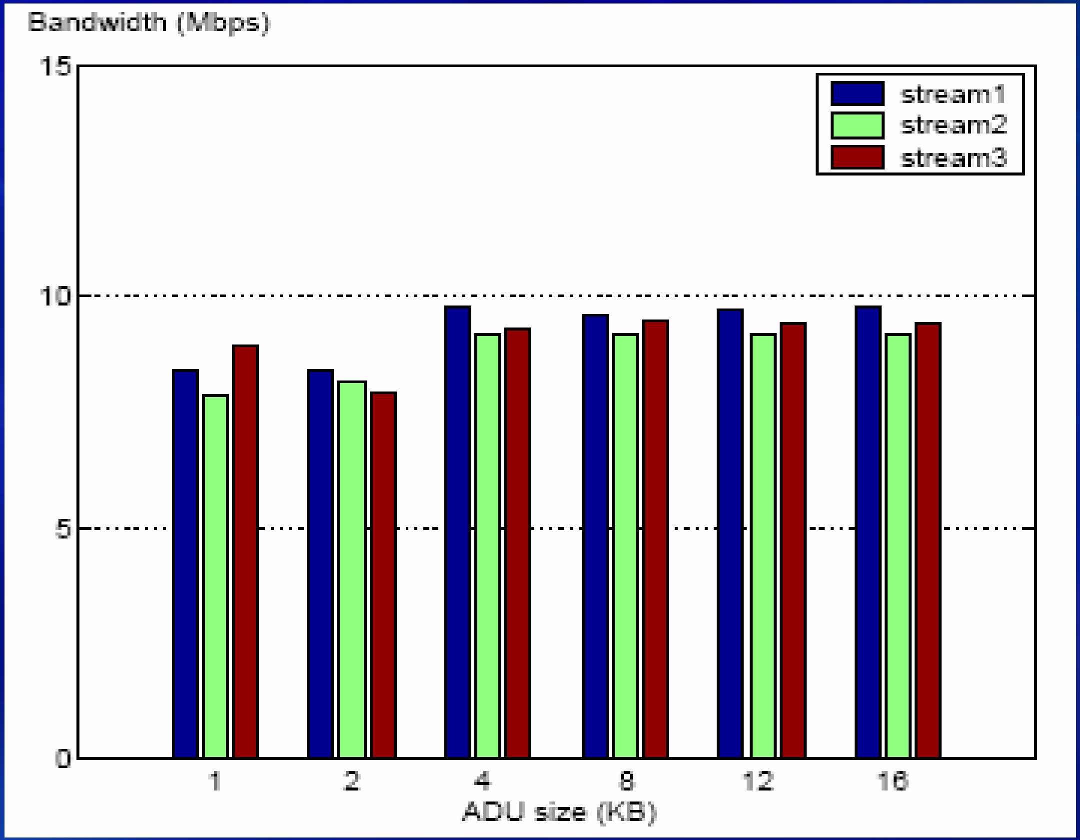




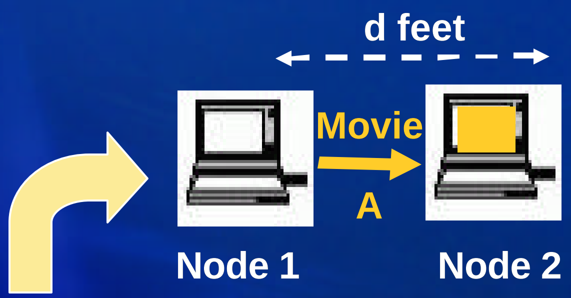


Observations

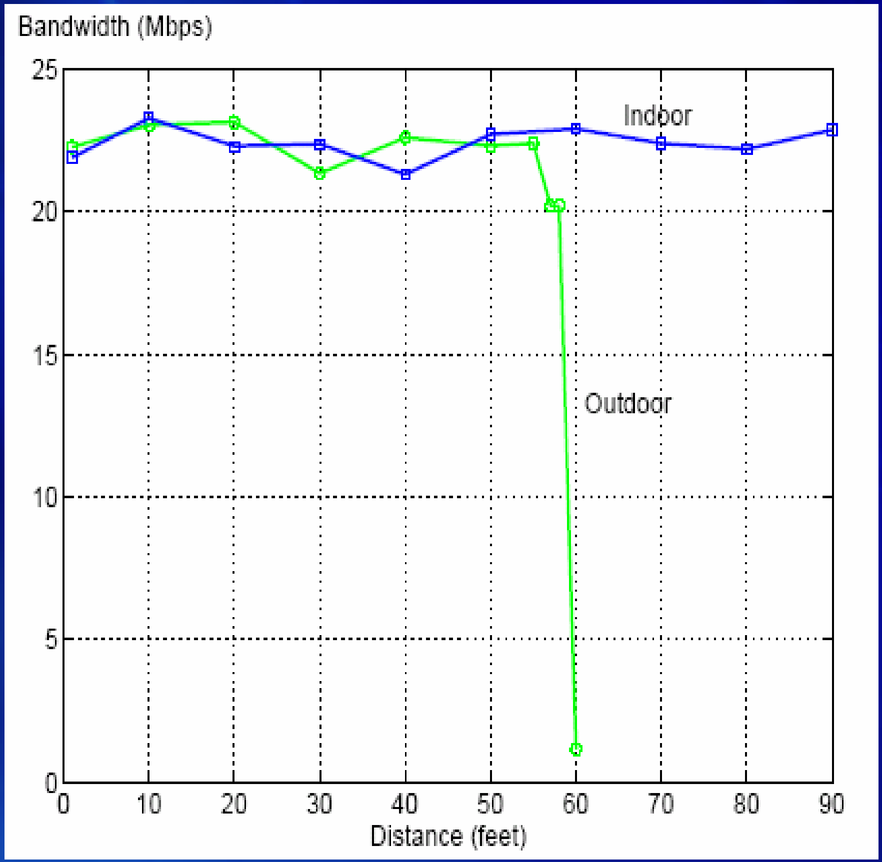
- TCP and UDP bandwidth drops by 1/3 as compared to 1:1
  - 3 senders contending for the medium
  - Loss rate for UDP is about 0.2%
- Allocation of bandwidth is approximately fair

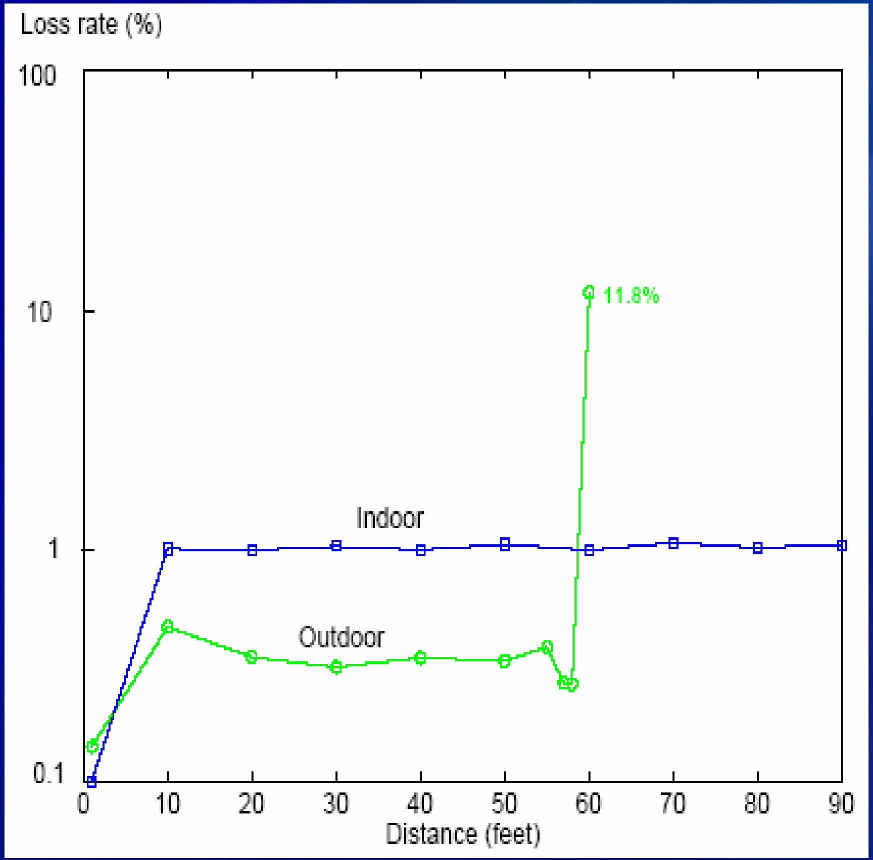


Distance experiments



- Carried out experiments with a **1:1 configuration** at USC track field, university housing (indoor experiments) and Marina-del-Rey beach





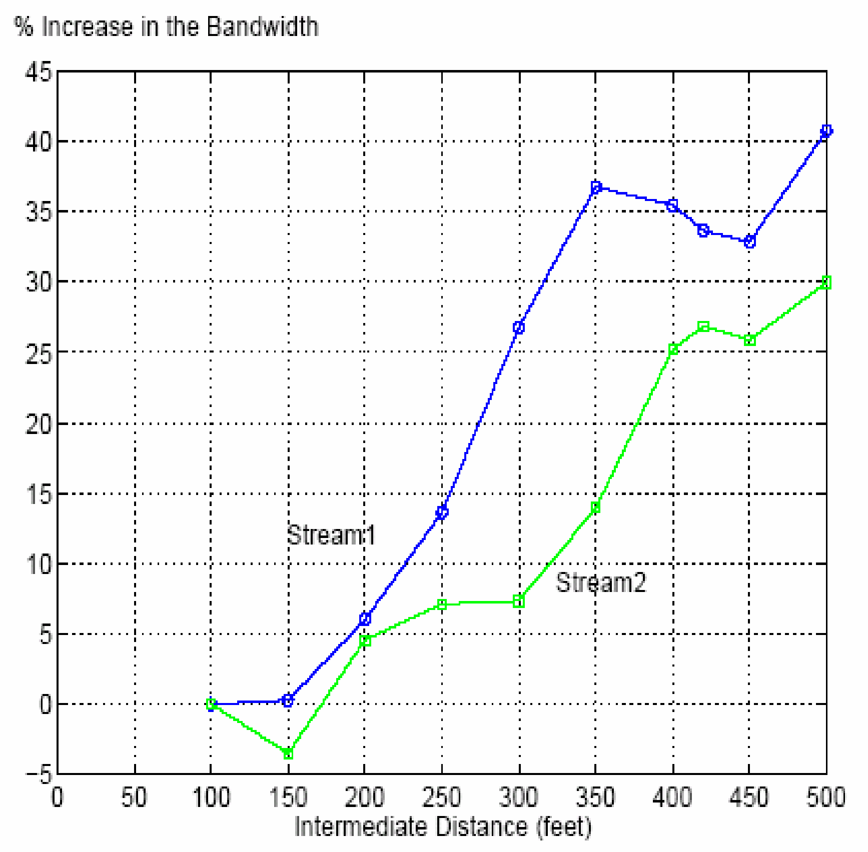
Exposed node limitation

- Related work has shown that exposed node[6] degrades the performance of 802.11 severely
- Experimental setup

- Two pairs of nodes spaced d feet apart
  - 100 MB of data with ADU size of 1KB

Results

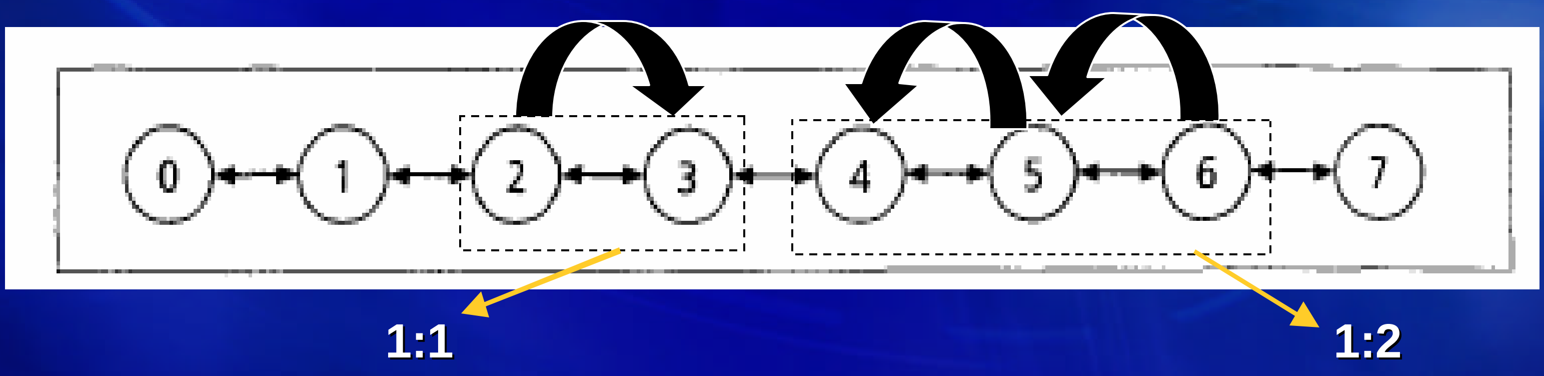
	Session 1	Session 2
d (feet)	Bandwidth	Bandwidth
100	12.24468	12.99614
150	12.2803	12.5572
200	13.02289	13.65804
250	14.09932	14.01428
300	16.23252	14.04708
400	17.80064	16.95107
450	17.34653	17.06635
500	18.8331	17.79747



- Results show that each stream observes a bandwidth of 12.2 – 14.4 Mbps up to 250 feet.

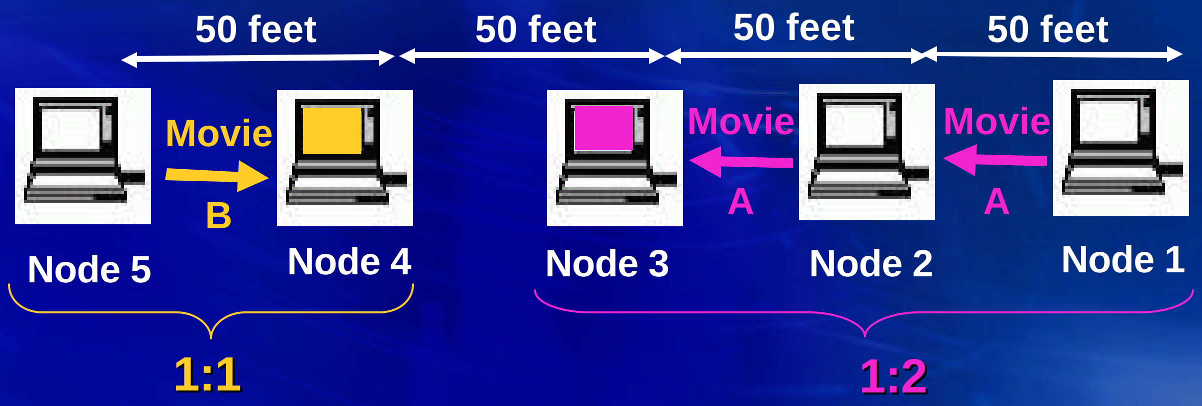
Related work

- [5] studies the feasibility of IEEE 802.11b as a viable candidate for wireless ad hoc networks
- TCP one-hop unfairness problem
  - Simulation study verified with empirical deployment



No Dropped connections

- Experimental setup



- Even with the 1-hop flow running on UDP, TCP does not drop connections.
- Allocation of bandwidth is fair across UDP and TCP flows

Transmission	$N1 \rightarrow N2$	$N2 \rightarrow N3$	$N5 \rightarrow N4$
Protocol	TCP	TCP	TCP
Bandwidth (Mbps)	6.029	6.028	6.178

Transmission	$N1 \rightarrow N2$	$N2 \rightarrow N3$	$N5 \rightarrow N4$
Protocol	TCP	TCP	UDP
Rate of Loss (%)	0	0	0.09961
Bandwidth (Mbps)	6.361	6.361	6.869

Differences between IEEE 802.11a and IEEE 802.11b

- IEEE 802.11a
  - Has 12 channels (compared to 3 for 802.11b)
    - 8 for indoor and 4 for outdoor use
    - Lower co-channel interference
  - Allows for higher user densities and higher system data throughput
  - Higher bandwidth 54Mbps as compared to 11Mbps for 802.11b
    - Higher system capacity

Related work

- Does not contradict [3,4] using TCP-ELFN and TCP-ECN
- [6] does an empirical study with IEEE 802.11b
- [7] MIT Roofnet project
- [8] Microsoft Research Meshnet project
- [9] IEEE 802.11a paper by Atheros
  - Comparison between IEEE 802.11b and IEEE 802.11a in an office environment

Conclusions

- IEEE 802.11a is feasible for the class of applications such as H20
  - Bandwidth and Loss rate observed in experiments across the different dimensions were sufficient for DVD quality display
  - A protocol with flow control and congestion control is needed for streaming in the H20 environment
  - The allocation of bandwidth among multiple competing 1-hop TCP and UDP flows is fair
  - Exposed node limitation does not affect 802.11a severely
  - No one-hop unfairness observed with 802.11a

Future work

- A simulation and analytical model to capture the behavior
- Streaming issues
  - Hiccups and start-up latency
  - Pre-fetching/Buffering
- Experimentation with
  - Different variants of TCP
  - 802.11e cards (when they become available)
- Data placement and statistical admission control
- Mobility
  - C2P2 (Car-to-Car Peer-to-Peer) Networks

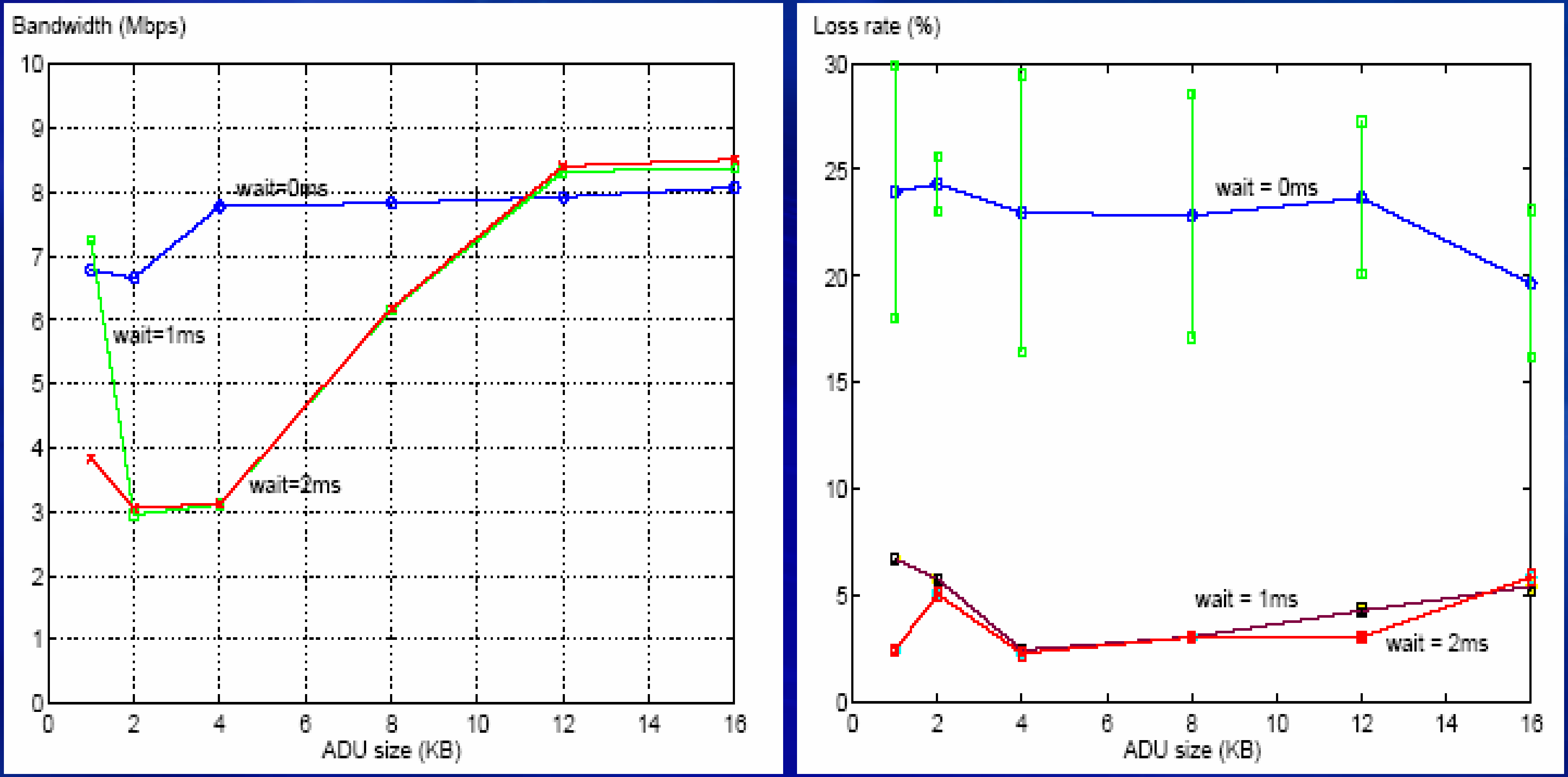
References

- [1] V.Bush, As We May Think. *The Atlantic Monthly, 127(6):101-108, July 1945*
- [2] J.Gemmell, B.Gordon, R.Lueder, S.Drucker, and C.Wong, MyLifeBits:Fullfilling the Memex *Vision. In ACM Multimedia, December 2002*
- *[3] G.Holland and N.H.Vaidya, "Analysis of TCP performance over Mobile Ad Hoc Networks", Mobile Computing and Networking, pages 219-230, 1999.*
- *[4] S.Floyd and K.Ramakrishnan, "TCP with ECN: The Treatment of Retransmitted Data Packets", 2000*
- *[5] S. Xu and T. Saadawi, "Does the IEEE 802.11 MAC Protocol Work Well in Multihop Wireless Ad Hoc Networks?", IEEE Communications Magazine, pages 130-137, June 2001*
- *[6] G. Anastasi, E. Borgia, M.Conte, E.Gregori, "IEEE 802.11 Ad Hoc Networks: Performance Measurements",* 1999.
- *[7] http://www.pdos.lcs.mit.edu/roofnet/*
- *[8] http://research.microsoft.com/sn/mesh/*
- *[9] Atheros Communications, "Measured Performance of 5-GHz 802.11a Wireless LAN Systems", 2001, http://epsfiles.intermec.com/eps_files/eps_wp/AtherosRangeCapacityPaper.pdf*

Questions

THANK YOU

Data Flow Control



Bandwidth and loss rate with UDP for a 1:3 hop connection with wait-time.

Observations

- Loss reduces significantly with wait-time
  - Data is sent out at a slower rate
- With ADU of 1KB bandwidth observed with a wait-time of 1ms is higher than that observed with 2ms
  - With 1ms wait-time the transmission time eclipses the wait-time
  - With 2ms wait-time exceeds the transmission time
    - Network remains idle giving lower bandwidth
  - Execution times for 0ms,1ms and 2ms are 961,1106 and 2187 seconds.
- For ADU size > 2KB bandwidth and loss for wait-time=1ms and wait-time=2ms is almost identical
  - With 2KB minimum transmission time with 1ms and 2ms wait is 524s and 1048s respectively
  - With wait-time = 0ms taken to complete experiment = 976s
- With a wait-time bandwidth increases with ADU size
  - Delay causes network to remain idle but idle time reduces with ADU size

Observations (contd)

- Large losses seen in 1:k configuration
  - Trends seen are similar in 1:2, 1:4, 1:5 configurations
- Loss has a high variance
- To investigate losses further we used routing at the operating system level and 2 network cards per computer

Application and Operating system level routing results of UDP for ADU size = 1KB

Experiment	Single Channel		Multiple Channels	
	Bandwidth (Mbps)	Loss rate (%)	Bandwidth (Mbps)	Loss rate (%)
A 3 node experimental design				
2:1-hop	12.59 ± 0.79 (6.29%)	0.32 ± 0.17 (52.82%)	12.43 ± 0.84 (6.77%)	0.49 ± 0.5 (108.45%)
1:2-hop, 1 card, App routing	11.74 ± 0.13 (1.13%)	1.77 ± 1.55 (87.65%)	11.29 ± 0.16 (1.41%)	5.51 ± 3.22 (58.41%)
1:2-hop, 2 cards, App routing	18.07 ± 0.17 (0.95%)	1.22 ± 0.58 (47.82%)	11.17 ± 0.23 (2.07%)	3.32 ± 1.91 (57.39%)
1:2-hop, 1 card, OS routing	10.57 ± 0.55 (5.19%)	10.48 ± 7.56 (72.11%)	10.59 ± 0.23 (2.21%)	5.49 ± 4.24 (77.28%)
1:2-hop, 2 cards, OS routing	15.90 ± 0.93 (5.85%)	0.18 ± 0.22 (119.62%)	11.73 ± 0.17 (1.46%)	1.0 ± 1.41 (141.23%)
A 4 node experimental design				
3:1-hop	8.44 ± 0.4 (4.69%)	0.36 ± 0.3 (84.37%)	8.39 ± 0.55 (6.55%)	0.36 ± 0.16 (44.07%)
1:3-hop, 1 card, App routing	7.73 ± 0.20 (2.63%)	5.14 ± 3.88 (75.42%)	7.18 ± 0.14 (1.89%)	16.00 ± 2.92 (18.23%)
1:3-hop, 2 cards, App routing	7.31 ± 0.17 (2.3%)	16.86 ± 4.29 (25.42%)	6.01 ± 0.5 (8.26%)	33.26 ± 8.1 (24.36%)
1:3-hop, 1 card, OS routing	5.93 ± 0.13 (2.23%)	25.22 ± 4.86 (19.28%)	5.98 ± 0.52 (8.77%)	24.82 ± 8.59 (34.59%)
1:3-hop, 2 cards, OS routing	6.64 ± 0.19 (2.86%)	25.36 ± 2.79 (11%)	7.35 ± 0.39 (5.35%)	15.22 ± 6.41 (42.11%)