Performance Anomaly of 802.11b

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Outline

- 802.11b Basics
- The Anomaly
- Simulation Verification
- Experimental Verification

Abstract

When one host on a IEEE 802.11b network is forced to transmit at less than the maximum bit rate of 11 Mbps then all other hosts are forced to also transmit at this lower rate

Behind the Problem

- Access method – Distributed Coordination Function (DCF)
  - Uses CSMA/CA
- Low quality radio transmissions will result in a decrease in bit rate
  - 5.5, 2, or 1 Mbps
- Performance anomaly caused
  - Privileges low speed hosts, penalize high speed hosts

DFC Performance

- Overall transmission time

  $T = t_{tr} + t_{ov}$

- Each packet has constant overhead time

  $t_{ov} = DIFS + t_{pr} + SIFS + t_{pr} + t_{ack}$

  DIFS = Time wait between senses of channel
  SIFS = Period access point waits to send ACK
  t_{pr} = PLPC Transmission time
  t_{ack} = MAC acknowledgement transmission time

Throughput Efficiency

- Equation to determine useful throughput
  - $P = (T_{tr}/T) * (1500/1534)$

- Result: 70% useful throughput
- Thus 11 Mbps has 7.74 Mbps useful data

Multiple Hosts

- Increases overall transmission time
- Decreases the proportion of useful throughput

$$P(N) = t_{tr}/T(N)$$

- T(N) = Overall transmission time due to multiple hosts

The Anomaly

- Since the slow hosts need more time to transmit the same data, all the hosts slow down to roughly the same speed
  - The slow host holds the channel for a proportionately longer amount of time!
- This anomaly occurs regardless of how many fast hosts are present
- Collisions and contention affect all hosts proportionally

Why the Anomaly Exists

- sd: Amount of data to be transmitted
- Time to transmit data = sd/(data rate)
- Over the long term, CSMA/CA provides each host with an equal probability of accessing the channel
  - Therefore, all hosts will have the opportunity to transmit the same amount of data
  - Fast hosts have a lower channel utilization

Further Discussions

- See Heuse, et. al. page 3 for the full mathematics.
  - Contention periods and collisions are accounted for.
- UDP is expected to obey the mathematical models as generally no ACK packets are sent.
- TCP behaves as though there is 2 slow hosts, but can be shown mathematically to behave similarly.
  - The second slow host is the ACK packets returning to it.
  - TCP also incorporates congestion control, so a host may stop transmitting when its data rate is substantially below the 1Mbps minimum.

Verification

- A simulation was conducted to verify the mathematical results.
  - Simulator is targeting a worst-case scenario: The channel is always busy the first time a node wants to transmit.
  - All nodes configured to use 802.11b with exponential backoff
- Simulation showed the mathematics are good, though not perfect
  - The error: Other factors, besides the proportion of collisions, affect the average time spent in collisions

Proportion of Collisions

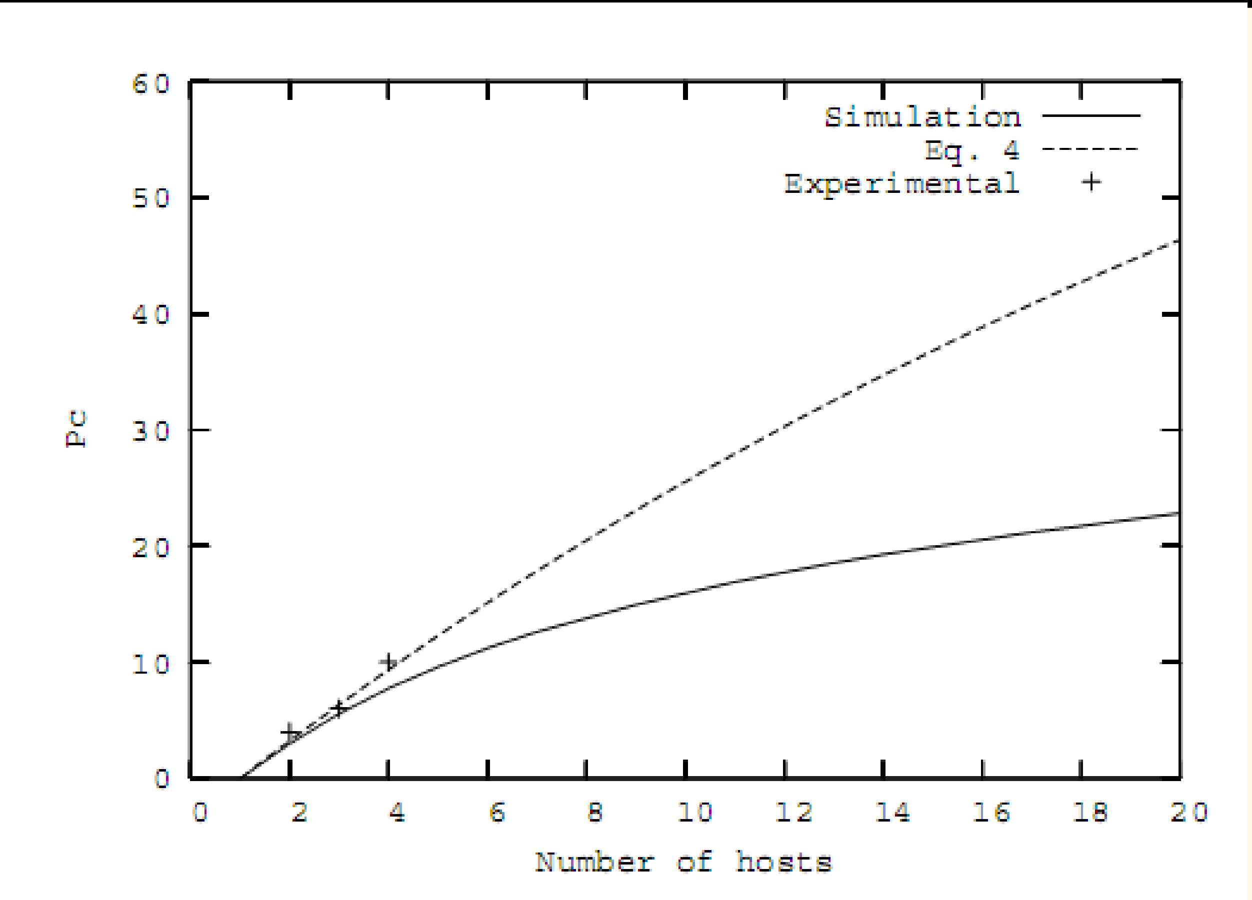

Figure 3

- The mathematics assume a greater number of collisions than the simulation shows, particularly for very large numbers of hosts

Throughput

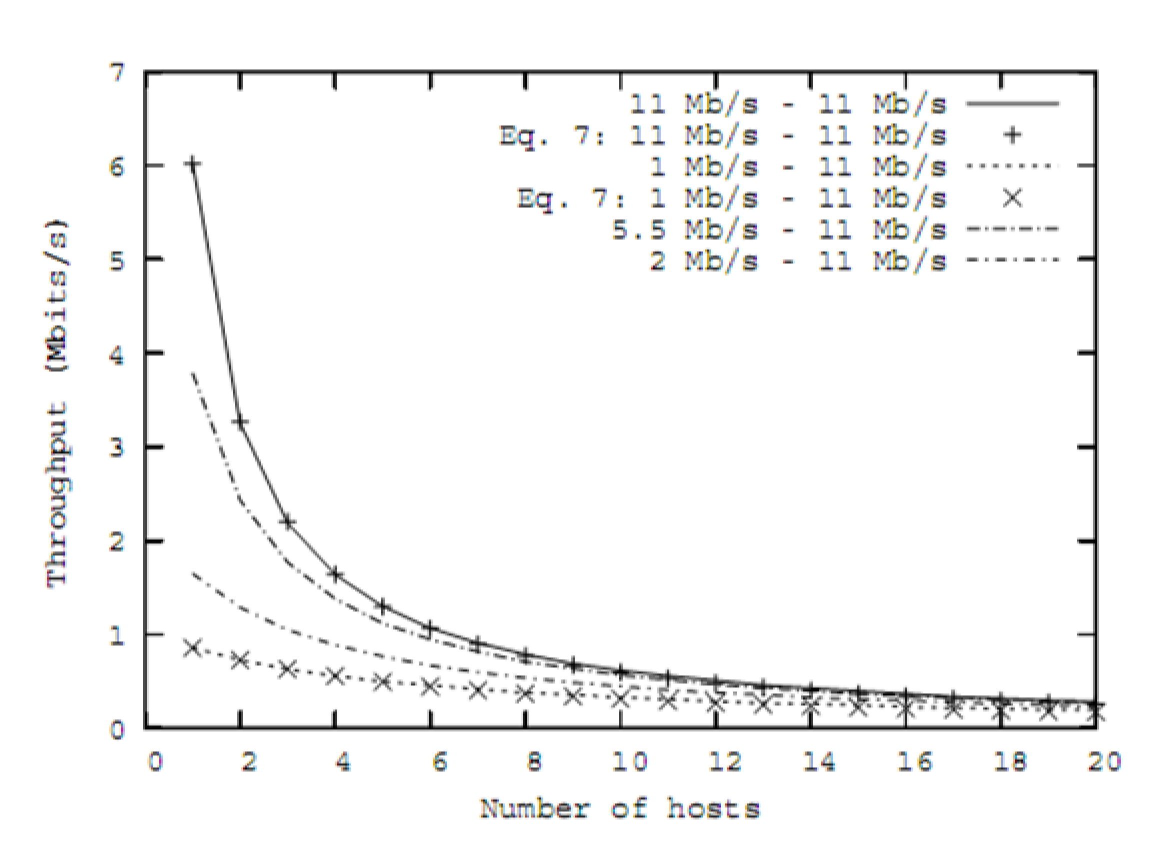

Figure 4

- The performance anomaly is observed. Note that no configuration gets acceptable throughput for very large numbers of hosts. This triggers TCP congestion control algorithms and may force hosts to stop transmitting.

Experimental Verification

- Measure Throughput
- Four notebooks(Marie, Milos, Kea, Bali)
- RedHat 7.3, 802.11b cards
- Access Point is not the bottleneck

Tool Used

- Netperf:: generates TCP or UDP traffic and measures throughput
- Tcpperf:: generates TCP traffic and measures the throughput
- Udpperf:: generates UDP traffic and measures the throughput
- Measurements done with netperf, compared to results of tcpperf and udpperf

Test 1: No Mobility

- All hosts near access point
- Force one to use degraded bit rate
- One test run with TCP, the other with UDP
- Using 2 hosts, 3 hosts, and 4 hosts, at bit rates 11, 5.5, 2, and 1 for Bali (slow host)
- For TCP, hosts are competing with the access point, which is sending TCP ACKs on behalf of the destination
- For UDP, hosts compete with each other

Bit rate of Bali	Bali	Marie	Milos	Kea	Eq. 10	observed P_c	Eq. 4	Figure No.
11	5.08	-	-	-	7.21	4%	3.1%	-
5.5	3.37	-	-	-	4.12	4%	3.1%	-
2	1.55	-	-	-	1.65	4%	3.1%	-
1	0.83	-	-	-	0.83	4%	3.1%	-
11	2.52	2.48	-	-	3.48	8%	6.2%	5
5.5	2.04	1.96	-	-	2.51	8%	6.2%	5
2	1.12	1.11	-	-	1.27	8%	6.2%	5
1	0.67	0.63	-	-	0.70	8%	6.2%	5
11	1.65	1.54	1.52	-	2.24	8%	9.1%	7
5.5	1.36	1.39	1.47	-	1.77	8%	9.1%	7
2	0.83	0.89	0.95	-	1.02	8%	9.1%	7
1	0.57	0.52	0.64	-	0.62	8%	9.1%	7
11	1.15	0.92	1.21	1.02	1.63	9%	12.0%	9
5.5	1.16	0.83	1.11	0.83	1.35	9%	12.0%	9
2	0.74	0.41	0.65	0.55	0.85	9%	12.0%	9
1	0.56	0.32	0.41	0.27	0.53	9%	12.0%	9

TABLE I

MEASURED THROUGHPUTS IN MB/S FOR A VARYING NUMBER OF HOST, TCP TRAFFIC

Bit rate of Bali	Bali	Marie	Milos	Kea	Eq. 7	observed P_c	Eq. 4	Figure No.
11	3.09	3.36	-	-	3.26	4%	3.1%	6
5.5	2.38	2.42	-	-	2.44	4%	3.1%	6
2	1.30	1.26	-	-	1.29	4%	3.1%	6
1	0.76	0.76	-	-	0.73	4%	3.1%	6
11	2.26	2.0	2.23	-	2.20	6%	6.2%	8
5.5	2.01	1.56	1.89	-	1.77	6%	6.2%	8
2	1.17	0.90	1.16	-	1.06	6%	6.2%	8
1	0.74	0.58	0.69	-	0.63	6%	6.2%	8
11	1.71	1.41	1.8	1.41	1.64	10%	9.1%	10
5.5	1.66	1.16	1.59	1.19	1.38	10%	9.1%	10
2	0.96	0.84	0.81	0.72	0.89	10%	9.1%	10
1	0.69	0.47	0.63	0.49	0.56	10%	9.1%	10

TABLE II

MEASURED THROUGHPUTS IN MB/S FOR A VARYING NUMBER OF HOSTS, UDP TRAFFIC

Test 1: Discussion

- Measured values correspond well to analytical values (better for UDP)
- TCP traffic pattern more complex, due to Access Point competing with hosts (TCP ACKs), dependence on overall RTT and bottleneck link
- Pattern can become correlated with data segment traffic, since TCP ACK is sent upon arrival of data segment

Test 2: Mobile Hosts

- Bali (slow host) is a mobile host, bit rate automatically adapts to varying transmission conditions
- Other hosts located near access point with good conditions

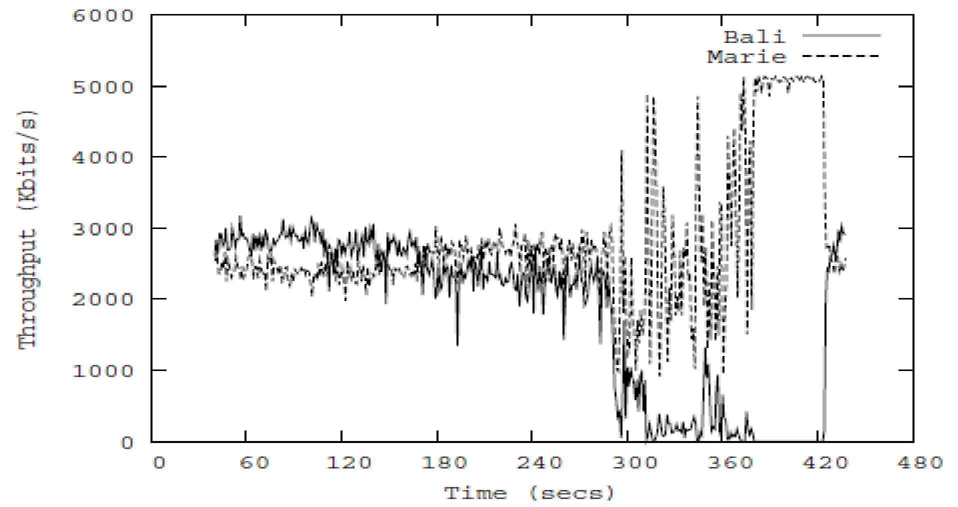

Fig. 11. Measured throughput in Mb/s for two hosts (one mobile), TCP traffic

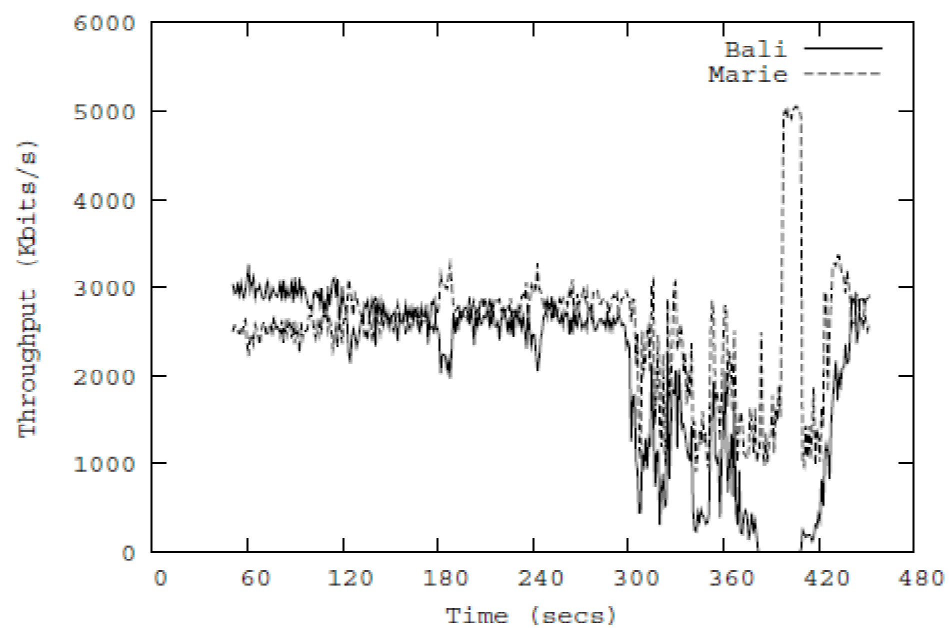

Fig. 13. Measured throughput in Mb/s for two hosts (one mobile), UDP traffic

Test 2: Discussion

- For TCP, when transmission conditions are bad (300-380) the throughput of Marie increases. This is due to Bali limiting its sending rate in adverse conditions
- Note, at 380, Bali stops sending completely even if its bit rate is not 0, and Marie gains almost all available throughput
- UDP shows similar results, although Marie's gains during adverse conditions are not quite as large, unless Bali stops sending

Related Work

- There have been many other papers studying 802.11 WLANs, but no prior papers use varying bit rates for hosts
- Most other papers use simulations, rather than analysis, which can give complex results
- Short-term unfairness of CSMA-based medium access protocols is also a topic of interest

Conclusions

- Throughput much lower than nominal bit rate
- Proportion of useful throughput depends strongly on number of hosts
- If a host degrades its bit rate due to bad transmission conditions, other hosts throughputs will drop roughly to the rate of the slower host
- However, in real conditions using TCP, the slow host will be subject to packet loss, limiting its sending rate, allowing other hosts to take advantage of the unused capacity