802.11 THROUGHPUT

comp40660 Assignment 1, February 2020

This assignment is worth 18% of the overall grade

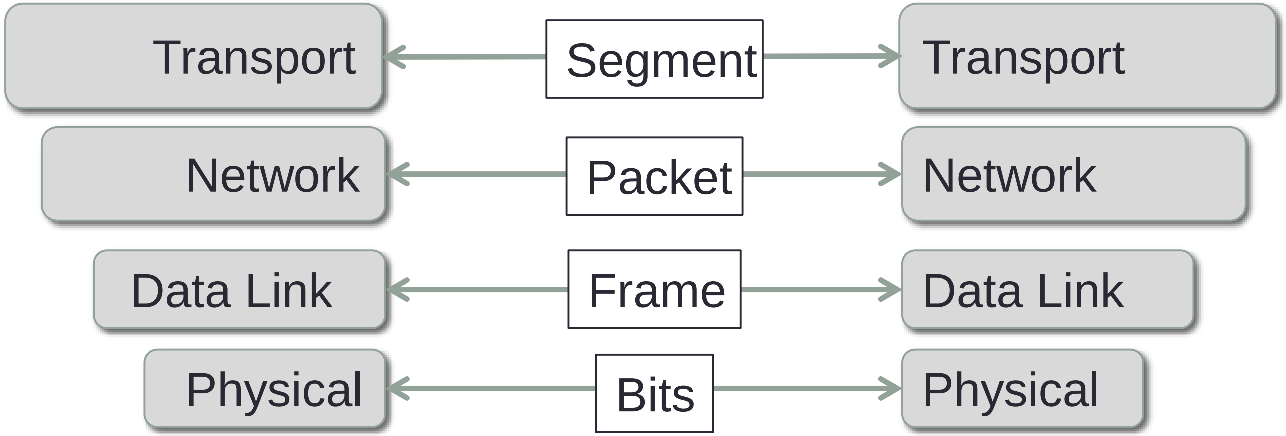
Motivation

- Build a simple model of 802.11 frame exchange for TCP and UDP, using OFDM of 802.11a and 802.11g
- The model will approximate the ***actual throughput*** of the network
- **RTS/CTS mechanism is enabled**
- **No contention**

- Demonstration of the calculation for 802.11a – UDP case; work on TCP case in lab.
- Assignment will be to modify for the .11g/n/ac/ax case for both TCP and UDP.

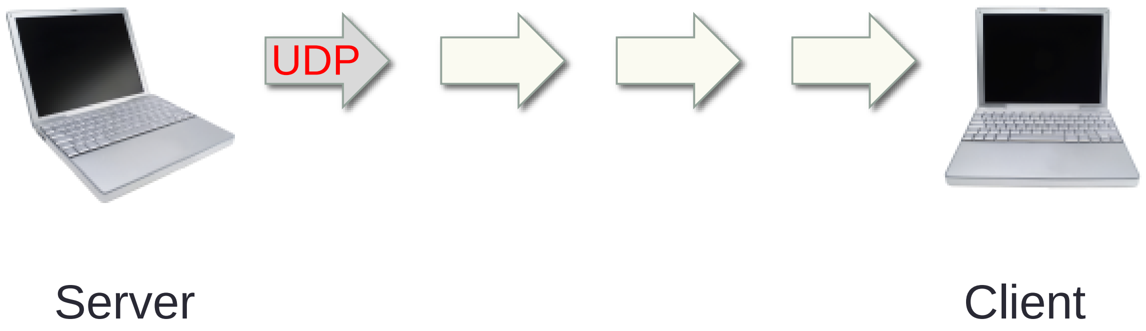
802.11 Model

- Basic transactional model – 2 different transaction types, namely UDP and TCP.
- Any 802.11 transmission of data (from higher layer) requires an acknowledgement (ACK) by the .11 MAC.
- Each TCP / UDP packet is encapsulated in a single 802.11 frame.



802.11 Frame Exchange

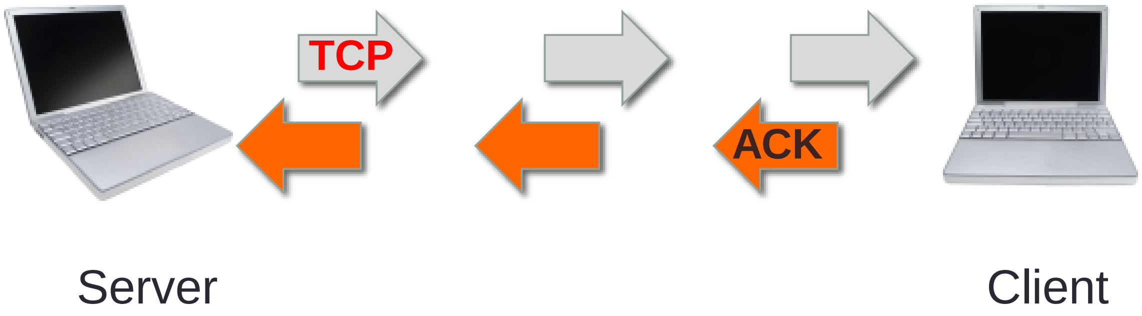
UDP Case



- No guarantee of delivery
- Suitable for real-time applications such as VoIP, VoD
- UDP data encapsulated into 802.11 frame and transmitted. Receiving station transmits 802.11 ACK.

802.11 Frame Exchange

TCP Case

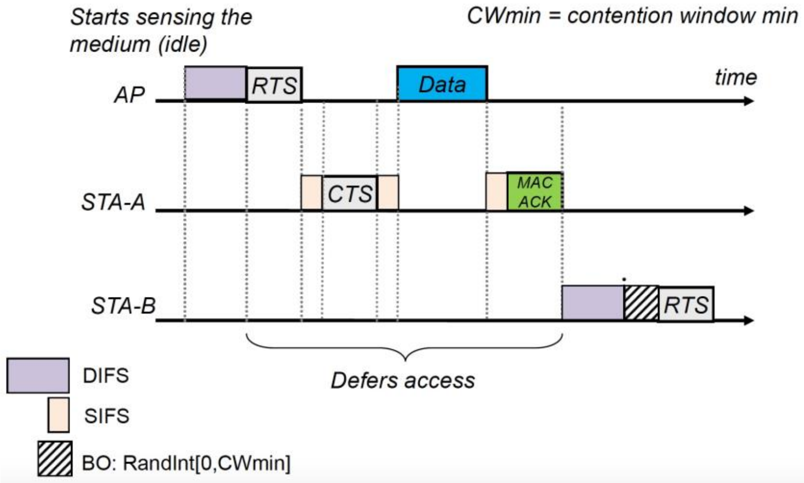


- Reliable delivery service guaranteeing that all bytes are received and in correct order through TCP ACKs

- *How is this different from the UDP case?*

Data Transmission

- 802.11 uses different inter-frame spaces:
  - SIFS (Short Interframe Space)
    - High-priority transmissions can begin once SIFS has elapsed
    - ACK, RTS, CTS
  - DIFS (DCF Interframe Space)
    - Minimum idle time for contention-based services
    - Stations can have access to the medium if it has been free for a period longer than DIFS



Packet Headers

- 1500 bytes packet (TCP/UDP) is encapsulated:
  - MAC header = 34 bytes
  - SNAP LLC header = 8 bytes
    - 3 bytes LLC (logical link control) header
    - 5 bytes SNAP (sub-network access protocol) header

=> Total size = 1542 bytes

802.11a

- Amendment to the IEEE 802.11 specification
- 1999
- 5Ghz band
- Maximum data rate: 54 Mbps
- OFDM (Orthogonal Frequency Division Multiplexing)
- Available data rates: 54, 48, 36, 24, 18, 12, 9, 6 Mbps

802.11g

- 2003
- 2.4Ghz (same as 802.11b)
- Maximum data rate: 54 Mbps
- OFDM (copied from 802.11a)
- Available data rates: 54, 48, 36, 24, 18, 12, 9, 6 Mbps

802.11n

- 2009
- Both 2.4Ghz and 5Ghz
- Maximum data rate (20 MHz, 1 Spatial Streams): 72.2 Mbps
- Maximum optional data rate (40 MHz, 4 Spatial Streams): 600 Mbps
- OFDM with HT (High Throughput)
- Available data rates: 72.2, 65, 57.8, 43.3, 28.9, 21.7, 14.4, 7.2 Mbps

802.11ac

- 2013
- 5GHz band
- Maximum data rate (20MHz, 1 Spatial Stream): 96.3 Mbps
- Maximum wave 1 optional data rate (80MHz, 3 Spatial Streams): 1300 Mbps
- Maximum wave 2 optional data rate (160MHz, 8 Spatial Streams): 6933.6 Mbps
- OFDM with VHT (Very High Throughput)
- Available data rates: 96.3, 86.7, 72.2, 65, 57.8, 43.3, 28.9, 21.7, 14.4, 7.2 Mbps

802.11ax

- 2019
- Both 5Ghz and 2.4GHz band
- Maximum data rate (20MHz, 1 Spatial Stream): 143.4 Mbps
- Maximum data rate (160MHz, 8 Spatial Streams): 9607.8 Mbps
- Introduce Modulation and Coding Sets (MCS) with 1024-QAM
- Available data rates: 143.4, 129.0, 114.7, 103.2, 86.0, 77.4, 68.8, 51.6, 34.4, 25.8, 17.2, 8.6 Mbps

Example Calculation - UDP

- Case: **802.11a @ 54Mbps**

SIFS	16 µs
Slot Time	9 µs
DIFS=(2*Slot Time) + SIFS	34 µs

- A single data frame exchange:
  1) Wait 1 DIFS
  2) Send RTS
  3) Wait 1 SIFS
  4) Send CTS
  5) Wait 1 SIFS
  6) Transmit data
  7) Wait 1 SIFS to send ACK
  8) Send ACK

Example Calculation - UDP (cont.)

- Data is divided into symbols before transmission.
- Different amount of bits per symbol for each data rate
  - See later slides of this set
- @54Mbps: 1 symbol encodes 216 bits
- Each symbol takes **4µs** to transmit (11a/g only)
- Using OFDM each frame has 6 bits (tail) appended

⇒1542*8+6 = 12,342 bits

⇒12,342 bits / 216 bits = 58 symbols

=>**232 µs to transmit the data frame**

- RTS is a 20 byte long Control Frame and CTS is a 14 byte long Control Frame ➔ (20*8+6)/216 = 1 symbol and (14*8 + 6)/216 = 1 symbol for RTS and CTS respectively ➔ **4 µs** transmission for each frame.

Example Calculation – UDP (cont.)

- 802.11 ACK: 1 symbol (only 14 bytes) => **4 μs**
- 20μs (Preamble) sync header is transmitted before each frame

DIFS + Preamble + RTS + SIFS + Preamble + CTS + SIFS + Preamble + Data + SIFS + Preamble + ACK =

34μs+ 20μs + 4μs +16μs + 20μs + 4μs + 16μs + 20μs + 232μs + 16μs + 20μs + 4μs = 406μs

So: time to send 1500 bytes (including IP and UDP headers) : 406 μs

Q: What is the throughput [Mbps] ?

In the practical: Do the same for TCP.

Assignment

- Calculate the ***actual throughput*** for 802.11a/g/n/ac/ax and for all available data rates, for both UDP and TCP.
- Your program should accept 3 arguments:
  - Protocol (UDP/TCP)
  - Standard (802.11a, 802.11g, 802.11n, 802.11ac_w1, 802.11ac_w2, 802.11ax)
  - Available data rate for each standard (e.g. 802.11a/g: 54, 48, 36,…)
  - **Note:** For standard .11n/ac, consider SDur = 3.6μs **only**
- Your program must return for each scenario:
  - The actual throughput [Mbps] in the **normal case** (20MHz and 1SS) AND the **best case**:
    - 40MHz/4SS for .11n
    - 80MHz/3SS for .11ac_w1 ; 160MHz/8SS for .11ac_w2
    - 160MHz/8SS for .11ax
  - The amount of time needed to transfer 10 GB of data.

Assignment (cont.)

- Languages: C/C++, Java, Python
- Code must compile & run with no errors and be appropriately commented throughout.
- A “Readme” file is required – detailing usage, and explaining:
  - Why there is a difference between the **actual throughput** and the **advertised data rate**.
  - 802.11 performance improves after each release. Briefly discuss the trade-offs involved in such improvements.

Assignment (cont.)

- Submission: Friday 28th February 2020, 23:59 **sharp!!**
- .zip file with source code + readme file
- Submit .zip through comp40660 page on CS Moodle

- This is an individual assignment: no group submissions will be accepted and there should be **no collaboration** on the assignment.
- Anti-plagiarism tools and techniques will be used to check your submission.

Notes

- The differences between .11a and .11g that you have to take into account:
  - For 802.11g, SIFS = 10 μs
  - Signal Extension appended to every 802.11g frame = 6 μs
  - All other parameters, headers, tails etc. remain the same as .11a

Notes (cont.)

- Specificities of .11n and .11ac/ax that you have to take into account:
  - 11n/ac MAC header = 40 bytes
  - 802.11n/ac/ax SIFS = 16 μs
  - Symbol duration of 802.11ax: 13.6μs
  - Symbol duration of 802.11n/ac: 3.6μs (short symbol duration)
  - The preamble in .11n is 46 μs (using 4 Spatial Streams)
  - The preamble in .11ac_w1 is 56.8 μs (using 3 Spatial Streams)
  - The preamble in .11ac_w2/ax is 92.8 μs (using 8 Spatial Streams)
  - All other parameters, headers, tails etc. remain the same as .11a/g

Notes (cont.)

- 802.11n with 600 Mbps rate
  - Maximum 4 Spatial Streams
  - Maximum 40 MHz channels
- 802.11ac wave1 (802.11ac_w1) with 1300 Mbps rate
  - Maximum 3 Spatial Streams
  - Maximum 80 MHz channels
- 802.11ac wave2 (802.11ac_w2) with 6933.6 Mbps rate
  - Maximum 8 Spatial Streams
  - Maximum 160 MHz channels
- 802.11ax with 9608 Mbps rate
  - Maximum 8 Spatial Streams
  - Maximum 160 MHz channels

802.11a/g Encoding Block Sizes

- Symbol duration (**SDur**)
- Bits per symbol (**NBits**)
- Coding Rate (**CRate**)
- Number of sub-channels (**NChan**)

Data Rate = (1/SDur)*(NBits*CRate)*NChan

Data bits per OFDM symbol = NBits * CRate * NChan

Modulation	NBits	CRate	NChan	SDur (micro sec)	Data Rate (Mbps)
BPSK	1	1/2	48	4	6
BPSK	1	3/4	48	4	9
QPSK	2	1/2	48	4	12
QPSK	2	3/4	48	4	18
16-QAM	4	1/2	48	4	24
16-QAM	4	3/4	48	4	36
64-QAM	6	2/3	48	4	48
64-QAM	6	3/4	48	4	54

11a/11g Data Rates

802.11n/ac Encoding Block Sizes

802.11n/ac supports both Symbol duration 4μs (for back compatibility with 802.11a/g) and 3.6μs (short symbol duration) – you should ONLY consider SDur = 3.6μs

Modulation	NBits	CRate	NChan	Data Rate (Mbps) SDur=4us	Data Rate (Mbps) SDur=3.6us
BPSK	1	1/2	52	6.5	7.2
QPSK	2	1/2	52	13	14.4
QPSK	2	3/4	52	19.5	21.7
16-QAM	4	1/2	52	26	28.9
16-QAM	4	3/4	52	39	43.3
64-QAM	6	2/3	52	52	57.8
64-QAM	6	3/4	52	58.5	65
64-QAM	6	5/6	52	65	72.2
256-QAM (11ac)	8	3/4	52	78	86.7
256-QAM (11ac)	8	5/6	52	86.7	96.3

11n and 11ac Data Rates (20 MHz, 1 SS)

802.11n/ac Maximum Data Rates

- Number of Spatial Streams (**Nss**): matching number of antenna pairs at the sender and the receiver ends

Channel Width	NBits	CRate	NChan	Data Rate (Mbps) SDur=3.6us (Nss=1)	11n Max Rate (Nss=4)
20 Mhz	6	5/6	52	72.2	288.8
40 Mhz	6	5/6	108	150	600

11n Max Data Rates

Channel Width	NBits	CRate	NChan	Data Rate (Mbps) SDur=3.6us (Nss=1)	11ac Max Rate (Nss=8)
20 Mhz	8	5/6	52	96.3	770.4
40 Mhz	8	5/6	108	200	1600
80 Mhz	8	5/6	234	433.3	3466.4
160 Mhz	8	5/6	468	866.7	6933.6

11ac Max Data Rates

802.11ax Maximum Data rates

- 01 Spatial Stream（**Nss**）:

	Modulation	NBits	CRate	NChan	Symbol duration (us)	Data Rate (Mbps)
20MHz	BPSK	1	1/2	234	13.6	8.6
	QPSK	2	1/2	234	13.6	17.2
	QPSK	2	3/4	234	13.6	25.8
	16-QAM	4	1/2	234	13.6	34.4
	16-QAM	4	3/4	234	13.6	51.6
	64-QAM	6	2/3	234	13.6	68.8
	64-QAM	6	3/4	234	13.6	77.4
	64-QAM	6	5/6	234	13.6	86.0
	256-QAM	8	3/4	234	13.6	103.2
	256-QAM	8	5/6	234	13.6	114.7
	1024-QAM	10	3/4	234	13.6	129
	1024-QAM	10	5/6	234	13.6	143.4

802.11ax Maximum Data rates

- 08 Spatial Streams (**Nss**):

	Modulation	NBits	CRate	NChan	Symbol duration (us)	Data Rate (Mbps)
160MHz	BPSK	1	1/2	1960	13.6	576.5
	QPSK	2	1/2	1960	13.6	1152.9
	QPSK	2	3/4	1960	13.6	1729.4
	16-QAM	4	1/2	1960	13.6	2305.9
	16-QAM	4	3/4	1960	13.6	3458.8
	64-QAM	6	2/3	1960	13.6	4611.8
	64-QAM	6	3/4	1960	13.6	5188.2
	64-QAM	6	5/6	1960	13.6	5764.7
	256-QAM	8	3/4	1960	13.6	6917.6
	256-QAM	8	5/6	1960	13.6	7686.3
	1024-QAM	10	3/4	1960	13.6	8647.1
	1024-QAM	10	5/6	1960	13.6	9607.8