Question 1

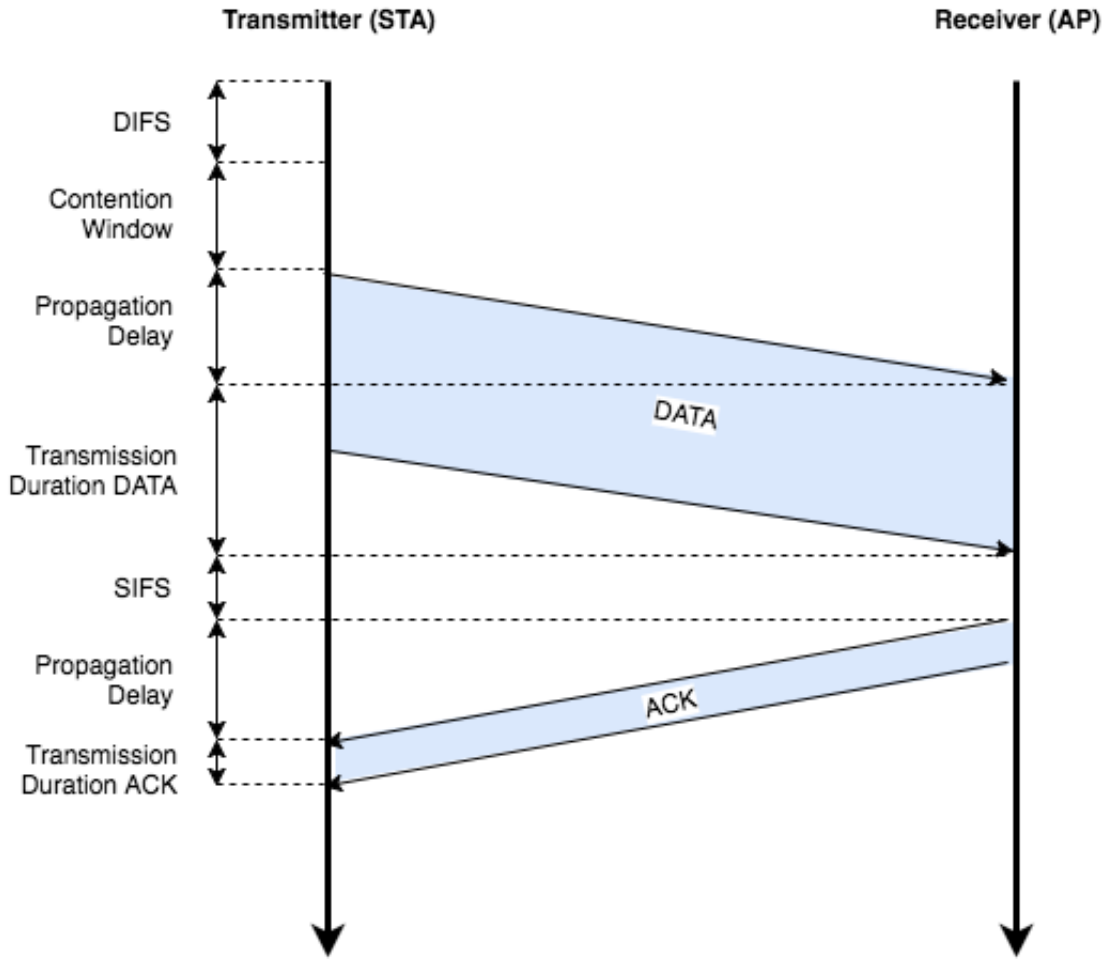
a) Data throughput with and without RTS/CTS

The following figure gives an overview of the data flow from a STA to an AP without using RTS/CLS mechanism. A few general assumptions were made:

- no loss or collsion during transmission
- no interference
- no hidden or exposed terminals
- no fragmentation

Without RTS/CTS

Flow diagram:



Defintions:

- DIFS time: $t_{DIFS} = 34\ \mu s$
- Slot Time: $t_{ST} = 9\ \mu s$
- Maximum backoff slots: $b_{max} = 15$
- Random backoff: $RB = \{n : \text{n is an integer; and } 1 \leq n \leq b_{max}\}$
- Expected backoff: $b_{expt} = \frac{b_{max}+1}{2} = 8$
- Contention window: $t_{CW} = b_{expt} \cdot t_{ST} = 72\ \mu s$
- Propagation delay: $t_{pd} = 1\ \mu s$
- SIFS time: $t_{SIFS} = 16\ \mu s$
- PHY layer overhead = $t_{phy} = 20\ \mu s$
- OFDM symbol duration = $t_{ODFM} = 4\ \mu s$
- MAC layer data payload = $d_{mpay} = 1452\ B$
- MAC header size = $d_{mhead} = 28\ B$
- MAC ack size = $d_{mack} = 14\ B$
- PHY Layer transmission rate: $r = 54\ \text{Mbps} = 7.077888\ \frac{B}{\mu s}$
- Transmission duration data: $t_{data} = t_{phy} + t_{ODFM} + \frac{d_{mhead}+d_{mpay}}{r} \approx 243\ \mu s$

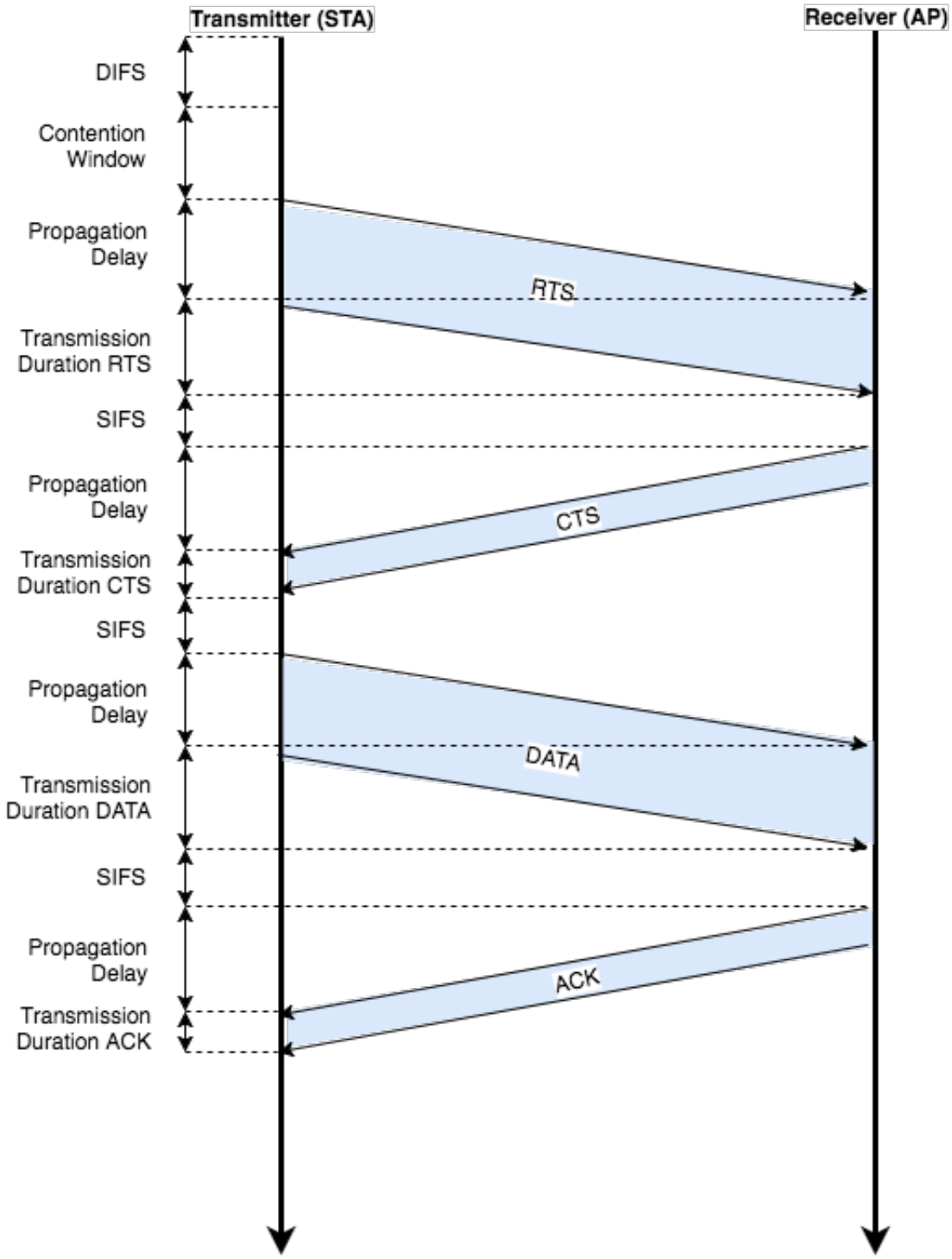
- Transmission duration ack: $t_{ack} = t_{phy} + t_{ODFM} + \frac{d_{mhead} + d_{mack}}{r} \approx 30\ \mu s$
- Total Time: $t_{total} = t_{DIFS} + t_{CW} + 2 \cdot t_{pd} + t_{data} + t_{SIFS} + t_{ack} \approx 397\ \mu s$

Actual Transmission Rate:

$$r_{act} = \frac{dmpay}{t_{total}} \approx \frac{1452\ B}{397\ \mu s} \approx \frac{1.11 \cdot 10^{-2}\ Mbit}{3.97 \cdot 10^{-4}\ s} \approx 28.0\ \text{Mbps}$$

With RTS/CTS

Flow diagram:



Additional Definitions to the previous:

- CTS size: $d_{cts} = 14\ B$
- RTS size: $d_{rts} = 20\ B$
- Transmission duration CTS: $t_{cts} = t_{phy} + t_{ODFM} + \frac{d_{mhead} + d_{cts}}{r} \approx 30\ \mu s$
- Transmission duration CTS: $t_{cts} = t_{phy} + t_{ODFM} + \frac{d_{mhead} + d_{rts}}{r} \approx 31\ \mu s$
- Total Time: $t_{total} = t_{DIFS} + t_{CW} + 4 \cdot t_{pd} + t_{rts} + t_{cts} + t_{data} + 3 \cdot t_{SIFS} + t_{ack} \approx 493\ \mu s$

Actual Transmission Rate:

$$r_{act} = \frac{dmpay}{t_{total}} \approx \frac{1452\ B}{493\ \mu s} \approx \frac{1.11 \cdot 10^{-2}\ Mbit}{4.93 \cdot 10^{-4}\ s} \approx 22.5\ \text{Mbps}$$

Conclusion

With RTS/CTS disabled there is a theoretical transmission rate of about 28.0 Mbps. With RTS/CTS enabled it is about 22.5 Mbps. That is 20 % less throughput. The reason are the additional frames for the handshake and the addtional propagation delays and SIFS.

b) Data throughput with and without RTS/CTS

Terminology:

- N6 = Node 6
- N15 = Node 15
- ST = Stepping Stone

Setup

- N6 is set as the AP?

  N6: `iw wlan0 info | grep type`

  Output: `type AP`

- Get N6 IP address N6: `ifconfig wlan0 | grep "inet addr"`

  Output: `inet addr:172.17.5.10 Bcast:172.17.5.255 Mask:255.255.255.0`

- N15 is set as client and connected to AP of N6

  N15: `ping -I wlan0 172.17.5.10`

  Output (trunc): `64 bytes from 172.17.5.10: seq=0 ttl=64 time=0.898 ms`

- Enable RTS/CTS on N15:

N15: `iw phy phy0 set rts 100`

- Set bitrates on both interfaces:

  N15: `iw wlan0 set bitrates legacy-2.4 54.0` N6: `iw wlan0 set bitrates legacy-2.4 54.0`

- Set tx power on client

  N15: `iw wlan0 set txpower fixed 30.0`

- Review settings on client

  N15: `iwinfo`

  Output:

```
wlan0 ESSID: "group06_ap"
      Access Point: 00:1B:B1:07:DB:9B
      Mode: Client  Channel: 11 (2.462 GHz)
      Tx-Power: 30 dBm  Link Quality: 70/70
      Signal: -38 dBm  Noise: -96 dBm
      Bit Rate: 54.0 MBit/s
      Encryption: none
      Type: nl80211  HW Mode(s): 802.11abg
      Hardware: 168C:0013 185F:1012 [Generic MAC80211]
      TX power offset: unknown
      Frequency offset: unknown
      Supports VAPs: yes  PHY name: phy0
```

- Start iperf server

  N6: `iperf -s -u`

- Start client with 1400 B UDP datagrams CTS/RTS Threshold 100 B

```
for i in `seq 10`; do
    iperf -c 172.17.5.10 -u -b 54M -t 30 -l 1400
    sleep 2
done
```

- Start client with 200 B UDP datagrams CTS/RTS Threshold 100 B

```
for i in `seq 10`; do
    iperf -c 172.17.5.10 -u -b 54M -t 30 -l 200
    sleep 2
done
```

- disable CTS/RTS

  N15: `iw phy phy0 set rts off`

- Start client with 1400 B UDP datagrams CTS/RTS off

```
for i in `seq 10`; do
    iperf -c 172.17.5.10 -u -b 54M -t 30 -l 1400
    sleep 2
done
```

- Start client with 200 B UDP datagrams CTS/RTS off

```
for i in `seq 10`; do
    iperf -c 172.17.5.10 -u -b 54M -t 30 -l 200
    sleep 2
done
```

Boxplots