IEEE WLANs in 5 vs 6 GHz: A Comparative Study

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6 GHz Unlicensed Bands

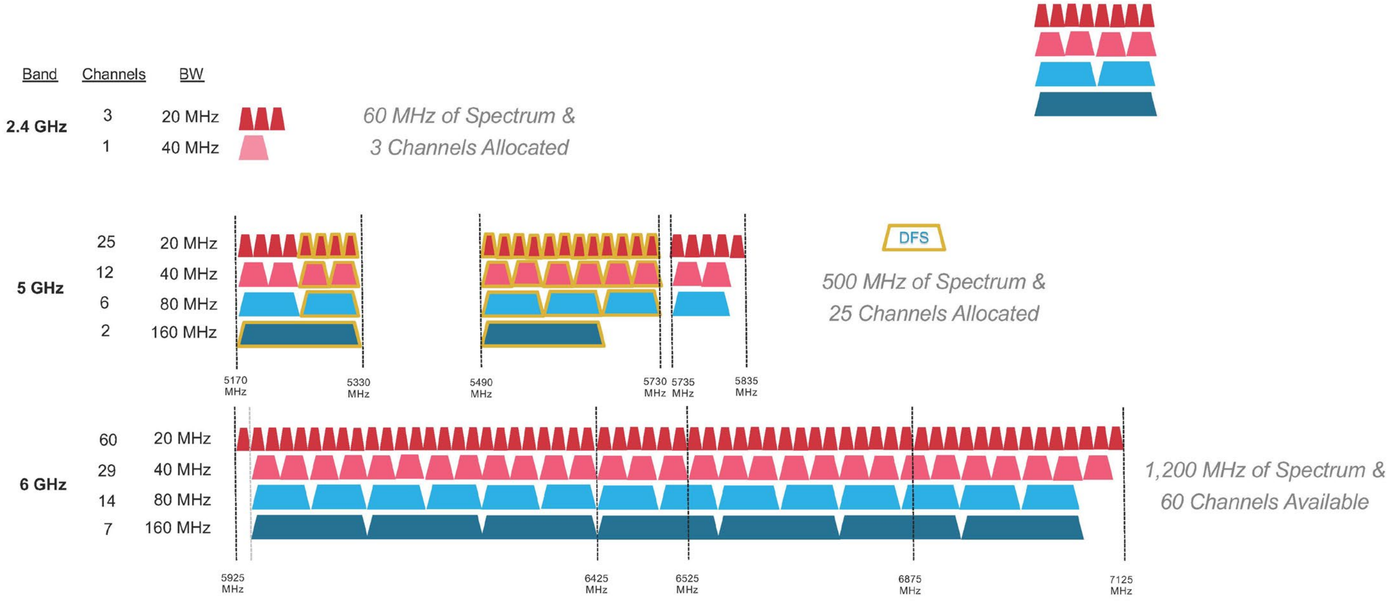


Fig. Wi-Fi Frequency bands [1]

Main benefits

- More Spectrum

Up to 1.2 GHz more Wi-Fi spectrum in 6 GHz band

- Low latency

Less channel contention

- High Capacity

No legacy device operation in 6 GHz

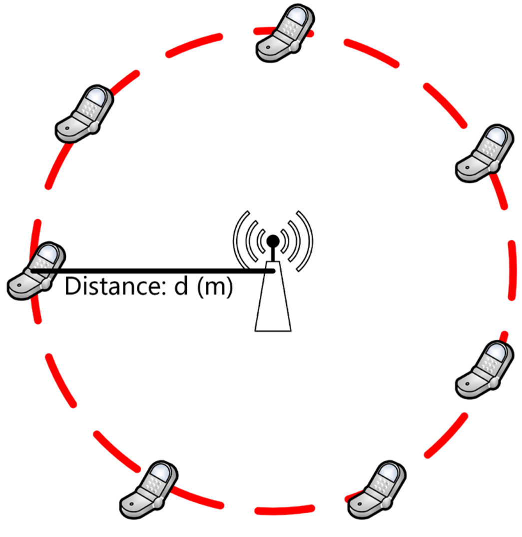
[1] Broadcom Wi-Fi 6E, online: https://www.broadcom.com/info/wifi6e

Power Rules

Device type	Frequency	Max power for bandwidth			
		20 MHz	40 MHz	80 MHz	160 MHz
Low power AP Max 30 dBm (1 W)	6 GHz	18.01 dBm (63.2 mW)	21.02 dBm (126.4 mW)	24.03 dBm (252.8 mW)	27.04 dBm (505.6 mW)
	5 GHz	30 dBm	30 dBm	30 dBm	30 dBm
Low power STA Max 24 dBm (250 mW)	6 GHz	12.04 dBm (16 mW)	15.05 dBm (32 mW)	18.06 dBm (64 mW)	21.07 dBm (128 mW)
	5 GHz	24 dBm	24 dBm	24 dBm	24 dBm

- Different power rules -> coverage (throughput vs distance)
- Unequal transmission power between AP and STA

Scenario and Assumptions



- A single cell infrastructure network
- All nodes are assumed with single-input single-output (SISO) PHY
- All fixed length PHY packets are sent using a common transmit power P_{TX} over a channel bandwidth B.
- The transmitted packets are passed through a frequency-flat wide-band channel with free space path loss and additive Gaussian noise at the receiver – easier to calculate the PHY error based on the distance

Analytical Model - PHY

- RX Chain Processing: Noise floor calculation

$$\begin{aligned} N_{floor} &= N_{figure} + 10\log_{10}(N_{thermal}) \\ &= -174 + N_{figure} + 10\log_{10}(B). \end{aligned}$$

- Link Budget: The received signal power (SRX) at the receiver input corresponding to the transmitter signal power (STX) emitted

$$S_{RX} = S_{TX} + G_{TX} + G_{RX} - L_{PL}$$

$$L_{PL} = 20\log(d) + 20\log(f) + 20\log(d) + 20\log(\frac{4\pi}{c})$$

- SNR and Packet Error Rate

$$\gamma_{RX} = \frac{S_{RX}}{N_{floor}} \qquad P_e = 1 - (1 - P_{e,0})^{l/l_0}$$

Analytical Model - MAC

- Channel access probability

$$\tau = \frac{2}{W_0\left(\frac{(1-(2P)^{m+1})(1-P)+2^m\left(P^{m+1}-P^{R+1}\right)(1-2P)}{(1-2P)\left(1-P^{R+1}\right)}\right)+1}$$

- At least one node transmitting in a slot

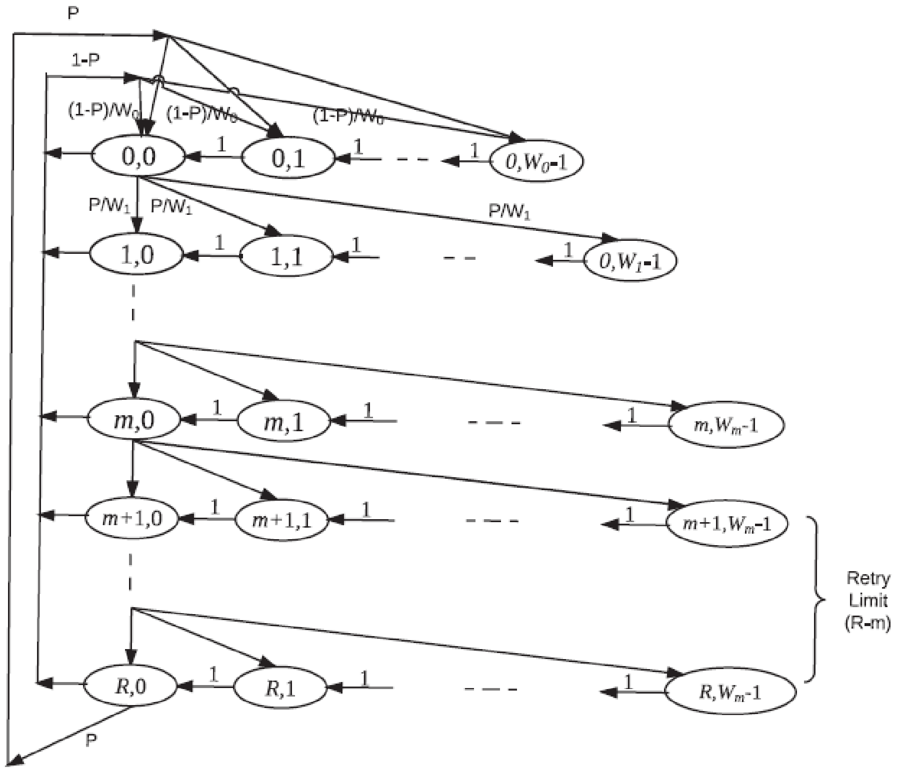
$$P_{tr} = 1 - (1-\tau)^n$$

- Successful transmission probability

$$P_s = \binom{n}{1}\frac{\tau(1-\tau)^{n-1}}{P_{tr}} = \frac{n\tau(1-\tau)^{n-1}}{P_{tr}}$$

- Normalized throughput

$$Tpt = \frac{P_s P_{tr} E[Pkt]}{(1-P_{tr})\sigma + P_{tr}P_s(1-P_e)T_s + P_{tr}(1-P_s)T_c + P_{tr}P_sP_eT_e},$$



- Probability of failed transmission

$$P = 1-(1-P_e)(1-P_c) = P_e + P_c - P_eP_c$$

Analytical Model – Unequal Power

- Collision probability in can be written for AP and STAs

$$P_c^{AP} = 1 - (1 - \tau^{STA})^{n-1},$$
$$P_c^{STA} = 1 - (1 - \tau^{AP})(1 - \tau^{STA})^{n-2}.$$

- Normalized throughput $Tpt = Tpt^{AP} + Tpt^{STA}$

$$P_{tr}^{AP} = P_{tr}^{STA} = 1 - (1 - \tau^{AP})(1 - \tau^{STA})^{n-1}$$

$$P_s^{STA} = \frac{(n-1)\tau^{STA}(1 - \tau^{AP})(1 - \tau^{STA})^{n-2}}{P_{tr}^{STA}},$$

$$P_s^{AP} = \frac{\tau^{AP}(1 - \tau^{STA})^{n-1}}{P_{tr}^{AP}}.$$

Algorithm 1: Interactive Algorithm to Obtain the Probability Variables

1. Sample values from $(0, 1)$ for P_c^{STA} uniformly, i.e. $P_c^{STA} = range(0.0, 1.0, 1000)$;
2. Calculate $P^{STA} = P_c^{STA} + P_e^{STA} - P_c^{STA} P_e^{STA}$;
3. Calculate the τ^{STA} using Eq. (6) (τ^{STA} only depends on P^{STA});
4. Calculate P_c^{AP} using Eq. (15) and then calculate P^{AP}, τ^{AP} sequentially similar as step 2, 3;
5. Obtain $\hat{P}_c^{STA}$ from τ^{AP} and τ^{STA} using Eq. (16);
6. Find the j^{th} sample that has the minimum error:
$$\tilde{j} = \arg\min |\hat{P}_c^{STA} - P_c^{STA}|$$
7. Finally, get all the variables as the $\tilde{j}^{th}$ value in the vectors.

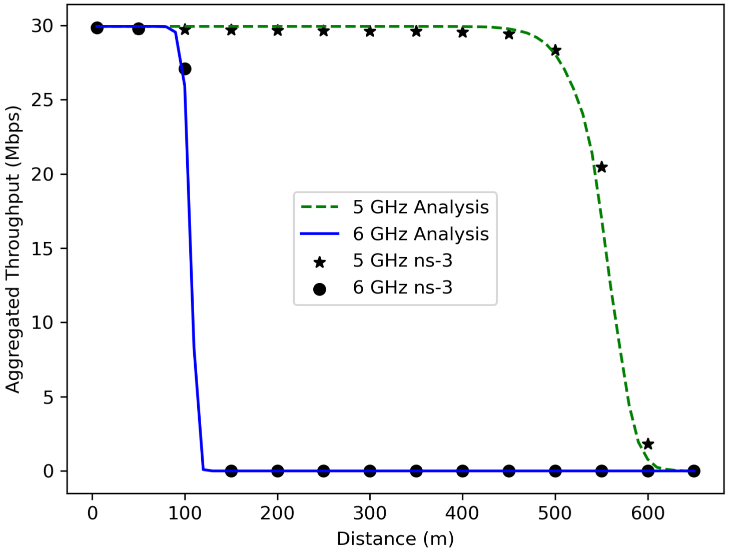
Simulation Setup

- Different power rules -> coverage (throughput vs distance)
- Unequal transmission power between AP and STA

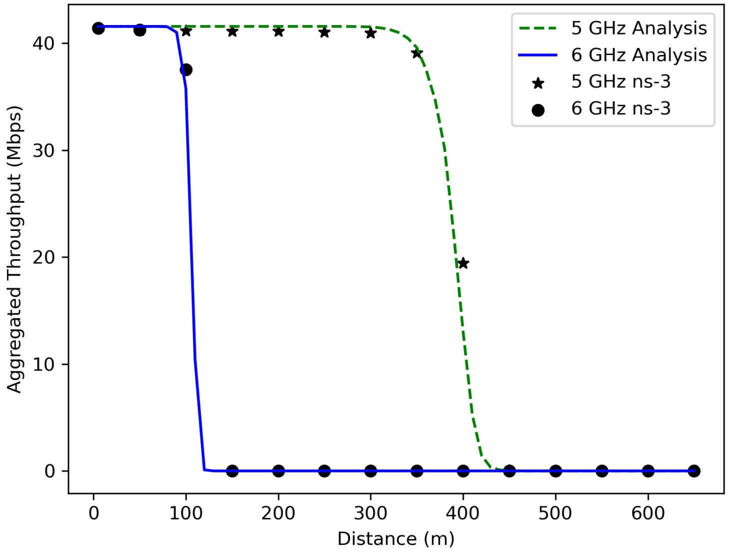
Table 2: Parameters for Simulation (802.11ax)

Slot time σ (μs)	9
$SIFS$ (μs)	16
$DIFS$ (μs)	34
$EIFS$ (μs)	$SIFS + ACK + DIFS$
PHY preamble & header duration(μs)	20
Upper Layer Headers (Bytes)	36
OFDM Guard Interval (μs)	0.8
CW_{min}	16
CW_{max}	1024
m	6
Aggregation Type	None
Propagation model	LogDistancePropagationLossModel
Error model	TableBasedErrorRateModel

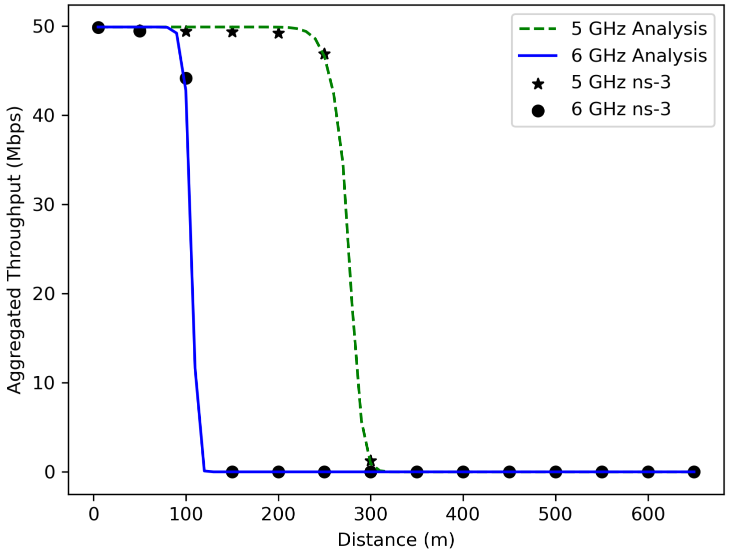
Simulation Results – UL Only



20 MHz



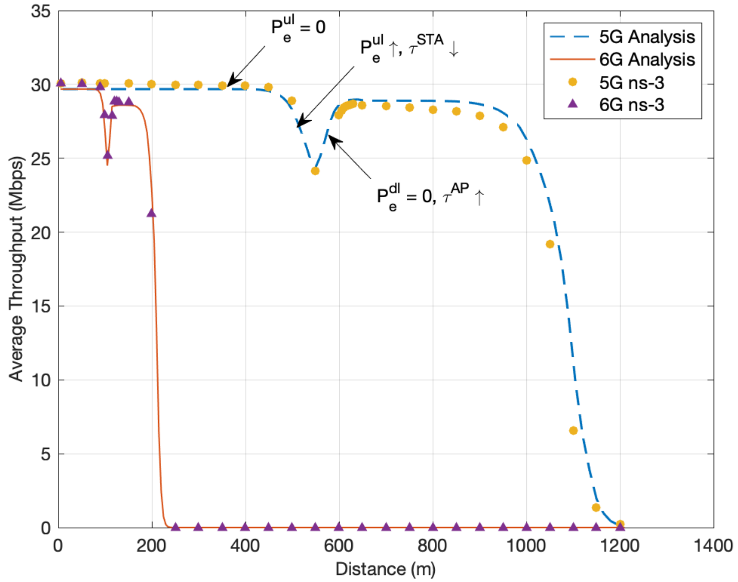
40 MHz



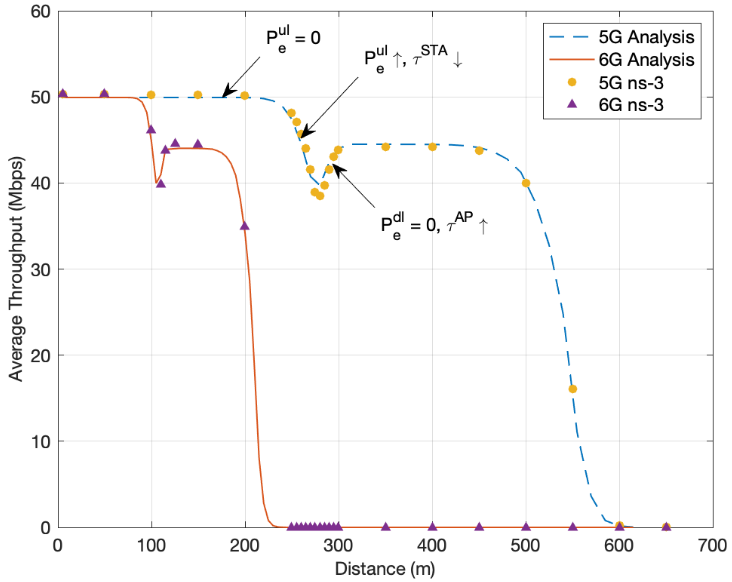
80 MHz

- As the distance increases, the received power and SNR decreases, the packet error rate increases, and the aggregated throughput drops.
- As the channel bandwidth increases, the transmission range of the 5 GHz band decreases while the transmission range in the 6 GHz band remains the same

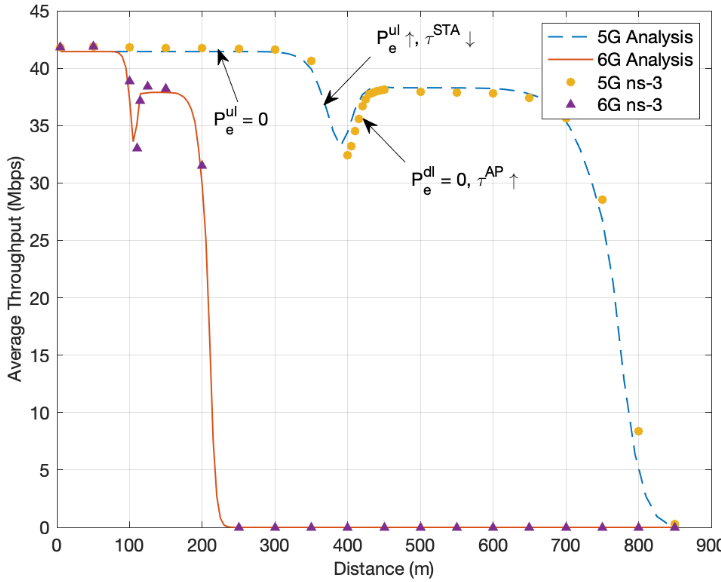
Simulation Results – Unequal Power



20 MHz



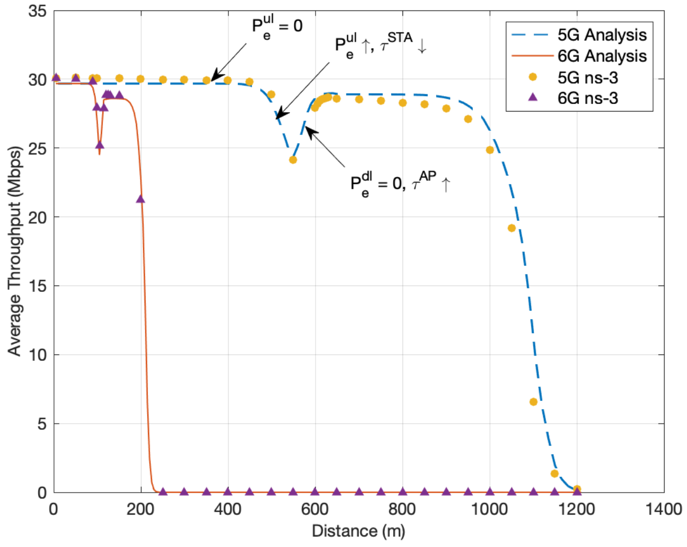
40 MHz

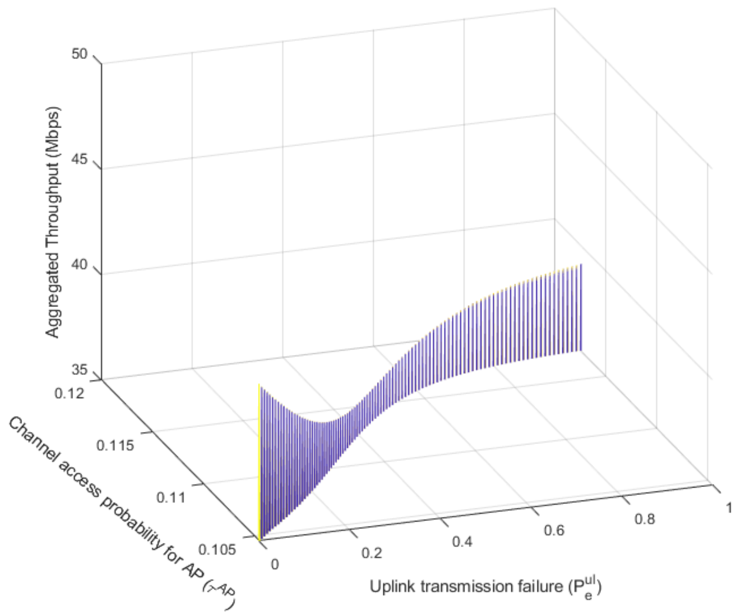


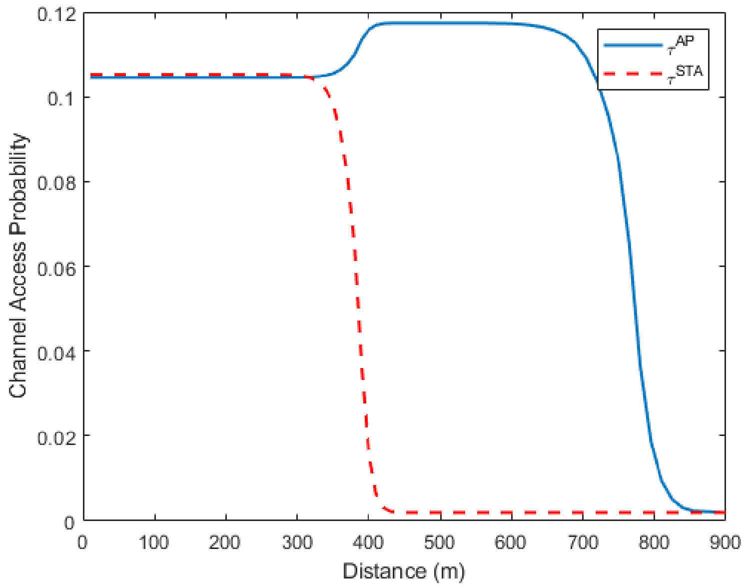
80 MHz

- AP and the STAs have the same probability to access the channel.
- Anytime AP transmits, it does so to one of the stations with a higher power.

Simulation Results - Analysis

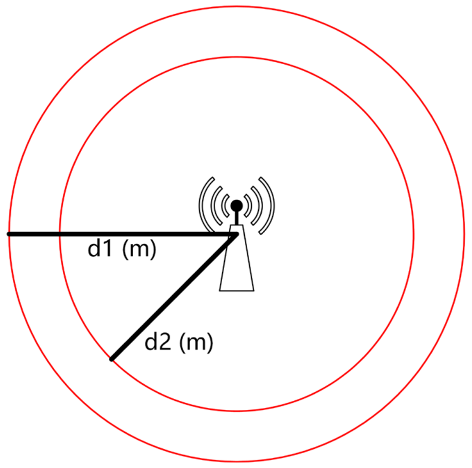




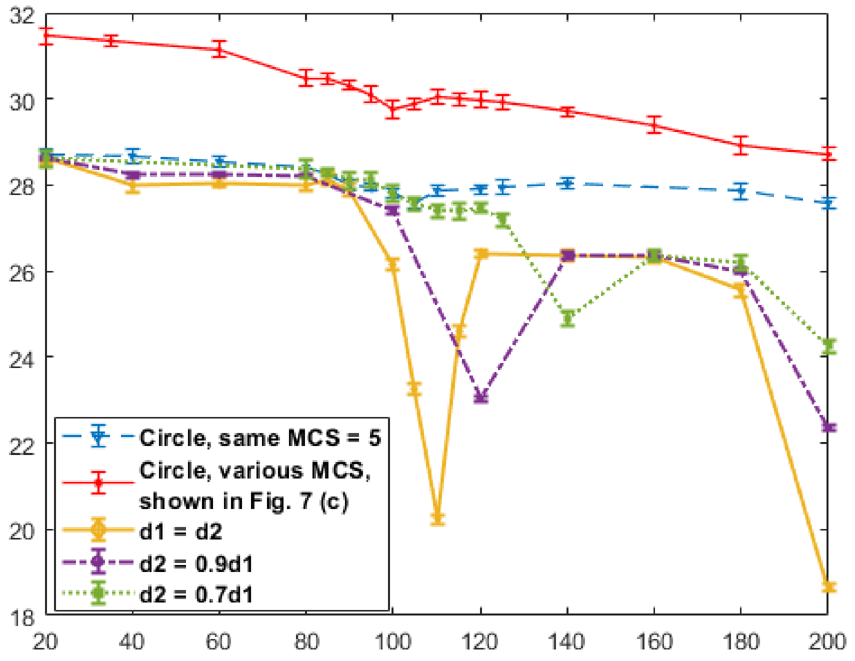


- 1st Drop: STA PER increases. STA power decreases to margin, and the STA has some packets successfully trasmitted but not to 0 (still 5 nodes, backoff window [Cwmin, CWmax]);
- Increase: All the STAs’ tpt drops to 0 (backoff window Cwmax, lower collision probability), only AP sending packets successfully
- 2nd Drop: AP power decreases to margin, AP PER increases

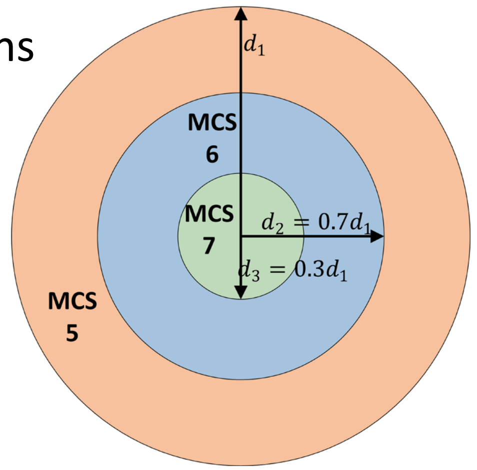
Simulation Results – Ring Structure



- Case 1: the stations are uniformly distributed within a ring bounded by the outer radius $d1$ and the inner radius $d2$
- Case 2: the stations are uniformly distributed within a circle with radius $d1$
- Case 3: the stations are uniformly distributed within a circle with three rings with radius $d1$, $d2$ = 0.7$d1$, and $d3$ = 0.3$d1$



- In these cases, the uplink PERs for different stations vary based on their ring location, so the prior equations do not apply.
- We conduct simulations using the ns-3 to verify whether the ’undershoot’ still occurs
- The minimum throughput value (at the bottom of ’undershoot’) increases as $d2/d1$ decreases



Thank you!