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Throughput Analysis of WiFi with Varying Distance

Computer Networks Lab (CSL355)

Submitted by

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Abstract

This project investigates the effect of distance on the throughput of a WiFi network using IEEE 802.11g standard. Through simulation in NetSim, we evaluate how increasing the physical separation between an access point and a wireless node impacts achievable application layer throughput. A consistent experimental setup is used to measure throughput at fixed distances, offering both predicted and simulated data for comparative analysis. The study helps in understanding performance degradation in real-world wireless deployments.

1. Literature Review

1.1 Introduction

In wireless networks like WiFi, the performance of data transfer is significantly affected by the distance between the devices involved. This experiment studies how the downlink UDP throughput between an Access Point (AP) and a Station (STA) changes with varying distances. While the MAC protocol behaviour remains unchanged (as defined in the IEEE 802.11 standard), the PHY data rate depends on the received signal power at the STA. Since we consider a single AP-STA setup, there is no interference or contention from other devices, simplifying the analysis.

As distance increases, the received signal strength drops. This results in a reduced PHY rate, which means longer time to send each packet. The total time to transmit a packet includes:

- An average backoff period (due to CSMA/CA),
- Protocol-related overheads (headers, inter-frame spacings)
- The actual time to transmit the data, which depends on the PHY rate.

The effective transmission time can be expressed as:

$$MeanEffectiveTransmissionTime = MeanInitialBackoff + PacketOverhead + \frac{PacketLength}{PHYRate}$$

Hence, throughput is inversely proportional to this effective time:

$$PacketThroughput = 1/MeanEffectiveTransmissionTime$$

While this formula assumes no packet loss, in reality, packet errors can occur due to fading or shadowing, which cause fluctuations in received power. However, in this project, fading and shadowing are disabled, and a fixed path loss model is used.

1.2 Wi-Fi Technology Overview

Wi-Fi is the common name for the family of IEEE 802.11 wireless-LAN standards that enable devices to exchange data over unlicensed radio spectrum—primarily the 2.4 GHz and 5 GHz bands, and more recently the 6 GHz band (Wi-Fi 6E). Introduced in 1997 and refined through successive amendments (802.11b/g/n/ac/ax, etc.), Wi-Fi combines carrier-sense multiple access with collision avoidance (CSMA/CA) at the MAC layer and a variety of modulation and coding schemes (MCS) at the physical (PHY) layer to provide data rates ranging from a few megabits per second up to several gigabits per second. Each new generation has aimed to:

- Increase raw throughput via wider channels, higher-order modulation (e.g., 64-QAM, 1024-QAM), and multi-stream MIMO.
- Improve spectral efficiency with techniques such as OFDM, OFDMA, and spatial reuse.
- Enhance reliability and range through forward-error correction, beamforming, and adaptive rate control.

Because Wi-Fi operates in shared spectrum, its real-world performance is shaped by environmental factors such as distance, interference, multipath fading, and contention among nearby devices. Understanding how these parameters influence effective throughput is essential for network design, capacity planning, and quality-of-service (QoS) provisioning.

1.3 Simplified Path Loss Model

To estimate how distance affects signal strength, we use a commonly accepted path loss formula:

$$P_r = P_t \times c_0 \times \left(\frac{d_0}{d}\right)^{\eta}$$

Where:

- P_r is the received power
- P_t is the transmitted power
- c_0 is the reference path loss at 1 meter
- d is the distance between AP and STA
- η is the path loss exponent (typically between 3 and 5 for indoor environments)

In dB form, this becomes:

$$P_r(dBm) = P_t(dBm) + c_0\ (dB) - 10 \times \eta \times \log_{10}\left(\frac{d}{d_0}\right)$$

This tells us that every time distance doubles, received power drops by about 3·η dB. For example, if η=3.5, doubling the distance reduces power by around 10.5 dB.

1.4 The IEEE 802.11g PHY Rates Table

IEEE 802.11g defines several PHY bit rates (6 Mbps to 54 Mbps), each requiring a minimum signal strength to function reliably. The Modulation and Coding Scheme (MCS) used depends on the Received Signal Strength (RSS)**.** Higher RSS allows for more complex modulation and higher rates.

The MCS defines the numbers of useful bits which can carried by one symbol. In Wi-Fi IEEE 802.11g standard, the MCS depends on the received signal strength (RSS). The higher the signal strength the higher the MCS and more useful bits can be transmitted in a symbol. Thus, the PHY bit rate depends on the MCS chosen. IEEE 802.11g devices can transmit at speeds of 6, 9, 12, 18, 24, 36, 48 and 54Mbps as shown in the table below:

Index	Rx Sensitivity (dBm)	Modulation	Code Rate	Bit Rate
0	-82	BPSK	1/2	6 Mbps
1	-81	BPSK	3/4	9 Mbps
2	-79	QPSK	1/2	12 Mbps
3	-77	QPSK	3/4	18 Mbps
4	-74	16 QAM	1/2	24 Mbps
5	-70	16 QAM	3/4	36 Mbps
6	-66	64 QAM	2/3	48 Mbps
7	-65	64 QAM	3/4	54 Mbps

In simulations, it is assumed that the transmitter knows the RSS at the receiver and selects the highest rate that meets the sensitivity threshold.

1.5 Calculating Distance Thresholds for Each PHY Rate

Using the above model, we can compute the distance ranges over which each PHY rate is valid. Assuming:

- Pt=20 dBm,
- η=3.5,
- c0=40.09 dB (at 2.4 GHz),

We find that, for example, 54 Mbps is supported up to about 19.19 meters, and 6 Mbps is supported until 58.72 meters. Beyond this, the PHY rate drops to zero. Similarly, we compute the AP-PHY distance for all the rates and arrive at the table below:

Rx Sensitivity (dBm)	Bit Rate	$d_{max}\ (m)$	$d_{min}\ (m)$
-82	6 Mbps	58.72	55.00
-81	9 Mbps	54.99	48.22
-79	12 Mbps	48.21	42.28
-77	18 Mbps	42.27	34.69
-74	24 Mbps	34.68	26.68
-70	36 Mbps	26.67	20.52
-66	48 Mbps	20.50	19.20
-65	54 Mbps	19.19	1.00

1.6 Predicting the Throughput

We know that application throughput θ is

$$\theta = \frac{Application\ Payload\ in\ Packet\ (bits)}{Average\ Time\ per\ Packet(\mu s)}$$

$Average\ time\ per\ packet$ (µs) = $DIFS + Average\ Backoff\ time + Packet\ Transmission\ Time + SIFS + ACK\ Transmission\ Time$

Therefore,

$$\theta = \frac{L_{pkt} \times 8}{T_{DIFS} + \left(\frac{CW_{min}}{2} \times T_{slot}\right) + \left(T_{preamble} + \frac{(L_{pkt} + OH) \times 8}{PHYRate}\right) + T_{SIFS} + \left(T_{preamble} + \frac{L_{ACK} \times 8}{PHYRate_{min}}\right)}$$

In the above formula θ is in Mbps as the time in the denominator is in μs.

The predicted application throughput for a 1450B packet, with 68B overheads, ACK size of 14B, and PHY Rate of 54 Mbps is

$$\theta = \frac{1450 \times 8}{34 + \left(\frac{15}{2} \times 9\right) + \left(20 + \frac{(1450 + 68) \times 8}{54}\right) + 16 + \left(20 + \frac{14 \times 8}{6}\right)} = \frac{11600}{401.04} = 28.92\ Mbps$$

Doing the same computation for the different PHY rates leads to the following application throughput predictions.

PHY rate (Mbps)	Predicted Application
54	28.92
48	27.02
36	22.59
24	17.00
18	13.63
12	9.76
9	7.60
6	5.27

This table presents the predicted application-layer throughput values corresponding to various PHY data rates in IEEE 802.11g.

3. Experimental Setup

3.1 Simulation Environment

This project utilizes NetSim v13.3 to model and analyse how distance affects downlink UDP throughput in Wi-Fi networks conforming to the IEEE 802.11g standard.

All simulations are conducted with:

- Single AP-STA pair (no interference)
- No rate adaptation
- Constant pathloss model
- UDP-based traffic (no TCP acknowledgment delays)

3.2 Network Topology

- Wired_Node_2 acts as the CBR traffic source.
- Router_1 routes traffic from the wired node to the wireless domain.
- Access_Point_3 (802.11g enabled) serves as the transmitter.
- Wireless_Node_4 is the receiver (STA), placed at varying distances from the AP.
- Additional wired nodes (Wired_Node_5 and Wired_Node_6).

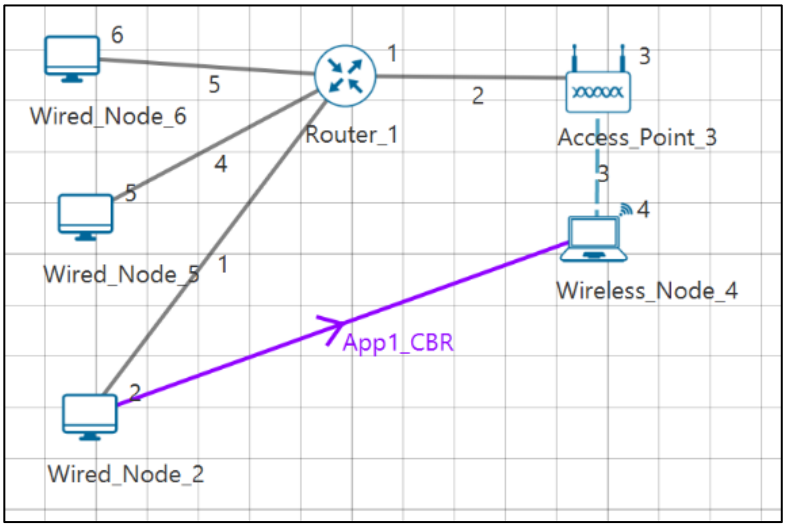


Fig: Network set up for studying the Impact of distance on Wi-Fi throughput

3.3 Application Configuration

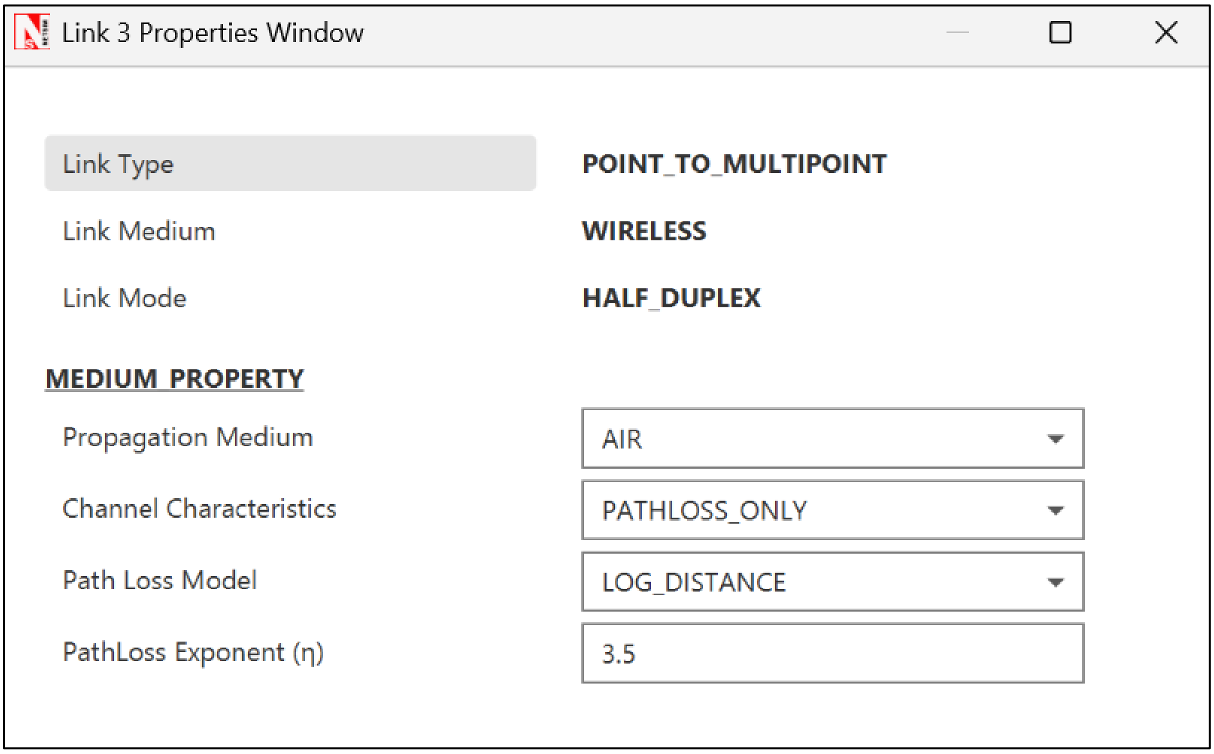
Parameter	Value
Transport Protocol	UDP
Application Protocol	NONE (Raw Data)
Priority	Low (Best Effort)
Packet Size	1450 Bytes
Inter-Arrival Time	200 µs (constant)
Session Time	100 seconds

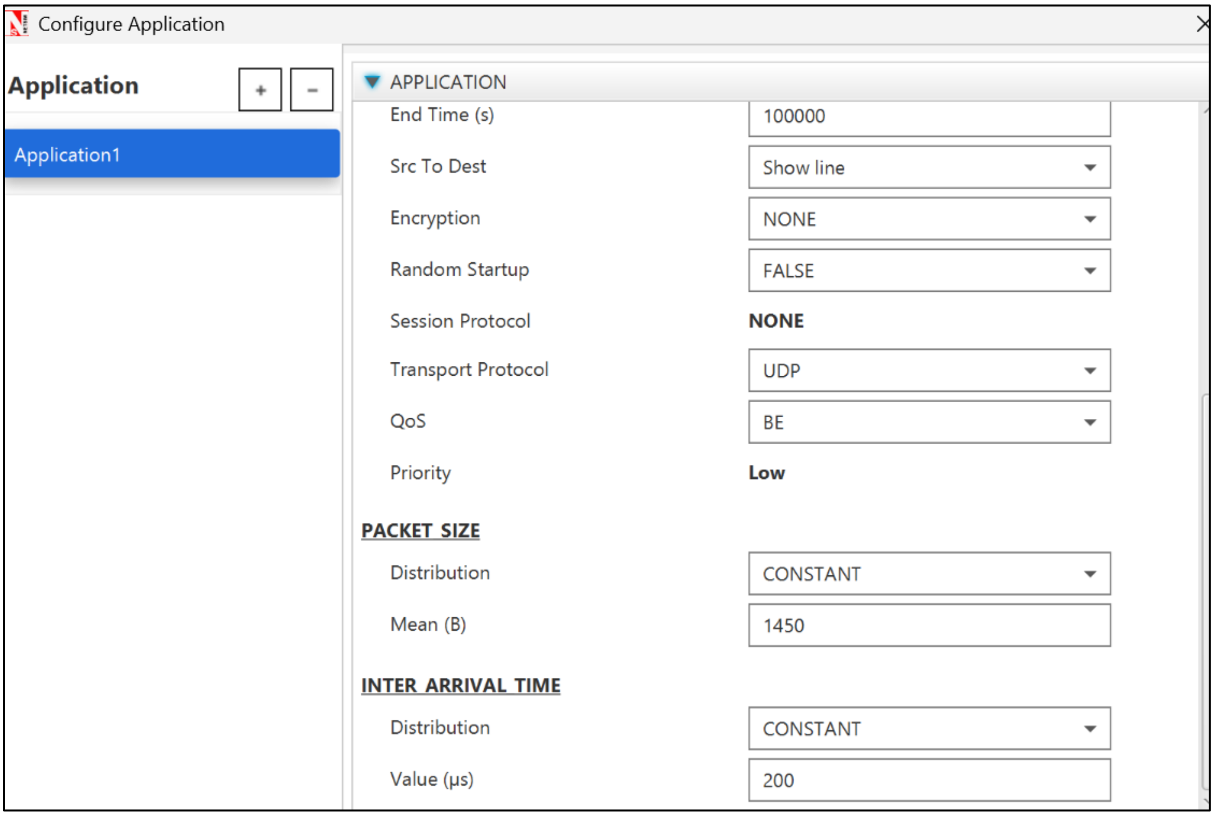
- The application generates a constant stream of packets from Wired_Node_2 to Wireless_Node_4.
- QoS set to Best Effort (BE) to avoid any special traffic prioritization.
- No random startup or encryption enabled.

Distance Values Tested: 10m, 45m, 60m

Wired Link Properties	
Max Uplink Speed (Mbps)	100
Max Downlink Speed (Mbps)	100
Uplink BER	0
Downlink BER	0
Uplink Propagation Delay (µs)	0
Downlink Propagation Delay (µs)	0

Wireless Link Properties	
Channel	Path Loss Only
Path Loss Model	Log Distance
Path Loss Exponent	3.5

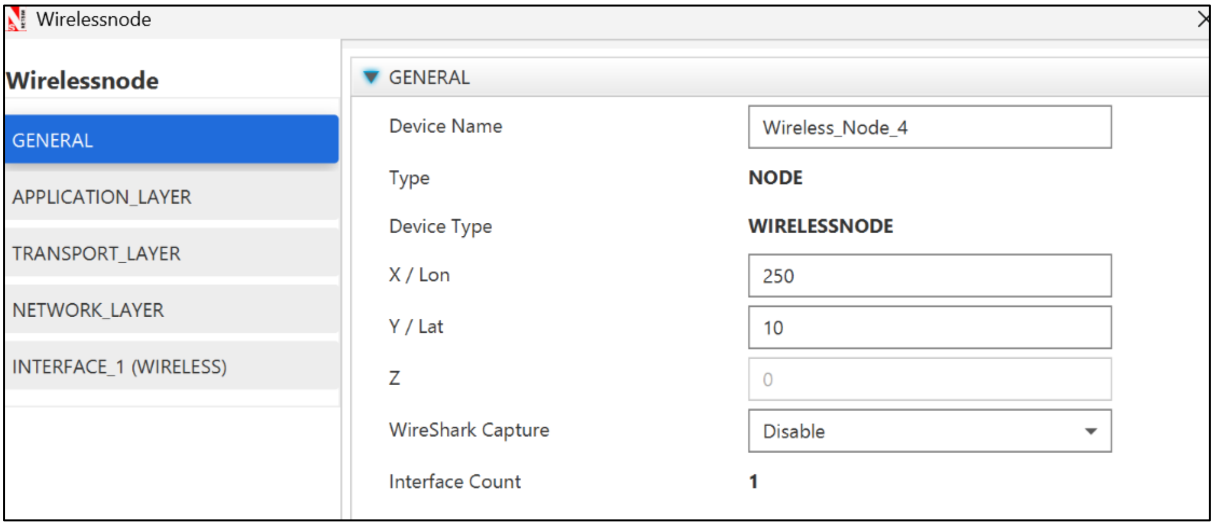

Link 3 Properties Window
Link Type
POINT_TO_MULTIPOINT
Link Medium
WIRELESS
Link Mode
HALF_DUPLEX
MEDIUM_PROPERTY
Propagation Medium
AIR
Channel Characteristics
PATHLOSS_ONLY
Path Loss Model
LOG_DISTANCE
PathLoss Exponent (η)
3.5

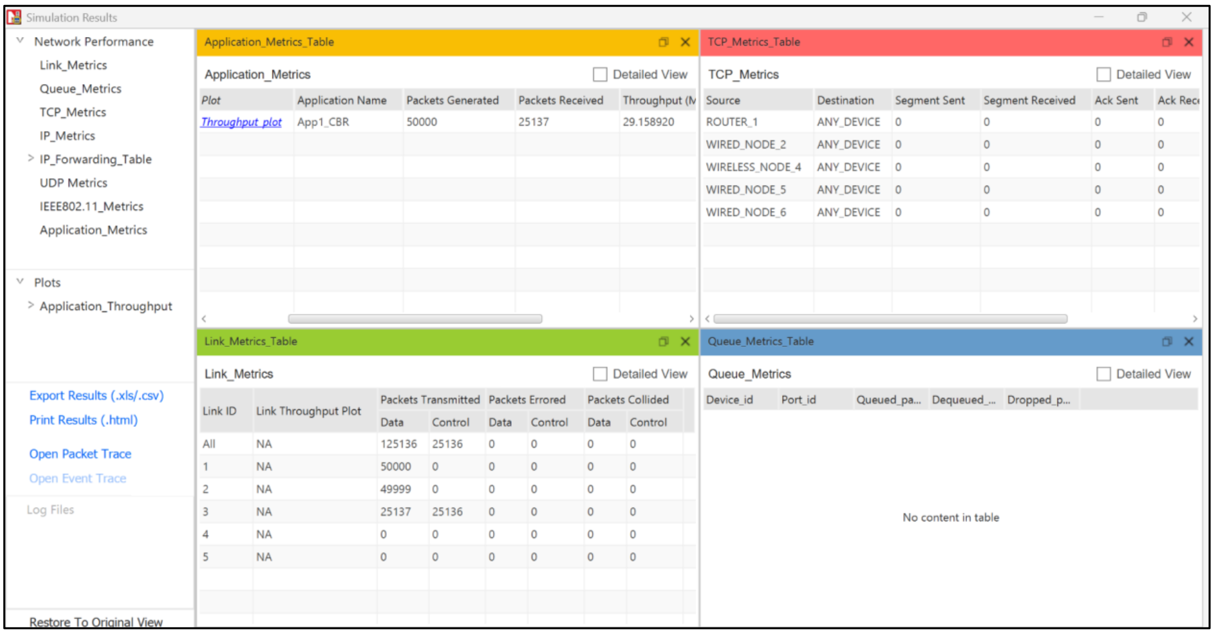

Configure Application
Application
+
-
Application1
APPLICATION
End Time (s)
100000
Src To Dest
Show line
Encryption
NONE
Random Startup
FALSE
Session Protocol
NONE
Transport Protocol
UDP
QoS
BE
Priority
Low
PACKET_SIZE
Distribution
CONSTANT
Mean (B)
1450
INTER_ARRIVAL_TIME
Distribution
CONSTANT
Value (μs)
200

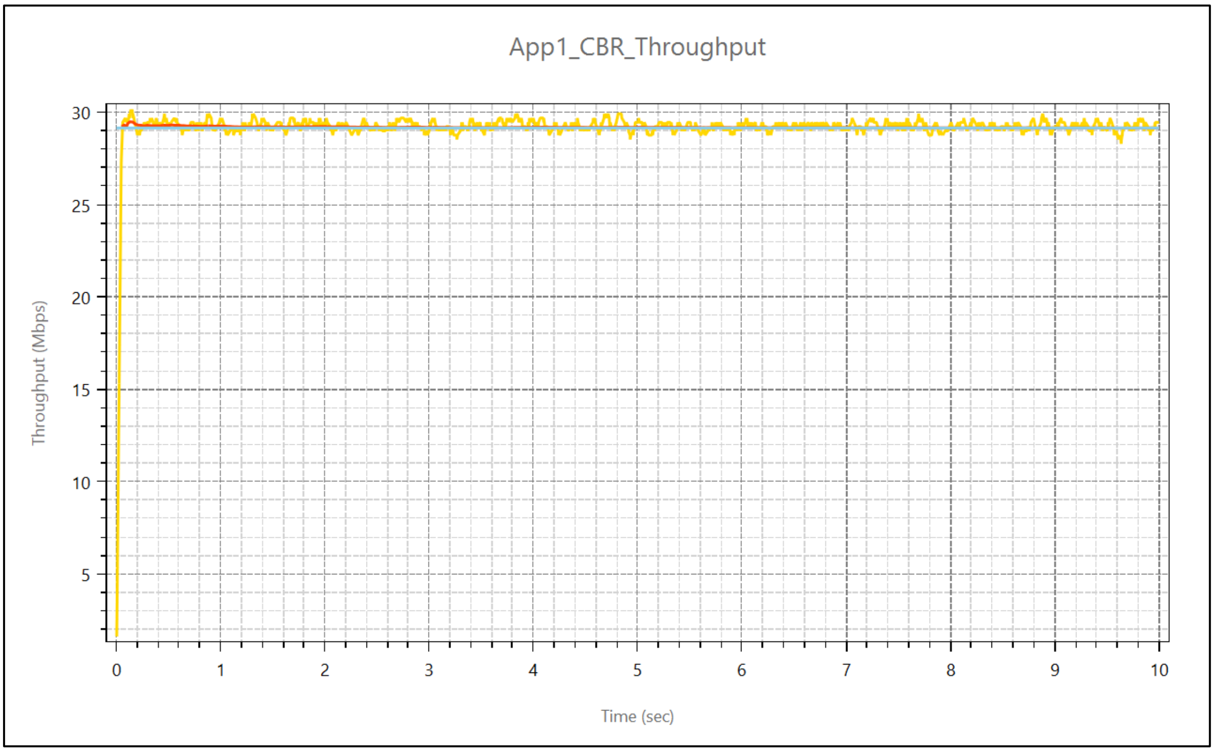
3. Results

3.1 Analysis for 10m

In the first simulation, Wireless_Node_4 was placed at coordinates **(250, 10)** while the Access Point remained fixed, making the effective **distance = 10 meters**.







	ET_ID	SEGMENT_ID	PACKET_	CONTROL	SOURCE_	DESTINA	TRANSMI	RECEIVEI	APP_LAY	TRX_LAYI	NW_LAYI	MAC_LAY	PHY_LAYER_ARRIVAL_TIM	PHY_LAY	PHY_L
2	1	0	CBR	App1_CBR	NODE-2	NODE-4	NODE-2	ROUTER-1	0	0	0	0	0.96	121.28	1
3	1	0	CBR	App1_CBR	NODE-2	NODE-4	ROUTER-1	ACCESSPOII	0	0	121.28	121.28	121.28	241.6	
4	2	0	CBR	App1_CBR	NODE-2	NODE-4	NODE-2	ROUTER-1	200	200	200	200	200	320.32	3
5	2	0	CBR	App1_CBR	NODE-2	NODE-4	ROUTER-1	ACCESSPOII	200	200	320.32	320.32	320.32	440.64	4
6	3	0	CBR	App1_CBR	NODE-2	NODE-4	NODE-2	ROUTER-1	400	400	400	400	400	520.32	5
7	1	0	CBR	App1_CBR	NODE-2	NODE-4	ACCESSPOII	NODE-4	0	0	121.28	241.6	365.6	610.6	6
8	3	0	CBR	App1_CBR	NODE-2	NODE-4	ROUTER-1	ACCESSPOII	400	400	520.32	520.32	520.32	640.64	6
9	0	N/A	Control_Pa	WLAN_ACK	NODE-4	ACCESSPOII	NODE-4	ACCESSPOII	N/A	N/A	N/A	610.61	626.61	665.61	6
10	4	0	CBR	App1_CBR	NODE-2	NODE-4	NODE-2	ROUTER-1	600	600	600	600	600	720.32	7
11	4	0	CBR	App1_CBR	NODE-2	NODE-4	ROUTER-1	ACCESSPOII	600	600	720.32	720.32	720.32	840.64	8
12	5	0	CBR	App1_CBR	NODE-2	NODE-4	NODE-2	ROUTER-1	800	800	800	800	800	920.32	9
13	2	0	CBR	App1_CBR	NODE-2	NODE-4	ACCESSPOII	NODE-4	200	200	320.32	440.64	717.72	962.72	9
14	0	N/A	Control_Pa	WLAN_ACK	NODE-4	ACCESSPOII	NODE-4	ACCESSPOII	N/A	N/A	N/A	962.73	978.73	1017.73	10
15	5	0	CBR	App1_CBR	NODE-2	NODE-4	ROUTER-1	ACCESSPOII	800	800	920.32	920.32	920.32	1040.64	10
16	6	0	CBR	App1_CBR	NODE-2	NODE-4	NODE-2	ROUTER-1	1000	1000	1000	1000	1000	1120.32	11
17	6	0	CBR	App1_CBR	NODE-2	NODE-4	ROUTER-1	ACCESSPOII	1000	1000	1120.32	1120.32	1120.32	1240.64	12
18	7	0	CBR	App1_CBR	NODE-2	NODE-4	NODE-2	ROUTER-1	1200	1200	1200	1200	1200	1320.32	13
19	3	0	CBR	App1_CBR	NODE-2	NODE-4	ACCESSPOII	NODE-4	400	400	520.32	640.64	1150.84	1395.84	13
20	7	0	CBR	App1_CBR	NODE-2	NODE-4	ROUTER-1	ACCESSPOII	1200	1200	1320.32	1320.32	1320.32	1440.64	14
21	0	N/A	Control_Pa	WLAN_ACK	NODE-4	ACCESSPOII	NODE-4	ACCESSPOII	N/A	N/A	N/A	1395.85	1411.85	1450.85	14

Data rate can be calculated from packet trace by using the formula given below:

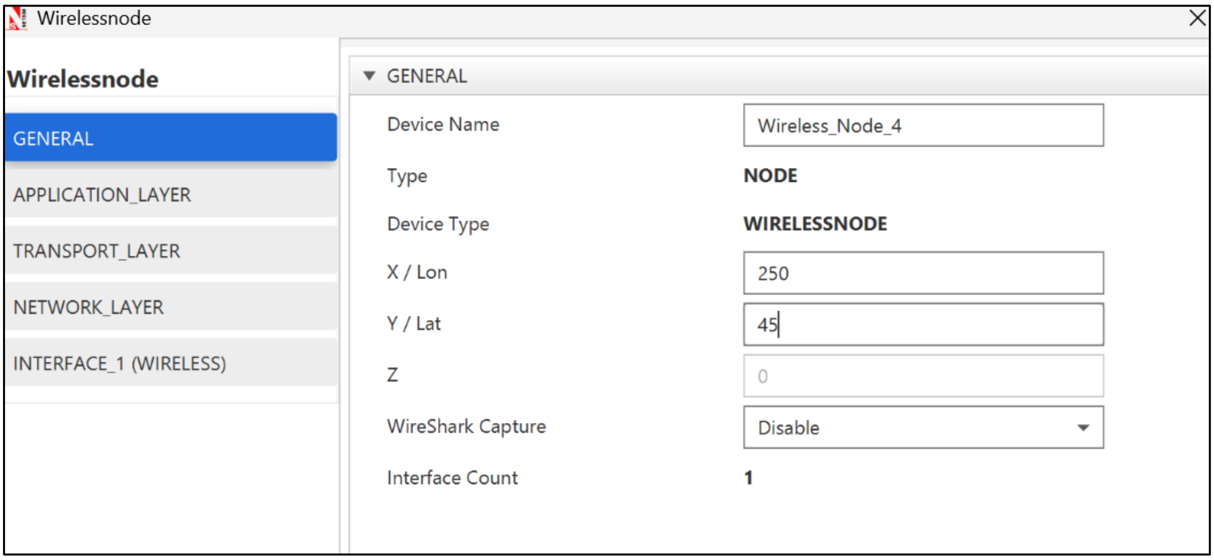
$$PHYRate\ (Mbps) = \frac{PHYLayerPayload\ (B) \times 8}{PHYEndTime\ (\mu s) - PHYArrivalTime(\mu s) - 20(\mu s)}$$

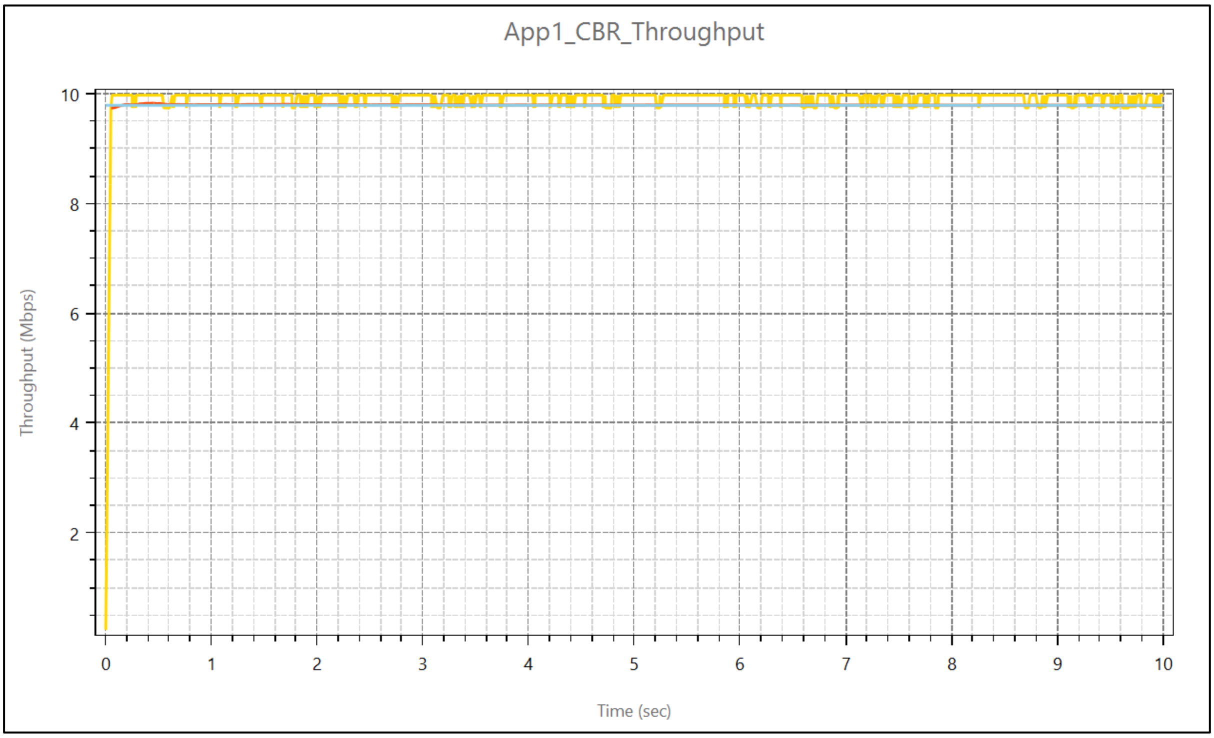
These values can be obtained from the excel sheet of packet trace.

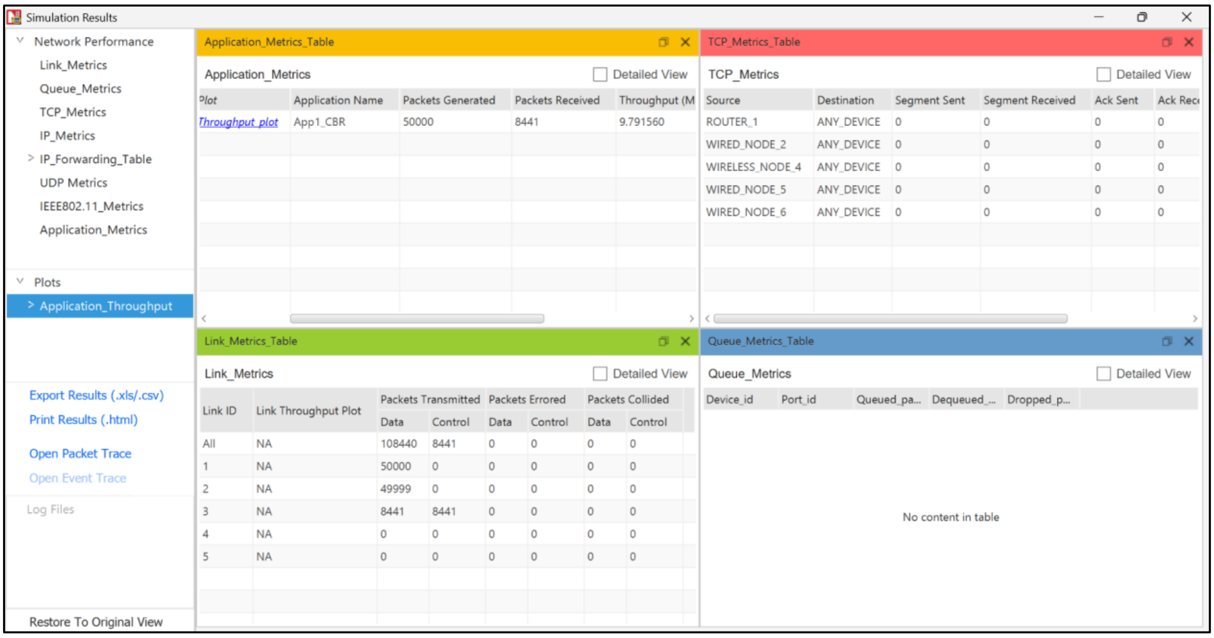
After putting the values in the formula, **we get Throughput for 10m as 29.15 Mbps.**

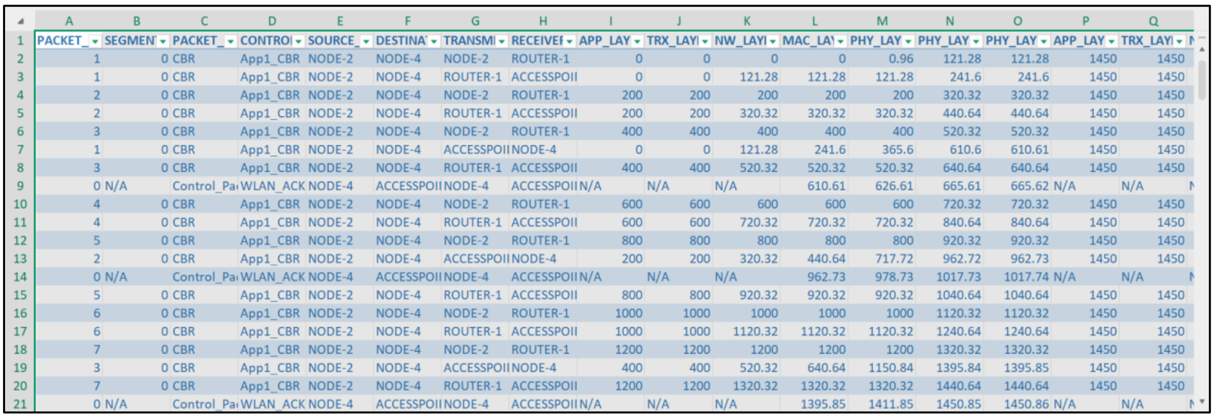
3.2 Analysis for 45m

In the first simulation, `Wireless_Node_4` was placed at coordinates **(250, 45)** while the Access Point remained fixed, making the effective **distance = 45 meters**.









	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	PACKET_	SEGMEN	PACKET_	CONTROI	SOURCE_	DESTINA	TRANSMI	RECEIVEI	APP_LAY	TRX_LAYI	NW_LAYI	MAC_LA	PHY_LAY	PHY_LAY	PHY_LAY	APP_LAY	TRX_LAYI
2	1	0	CBR	App1_CBR	NODE-2	NODE-4	NODE-2	ROUTER-1	0	0	0	0	0.96	121.28	121.28	1450	1450
3	1	0	CBR	App1_CBR	NODE-2	NODE-4	ROUTER-1	ACCESSPOII	0	0	121.28	121.28	121.28	241.6	241.6	1450	1450
4	2	0	CBR	App1_CBR	NODE-2	NODE-4	NODE-2	ROUTER-1	200	200	200	200	200	320.32	320.32	1450	1450
5	2	0	CBR	App1_CBR	NODE-2	NODE-4	ROUTER-1	ACCESSPOII	200	200	320.32	320.32	320.32	440.64	440.64	1450	1450
6	3	0	CBR	App1_CBR	NODE-2	NODE-4	NODE-2	ROUTER-1	400	400	400	400	400	520.32	520.32	1450	1450
7	1	0	CBR	App1_CBR	NODE-2	NODE-4	ACCESSPOII	NODE-4	0	0	121.28	241.6	365.6	610.6	610.61	1450	1450
8	3	0	CBR	App1_CBR	NODE-2	NODE-4	ROUTER-1	ACCESSPOII	400	400	520.32	520.32	520.32	640.64	640.64	1450	1450
9	0	N/A	Control_Pa	WLAN_ACK	NODE-4	ACCESSPOII	NODE-4	ACCESSPOII	N/A	N/A	N/A	610.61	626.61	665.61	665.62	N/A	N/A
10	4	0	CBR	App1_CBR	NODE-2	NODE-4	NODE-2	ROUTER-1	600	600	600	600	600	720.32	720.32	1450	1450
11	4	0	CBR	App1_CBR	NODE-2	NODE-4	ROUTER-1	ACCESSPOII	600	600	720.32	720.32	720.32	840.64	840.64	1450	1450
12	5	0	CBR	App1_CBR	NODE-2	NODE-4	NODE-2	ROUTER-1	800	800	800	800	800	920.32	920.32	1450	1450
13	2	0	CBR	App1_CBR	NODE-2	NODE-4	ACCESSPOII	NODE-4	200	200	320.32	440.64	717.72	962.72	962.73	1450	1450
14	0	N/A	Control_Pa	WLAN_ACK	NODE-4	ACCESSPOII	NODE-4	ACCESSPOII	N/A	N/A	N/A	962.73	978.73	1017.73	1017.74	N/A	N/A
15	5	0	CBR	App1_CBR	NODE-2	NODE-4	ROUTER-1	ACCESSPOII	800	800	920.32	920.32	920.32	1040.64	1040.64	1450	1450
16	6	0	CBR	App1_CBR	NODE-2	NODE-4	NODE-2	ROUTER-1	1000	1000	1000	1000	1000	1120.32	1120.32	1450	1450
17	6	0	CBR	App1_CBR	NODE-2	NODE-4	ROUTER-1	ACCESSPOII	1000	1000	1120.32	1120.32	1120.32	1240.64	1240.64	1450	1450
18	7	0	CBR	App1_CBR	NODE-2	NODE-4	NODE-2	ROUTER-1	1200	1200	1200	1200	1200	1320.32	1320.32	1450	1450
19	3	0	CBR	App1_CBR	NODE-2	NODE-4	ACCESSPOII	NODE-4	400	400	520.32	640.64	1150.84	1395.84	1395.85	1450	1450
20	7	0	CBR	App1_CBR	NODE-2	NODE-4	ROUTER-1	ACCESSPOII	1200	1200	1320.32	1320.32	1320.32	1440.64	1440.64	1450	1450
21	0	N/A	Control_Pa	WLAN_ACK	NODE-4	ACCESSPOII	NODE-4	ACCESSPOII	N/A	N/A	N/A	1395.85	1411.85	1450.85	1450.86	N/A	N/A

Data rate can be calculated from packet trace by using the formula given below:

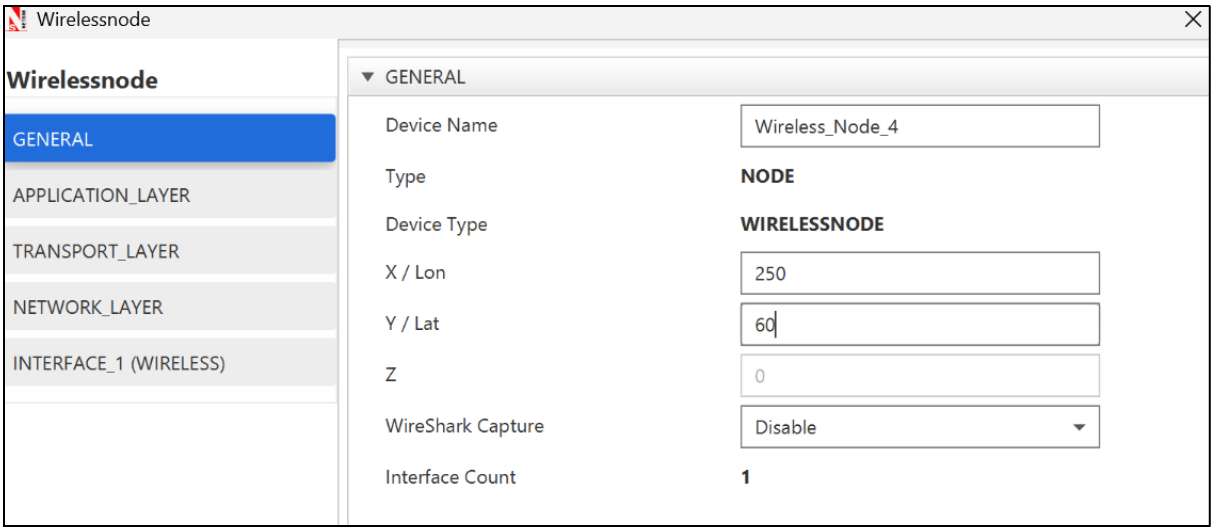
$$PHYRate\ (Mbps) = \frac{PHYLayerPayload\ (B) \times 8}{PHYEndTime\ (\mu s) - PHYArrivalTime(\mu s) - 20(\mu s)}$$

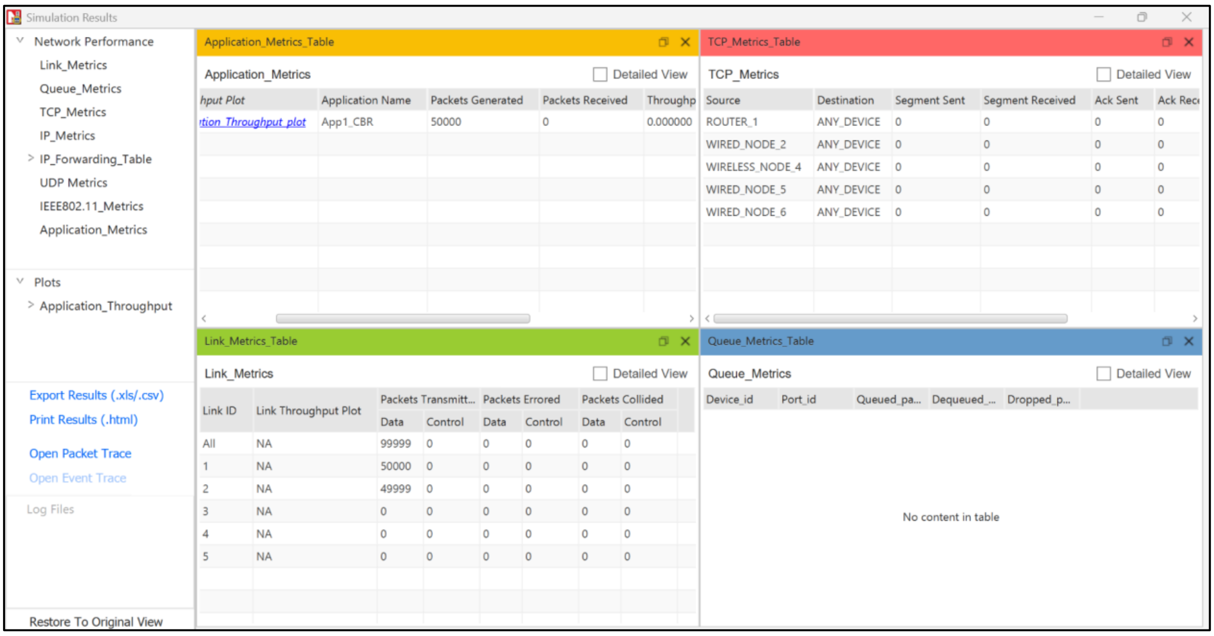
These values can be obtained from the excel sheet of packet trace.

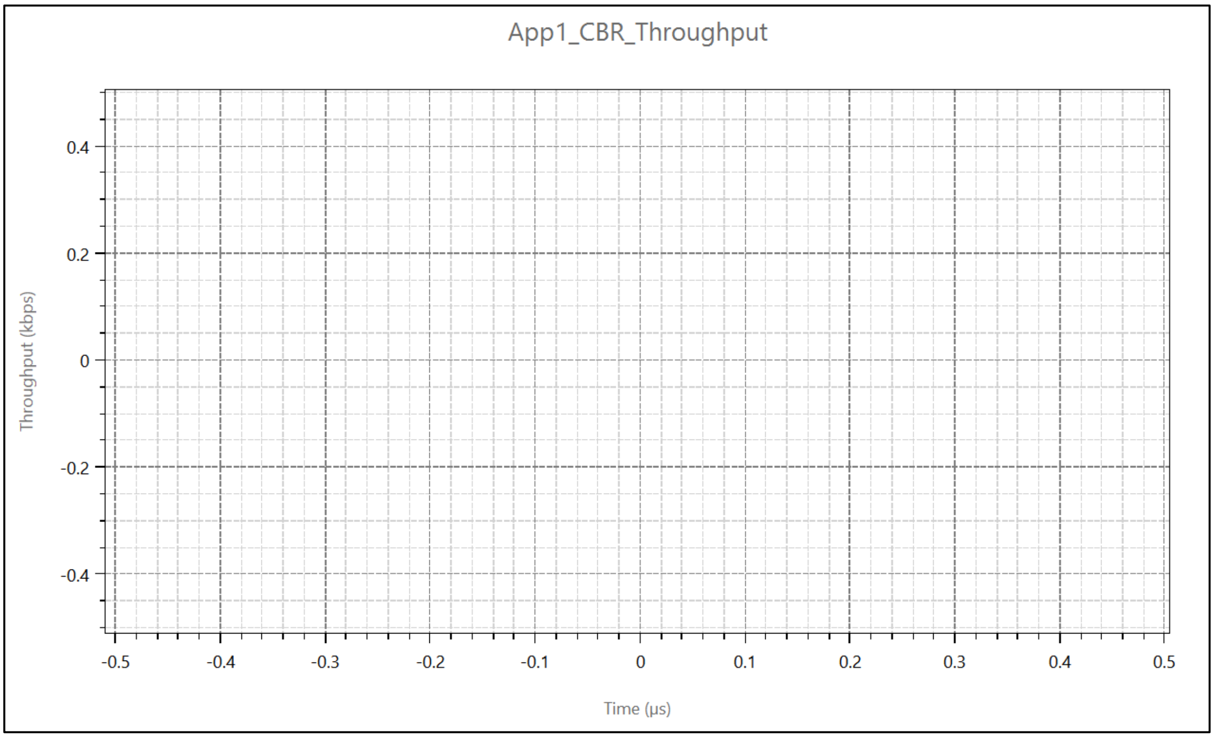
After putting the values in the formula, **we get Throughput for 45m as 9.79 Mbps.**

3.3 Analysis for 60m

In the first simulation, `Wireless_Node_4` was placed at coordinates **(250, 60)** while the Access Point remained fixed, making the effective **distance = 60 meters**.







	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	PACKET_	SEGMEN	PACKET_	CONTROI	SOURCE_	DESTINA	TRANSMI	RECEIVEI	APP_LAY	TRX_LAYI	NW_LAYI	MAC_LA	PHY_LAY	PHY_LAY	PHY_LAY	APP_LAY	TRX_LAYI
2	1	0	CBR	App1_CBR	NODE-2	NODE-4	NODE-2	ROUTER-1	0	0	0	0	0.96	121.28	121.28	1450	1450
3	1	0	CBR	App1_CBR	NODE-2	NODE-4	ROUTER-1	ACCESSPOII	0	0	121.28	121.28	121.28	241.6	241.6	1450	1450
4	2	0	CBR	App1_CBR	NODE-2	NODE-4	NODE-2	ROUTER-1	200	200	200	200	200	320.32	320.32	1450	1450
5	2	0	CBR	App1_CBR	NODE-2	NODE-4	ROUTER-1	ACCESSPOII	200	200	320.32	320.32	320.32	440.64	440.64	1450	1450
6	3	0	CBR	App1_CBR	NODE-2	NODE-4	NODE-2	ROUTER-1	400	400	400	400	400	520.32	520.32	1450	1450
7	1	0	CBR	App1_CBR	NODE-2	NODE-4	ACCESSPOII	NODE-4	0	0	121.28	241.6	365.6	610.6	610.61	1450	1450
8	3	0	CBR	App1_CBR	NODE-2	NODE-4	ROUTER-1	ACCESSPOII	400	400	520.32	520.32	520.32	640.64	640.64	1450	1450
9	0	N/A	Control_Pa	WLAN_ACK	NODE-4	ACCESSPOII	NODE-4	ACCESSPOII	N/A	N/A	N/A	610.61	626.61	665.61	665.62	N/A	N/A
10	4	0	CBR	App1_CBR	NODE-2	NODE-4	NODE-2	ROUTER-1	600	600	600	600	600	720.32	720.32	1450	1450
11	4	0	CBR	App1_CBR	NODE-2	NODE-4	ROUTER-1	ACCESSPOII	600	600	720.32	720.32	720.32	840.64	840.64	1450	1450
12	5	0	CBR	App1_CBR	NODE-2	NODE-4	NODE-2	ROUTER-1	800	800	800	800	800	920.32	920.32	1450	1450
13	2	0	CBR	App1_CBR	NODE-2	NODE-4	ACCESSPOII	NODE-4	200	200	320.32	440.64	717.72	962.72	962.73	1450	1450
14	0	N/A	Control_Pa	WLAN_ACK	NODE-4	ACCESSPOII	NODE-4	ACCESSPOII	N/A	N/A	N/A	962.73	978.73	1017.73	1017.74	N/A	N/A
15	5	0	CBR	App1_CBR	NODE-2	NODE-4	ROUTER-1	ACCESSPOII	800	800	920.32	920.32	920.32	1040.64	1040.64	1450	1450
16	6	0	CBR	App1_CBR	NODE-2	NODE-4	NODE-2	ROUTER-1	1000	1000	1000	1000	1000	1120.32	1120.32	1450	1450
17	6	0	CBR	App1_CBR	NODE-2	NODE-4	ROUTER-1	ACCESSPOII	1000	1000	1120.32	1120.32	1120.32	1240.64	1240.64	1450	1450
18	7	0	CBR	App1_CBR	NODE-2	NODE-4	NODE-2	ROUTER-1	1200	1200	1200	1200	1200	1320.32	1320.32	1450	1450
19	3	0	CBR	App1_CBR	NODE-2	NODE-4	ACCESSPOII	NODE-4	400	400	520.32	640.64	1150.84	1395.84	1395.85	1450	1450
20	7	0	CBR	App1_CBR	NODE-2	NODE-4	ROUTER-1	ACCESSPOII	1200	1200	1320.32	1320.32	1320.32	1440.64	1440.64	1450	1450
21	0	N/A	Control_Pa	WLAN_ACK	NODE-4	ACCESSPOII	NODE-4	ACCESSPOII	N/A	N/A	N/A	1395.85	1411.85	1450.85	1450.86	N/A	N/A

Data rate can be calculated from packet trace by using the formula given below:

$$PHYRate\ (Mbps) = \frac{PHYLayerPayload\ (B) \times 8}{PHYEndTime\ (\mu s) - PHYArrivalTime(\mu s) - 20(\mu s)}$$

These values can be obtained from the excel sheet of packet trace.

After putting the values in the formula, **we get Throughput for 60m as 0 Mbps.**

4. Conclusion

This project successfully demonstrated how Wi-Fi throughput varies with distance using the IEEE 802.11g standard. Simulations were carried out in NetSim by placing a wireless node at increasing distances from the access point and recording the resulting application-layer throughput.

It was observed that as the distance increased, the received signal strength decreased, which caused the PHY data rate to drop. This led to lower throughput values at the application level. For example, at 10 meters, the throughput was around 29.15 Mbps, while at 45 meters it dropped to 9.79 Mbps, and at 60 meters it became 0 Mbps due to packet losses.

The experiment aligned well with the theoretical predictions based on path loss models and PHY rate sensitivity thresholds. These results show the importance of optimal placement of access points in real-world scenarios to ensure stable and high-speed wireless communication.

This study helped us understand the fundamental relationship between distance, signal strength, PHY rate, and throughput in a wireless network and highlights the need for careful planning in Wi-Fi deployments.