QUANTITATIVE ANALYSIS OF HWMP BASED WIRELESS MESH NETWORKS USING NS-3

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ABSTRACT: Wireless mesh network deployments are considered as a cost-effective means to provide broadband connectivity to a large population. With an increase in network usage, the network planners need to enhance the existing mesh network to provide additional capacity. This work analyzes the HWMP protocol's performance with varied grid size, packet size, and number of interfaces / radios. It is observed that HWMP protocol perform well with more number of radios and larger grid size as long as the packet size is limited to 2K bytes. The performance degrades drastically beyond 2K bytes of packets and is not suitable to operate with larger packet sizes.
KEYWORDS: HWMP, IEEE 802.11s, Multi-Radio, NS3, WMNs

1. Introduction

WMNs [1] are projected as a most preferred solution for the next generation (NG) wireless communications. WMNs essentially make use of multi hop communication in order to support wireless services over a large geographical area. At the heart, the Mesh Router (MR) provides internet access to the mesh clients (MC). The MRs can be built out of general purpose systems, PCs, and/or on dedicated systems. The simplicity in adding the new routers make WMNs as the preferred technology for applications viz., intrusion detection systems, remote video surveillance, smart grids, environmental monitoring. In many applications, WMNs are expected to support internet services to heterogeneous clients.

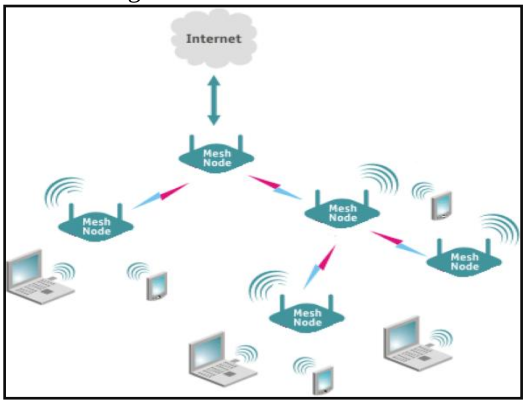


Figure 1 Multi-Radio WMN

Figure *1* depicts the need for supporting Multi-Radio functionality on MRs. The multi radio support on MCs may not be necessary. But multi radio feature may be enabled on mesh routers and gateways to obtain the best results out of WMNs.

2. Related Work

A lot of research has gone into understanding and evaluating the performance of WMNs with different grid sizes (node densities). The authors of [2] have derived the performance of 802.1s as compared to 802.11a/b/g nodes. They have observed that the multi-hopping substantially decreases the performance of IEEE 802.11n. They have also observed that WMN with network layer routing (ex. AODV) provides better performance as compared to link layer routing (ex. HWMP, PMP). It is also observed that the 802.11n with multi-hopping decreases the performance drastically.

From [3] it is inferred that the network performance can be enhanced by using multiple channels simultaneously (multi radio) over different frequency bands. But for this mechanism to work properly the channels shall be separated spatially far apart to avoid any interference to other communications over other channels at the same time. It is also observed the channels (1, 6, 11, and 14) or (2, 7, 12) or (3, 8, 13) can be used by nodes simultaneously over multiple logical or physical radios. Supporting multiple simultaneous communications over channels separated in frequency domain is called as multi-radio / multi-interface based communication. The multi radio feature can supported over existing 802.11b/g/n hardware with software update or with brand new hardware to support the multi-radio functionality over multiple antennas.

Authors of [4] have inferred that the maximum size of internet packet (application packet size) can be 65535 (2^{16}-1) bytes.

From [5] it is observed that the supporting multiple radios over the existing hardware is a preferred choice to support higher throughput. But radios shall be fabricated within the same device which works over multiple frequency bands. This work analyses the BATMAN and HWMP protocols' performance with respect to PDR, throughput, routing overhead, and E-to-E delay. The authors have inferred in a wide network, BATMAN outperforms HWMP in terms of Packet Delivery Ratio, Route Maintenance Overhead, T-put, , and E-to-E delay. When the network size is small HWMP performs better than BATMAN.

None of the existing literature has discussed about the optimal size of the application packet to achieve the best results from WMNs. Identification of the optimal packet size is the main objective of this work with variation in number of radio interfaces and grid sizes. In addition we have tried to infer the optimal number of radio interfaces to obtain the optimum results.

In order to achieve this objective, we ran simulation using NS-3 (ns3.24) with various parameters mentioned in Table. 1. Specifically variation of Grid Size (3x3, 4x4 … 7x7), Payload Size (0.5K, 1K, 1.5K, 2K,… 10K bytes) and number of radios (1, 2, 3, 4) are considered. The network performance is analyzed in terms of PDF, E-E Delay, and Throughput.

Table 1- Simulation parameters

Parameter	**Values**
Operating System	Ubuntu 12.04 LTS
Grid size (M x N)	3x3, 4x4, 5x5, 6x6, 7x7
Step size (metres)	170
Radio Propagation Model	ns3::ConstantSpeedPropagationDelay Model
Propagation Loss Model	ns3::LogDistancePropagationLossMod el
Payload size (bytes)	500, 1000, 1500, 2000, … 10000
Simulation time (s)	240
No of simulation scenarios (driven by diff random seed numbers, **RngRun** = 11, 22, 33, 44, 55, 66, 77, 88, 99, 101, 111, 122, 133, 144, 155, 166, 177, 188, 199, 211)	20
Topology	Grid
Routing protocols considered	HWMP
Number of radio interfaces (channel no. – 0, 5, 10, 13)	1 / 2 / 3 / 4
Number of nodes = M x N	9 / 16 / 25 / 36 / 49
No. of Connections	9 / 16 / 25 / 36 / 49
EnergyDetectionThreshold	-89.0 dbm
CcaMode1Threshold	-62.0 dbm
WifiPhyStandard	WIFI_PHY_STANDARD_80211b
User application	ns3::OnOffApplication
Application data rate	150kbps

3. Equations

Packet Delivery Function (%): The ratio of the count of the data packets delivered to the total number of packets sent. This illustrates the level of delivered data to the destination.

$$PDF = \frac{\sum \text{Number of packets received}}{\sum \text{Number of packets sent}} \quad (1)$$

Greater the value of packet delivery ratio means the better performance of the protocol.

End-to-end Delay (milli seconds): The average time taken by a data packet to arrive at the destination. It includes the delay introduced by route discovery process and the queue in data packet transmission. Only the data packets that are successfully delivered to destinations are considered.

$$\text{End-to-end Delay} = \frac{\sum (\text{arrival time} - \text{sent time})}{\sum \text{Number of connections}} \quad (2)$$

Lower value of end to end delay means the better performance of the protocol.

Throughput (bps): it is a measure of number of application data bytes received by the receiver in one unit of time.

$$\text{Throughput} = \frac{\sum \text{Total no. of application data bytes received}}{\sum \text{Total simulation time}} \quad (3)$$

Higher the value of throughput better is the performance of the protocol.

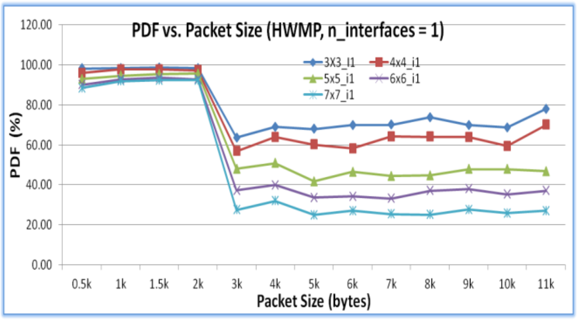
4. Tables and figures

PDF analysis

Table 2 - PDF values for different packet size, grid size and interfaces.

PDF	**0.5k**	**1k**	**1.5k**	**2k**	**3k**	**4k**	**5k**	**6k**	**7k**	**8k**	**9k**	**10k**	**11k**
3X3_i1	98.15	98.29	98.67	98.25	63.53	68.92	67.93	69.91	69.98	73.83	69.82	68.68	77.95
4x4_i1	96.00	97.77	97.70	97.31	56.84	63.92	60.17	58.11	64.24	64.04	63.86	59.43	70.04
5x5_i1	92.88	94.55	95.38	95.56	48.10	50.85	41.82	46.53	44.44	44.73	47.91	47.82	46.85
6x6_i1	90.07	92.74	93.48	92.74	37.28	39.97	33.66	34.23	33.22	37.14	37.97	35.30	37.14
7x7_i1	88.38	91.90	92.33	92.41	27.53	31.97	24.95	27.13	25.38	25.09	27.63	25.96	27.13
3X3_i2	98.62	97.60	99.58	98.84	59.78	58.66	52.79	57.34	58.83	63.75	61.27	60.54	66.39
4x4_i2	96.52	98.27	96.28	97.51	65.06	64.77	64.19	66.95	65.72	65.72	68.42	63.98	64.27
5x5_i2	93.17	96.75	96.31	97.42	54.12	57.46	51.88	54.63	55.26	58.50	55.28	55.74	55.03
6x6_i2	93.15	93.94	94.77	94.99	46.20	45.03	43.60	42.69	43.10	41.22	42.46	42.23	44.53
7x7_i2	88.78	90.16	91.42	90.43	31.76	36.03	31.29	32.13	29.95	30.95	32.45	29.80	31.32
3X3_i3	97.91	97.63	96.11	98.06	53.91	59.31	59.72	56.80	61.70	56.45	62.98	61.81	57.39
4x4_i3	95.89	97.88	98.31	98.69	67.14	70.44	66.59	68.40	68.46	67.28	68.10	68.53	67.62
5x5_i3	93.48	94.76	96.35	95.10	55.20	55.06	53.63	53.14	48.71	53.22	52.75	52.28	51.07
6x6_i3	89.53	93.06	92.87	92.74	37.38	38.80	36.68	38.04	36.33	38.75	37.63	37.16	37.30
7x7_i3	89.13	90.74	91.33	92.84	43.47	45.07	40.98	42.37	43.17	39.91	41.06	42.53	41.95
3X3_i4	98.64	98.17	98.19	98.66	51.91	51.47	50.04	51.56	55.43	54.23	58.40	54.42	55.46
4x4_i4	95.72	98.07	96.47	97.91	54.21	53.76	53.37	55.20	54.73	53.56	53.88	56.57	54.96
5x5_i4	92.90	94.15	95.26	95.32	49.58	50.66	46.88	47.80	47.89	51.67	53.96	52.78	48.92
6x6_i4	88.76	91.69	92.56	93.16	47.81	49.56	47.82	50.80	48.47	49.03	50.42	51.20	48.50
7x7_i4	86.96	88.85	88.47	88.63	38.55	37.12	35.62	37.20	36.15	37.40	39.60	38.55	38.38

Note: each cell value indicates the PDF value(%) with specific grid size – 3x3, 4x4, … 7x7 and n_interfaces – 1, 2, 3, 4



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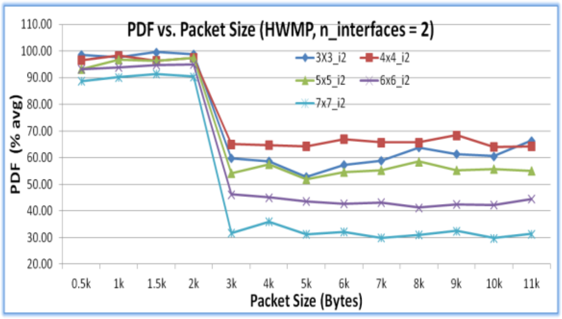

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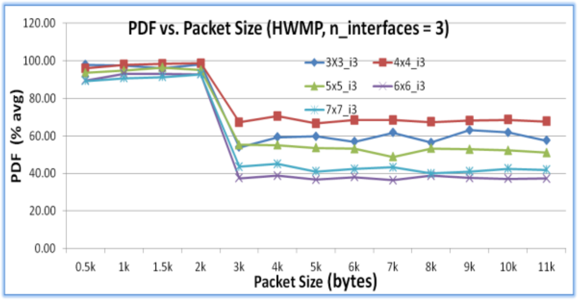

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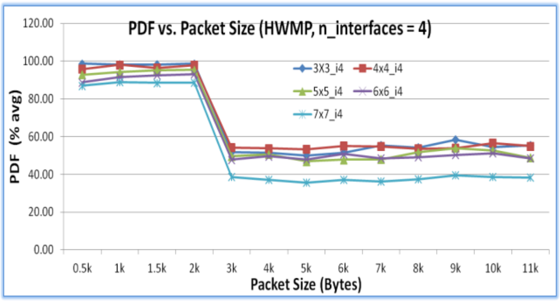


(n_interfaces=4)

Figure 2 PDF vs. PacketSize (n_interfaces=1, 2, 3, 4)

From Figure *2* it can be inferred that

- The PDF keeps increasing as the packet size increases. Maximum PDF is achieved when packet size equal to 2K bytes. With further increase in packet size, PDF decreases drastically.
- From the simulations, it is observed that the PDF drops substantially beyond 11K bytes of packet size.
- At larger packet sizes, the nodes with lesser number of radio interfaces do perform better than nodes with more number of interfaces.
- The lower bound on the PDF at higher sized packets can be attributed to higher probability of collision, because each of the packets might have been fragmented into a number of smaller fragments. Even if one / few of the fragment is garbled, all the fragments of that packet shall be retransmitted. Thus larger sized packets lead to PDF degradation and hence may not be preferred for wireless networks.

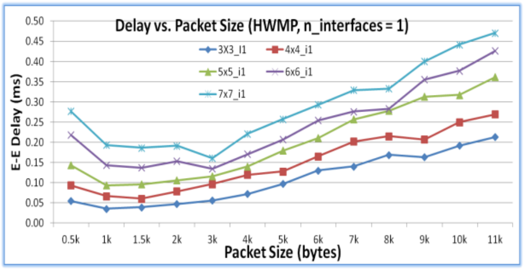
End-to-End Delay analysis

Table 3 - Delay values for different packet size, grid size and interfaces.

DELAY	0.5k	1k	1.5k	2k	3k	4k	5k	6k	7k	8k	9k	10k	11k
3X3_i1	0.06	0.04	0.04	0.05	0.06	0.07	0.10	0.13	0.14	0.17	0.16	0.19	0.21
4x4_i1	0.09	0.07	0.06	0.08	0.10	0.12	0.13	0.17	0.20	0.22	0.21	0.25	0.27
5x5_i1	0.14	0.09	0.10	0.11	0.12	0.14	0.18	0.21	0.26	0.28	0.31	0.32	0.36
6x6_i1	0.22	0.14	0.14	0.15	0.13	0.17	0.21	0.25	0.28	0.28	0.36	0.38	0.43
7x7_i1	0.28	0.19	0.19	0.19	0.16	0.22	0.26	0.29	0.33	0.33	0.40	0.44	0.47
3X3_i2	0.05	0.03	0.03	0.04	0.06	0.09	0.09	0.10	0.12	0.14	0.18	0.19	0.21
4x4_i2	0.07	0.05	0.05	0.06	0.08	0.11	0.12	0.16	0.19	0.25	0.22	0.28	0.28
5x5_i2	0.07	0.06	0.07	0.09	0.11	0.14	0.16	0.21	0.23	0.25	0.28	0.31	0.35
6x6_i2	0.11	0.09	0.10	0.12	0.14	0.18	0.21	0.25	0.29	0.35	0.38	0.39	0.43
7x7_i2	0.15	0.13	0.14	0.17	0.19	0.22	0.26	0.29	0.38	0.39	0.44	0.48	0.52
3X3_i3	0.05	0.03	0.03	0.05	0.06	0.07	0.12	0.10	0.15	0.15	0.18	0.16	0.20
4x4_i3	0.05	0.04	0.05	0.06	0.08	0.10	0.12	0.15	0.20	0.22	0.22	0.25	0.28
5x5_i3	0.06	0.06	0.07	0.09	0.11	0.15	0.18	0.21	0.24	0.28	0.28	0.34	0.35
6x6_i3	0.10	0.10	0.11	0.13	0.14	0.18	0.22	0.28	0.34	0.33	0.35	0.40	0.45
7x7_i3	0.11	0.12	0.14	0.16	0.21	0.25	0.29	0.33	0.39	0.44	0.46	0.53	0.55

3X3_i4	0.04	0.03	0.04	0.04	0.05	0.06	0.08	0.12	0.12	0.14	0.16	0.19	0.19
4x4_i4	0.04	0.04	0.05	0.06	0.07	0.10	0.11	0.14	0.16	0.19	0.21	0.23	0.24
5x5_i4	0.07	0.07	0.08	0.09	0.11	0.15	0.18	0.21	0.27	0.28	0.28	0.31	0.34
6x6_i4	0.10	0.10	0.11	0.13	0.30	0.20	0.22	0.26	0.31	0.35	0.36	0.42	0.47
7x7_i4	0.10	0.12	0.14	0.17	0.18	0.24	0.28	0.31	0.36	0.43	0.45	0.46	0.51

Note: each cell value indicates the E-E delay value(milliseconds) with specific grid size – 3x3, 4x4, … 7x7 and n_interfaces – 1, 2, 3, 4



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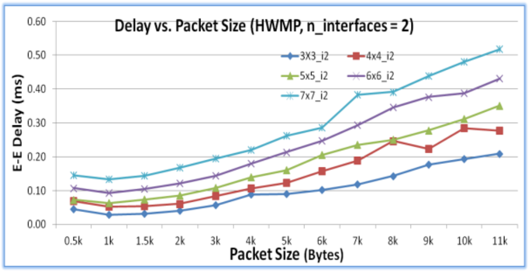

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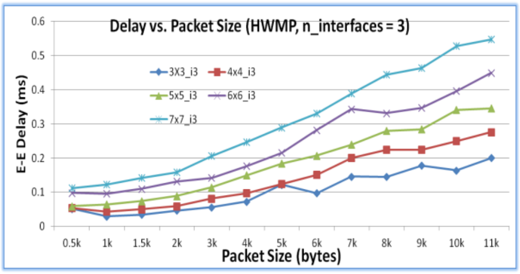

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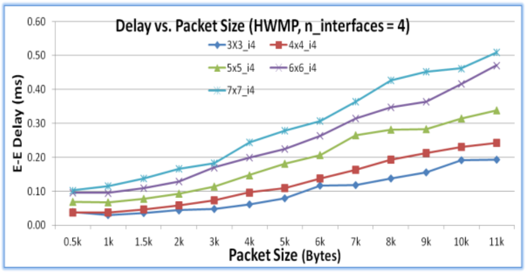


(n_interfaces=4)

Figure 3 Delay vs. PacketSize (n_interfaces=1, 2, 3, 4)

From Figure *3* it can be inferred that

- The E-E delay keeps increasing with increase in grid size (higher number of nodes). This may be linked to longer propagation delays over links, processing and queuing delays at routers.
- If the real time applications are to be supported over MWN, it shall be made sure that the Mesh Clients and Routers are separated by minimum possible number of hops. On the other hand non real time applications may be supported over longer distance between Mesh Clients and Routers.
- On an average, larger grid areas (more number of nodes) lead to larger E-E delays. This can attributed to accumulated processing times at each of the intermediate mesh routers before the packet is delivered to final destination.

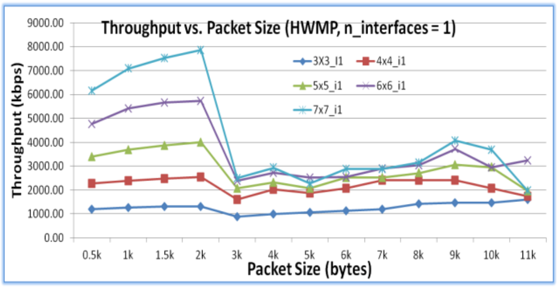
Throughout analysis

Table 4 - Throughput values for different packet size, grid size and interfaces.

T-PUT	**0.5k**	**1k**	**1.5k**	**2k**	**3k**	**4k**	**5k**	**6k**	**7k**	**8k**	**9k**	**10k**	**11k**
3X3_i1	1198.37	1256.82	1303.31	1310.43	891.54	994.07	1052.70	1135.47	1193.58	1430.79	1461.75	1458.55	1597.77
4x4_i1	2264.32	2381.91	2483.10	2545.46	1593.34	2017.16	1865.16	2080.94	2406.76	2402.50	2402.76	2067.32	1726.56
5x5_i1	3405.33	3682.43	3860.73	4009.77	2067.29	2325.23	2069.31	2523.31	2516.47	2711.55	3051.19	2958.12	1964.49
6x6_i1	4759.38	5409.86	5658.88	5722.03	2382.51	2727.82	2528.04	2543.04	2893.88	3045.08	3722.17	2947.32	3243.07
7x7_i1	6159.80	7088.57	7530.63	7867.50	2501.08	2935.16	2263.57	2878.20	2888.43	3142.33	4071.91	3695.50	1970.86
3X3_i2	1170.87	1211.44	1242.15	1298.32	859.35	934.30	854.13	949.40	1140.92	1237.85	1385.83	1397.67	1174.34
4x4_i2	2287.68	2425.37	2447.31	2515.03	1787.49	1808.29	1920.77	2097.99	2323.49	2454.48	2798.11	2591.23	1642.80
5x5_i2	3604.16	3858.11	3965.25	4184.61	2516.53	2524.69	2547.95	3395.28	3125.59	3168.92	3653.53	2600.85	3081.71
6x6_i2	5241.29	5649.66	5779.50	6024.90	3137.49	3328.95	3452.93	3666.50	3586.98	4115.54	4140.70	3349.45	504.52
7x7_i2	6824.58	7548.69	7917.66	8218.16	2995.56	3528.16	3493.01	3523.88	3272.37	3340.40	4548.92	2602.95	2044.95

3X3_i3	1189.26	1249.02	1255.53	1305.44	805.30	912.02	976.13	967.99	1166.84	1206.91	1359.49	1250.95	955.26
4x4_i3	2323.36	2441.84	2551.93	2632.26	1906.95	2121.69	2001.89	2412.78	2670.66	2773.36	2806.82	2635.99	1532.38
5x5_i3	3545.27	3888.07	3971.98	4119.00	2571.87	2832.45	2858.31	3122.50	3219.57	3991.04	3401.40	2084.04	1396.17
6x6_i3	5343.86	5621.21	5908.22	6211.70	2679.59	2917.64	2722.48	3052.48	2601.86	3831.00	3901.38	1511.67	1912.83
7x7_i3	7257.01	7980.23	8190.92	8480.66	3919.70	4714.23	4935.84	4577.10	4109.50	5845.78	6131.31	3838.86	1107.19
3X3_i4	1112.24	1157.88	1189.98	1215.90	715.44	753.95	791.06	937.78	979.53	1063.39	1167.20	1329.92	1276.46
4x4_i4	2276.14	2403.44	2438.14	2534.57	1533.32	1586.88	1709.63	1812.24	2026.63	2235.54	2529.41	1603.02	1351.86
5x5_i4	3595.01	3832.95	3982.24	4105.34	2345.51	2634.11	2754.20	2998.65	3104.89	3959.47	4197.29	2065.21	671.45
6x6_i4	5312.84	5631.78	5940.64	6224.56	3454.19	3573.63	3891.21	3801.97	4541.27	3873.40	5245.99	2882.74	4791.55
7x7_i4	7401.72	7865.38	8436.97	8830.83	3748.38	4020.23	4438.56	5074.22	4757.47	4970.52	4883.07	5244.08	2615.10

Note: each cell value indicates the Throughput value(kbps) with specific grid size – 3x3, 4x4, … 7x7 and n_interfaces – 1, 2, 3, 4



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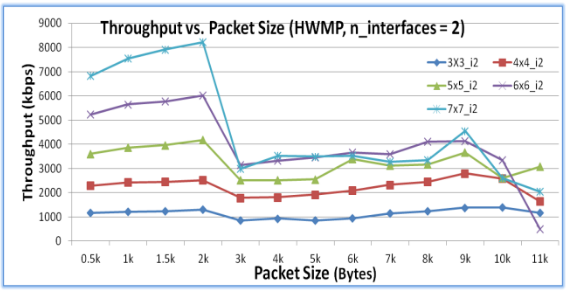

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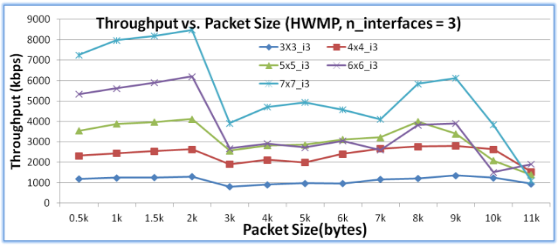

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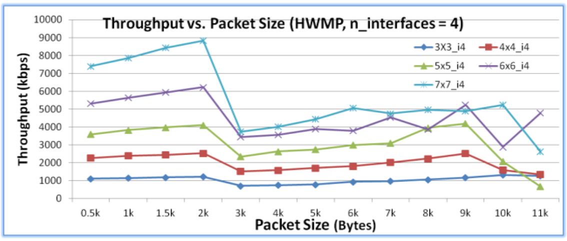

(n_interfaces=4)

Figure 4 T-put vs. PacketSize (n_interfaces=1,2,3,4)

From Figure *4* it can be inferred that

- Throughput increases with increase in node density as long as the packet size is less than or equal to 2K bytes. The throughput drops significantly at larger packet sizes. This may be impacted due to increased collisions with larger grid sizes and more number of radio interfaces.
- At larger values of packet size, the throughput observed to be better with larger grid size and more number of interfaces.

5. Conclusion

In this paper, we have presented a detailed analysis of performance of HWMP protocol based Wireless Mesh Networks with varied grid size, packet size, and number of radio interfaces. Very often researchers think of enabling more number of logical interfaces over the commercially available routers with a software update to support higher throughput. This assumption may go wrong if the packet size is increased beyond 2K bytes. If the packet size is limited to 2K bytes, it is preferred to operate with more number of radio interfaces and over a large grid area. If the coverage is required over a small area (smaller grid size) it is suggested to operate with lesser number of radio interfaces as there is no gain in throughput with higher number of radio interfaces.

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