Performance analysis of 802.15.4 based wireless sensor networks using NetSim

Applicable Release: NetSim v13.3.12 or higher
Applicable Version(s): All (Academic, Standard and Pro)
Project download link: See Appendix-1. The URL has the configuration files (scenario, settings, and other related files) of the examples discussed in this analysis for users to import and run in NetSim

Introductions

Wireless sensor networks (WSNs), was a concept that originated in the mid-1990s, have now reached a stage in their evolution, where world is covered with wireless sensor networks with access to them via Internet of Things (IoT). WSNs have unlimited potential for application in areas such as environmental, medical, military, transportation, entertainment, crisis management, homeland defence and smart spaces.

A WSN comprises nodes/motes equipped with a microprocessor, memory, radio, and battery, which combine the functions of sensing, computing, and wireless communication onto a miniature smart sensor node. IEEE 802.15.4-2006 is the standard which specifies the physical layer and media access control of these motes [1].

IEEE 802.15.4 is a low-cost, low-data-rate wireless access technology for devices that are operated or work on batteries. This describes how low-rate wireless personal area networks (LR-WPANs) function.

A major challenge in the area of WSNs is designing the network. A sensor network design is influenced by many factors, including fault tolerance, scalability, cost, operating environment, sensor network topology, hardware constraints, transmission media, power consumption, and so on. Various industrial applications based on sensor networks have different Quality-of-Service (QoS) requirements like bounded latency (time taken for a generated packet to reach the base station), guaranteed throughput, maximum network lifetime (energy efficiency), etc.

IEEE 802.15.4 relies on spread spectrum digital modulation of a 2 MHz bandwidth carrier in the 2.4 GHz ISM band, and CSMA/CA medium access control. The standard defines two types of CSMA/CA algorithms- slotted and unslotted and is named based on the algorithm chosen - beaconed and beaconless, respectively.

In this document, we study the performance of beaconless operation of IEEE 802.15.4 and are concerned with the performance analysis of WSNs that rely on beaconless IEEE 802.15.4 multi-hop wireless networks for interconnecting the sensors with the base station.

Pathloss, Transmission range and Carrier Sense (CS) Range

Pathloss: The standard pathloss equation is

$$RX_{power} = TX_{power} + G_T + G_R - PL_{d0} - 10 \times \eta \times \log\left(\frac{d}{d_o}\right)$$

where, TX_{power} is the transmitter Power, G_T is the transmit antenna gain, G_R is the receiver antenna gain, PL_{d0} is the reference distance pathloss, η is the pathloss exponent and d is the transmitter receiver separation in meters. The reference distance pathloss is given by

$$PL_{d0} = 20\log_{10}\left(\frac{\lambda}{(4 \times \pi \times d_0)}\right)$$

Per the 802.15.4 standard, the reference distance d_0 is 8m, while the operating frequency is 2.4×10^9 Hz. Applying these in the above formula, we get $PL_{d0} = 58\, dB$.

Transmission Range (d_T): The receive sensitivity in 802.15.4 is -85 dBm. Given a transmitter power of 1 mW or 0 dBm, zero gains for the transmit and receive antennas, and $\eta = 2$, we can compute the transmit range, d_T as follows:

$$RX_{power} = TX_{power} + G_T + G_R - PL_{d0} - 10 \times \eta \times \log\left(\frac{d_T}{d_0}\right) = RX_{Sens} = -85\ dBm$$

$$0 + 0 + 0 - 58.10 - 10 \times 2 \times \log\left(\frac{d_T}{d_0}\right) = -85$$

$$d_T = 10^{1.345} \times d_0 = 177.04\ m$$

Carrier Sense Range (d_{CS}): In the examples in this document, we set the CS threshold as 2 dB below the receive sensitivity. Thus, the CS range, d_{CS} can be computed as

$$RX_{power} = TX_{power} + G_T + G_R - PL_{d0} - 10 \times \eta \times \log\left(\frac{d_{cs}}{d_0}\right) = CS_{TH} = -87\ dBm$$

$$d_{CS} = 10^{1.495} \times d_0 = 222.88\ m$$

Simulation Scenarios

We use NetSim to simulate and analyse the performance four sensor network scenarios:

1. Case 1: The network consists of two sensors transmitting data to a common sink node. Each sensor is placed 150m away from the sink node, such that sensor 1 and sink node are in transmission range and similarly, sensor 2 and sink node are in transmission range. The two sensors, sensor 1 and sensor 2 are beyond CS Range of one another. In other words, the sensors are "hidden" from one another.
2. Case 2: The network has sensors placed, equally spaced, along east, west, north, and south directions of the sink node. The sensor nodes are kept 170m away from the sink node such that each sensor and the sink node will be in transmission range. However, any two sensors will be beyond CS Range of one another. This case is like Case # 1, except that we have 4 sensors instead of 2.
3. Case 3: The network has 20 sensors placed in a circular manner around the sink node. Each sensor is placed at a radius of 75m from the sink node. Therefore, all sensors are within CS range of one another. All the sensors transmit data to the sink node.
4. Case 4: Multi-hop transmission via a relay
5. Case 5: Multi-hop transmission via a relay-sensor which also generates traffic

Transmission time for a packet of size 100B (Application layer)

$$PHY\ Layer\ Packet\ Size = App\ Layer\ packet\ size + Overheads = 100 + 33 = 133B = 1064\ bits$$

$$Transmission\ Time = \frac{1064\ bits}{250 * 10^3\ bps} = 0.004256\ \text{sec} = 4256\ \mu sec$$

$$1\ symbol\ time = T_s = 16\mu sec$$

$$Transmission\ Time = 266\ T_s$$

Case 1: Two sensors equidistant from a sink. Both nodes transmitting and beyond CS range of each other

Network Layout

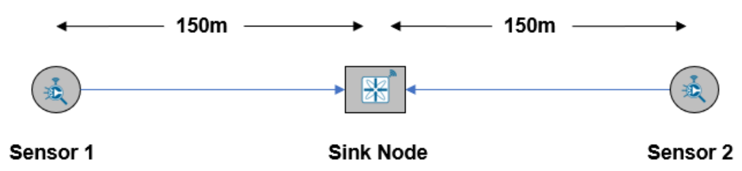

Fig 1: Schematic of network layout. The sources of traffic are Sensor 1 (S1), and Sensor 2 with destination Sink Node (SN). S1 – SN = 150m and S1 – S2 = 300m. Transmission range = 177m and CS Range = 223m. Therefore S1 – S2 are not in CS range.

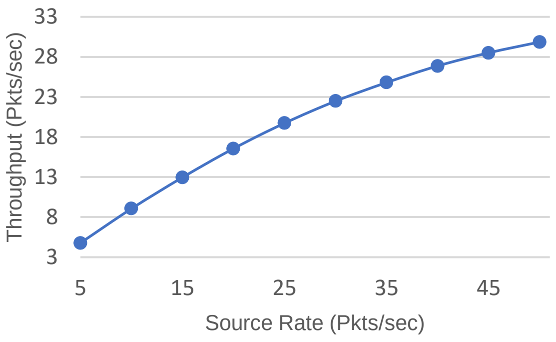

Fig 2:Throughput of Node 1 (θ_1) vs. Source rate. Source data: Table 5

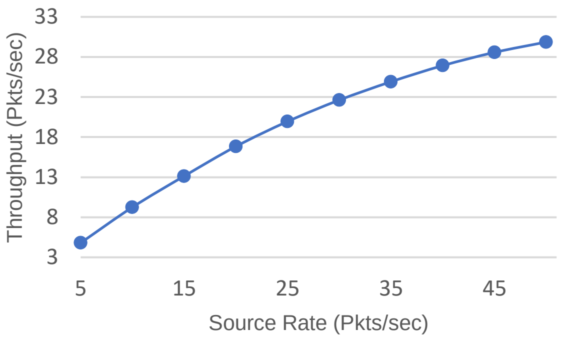

Fig 3: Throughput of Node 2 (θ_2) vs. Source rate. Source data:Table 5

Case 2: Four nodes equidistant from a sink. All nodes transmitting. No node within CS range.

Network Layout

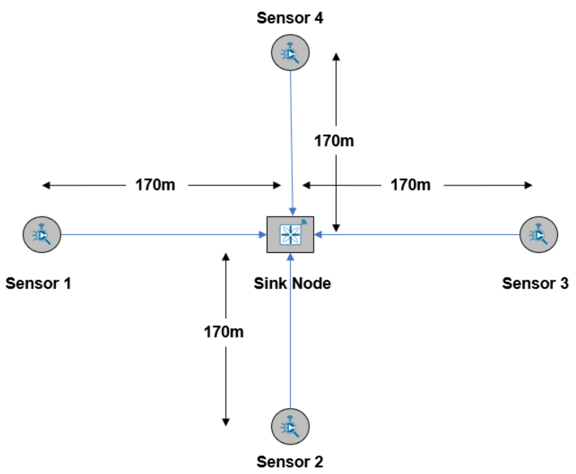

Fig 4 : Schematic of network layout. The sources of traffic are Sensor 1 (S1), Sensor 2 (S2), Sensor 3 (S3) and Sensor 4 (S4) with destination Sink Node (SN). S1–SN, S2-SN, S3- SN, S4-SN = 170m and S1–S2 = 240.42m. Transmission range = 177m and CS Range = 223m.

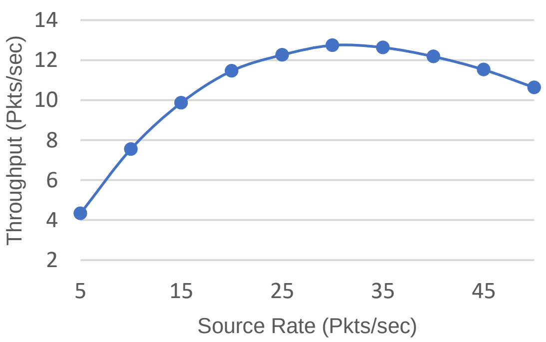

Fig 5: Throughput of Node 1 (θ_1) vs. Source rate. Source data:Table 7

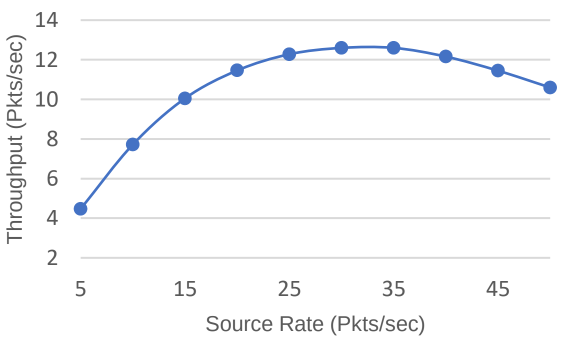

Fig 6: Throughput of Node 3 (θ_3) vs. Source rate. Source data:Table 7

Case 3: Twenty nodes equidistant from the sink. All transmitting. All in CS range of each other.

Network Layout

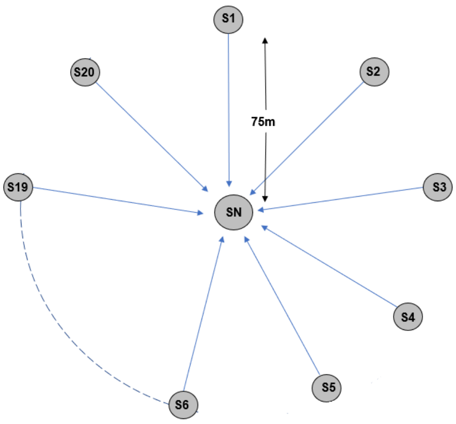

Fig 7: Schematic of network layout. The sources of traffic are Sensor 1 (S1), Sensor 2 (S2), Sensor 3 (S3) etc. Sensor 20 (S20) with destination Sink Node (SN). S1 – SN, S2-SN, S3- SN, S4-SN… S20-SN = 75m. Transmission range = 177m and CS Range = 223m.

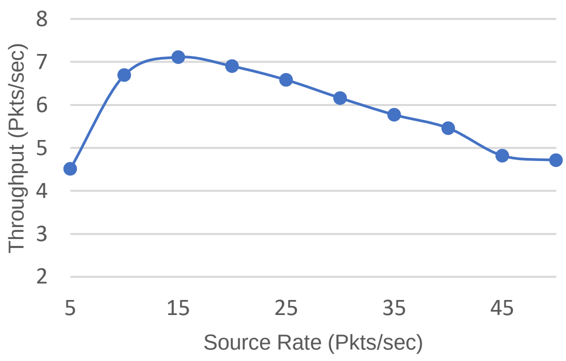

Fig 8: Throughput of Node 1 (θ_1) vs. Source rate. Source data: Table 9

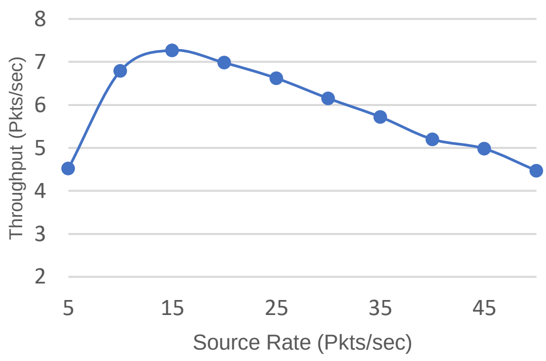

Fig 9: Throughput of Node 10 (θ_{10}) vs. Source rate. Source data: Table 9

Case 4A: multi-hop transmission via a relay. Two transmitting nodes.

Network Layout

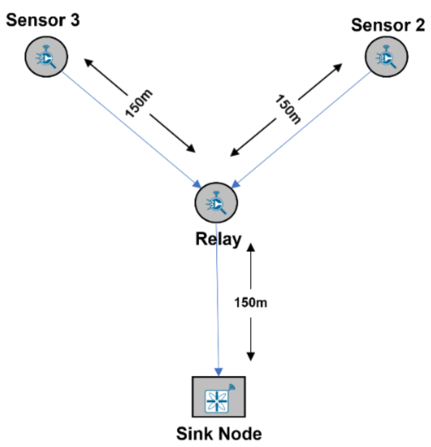

Fig 10 : Schematic of network layout. The sources of traffic are Sensor 2 (S2), Sensor 3 (S3) with destination Sink Node (SN). Each sensor is 150m from the relay and the relay is 150m from the sink node. Transmission range = 177m and CS Range = 223m.

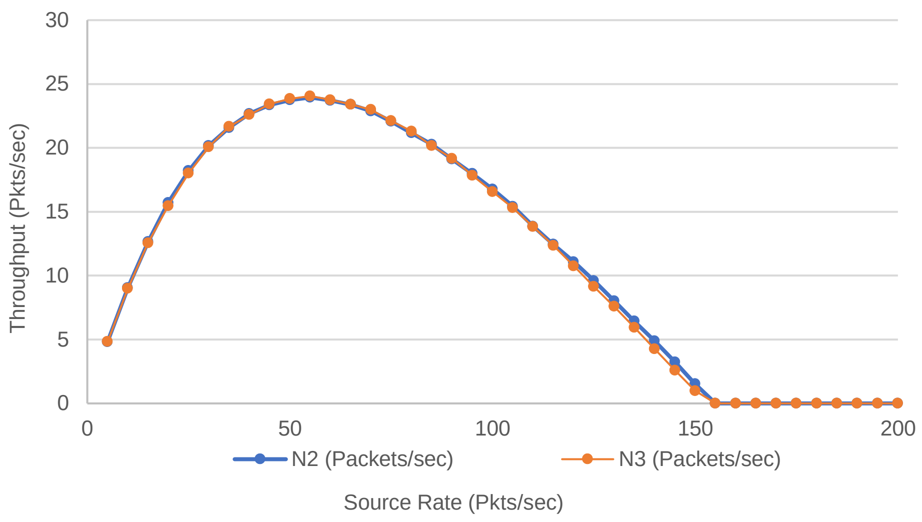

Fig 11: Throughput of Node 2 (θ_2) and Node 3 (θ_3) vs. Source rate. Source data: Table 11

Case 4B: multi-hop transmission via a relay. Two transmitting nodes.
Network Layout

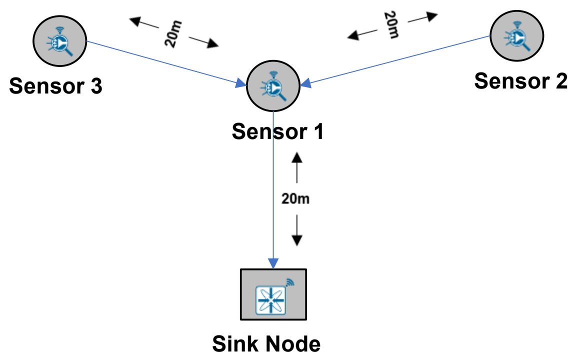

Fig 12: Schematic of network layout. The sources of traffic are Sensor 2 (S2), Sensor 3 (S3) with destination Sink Node (SN). Each sensor is 20m from the relay and the relay is 20m from the sink node. Transmission range = 177m and CS Range = 223m.

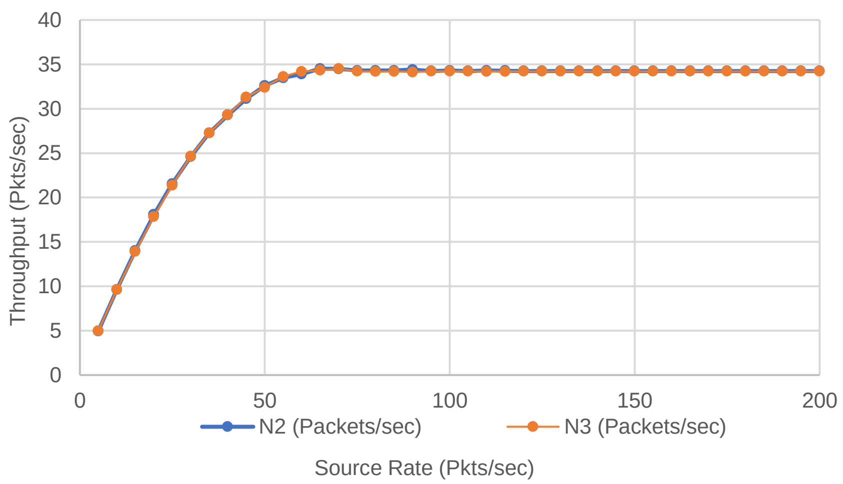

Fig 13: Throughput of Node 2 (θ_2) and Node 3 (θ_3) vs. Source rate. Source data: Table 13

Case 5A: multi-hop transmission via a relay sensor which also generates traffic. Three transmitting nodes

Network Layout

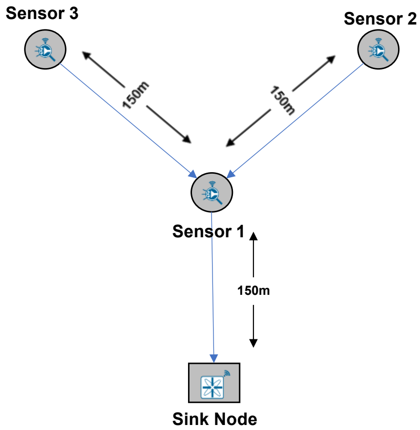

Fig 14 : Schematic of network layout. The sources of traffic are Relay, Sensor 2 (S2), Sensor 3 (S3) with destination Sink Node (SN). Each sensor is 150m from the relay and the relay are 150m from the sink node. Transmission range = 177m and CS Range = 223m.

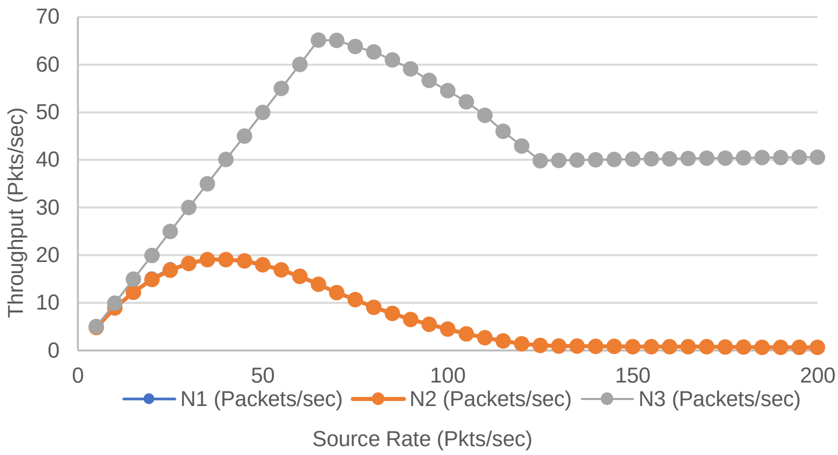

Fig 15 :Throughput of Node 1 (θ_1), Node 2 (θ_2) m Node 3 (θ_3) vs. Source rate. Source data: Table 15

Case 5B: multi-hop transmission via a relay sensor which also generates traffic. Three transmitting nodes

Network Layout

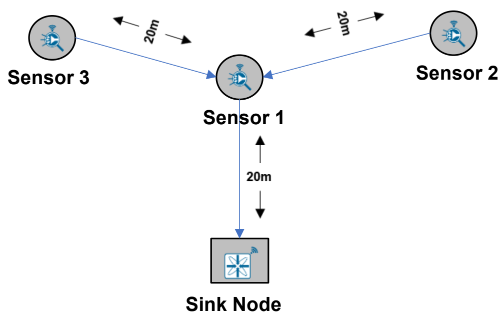

Fig 16 : Schematic of network layout. The sources of traffic are Sensor 1 (S1), Sensor 2 (S2), Sensor 3 (S3) with destination Sink Node (SN). Each sensor is 20m from each other. Transmission range = 177m and CS Range = 223m.

The results show that the relation between the input rate λ and the throughput μ can be divided into three distinct phases according to λ:

- $\lambda < \lambda 1$ (50 packet/s): It occurs when the source rate is within capacity. In this case no queues build up and μ is an increasing function of λ and it reaches its maximum at $\mu 1$ ($\mu 1 = \lambda 1$).
- $\lambda > \lambda 2$ (75 packet/s): It corresponds to the saturated regime, where the source always has packets to send.
- $\lambda 1 < \lambda < \lambda 2$: It is the phase during which a form of congestion collapse occurs. Indeed, μ is a decreasing function of λ in this region. This performance drop is caused by the queue build-up at the first relay that consumes resources.

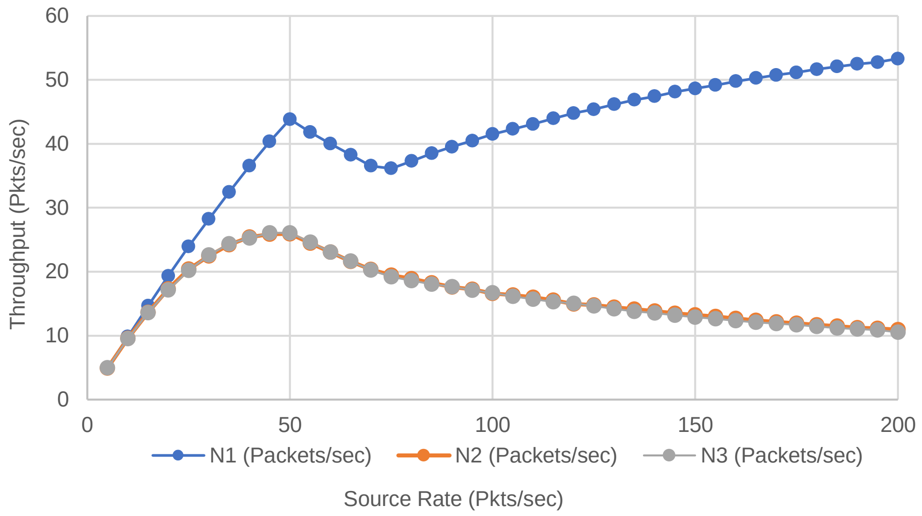

Fig 17: Throughput of Node 1 (θ_1), Node 2 (θ_2) m Node 3 (θ_3) vs. Source rate. Source data: Table 17

Appendix

Network Settings:

The following settings were configured in all the cases.

Sensor and Sink Node Properties	
General Properties	
Mobility Model	No Mobility
Interface Zigbee Properties- Physical Layer	
Frequency	2.4 GHz
PhySHRDuration (Symbols)	3
CCA Mode	Carrier Sense Only
Receiver Sensitivity (dBm)	-85
EDThreshold (dBm)	-87
Transmitter Power (mW)	1
Antenna Gain	0
Antenna Height (m)	1
Reference Distance d0 (m)	8
Interface Zigbee- Datalink Layer	
Ack Request	Disable
Beacon Mode	Disable
Max CSMA BO	4
Max Backoff Expo	5
Min Backoff Expo	3
Max Frame Retries	3

Table 1: Values set for different parameters in simulation

Application Properties	
Application Method	Unicast
Application Type	Custom
Source Id	Sensor_1, Sensor_2….12
Destination Id	WSN_Sink_13
Start Time(s)	0
Transport Protocol	UDP
Packet Size Distribution	Constant
Packet Size (B)	100
IAT Distribution	Exponential
IAT Mean (μs)	200000, 100000, 66667, 50000,40000,33333,28571, 25000,22222,20000

Table 2: Application properties set in these experiments.

Wireless Link Properties	
Channel Characteristics	Pathloss Only
Pathloss Model	Log Distance
Pathloss Exponent	2
Simulation Parameters	
Simulation Time(s)	1000

Table 3: Wireless Link parameter and Simulation time

Case 1
Network Scenario

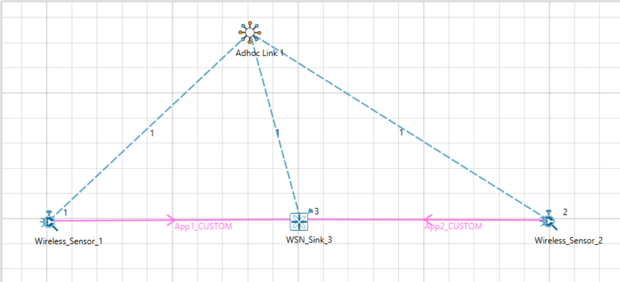

Fig 18: Network Scenario for Case 1

Static Route configuration

Static routes were configured in each source node such that the data gets transmitted directly from source to destination without any dynamic route formation by the routing protocols.

Static routes (whereby N_i always transmits to $N_{(i+1)}$) are set to ensure single hop transmission. Thereby each node transmits data to the next-hop node according to the topology.

To set the static routes, go to Wireless_Sensor properties > Network Layer > Enable Static Route IP.

The Static route IP were configured in Wireless_Sensor_1, and Wireless_ Sensor_2 as shown below:

Device	Network Destination	Gateway	Subnet Mask	Metrics	Interface ID
Wireless_ Sensor_1	11.1.1.0	11.1.1.1	255.255.255.0	1	1
Wireless_ Sensor_2	11.1.1.0	11.1.1.1	255.255.255.0	1	1

Table 4: Static route configured in devices

Results

Per node source rate, λ pkts/sec	Inter packet arrival time (µs) = $10^6/\lambda$	N1 throughput, θ_1 pkts/sec	N2 throughput, θ_2 pkts/sec
5	200,000	4.78	4.80
10	100,000	9.06	9.25

15	66,667	12.96	13.13
20	50,000	16.56	16.83
25	40,000	19.73	19.95
30	33,333	22.48	22.62
35	28,571	24.80	24.91
40	25,000	26.87	26.92
45	22,222	28.51	28.57
50	20,000	29.86	29.86

Table 5 :NetSim results for simulations of case 1

Case 2
Network Scenario

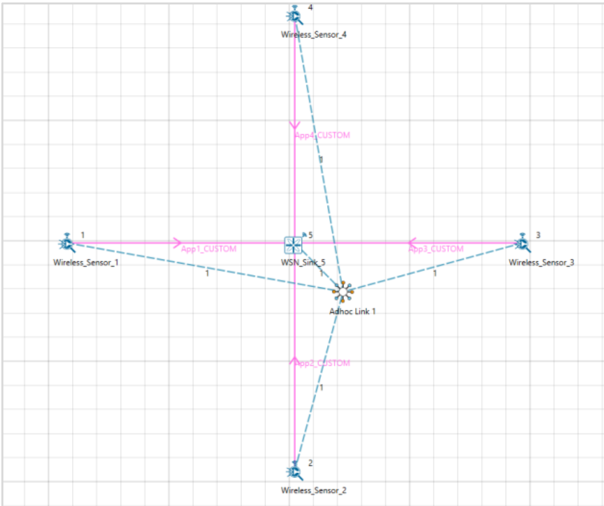

Fig 19 : Network Scenario for Case 2

Static Route configuration

Static routes were configured in each source node such that the data gets transmitted directly from source to destination without any dynamic route formation by the routing protocols.
Static routes (whereby N_i always transmits to $N_{(i+1)}$) are set to ensure single hop transmission. Thereby each node transmits data to the next-hop node according to the topology.

To set the static routes, go to Wireless_Sensor properties > Network Layer > Enable Static Route IP. The Static route IP were configured in Wireless_Sensor_1, Wireless_ Sensor_2, Wireless_Sensor_3 and Wireless_Sensor_4 as shown below:

Device	Network Destination	Gateway	Subnet Mask	Metrics	Interface ID
Wireless_ Sensor_1	11.1.1.0	11.1.1.1	255.255.255.0	1	1
Wireless_ Sensor_2	11.1.1.0	11.1.1.1	255.255.255.0	1	1
Wireless_ Sensor_3	11.1.1.0	11.1.1.1	255.255.255.0	1	1
Wireless_ Sensor_4	11.1.1.0	11.1.1.1	255.255.255.0	1	1

Table 6: Static route configured in devices

Results

Per node source rate, λ pkts/sec	Inter packet arrival time (µs) = $10^6/\lambda$	N1 throughput, θ_1 pkts/sec	N2 throughput, θ_2 pkts/sec	N3 throughput, θ_3 pkts/sec	N4 throughput, θ_4 pkts/sec
5	200,000	4.33	4.40	4.47	4.30
10	100,000	7.55	7.76	7.72	7.44
15	66,667	9.87	9.98	10.05	9.90
20	50,000	11.46	11.59	11.46	11.40

25	40,000	12.26	12.44	12.28	12.29
30	33,333	12.74	12.67	12.60	12.69
35	28,571	12.63	12.55	12.60	12.47
40	25,000	12.18	12.16	12.16	11.97
45	22,222	11.52	11.49	11.45	11.27
50	20,000	10.63	10.64	10.60	10.56

Table 7 : NetSim results for simulations of case 2.

Case 3
Network Scenario

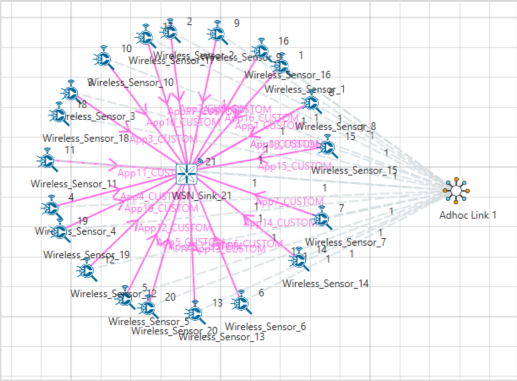

Fig 20: Network Scenario for Case 3

Static Route configuration

Static routes were configured in each source node such that the data gets transmitted directly from source to destination without any dynamic route formation by the routing protocols.
Static routes (whereby N_i always transmits to $N_{(i+1)}$) are set to ensure single hop transmission. Thereby each node transmits data to the next-hop node according to the topology.

To set the static routes, go to Wireless_Sensor properties > Network Layer > Enable Static Route IP. The Static route IP were configured in Wireless_Sensor_1, Wireless_ Sensor_2, Wireless_Sensor_3 etc. and Wireless_Sensor_20 as shown below:

Device	Network Destination	Gateway	Subnet Mask	Metrics	Interface ID
Wireless_ Sensor_1	11.1.1.0	11.1.1.1	255.255.255.0	1	1
Wireless_ Sensor_2	11.1.1.0	11.1.1.1	255.255.255.0	1	1
Wireless_ Sensor_3	11.1.1.0	11.1.1.1	255.255.255.0	1	1
Wireless_ Sensor_4	11.1.1.0	11.1.1.1	255.255.255.0	1	1
Wireless_Sensor_i	11.1.1.0	11.1.1.1	255.255.255.0	1	1
Wireless_Sensor_20	11.1.1.0	11.1.1.1	255.255.255.0	1	1

Table 8: Static route configured in devices

Results

Per node source rate, λ pkts/sec	Inter packet arrival time (μs) = $10^6/\lambda$	N1 throughput, θ_1 pkts/sec	N10 throughput, θ_{10} pkts/sec
5	200,000	4.51	4.52
10	100,000	6.69	6.79
15	66,667	7.11	7.27
20	50,000	6.90	6.98
25	40,000	6.58	6.62
30	33,333	6.16	6.15
35	28,571	5.77	5.72

40	25,000	5.46	5.20
45	22,222	4.82	4.98
50	20,000	4.71	4.47

Table 9: NetSim results for simulations of case 3

Case 4A
Network Scenario

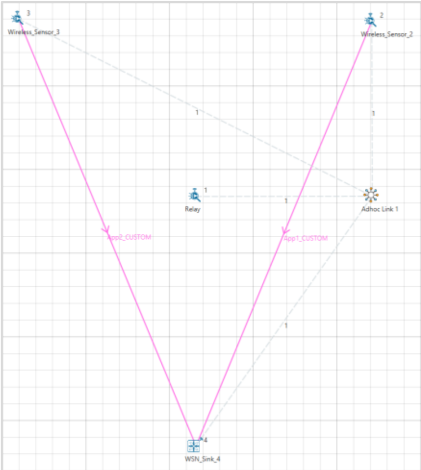

Fig 21 : Network Scenario for Case 4A

Static Route configuration

Static routes were configured in each source node such that the data gets transmitted to the destination through intermediate nodes.

To set the static routes, go to Wireless_Sensor properties > Network Layer > Enable Static Route IP. The Static route IP were configured in Wireless_Sensor_1, Wireless_ Sensor_2, Wireless_Sensor_3 as shown below:

Device	Network Destination	Gateway	Subnet Mask	Metrics	Interface ID
Wireless_ Sensor_1	11.1.1.1	11.1.1.1	255.255.255.255	1	1
Wireless_ Sensor_2	11.1.1.1	11.1.1.2	255.255.255.255	1	1
Wireless_ Sensor_3	11.1.1.1	11.1.1.2	255.255.255.255	1	1

Table 10: Static route configured in devices

Results

Per node source rate, λ pkts/sec	Inter packet arrival time (µs) = $10^6/\lambda$	N2 throughput, θ_2 pkts/sec	N3 throughput, θ_3 pkts/sec
5	200000	4.82	4.83
10	100000	9.05	8.99
15	66667	12.65	12.56
20	50000	15.72	15.47
25	40000	18.21	18.02
30	33333	20.18	20.08
35	28571	21.58	21.67
40	25000	22.68	22.59
45	22222	23.35	23.43
50	20000	23.75	23.85
55	18182	23.95	24.06
60	16667	23.71	23.76

65	15385	23.39	23.41
70	14286	22.88	22.99
75	13333	22.07	22.11
80	12500	21.17	21.30
85	11775	20.27	20.16
90	11111	19.11	19.17
95	10526	17.98	17.84
100	10000	16.77	16.57
105	9524	15.41	15.30
110	9091	13.86	13.83
115	8696	12.45	12.36
120	8333	11.08	10.76
125	8000	9.60	9.14
130	7692	8.02	7.59
135	7407	6.44	5.94
140	7143	4.88	4.25
145	6897	3.24	2.59
150	6667	1.52	0.99
155	6452	0.00	0.00
160	6250	0.00	0.00
165	6061	0.00	0.00
170	5882	0.00	0.00
175	5714	0.00	0.00
180	5556	0.00	0.00
185	5405	0.00	0.00
190	5263	0.00	0.00
195	5128	0.00	0.00
200	5000	0.00	0.00

Table 11: NetSim results for simulations of case 4A

Case 4B
Network Scenario

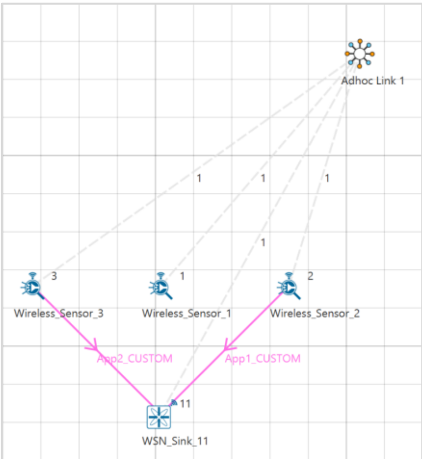

Fig 22 : Network Scenario for Case 4B

Static Route configuration

Static routes were configured in each source node such that the data gets transmitted to the destination through intermediate nodes.

To set the static routes, go to Wireless_Sensor properties > Network Layer > Enable Static Route IP. The Static route IP were configured in Wireless_Sensor_1, Wireless_ Sensor_2, Wireless_Sensor_3 as shown below:

Device	Network Destination	Gateway	Subnet Mask	Metrics	Interface ID
Wireless_ Sensor_1	11.1.1.1	11.1.1.1	255.255.255.255	1	1
Wireless_ Sensor_2	11.1.1.1	11.1.1.2	255.255.255.255	1	1
Wireless_ Sensor_3	11.1.1.1	11.1.1.2	255.255.255.255	1	1

Table 12: Static route configured in devices

Results

Per node source rate, λ pkts/sec	Inter packet arrival time (μs) = $10^6/\lambda$	N2 throughput, θ_4 pkts/sec	N3 throughput, θ_8 pkts/sec
5	200000	4.96	4.99
10	100000	9.64	9.62
15	66667	14.02	13.90
20	50000	18.08	17.85
25	40000	21.56	21.37
30	33333	24.60	24.66
35	28571	27.28	27.28
40	25000	29.28	29.32
45	22222	31.13	31.31
50	20000	32.60	32.39
55	18182	33.48	33.62
60	16667	33.91	34.19
65	15385	34.52	34.33
70	14286	34.49	34.50
75	13333	34.30	34.21
80	12500	34.31	34.18
85	11775	34.30	34.20
90	11111	34.41	34.13
95	10526	34.26	34.22
100	10000	34.31	34.22
105	9524	34.26	34.22
110	9091	34.31	34.20
115	8696	34.29	34.20
120	8333	34.26	34.22
125	8000	34.26	34.22
130	7692	34.26	34.22
135	7407	34.26	34.22
140	7143	34.26	34.22
145	6897	34.26	34.22
150	6667	34.26	34.22
155	6452	34.26	34.22
160	6250	34.26	34.22
165	6061	34.26	34.22
170	5882	34.26	34.22
175	5714	34.26	34.22
180	5556	34.26	34.22
185	5405	34.26	34.22
190	5263	34.26	34.22
195	5128	34.26	34.22
200	5000	34.26	34.22

Table 13: NetSim results for simulations of case 4B

Case 5A
Network Scenario

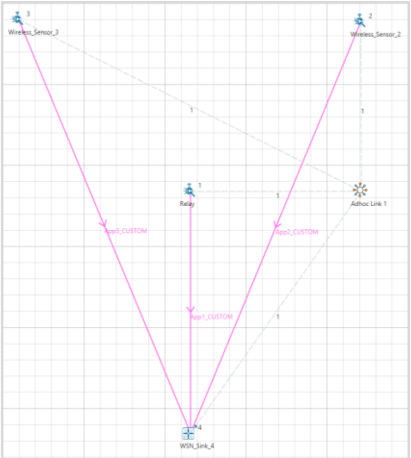

Fig 23 : Network Scenario for Case 5A

Static Route configuration

Static routes were configured in each source node such that the data gets transmitted to the destination through intermediate nodes.

To set the static routes, go to Wireless_Sensor properties > Network Layer > Enable Static Route IP. The Static route IP were configured in Wireless_Sensor_1, Wireless_ Sensor_2, Wireless_Sensor_3 as shown below:

Device	Network Destination	Gateway	Subnet Mask	Metrics	Interface ID
Wireless_ Sensor_1	11.1.1.1	11.1.1.1	255.255.255.255	1	1
Wireless_ Sensor_2	11.1.1.1	11.1.1.2	255.255.255.255	1	1
Wireless_ Sensor_3	11.1.1.1	11.1.1.2	255.255.255.255	1	1

Table 14: Static route configured in devices

Results

Per node source rate, λ pkts/sec	Inter packet arrival time (μs) = $10^6/\lambda$	N1 throughput, θ_1 pkts/sec	N2 throughput, θ_2 pkts/sec	N3 throughput, θ_3 pkts/sec
5	200000	4.77	4.82	5.03
10	100000	8.94	8.89	9.96
15	66667	12.31	12.24	14.95
20	50000	15.11	14.91	19.97
25	40000	17.10	16.88	25.00
30	33333	18.36	18.27	29.99
35	28571	18.88	19.10	34.98
40	25000	19.08	19.05	40.07
45	22222	18.61	18.77	45.03
50	20000	17.85	18.02	49.97
55	18182	16.75	16.90	55.01
60	16667	15.36	15.55	60.05
65	15385	13.81	13.87	65.15
70	14286	12.13	12.13	65.11
75	13333	10.53	10.69	63.84
80	12500	9.07	9.03	62.70
85	11775	7.73	7.76	60.98
90	11111	6.49	6.50	59.11
95	10526	5.38	5.52	56.72
100	10000	4.33	4.50	54.54
105	9524	3.42	3.50	52.21
110	9091	2.59	2.68	49.36

115	8696	1.98	2.02	46.01
120	8333	1.43	1.41	42.92
125	8000	1.02	1.05	39.80
130	7692	1.02	0.96	39.88
135	7407	0.98	0.92	39.96
140	7143	0.95	0.88	40.02
145	6897	0.91	0.85	40.08
150	6667	0.88	0.82	40.14
155	6452	0.85	0.79	40.21
160	6250	0.79	0.80	40.25
165	6061	0.76	0.78	40.30
170	5882	0.74	0.76	40.34
175	5714	0.72	0.73	40.39
180	5556	0.70	0.71	40.43
185	5405	0.68	0.69	40.47
190	5263	0.65	0.67	40.51
195	5128	0.64	0.65	40.55
200	5000	0.63	0.64	40.57

Table 15: NetSim results for simulations of case 5A

Case 5B
Network Scenario

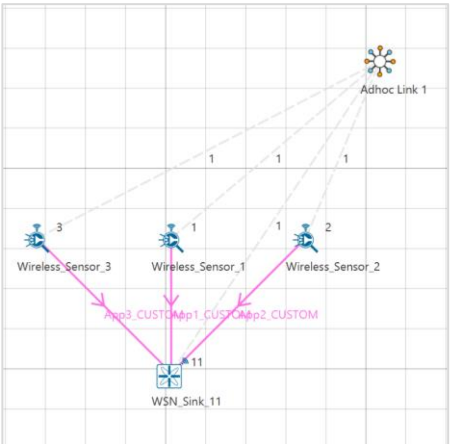

Fig 24 : Network Scenario for Case 5B

Static Route configuration

Static routes were configured in each source node such that the data gets transmitted to the destination through intermediate nodes.

To set the static routes, go to Wireless_Sensor properties > Network Layer > Enable Static Route IP. The Static route IP were configured in Wireless_Sensor_1, Wireless_ Sensor_2, Wireless_Sensor_3 as shown below:

Device	Network Destination	Gateway	Subnet Mask	Metrics	Interface ID
Wireless_ Sensor_1	11.1.1.1	11.1.1.1	255.255.255.255	1	1
Wireless_ Sensor_2	11.1.1.1	11.1.1.2	255.255.255.255	1	1
Wireless_ Sensor_3	11.1.1.1	11.1.1.2	255.255.255.255	1	1

Table 16: Static route configured in devices

Results

Per node source rate, λ pkts/sec	Inter packet arrival time (µs) = $10^6/\lambda$	N1 throughput, θ_2 pkts/sec	N2 throughput, θ_4 pkts/sec	N3 throughput, θ_8 pkts/sec
5	200000	5.01	4.94	4.97
10	100000	9.85	9.59	9.51
15	66667	14.65	13.63	13.59
20	50000	19.35	17.31	17.16
25	40000	23.95	20.39	20.19
30	33333	28.22	22.47	22.61
35	28571	32.44	24.21	24.38
40	25000	36.54	25.41	25.26
45	22222	40.36	25.86	26.05
50	20000	43.83	25.93	26.09
55	18182	41.82	24.45	24.62
60	16667	40.01	23.05	23.04
65	15385	38.28	21.61	21.64
70	14286	36.55	20.35	20.23
75	13333	36.16	19.44	19.18
80	12500	37.29	18.90	18.59
85	11775	38.50	18.23	18.05
90	11111	39.54	17.59	17.66
95	10526	40.47	17.23	17.08
100	10000	41.51	16.58	16.69
105	9524	42.32	16.33	16.13
110	9091	43.10	15.97	15.71
115	8696	43.96	15.54	15.28
120	8333	44.78	14.96	15.04
125	8000	45.39	14.77	14.62
130	7692	46.17	14.43	14.18
135	7407	46.86	14.12	13.81
140	7143	47.42	13.83	13.54
145	6897	48.13	13.48	13.18
150	6667	48.66	13.22	12.90
155	6452	49.17	12.99	12.62
160	6250	49.78	12.67	12.34
165	6061	50.29	12.41	12.08
170	5882	50.75	12.13	11.91
175	5714	51.16	11.93	11.69
180	5556	51.65	11.69	11.45
185	5405	52.09	11.47	11.21
190	5263	52.49	11.25	11.04
195	5128	52.77	11.11	10.90
200	5000	53.32	10.94	10.52

Table 17: NetSim results for simulations of case 5B

References

[1] S. M. Ladwa and A. Kumar, "An Analytical Performance Model for Beaconless," Master's Thesis, IISc, Bangalore, 2011.

[2] R. Srivastava and A. Kumar, "Performance Analysis of Beacon-Less IEEE 802.15.4 Multi-Hop Networks," *International Conference on Communication Systems and Networks (COMSNETS),* 2012.

Appendix 1 : Download Link

The configuration files (scenario, settings, and other related files) of the examples discussed in this analysis are available for users to import and run in NetSim.

Users can download the files from NetSim's git-repository.
Link: https://github.com/NetSim-TETCOS/Performance-Analysis-of-IEEE-802.15.4_v13.3/archive/refs/heads/main.zip

1. Click on the link given and download the folder
2. Extract the zip folder. The extracted project folder consists of one NetSim Experiments file, namely Performance-Analysis-of-802.15.4.netsimexp
3. Import as per steps given in section 4.10 in NetSim User Manual
4. All the experiments can now be seen folder wise within NetSim > Your Work. It will look like the image shown below