Project Presentation

ENSC 427 Final Project:

Simulation of the ZigBee PAN Protocol in OPNET as a Basis for the Comparison of Competing Sensor Network Technologies

Sonca Teng

Introduction

- Motivation and Overview
  - PAN Technologies examined for use for ENSC 440 Project
  - 802.15.4 Based Technologies:
    - ZigBee
      - Largest availability; stacks and support for many platforms, and transceivers cheap and highly available
    - MiWi
      - Much less availability, but much less complex, much smaller memory footprint
      - Allows for more space for main program in embedded devices
  - ISO Standard: “Dash 7”
      - Very little availability as it is a new protocol
      - Very good penetration (water, concrete) due to use of 433 MHz band
      - Very long range due to use of 433 MHz band, hops often not necessary in smaller areas, such as residential or commercial use

Introduction

	Underlying Standard	Frequencies Used	Penetrates Water	Penetrates Concrete	Range	Average Power Draw	Average Latency	Multi-Hop Capabilities	Interference from 802.11n	Maximum Bitrate
Dash7	ISO 18000-7	433 MHz	Yes	Yes	1 km	30-60 μW	2.5-5 s	Yes	No	200 Kbps
ZigBee	IEEE 802.15.4	2.4 GHz, 915 MHz, 868 MHz	No	No	30–500 m	125-400 μW	Varies from seconds to minutes	Yes	Yes	250 Kbps
MiWi P2P	IEEE 802.15.4	2.4 GHz	No	No	30-500 m	95-115 μW	Varies from seconds to minutes	No	Yes	250 Kbps

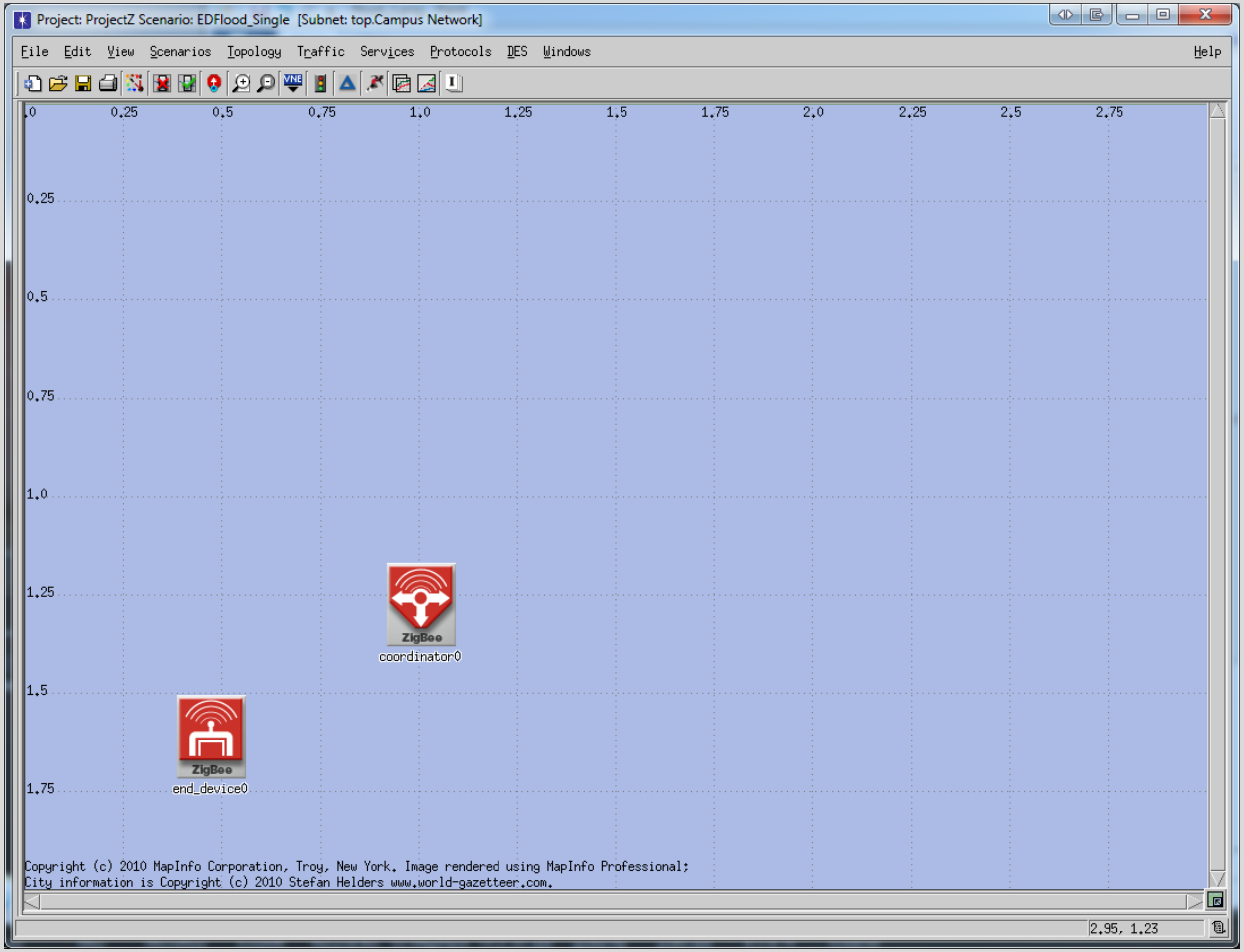
Project Description

- Three Case Studies
- 1)Determine effect of adding incrementally more end devices to network, effect on an end device's end-to-end delay between it and coordinator
- 2)Determine effect of suddenly flooding network with incrementally more devices, effect on an end device's end-to-end delay between it and coordinator
- 3)Determine effect of adding routers and therefore hops between end device and coordinator

Case 1

- In this series of scenarios, we add 1, 2, 7, 8, 9, 14, 15, 16, and 17 more end devices to the network and examine the results

Case 1


Project: ProjectZ Scenario: EDFlood_Single [Subnet: top.Campus Network]
File Edit View Scenarios Topology Traffic Services Protocols DES Windows Help
coordinator0
end_device0
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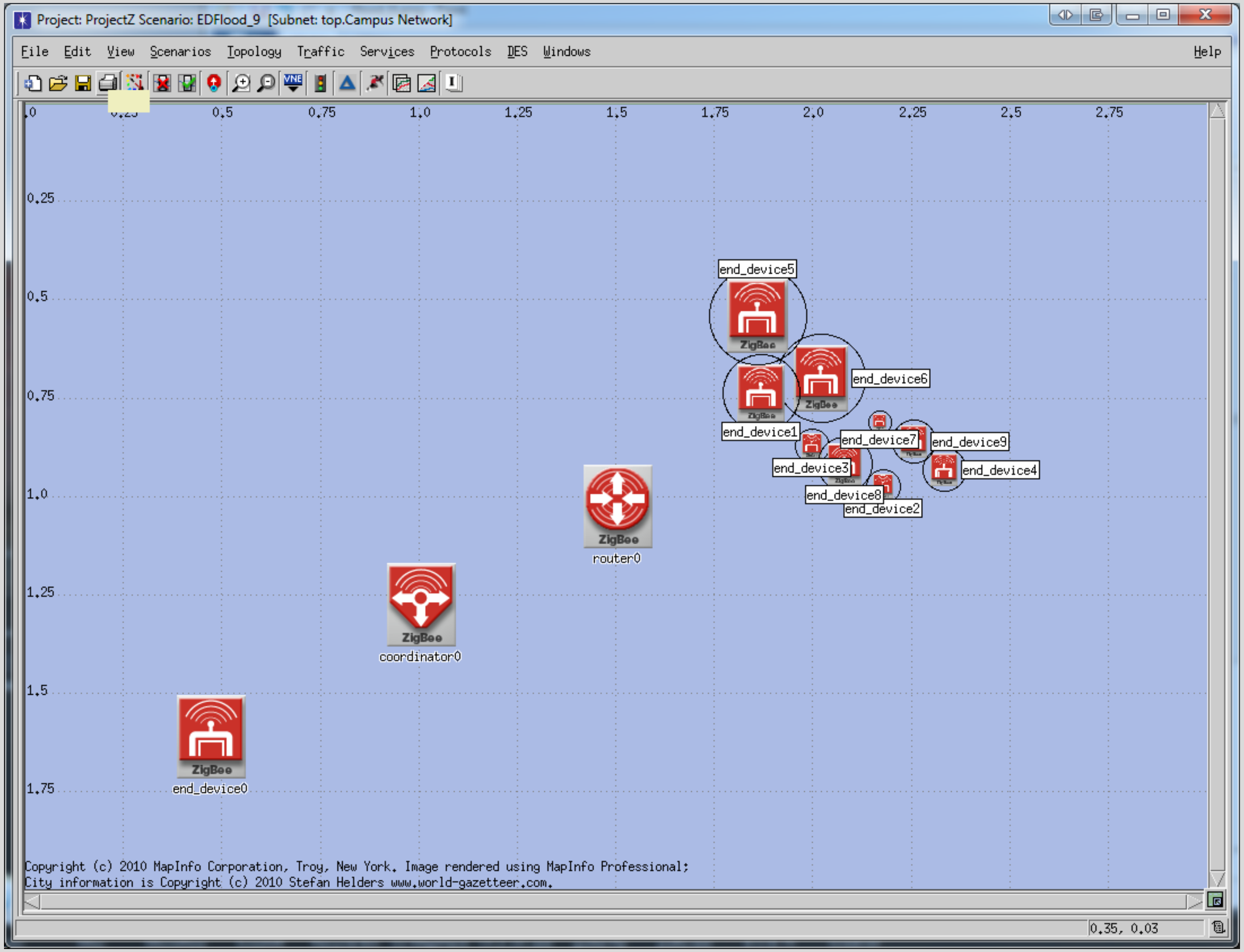
2.95, 1.23

Case 1


Project: ProjectZ Scenario: EDFlood_9 [Subnet: top.Campus Network]
File Edit View Scenarios Topology Traffic Services Protocols DES Windows Help
end_device5
end_device6
end_device1
end_device7
end_device9
end_device3
end_device4
end_device8
end_device2
router0
coordinator0
end_device0
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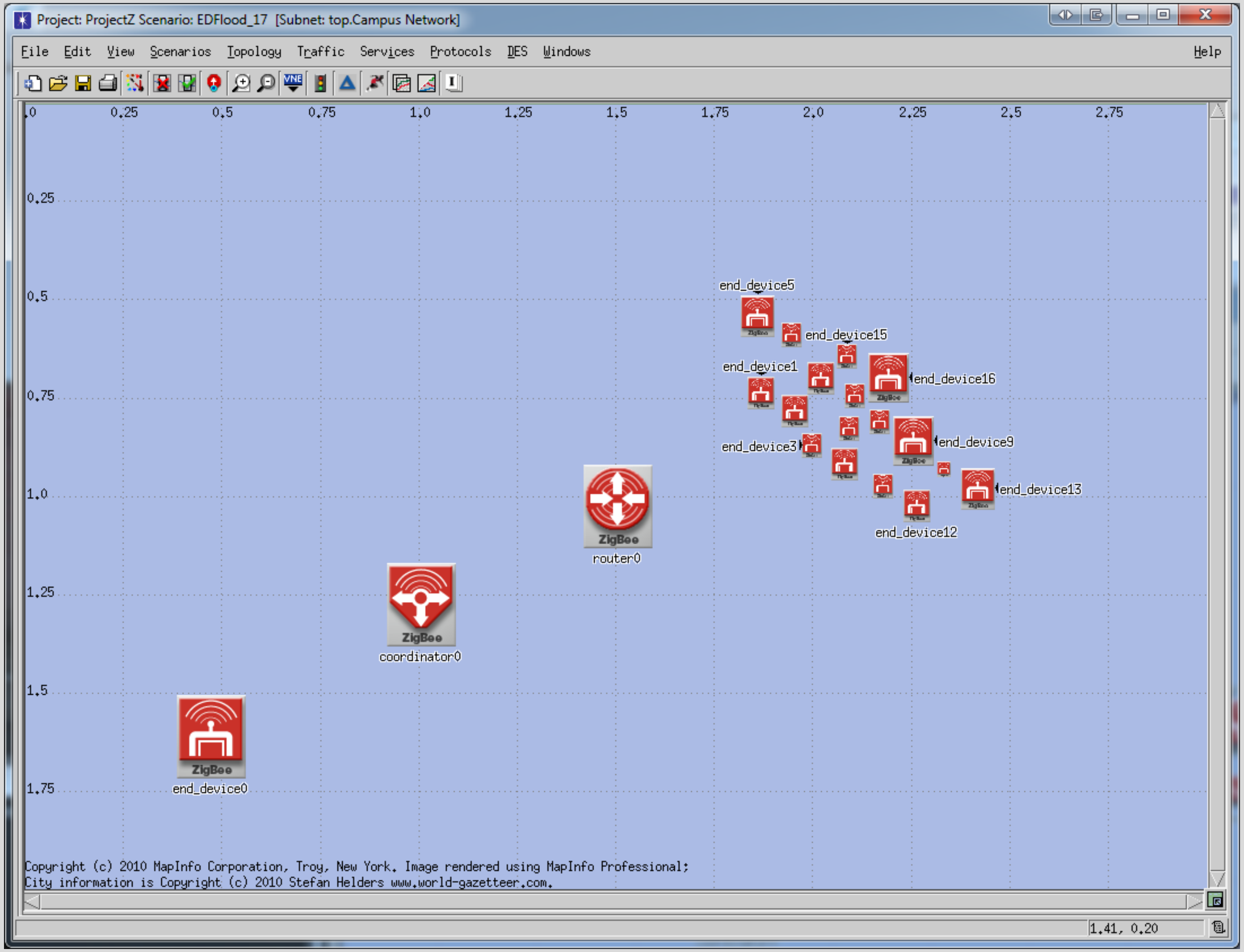
0.35, 0.03

Case 1


Project: ProjectZ Scenario: EDFlood_17 [Subnet: top.Campus Network]
File Edit View Scenarios Topology Traffic Services Protocols DES Windows Help
0 0.25 0.5 0.75 1.0 1.25 1.5 1.75 2.0 2.25 2.5 2.75
0.25
0.5
0.75
1.0
1.25
1.5
1.75
end_device5
end_device15
end_device1
end_device16
end_device9
end_device3
end_device13
end_device12
ZigBee
router0
coordinator0
end_device0
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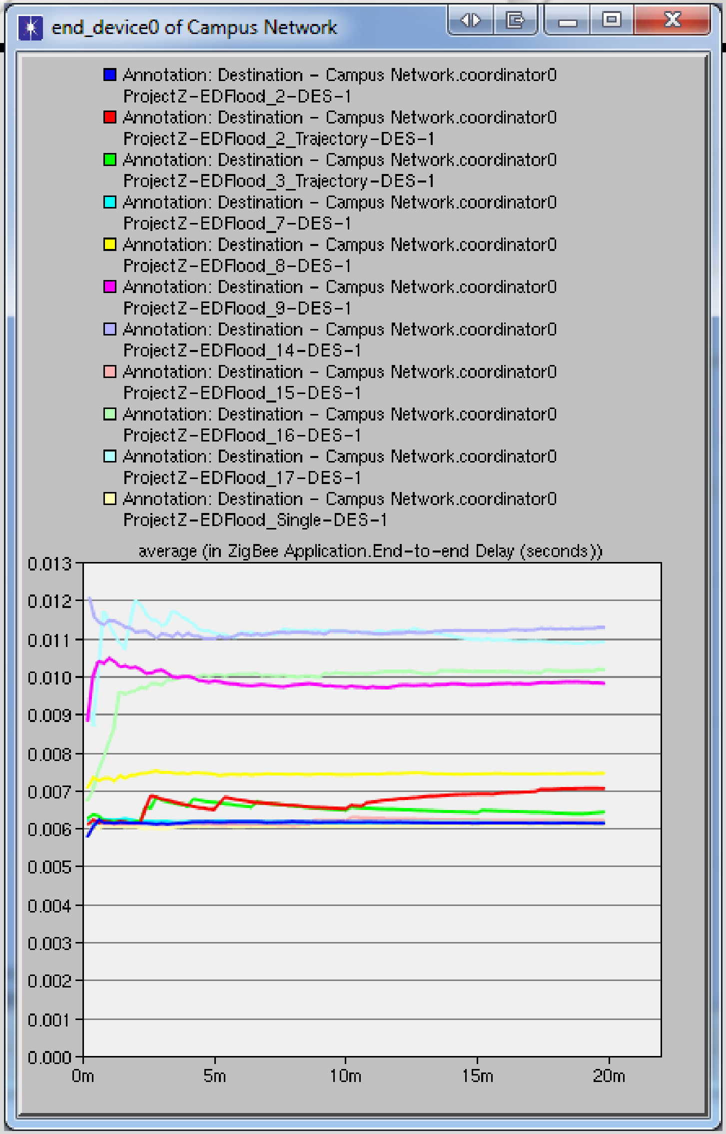
1.41, 0.20

Case 1

- When we reach 8 devices, we find that the end-to-end delay has suddenly jumped

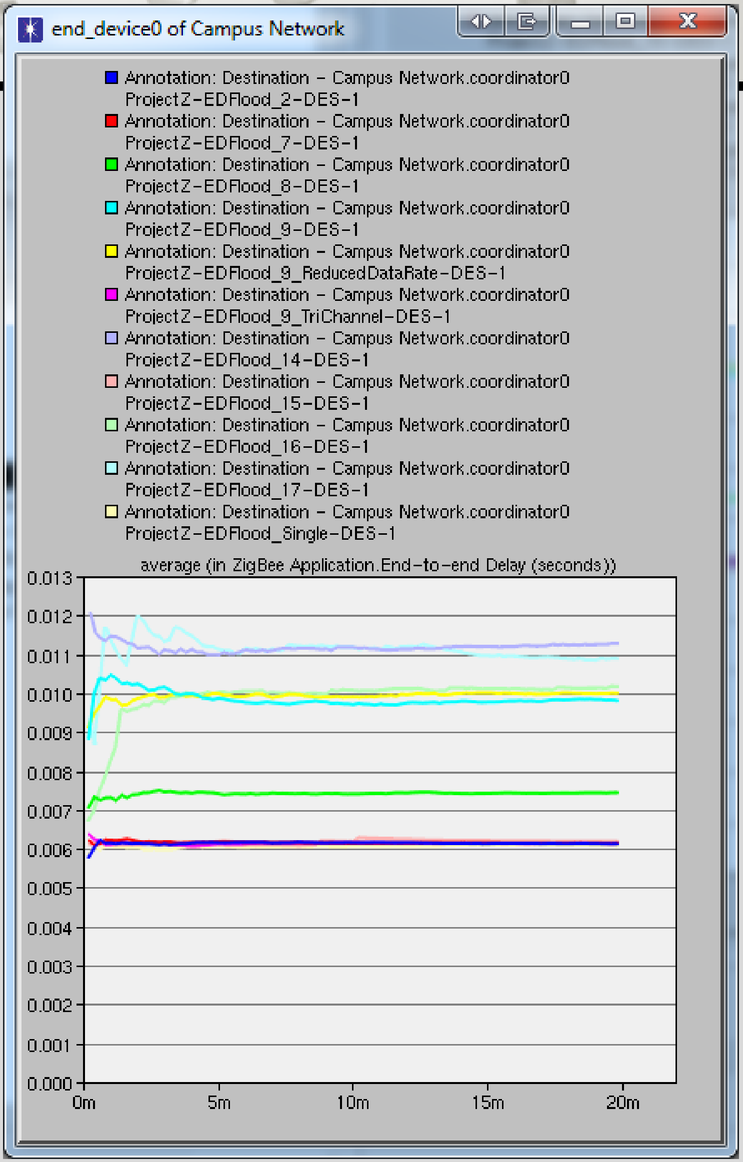
Case 1


end_device0 of Campus Network
Annotation: Destination - Campus Network.coordinator0 ProjectZ-EDFlood_2-DES-1
Annotation: Destination - Campus Network.coordinator0 ProjectZ-EDFlood_2_Trajectory-DES-1
Annotation: Destination - Campus Network.coordinator0 ProjectZ-EDFlood_3_Trajectory-DES-1
Annotation: Destination - Campus Network.coordinator0 ProjectZ-EDFlood_7-DES-1
Annotation: Destination - Campus Network.coordinator0 ProjectZ-EDFlood_8-DES-1
Annotation: Destination - Campus Network.coordinator0 ProjectZ-EDFlood_9-DES-1
Annotation: Destination - Campus Network.coordinator0 ProjectZ-EDFlood_14-DES-1
Annotation: Destination - Campus Network.coordinator0 ProjectZ-EDFlood_15-DES-1
Annotation: Destination - Campus Network.coordinator0 ProjectZ-EDFlood_16-DES-1
Annotation: Destination - Campus Network.coordinator0 ProjectZ-EDFlood_17-DES-1
Annotation: Destination - Campus Network.coordinator0 ProjectZ-EDFlood_Single-DES-1
average (in ZigBee Application.End-to-end Delay (seconds))
0.013
0.012
0.011
0.010
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0.000
0m
5m
10m
15m
20m

Case 1

- In an effort to determine why, we add two new scenarios:
  - Halve the datarate
  - Introduce two more frequency bands (915 MHz, 868 MHz) for 11 more channels (27 total)

Case 1



end_device0 of Campus Network
Annotation: Destination - Campus Network.coordinator0 ProjectZ-EDFlood_2-DES-1
Annotation: Destination - Campus Network.coordinator0 ProjectZ-EDFlood_7-DES-1
Annotation: Destination - Campus Network.coordinator0 ProjectZ-EDFlood_8-DES-1
Annotation: Destination - Campus Network.coordinator0 ProjectZ-EDFlood_9-DES-1
Annotation: Destination - Campus Network.coordinator0 ProjectZ-EDFlood_9_ReducedDataRate-DES-1
Annotation: Destination - Campus Network.coordinator0 ProjectZ-EDFlood_9_TriChannel-DES-1
Annotation: Destination - Campus Network.coordinator0 ProjectZ-EDFlood_14-DES-1
Annotation: Destination - Campus Network.coordinator0 ProjectZ-EDFlood_15-DES-1
Annotation: Destination - Campus Network.coordinator0 ProjectZ-EDFlood_16-DES-1
Annotation: Destination - Campus Network.coordinator0 ProjectZ-EDFlood_17-DES-1
Annotation: Destination - Campus Network.coordinator0 ProjectZ-EDFlood_Single-DES-1
average (in ZigBee Application.End-to-end Delay (seconds))
0.013
0.012
0.011
0.010
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0.000
0m
5m
10m
15m
20m

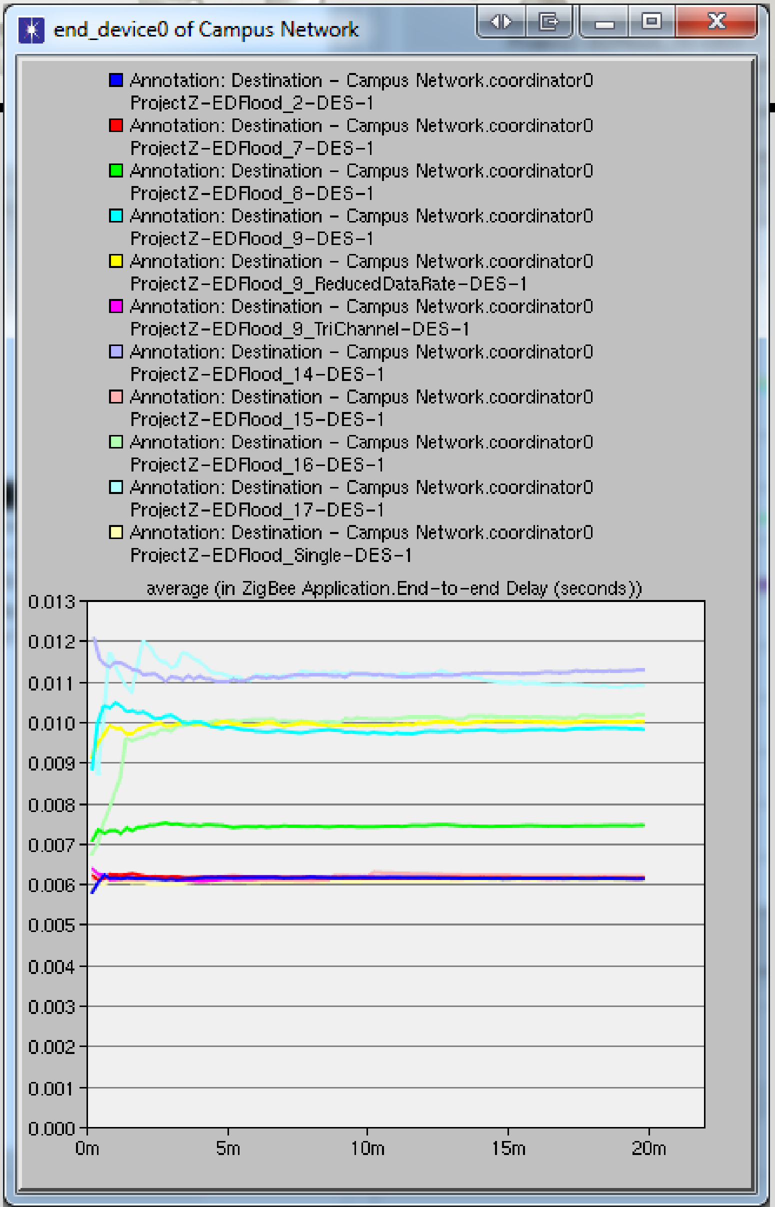
Case 1

- Effect of halving datarate:
  - None
- Effect of adding more channels:
  - Drastic

Case 1

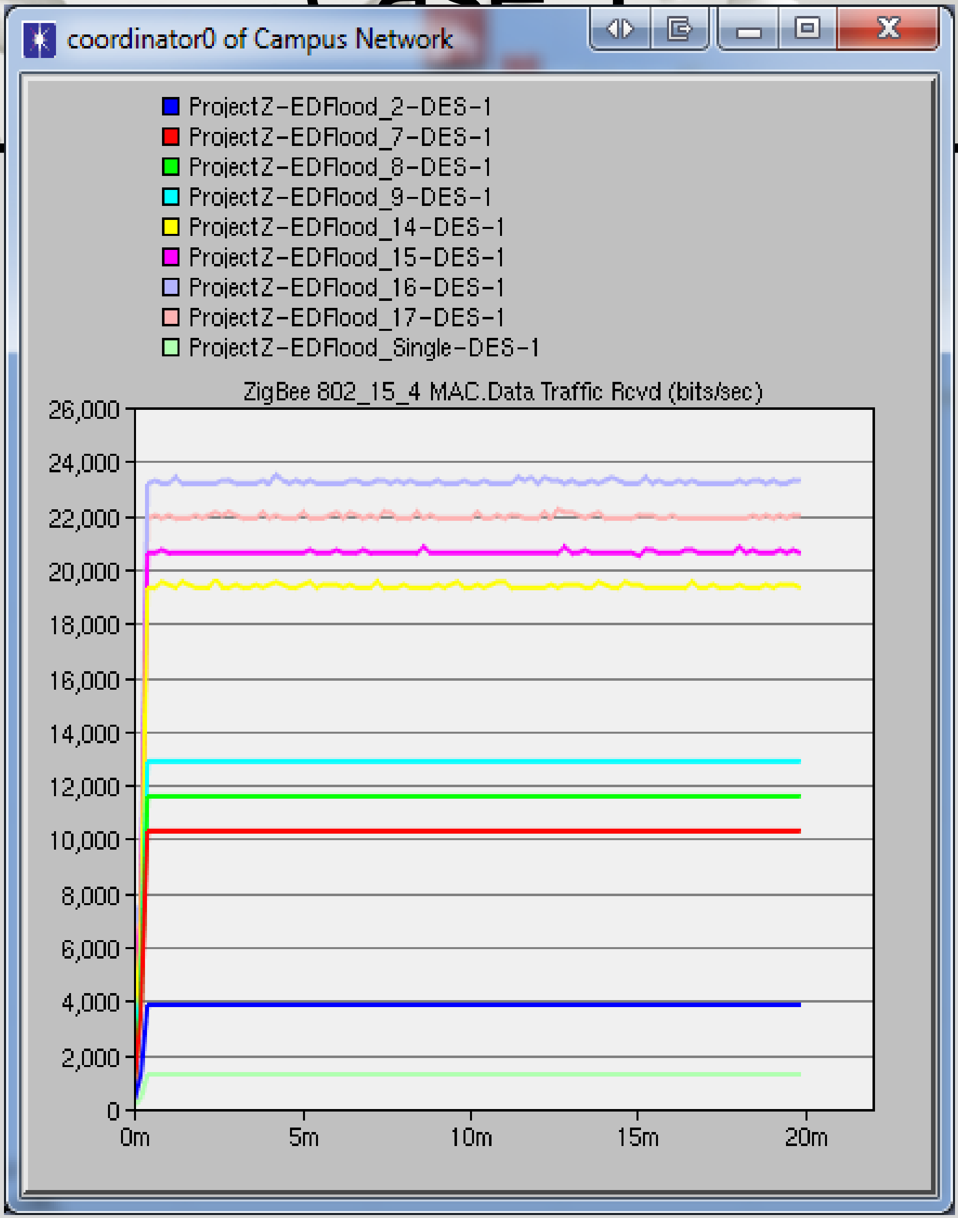
- Next, examine case of 14, 15, 16, and 17 added end devices.

Case 1



end_device0 of Campus Network
Annotation: Destination - Campus Network.coordinator0 ProjectZ-EDFlood_2-DES-1
Annotation: Destination - Campus Network.coordinator0 ProjectZ-EDFlood_7-DES-1
Annotation: Destination - Campus Network.coordinator0 ProjectZ-EDFlood_8-DES-1
Annotation: Destination - Campus Network.coordinator0 ProjectZ-EDFlood_9-DES-1
Annotation: Destination - Campus Network.coordinator0 ProjectZ-EDFlood_9_ReducedDataRate-DES-1
Annotation: Destination - Campus Network.coordinator0 ProjectZ-EDFlood_9_TriChannel-DES-1
Annotation: Destination - Campus Network.coordinator0 ProjectZ-EDFlood_14-DES-1
Annotation: Destination - Campus Network.coordinator0 ProjectZ-EDFlood_15-DES-1
Annotation: Destination - Campus Network.coordinator0 ProjectZ-EDFlood_16-DES-1
Annotation: Destination - Campus Network.coordinator0 ProjectZ-EDFlood_17-DES-1
Annotation: Destination - Campus Network.coordinator0 ProjectZ-EDFlood_Single-DES-1
average (in ZigBee Application.End-to-end Delay (seconds))
0.013
0.012
0.011
0.010
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0.000
0m
5m
10m
15m
20m

Case 1


coordinator0 of Campus Network
ProjectZ-EDFlood_2-DES-1
ProjectZ-EDFlood_7-DES-1
ProjectZ-EDFlood_8-DES-1
ProjectZ-EDFlood_9-DES-1
ProjectZ-EDFlood_14-DES-1
ProjectZ-EDFlood_15-DES-1
ProjectZ-EDFlood_16-DES-1
ProjectZ-EDFlood_17-DES-1
ProjectZ-EDFlood_Single-DES-1
ZigBee 802_15_4 MAC.Data Traffic Rcvd (bits/sec)
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
0m
5m
10m
15m
20m

Case 1

- We find that for 14, 15, and 16 added end devices, 1300*N bps as expected is received by the coordinator, but at the 17^{th} device, the received data drops far below what is expected
- This is because of the lack of the Beaconing and therefore Guaranteed Time Slot feature that is disabled in the OPNET 14.0 implementation of ZigBee

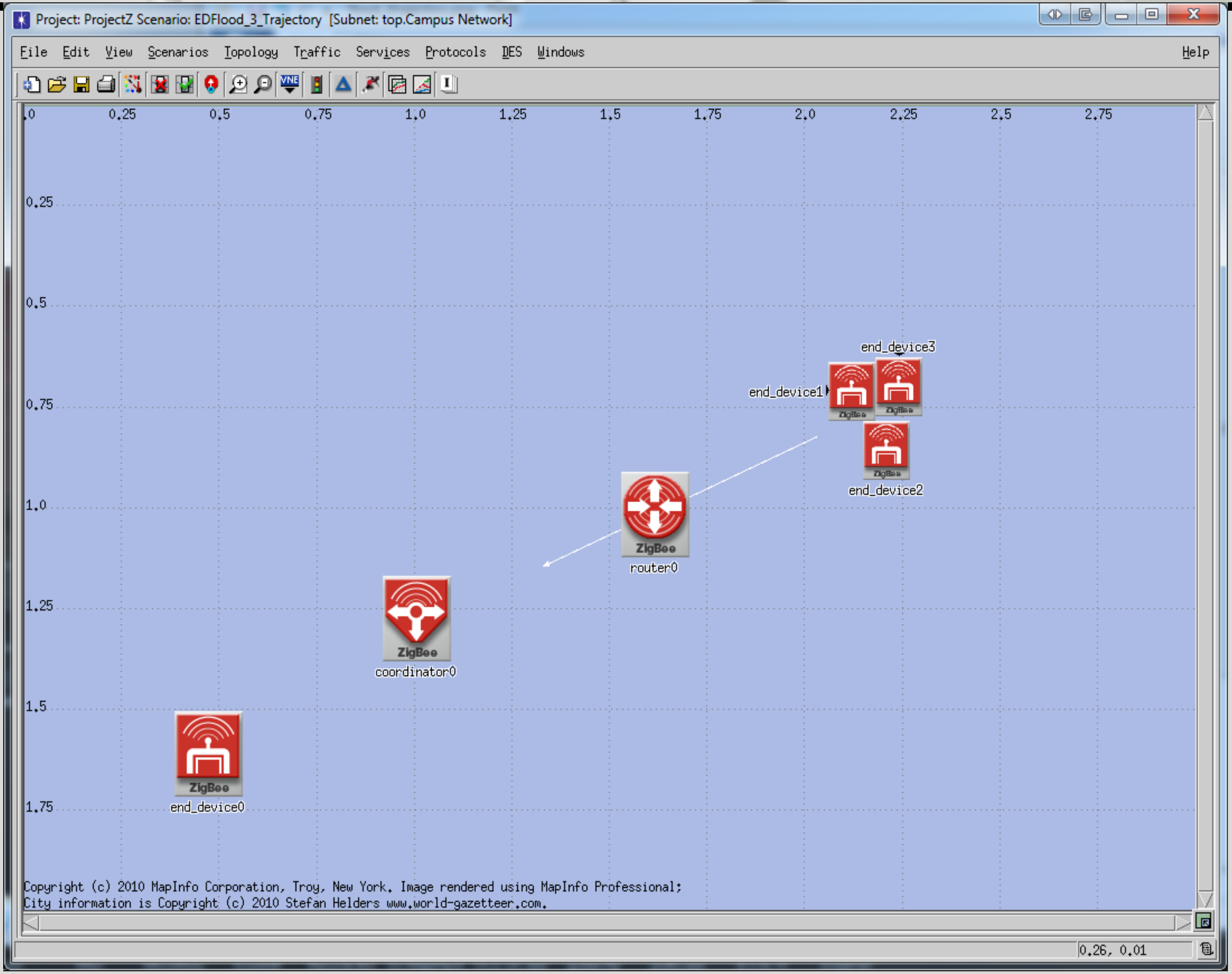
Case 2

- In Case 2, we re-examine Case 1, but with the difference that we have an intermediary router on a movement trajectory, only within range of both the coordinator and the added end devices in the center of travel
- In this way, we simulate the scenario of suddenly adding new devices in a flood to the network

Case 2

- In Case 2, we re-examine Case 1, but with the difference that we have an intermediary router on a movement trajectory, only within range of both the coordinator and the added end devices in the center of travel
- In this way, we simulate the scenario of suddenly adding new devices in a flood to the network

Case 2



Project: ProjectZ Scenario: EDFlood_3_Trajectory [Subnet: top.Campus Network]
File Edit View Scenarios Topology Traffic Services Protocols DES Windows Help
end_device3
end_device1
end_device2
router0
coordinator0
end_device0
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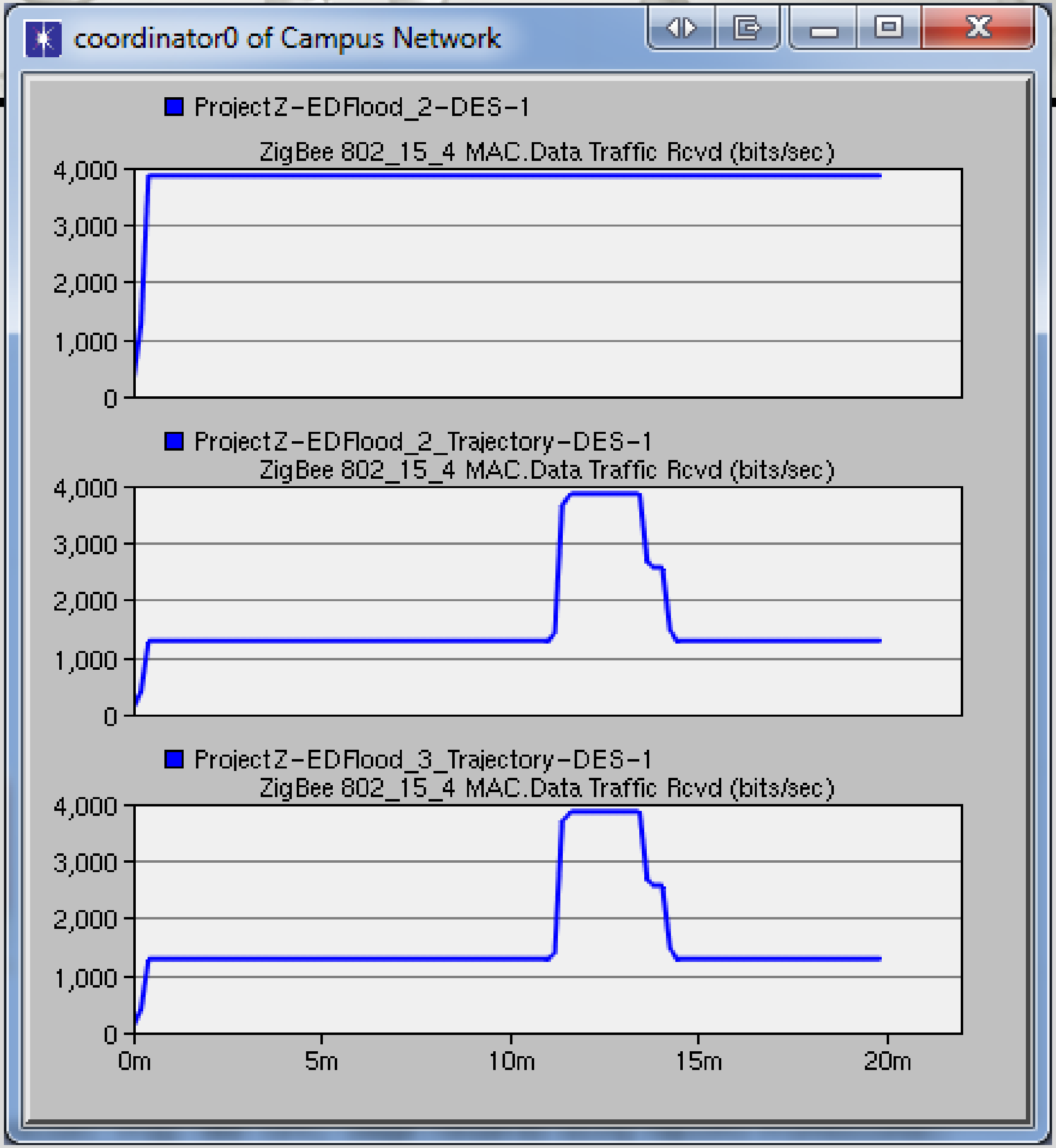
0.26, 0.01

Case 2

- However, we have an issue when we get to the scenario with three added devices, which becomes clear in the results that follow

Case 2



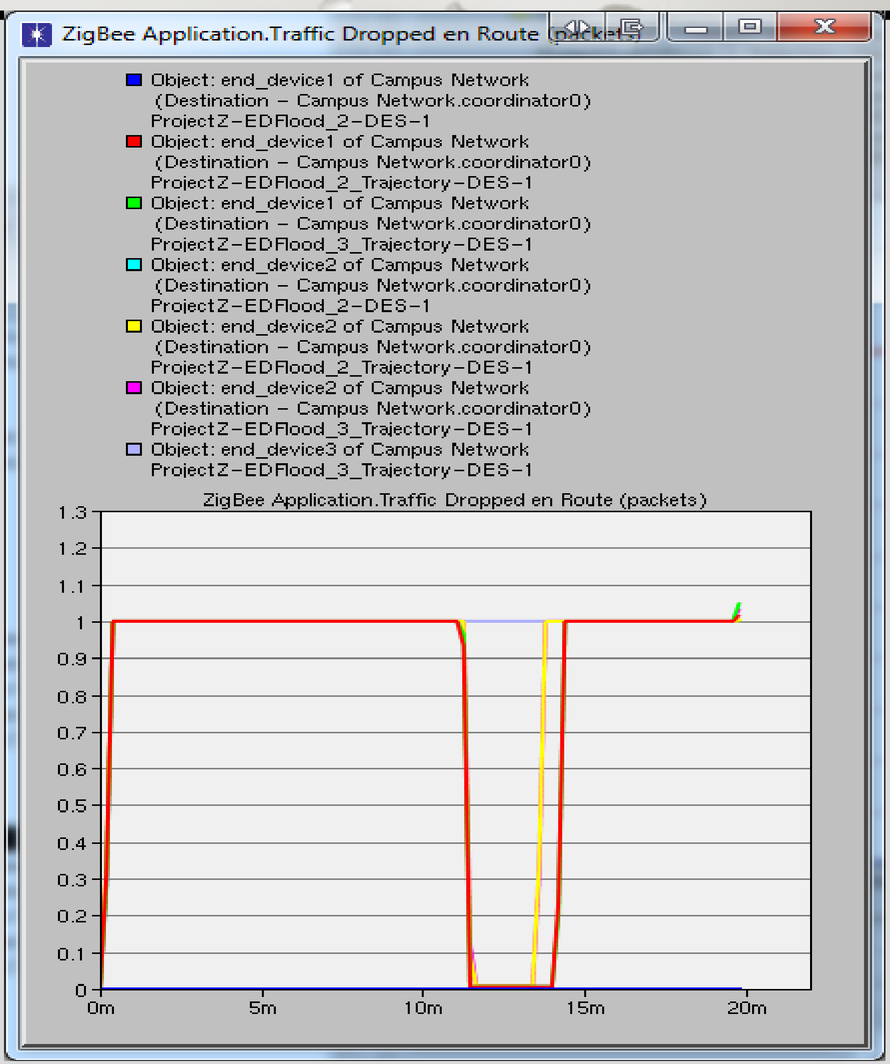
coordinator0 of Campus Network
ProjectZ-EDFlood_2-DES-1
ZigBee 802_15_4 MAC.Data Traffic Rcvd (bits/sec)
ProjectZ-EDFlood_2_Trajectory-DES-1
ZigBee 802_15_4 MAC.Data Traffic Rcvd (bits/sec)
ProjectZ-EDFlood_3_Trajectory-DES-1
ZigBee 802_15_4 MAC.Data Traffic Rcvd (bits/sec)
4,000
3,000
2,000
1,000
0
0m
5m
10m
15m
20m

Case 2

- We can see that there is not full data transfer to the coordinator.

- We examine dropped packets next.

Case 2



ZigBee Application.Traffic Dropped en Route (packets)
Object: end_device1 of Campus Network
(Destination – Campus Network.coordinator0)
ProjectZ-EDFlood_2-DES-1
Object: end_device1 of Campus Network
(Destination – Campus Network.coordinator0)
ProjectZ-EDFlood_2_Trajectory-DES-1
Object: end_device1 of Campus Network
(Destination – Campus Network.coordinator0)
ProjectZ-EDFlood_3_Trajectory-DES-1
Object: end_device2 of Campus Network
(Destination – Campus Network.coordinator0)
ProjectZ-EDFlood_2-DES-1
Object: end_device2 of Campus Network
(Destination – Campus Network.coordinator0)
ProjectZ-EDFlood_2_Trajectory-DES-1
Object: end_device2 of Campus Network
(Destination – Campus Network.coordinator0)
ProjectZ-EDFlood_3_Trajectory-DES-1
Object: end_device3 of Campus Network
ProjectZ-EDFlood_3_Trajectory-DES-1
ZigBee Application.Traffic Dropped en Route (packets)
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0m
5m
10m
15m
20m

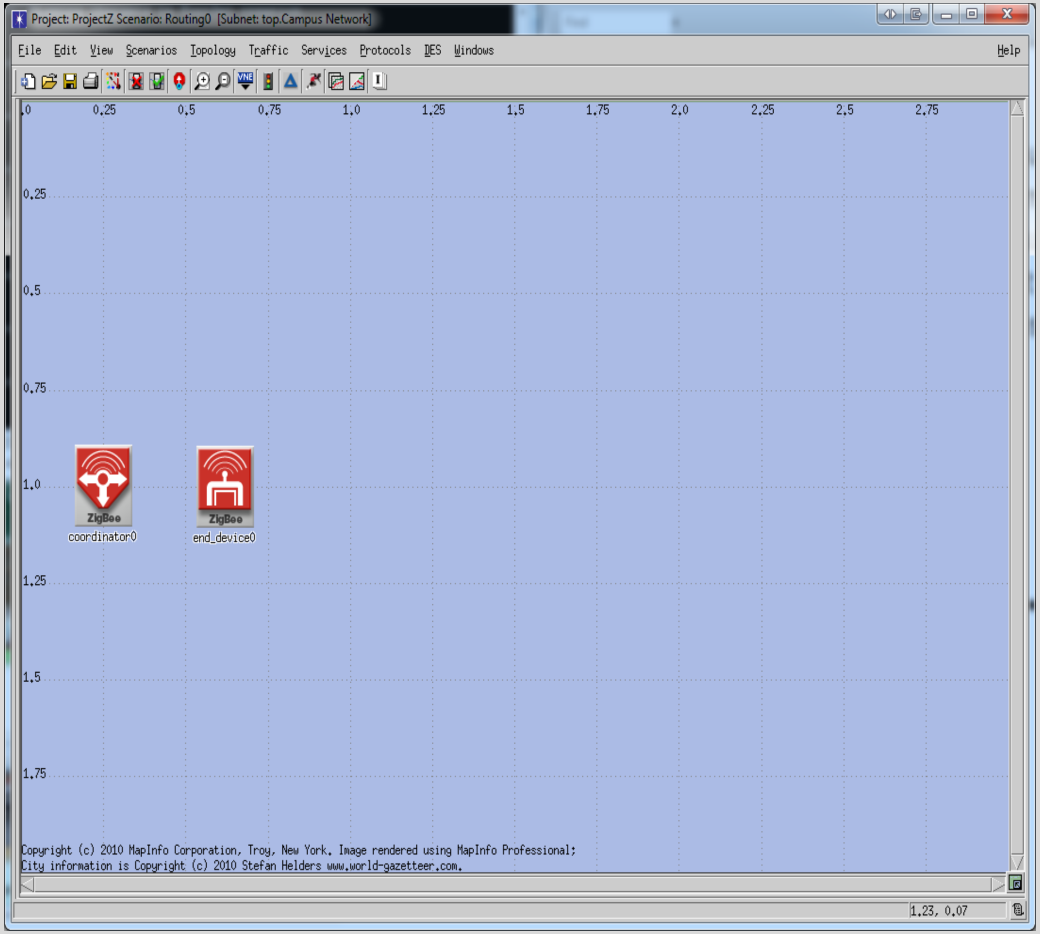
Case 2

- It becomes clear that 100% of packets are dropped for the third added end device.
- This is a limitation of the ZigBee model under OPNET 14.0.

Case 3

- In Case 3, we look into what happens when we add routers between nodes, and introduce incrementally more hops for the path between the end device and the coordinator.
- We start with the standard case of an end device and a coordinator, with no intermediary router

Case 3



Project: ProjectZ Scenario: Routing0 [Subnet: top.Campus Network]
File Edit View Scenarios Topology Traffic Services Protocols DES Windows Help
ZigBee
coordinator0
ZigBee
end_device0
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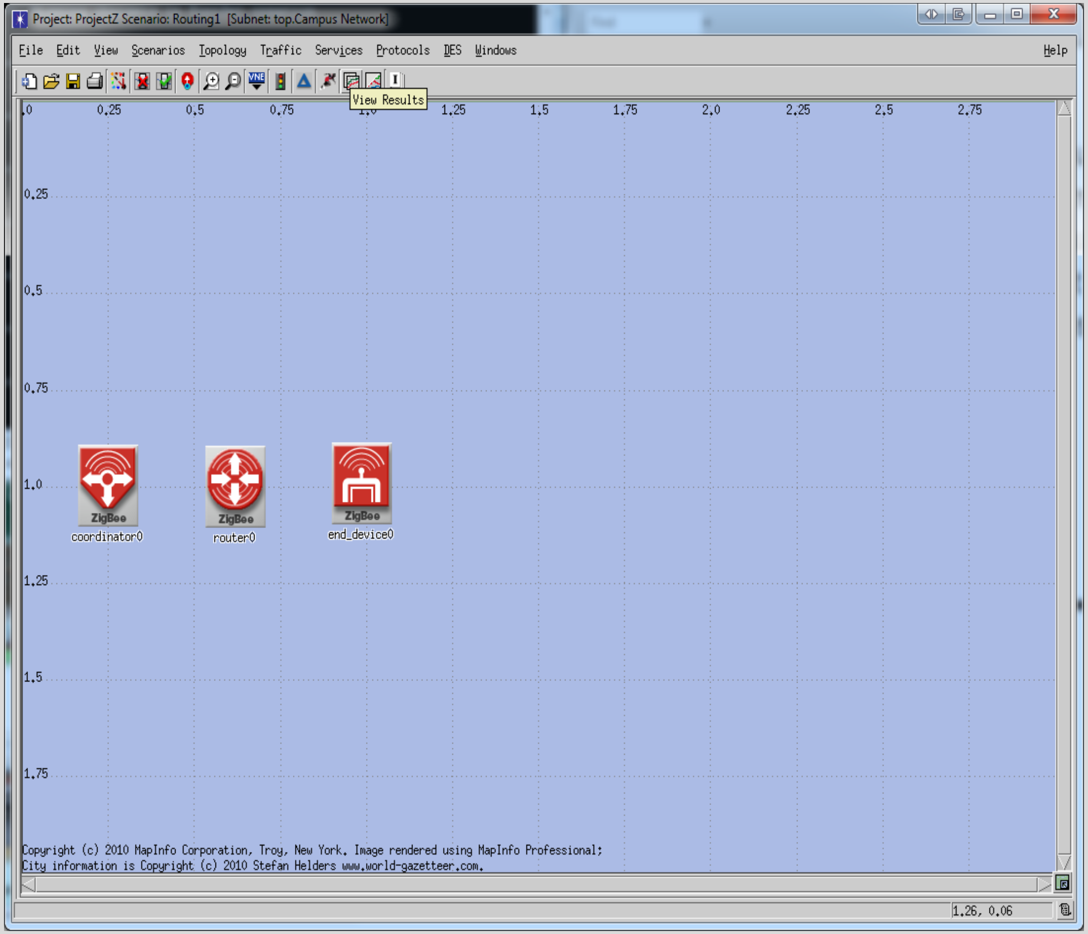
1.23, 0.07

Case 3


Project: ProjectZ Scenario: Routing1 [Subnet: top.Campus Network]
File Edit View Scenarios Topology Traffic Services Protocols DES Windows
Help
View Results
ZigBee
coordinator0
router0
end_device0
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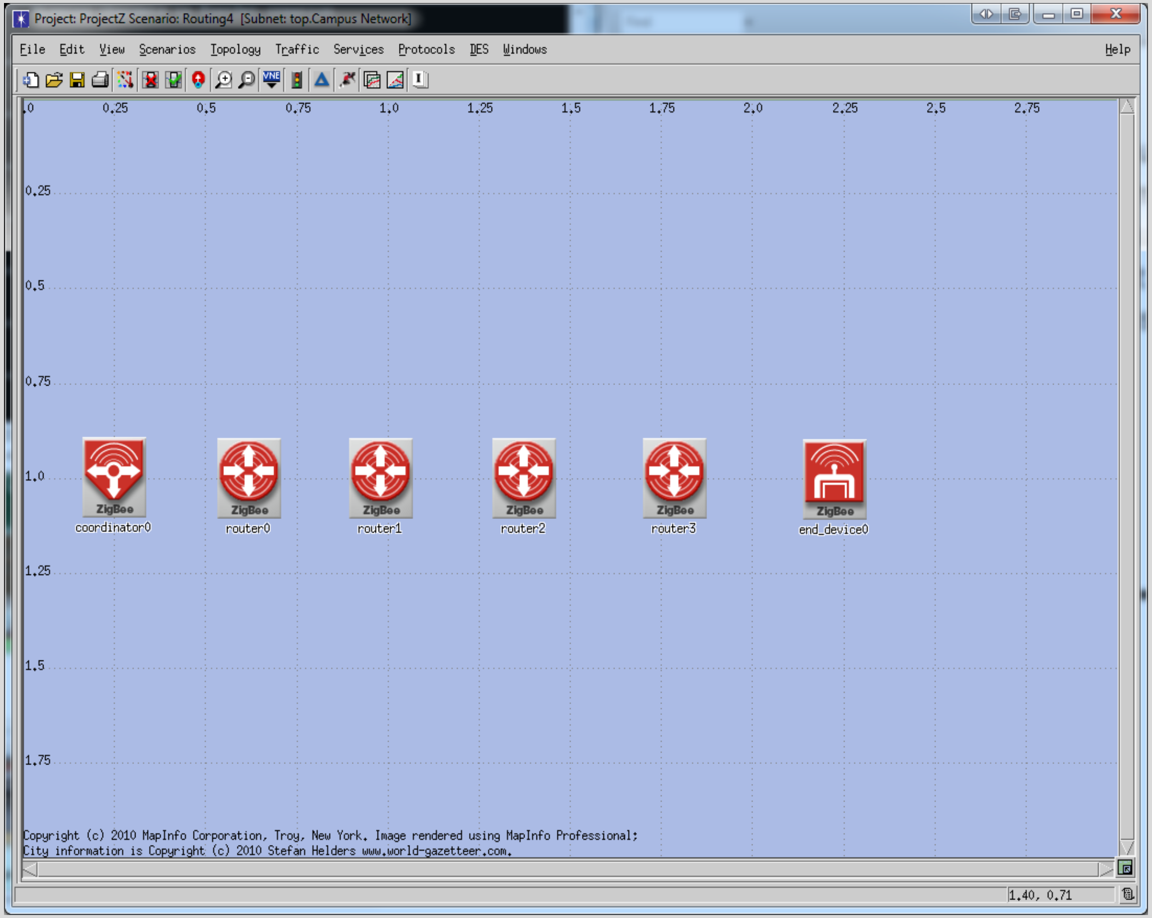
1.26, 0.06

Case 3

- …up to a total of four routers for five hops across the network.

Case 3


Project: ProjectZ Scenario: Routing4 [Subnet: top.Campus Network]
File Edit View Scenarios Topology Traffic Services Protocols DES Windows Help
coordinator0
router0
router1
router2
router3
end_device0
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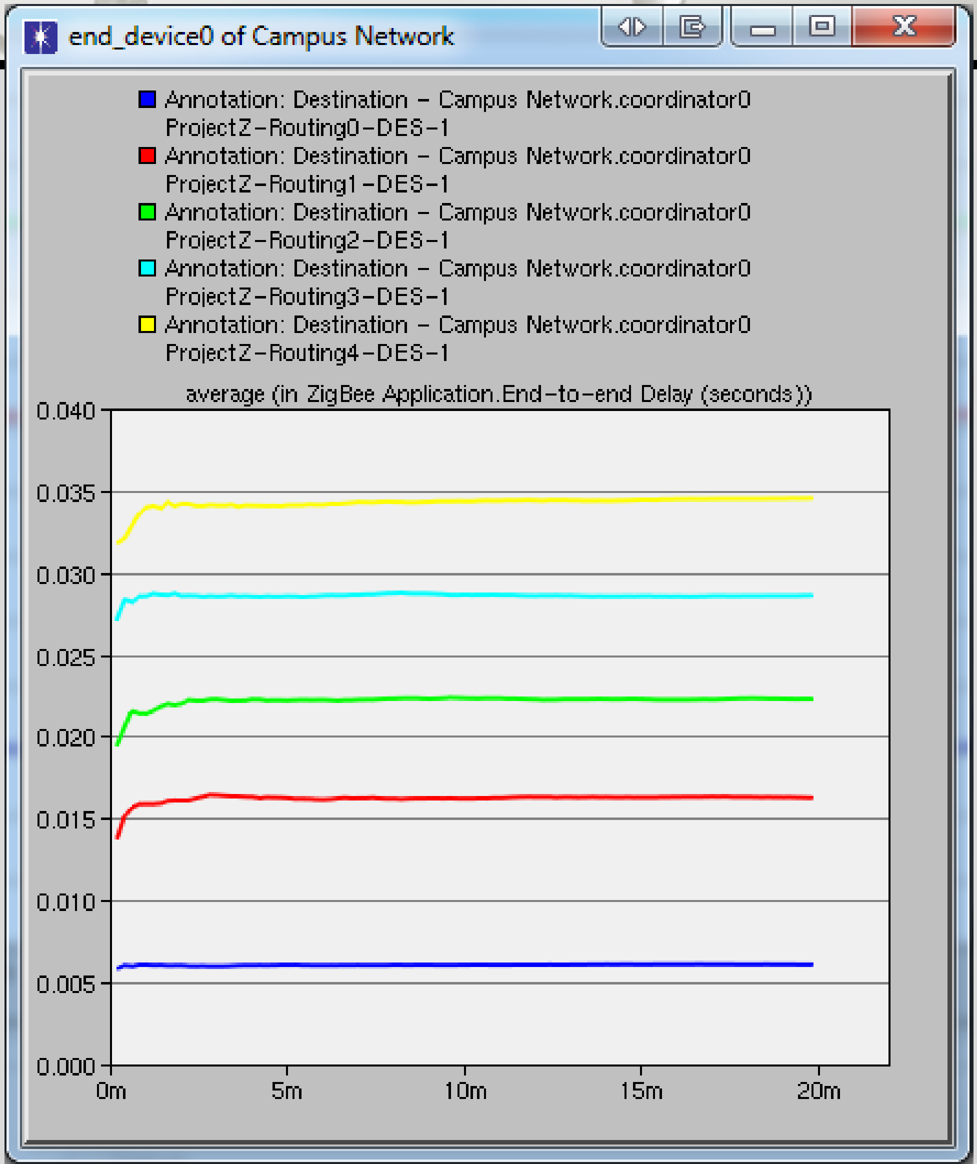
Case 3

- This is a total of four routers for five hops across the network.

Case 3


end_device0 of Campus Network
Annotation: Destination – Campus Network.coordinator0 ProjectZ-Routing0-DES-1
Annotation: Destination – Campus Network.coordinator0 ProjectZ-Routing1-DES-1
Annotation: Destination – Campus Network.coordinator0 ProjectZ-Routing2-DES-1
Annotation: Destination – Campus Network.coordinator0 ProjectZ-Routing3-DES-1
Annotation: Destination – Campus Network.coordinator0 ProjectZ-Routing4-DES-1
average (in ZigBee Application.End-to-end Delay (seconds))
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
0m
5m
10m
15m
20m

Case 3

Scenario	Number of Hops	Total End-to-End Delay
Routing0	1	6ms
Routing1	2	16ms
Routing2	3	22ms
Routing3	4	28ms
Routing4	5	34ms

Table 1 – End-to-End Delay Based on Number of Hops

- We can see then that the standard end to end delay between an end device and a coordinator is 6ms, and that adding progressively more hops increases the delay by additional 6ms, but that setting up routing for 1 or more hops introduces an additional fixed overhead of 4ms

Conclusion

- Case 1: Determined that standard end to end delay for a non-routed ZigBee PAN is 6ms between an end device and a coordinator, with no routing involved
  - At 8 devices, co-channel interference
  - At 16 devices, without Beaconing and therefore Guaranteed Time Slot, more devices cannot communicate

- Case 2: Major limitation with OPNET 14.0 ZigBee model is that cannot handle more than two devices per router if it is on a movement trajectory

- Case 3: Again noted expected end to end delay for ZigBee PAN, non-routed, is 6ms
  - Adding hops increases delay by 6ms progressively
  - Additional overhead of 4ms for routing

Questions

?

References

[1]I.S. Hammoodi, B.G. Stewart, A. Kocian, S.G. McMeekin, "A Comprehensive Performance Study of OPNET Modeler for ZigBee Wireless Sensor Networks Electrical and Computer Engineering", *Third International Conference on Next Generation Mobile Applications, Services and Technologies*, NGMAST '09, November 2009.

[2]Mishra, A.; Na, C; Rosenburgh, D., "On Scheduling Guaranteed Time Slots for Time Sensitive Transactions in IEEE 802.15.4 Networks", *Military Communications Conference, 2007,* MILCOM '07, October 2007.

[3]Gascon, D., "802.15.4 vs Zigbee", [Online document], Nov. 2008, [cited June 12th, 2010], Available: http://www.sensor-networks.org/index.php?page=0823123150.

[4]Yang, Y., "Microchip MiWi™ P2P Wireless Protocol", *Microchip Application Notes 2008,* January 2008.

[5]Norair, J. P., "Introduction to DASH7 Technologies", *Dash7 Alliance Low Power RF Technical Overview,* March 2009.

[6]S. Leung, W. Gomez, J. J. Kim, "ZigBee Mesh Network Simulation Using OPNET and Study of Routing Selection", SFU ENSC 427 Project Spring '09, December 2009.