ENSC 835: COMMUNICATION NETWORKS

FINAL PROJECT PRESENTATIONS
Spring 2009

Implementation of an IEEE 802.15.4 and ZigBee Protocol using the OPNET simulator

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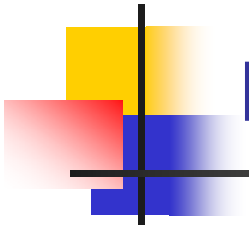


Road map

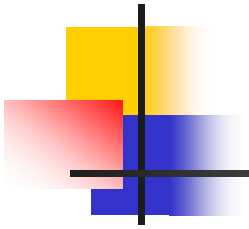
- Introduction:
  - Overview
  - ZigBee vs. Bluetooth
- Performance evaluation:
  - Simulation scenarios and parameters
  - Simulation results
- Conclusions
- Unfinished work:
  - Simulation scenario and parameters
  - Implementations details
- Future work
- References

Introduction - overview

- Transmission bands:
  - 868 MHz
  - 915 MHz
  - 2459 MHz
- Device type:
  - Full-function device (FFD)
    - PAN coordinator (IEEE 802.15.4) or ZC (ZigBee)
    - Coordinator (IEEE 802.15.4) or ZR (ZigBee)
  - Reduced-function device (RFD)
    - Device (IEEE 802.15.4) or ZED (ZigBee)

ZC: ZigBee Coordinator, ZR: ZigBee Router, ZED: ZigBee End Device

PAN: Personal Area Network

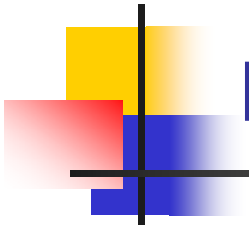


Introduction - overview

- Application layer features:
  - Generating and receiving application traffic
  - Initiating network discovery and network join
  - Failing and recovering ZigBee devices
- Network layer features:
  - Establishing a network
  - Joining a network and permitting network joins
  - Assigning an address
  - Maintaining a neighbor table
  - Mesh Routing Process
  - Network Broadcast
  - Tree routing process
  - Transmitting and receiving data
  - Mobility
  - Beacon scheduling
- MAC layer features:
  - Channel Scanning
  - CSMA/CA (Contention-based operation mode)

Introduction – ZigBee vs. Bluetooth

	ZigBee	Bluetooth
Transmission band	868, 915, and 2459 MHz	2.4 GHz
Data rate	250 Kbps (at 2.4 GHz)	1 Mbps
Operational range	10 – 75 m (1500 m for ZigBee Pro)	1, 10, and 100 m
Configuration	Master-slave	Peer-to-peer, master-slave
Maximum child	254	7 (active) + 255 (inactive)
Maximum power	1 mW	1, 2.5, and 100 mW
Wake up delay	15 msec	3 sec
Protocol stack	30 kwords	256 kwords
Protocol complexity	Lower	Higher
Price	less expensive	more expensive



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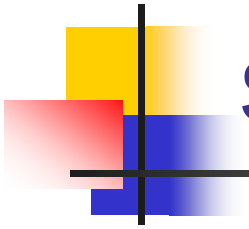

Simulation scenarios and parameters

- Simulation scenarios:
  - Star, Tree, and Mesh topologies
  - Single and multiple ZC
- Parameters:
  - 1,000 s simulated time
  - Destination: random
  - Packet inter-arrival time: constant, mean 1.0 s
  - Packet size: 1024 bytes, constant
  - Start time: uniform min 20 s, max 21 s

ZC: ZigBee Coordinator

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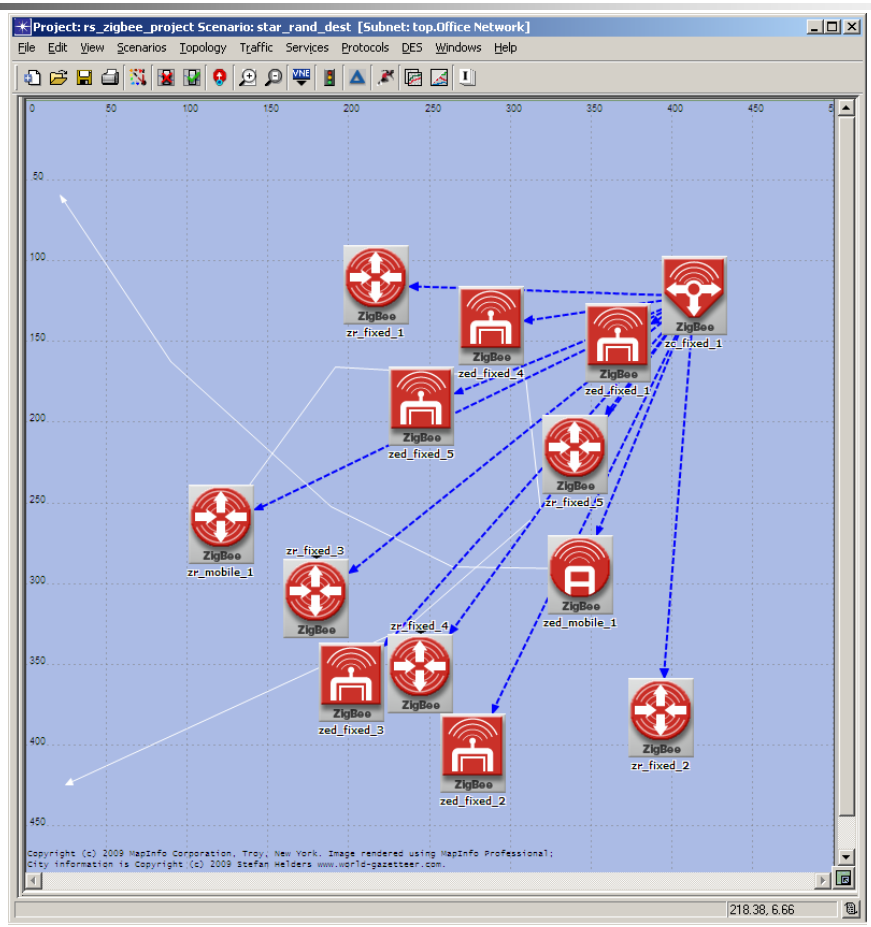
Star topology



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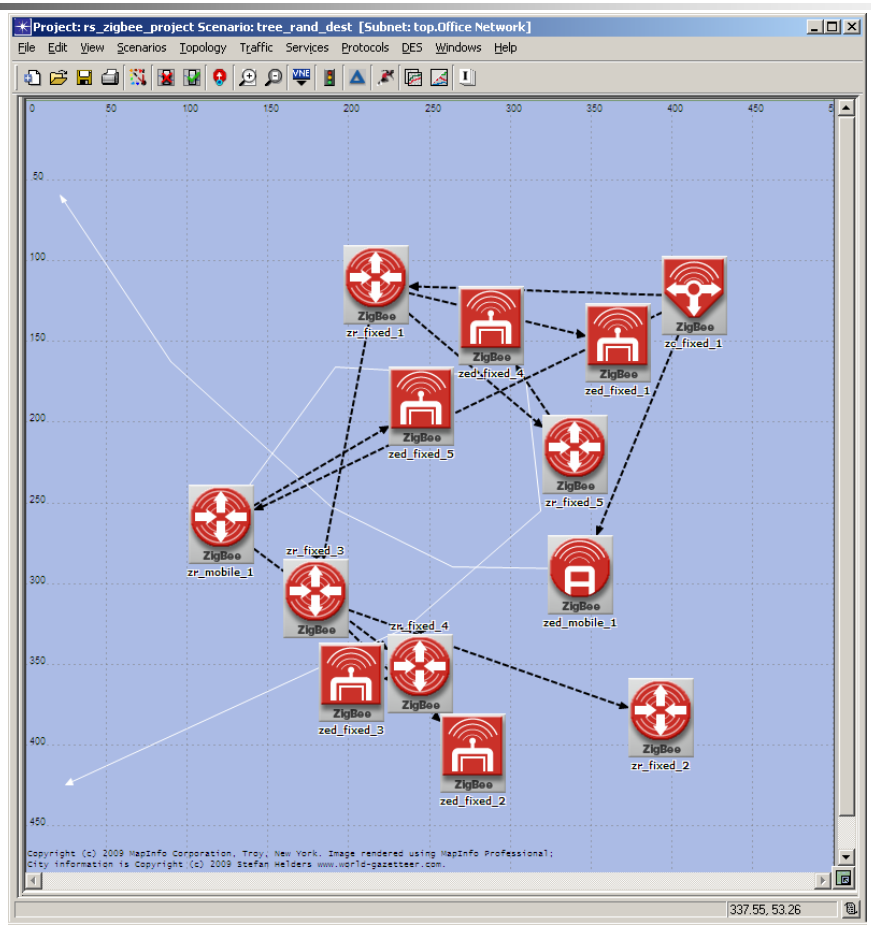
ZR: ZigBee Router

ZED: ZigBee End Device

Tree topology



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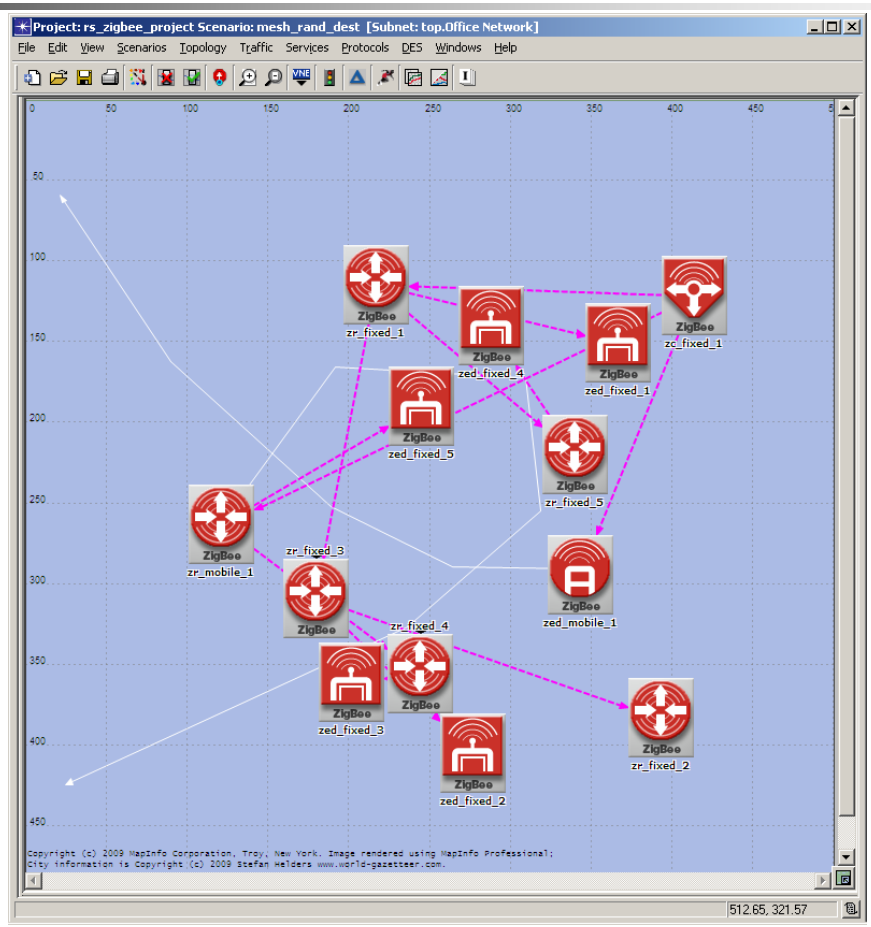
ZED: ZigBee End Device

Mesh topology



ZC: ZigBee Coordinator

ZR: ZigBee Router

ZED: ZigBee End Device

Network structure

Device Name	PAN ID			Parent		
	Star	Tree	Mesh	Star	Tree	Mesh
zc_fixed_1	0	0	0	n/a	n/a	n/a
zed_mobile_1	1	93	93	zc_fixed_1	zc_fixed_1	zc_fixed_1
zr_fixed_1	2	1	1	zc_fixed_1	zc_fixed_1	zc_fixed_1
zr_mobile_1	3	47	47	zc_fixed_1	zc_fixed_1	zc_fixed_1
zr_fixed_3	4	2	2	zc_fixed_1	zr_fixed_1	zr_fixed_1
zed_fixed_1	5	46	46	zc_fixed_1	zr_fixed_1	zr_fixed_1
zed_fixed_5	6	92	92	zc_fixed_1	zr_mobile_1	zr_mobile_1
zed_fixed_2	7	23	23	zc_fixed_1	zr_fixed_3	zr_fixed_3
zr_fixed_5	8	24	24	zc_fixed_1	zr_fixed_1	zr_fixed_1
zr_fixed_2	9	3	3	zc_fixed_1	zr_fixed_3	zr_fixed_3
zr_fixed_4	10	48	48	zc_fixed_1	zr_mobile_1	zr_mobile_1
zed_fixed_3	11	69	69	zc_fixed_1	zr_fixed_4	zr_fixed_4
zed_fixed_4	12	45	45	zc_fixed_1	zr_fixed_5	zr_fixed_5

ZC: ZigBee Coordinator, ZR: ZigBee Router, ZED: ZigBee End Device

PAN ID: Personal Area Network Identifier

Simulation parameters

ZigBee Parameters	Value		
	Star	Tree	Mesh
Maximum children	255	3	3
Maximum routers	0	2	2
Maximum depth	1	5	5
Achieved depth	1	3	3
Mesh routing	Disabled	Disabled	Enabled
Transmit power	0.05	0.05	0.05
Transmit band	2450 MHz	2450 MHz	2450 MHz
PAN ID	Auto assigned	Auto assigned	Auto assigned

PAN ID: Personal Area Network Identifier

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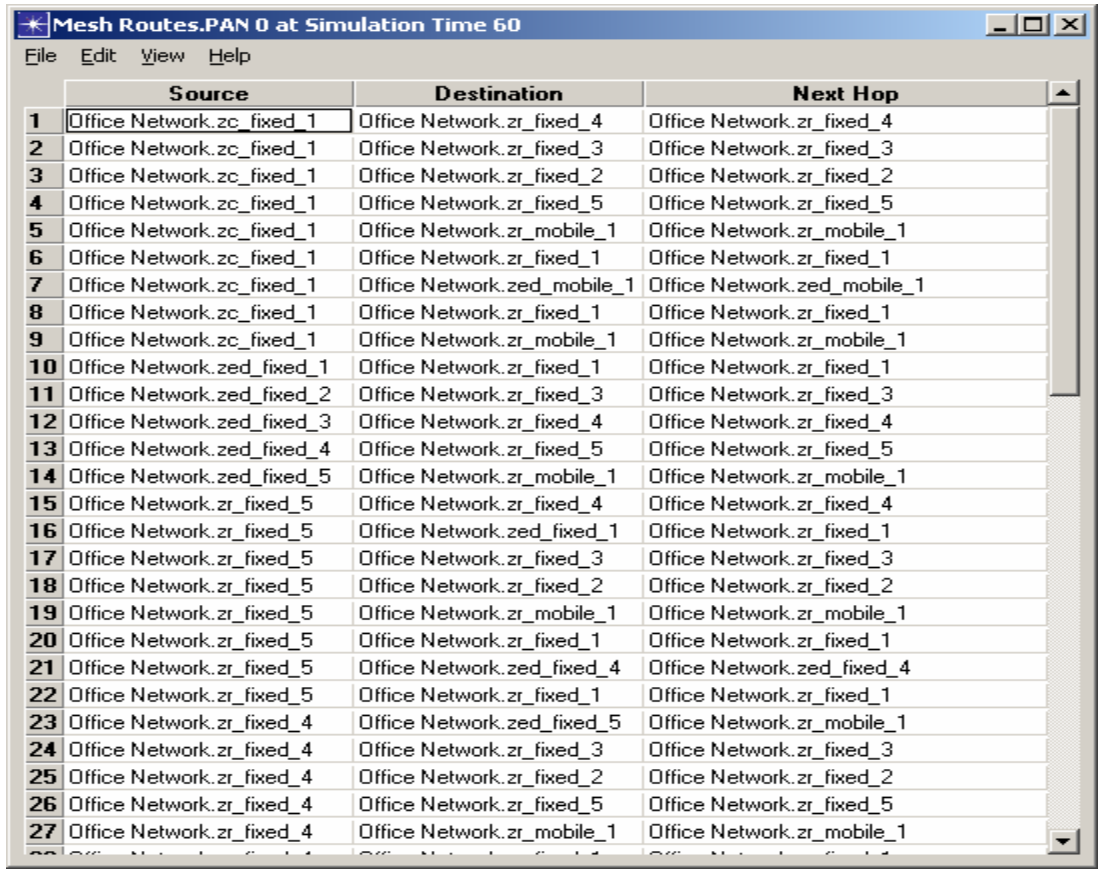
Simulation results

- Mesh routing table
- End-to-end delay
- Number of hops
- Throughput - ZC
- Throughput - global

ZC: ZigBee Coordinator

Mesh routing table



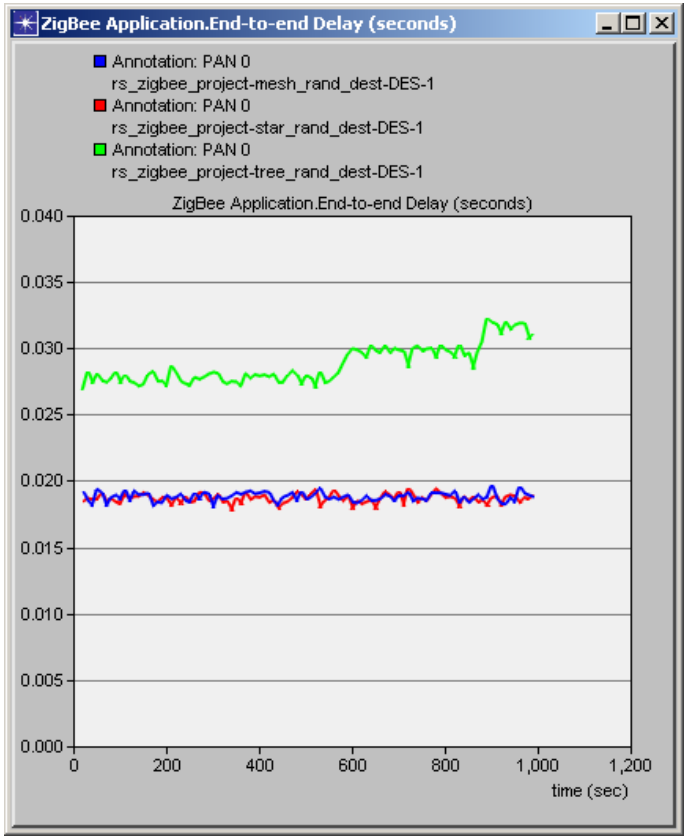
Mesh Routes.PAN 0 at Simulation Time 60

File Edit View Help

	Source	Destination	Next Hop
1	Office Network.zc_fixed_1	Office Network.zr_fixed_4	Office Network.zr_fixed_4
2	Office Network.zc_fixed_1	Office Network.zr_fixed_3	Office Network.zr_fixed_3
3	Office Network.zc_fixed_1	Office Network.zr_fixed_2	Office Network.zr_fixed_2
4	Office Network.zc_fixed_1	Office Network.zr_fixed_5	Office Network.zr_fixed_5
5	Office Network.zc_fixed_1	Office Network.zr_mobile_1	Office Network.zr_mobile_1
6	Office Network.zc_fixed_1	Office Network.zr_fixed_1	Office Network.zr_fixed_1
7	Office Network.zc_fixed_1	Office Network.zed_mobile_1	Office Network.zed_mobile_1
8	Office Network.zc_fixed_1	Office Network.zr_fixed_1	Office Network.zr_fixed_1
9	Office Network.zc_fixed_1	Office Network.zr_mobile_1	Office Network.zr_mobile_1
10	Office Network.zed_fixed_1	Office Network.zr_fixed_1	Office Network.zr_fixed_1
11	Office Network.zed_fixed_2	Office Network.zr_fixed_3	Office Network.zr_fixed_3
12	Office Network.zed_fixed_3	Office Network.zr_fixed_4	Office Network.zr_fixed_4
13	Office Network.zed_fixed_4	Office Network.zr_fixed_5	Office Network.zr_fixed_5
14	Office Network.zed_fixed_5	Office Network.zr_mobile_1	Office Network.zr_mobile_1
15	Office Network.zr_fixed_5	Office Network.zr_fixed_4	Office Network.zr_fixed_4
16	Office Network.zr_fixed_5	Office Network.zed_fixed_1	Office Network.zr_fixed_1
17	Office Network.zr_fixed_5	Office Network.zr_fixed_3	Office Network.zr_fixed_3
18	Office Network.zr_fixed_5	Office Network.zr_fixed_2	Office Network.zr_fixed_2
19	Office Network.zr_fixed_5	Office Network.zr_mobile_1	Office Network.zr_mobile_1
20	Office Network.zr_fixed_5	Office Network.zr_fixed_1	Office Network.zr_fixed_1
21	Office Network.zr_fixed_5	Office Network.zed_fixed_4	Office Network.zed_fixed_4
22	Office Network.zr_fixed_5	Office Network.zr_fixed_1	Office Network.zr_fixed_1
23	Office Network.zr_fixed_4	Office Network.zed_fixed_5	Office Network.zr_mobile_1
24	Office Network.zr_fixed_4	Office Network.zr_fixed_3	Office Network.zr_fixed_3
25	Office Network.zr_fixed_4	Office Network.zr_fixed_2	Office Network.zr_fixed_2
26	Office Network.zr_fixed_4	Office Network.zr_fixed_5	Office Network.zr_fixed_5
27	Office Network.zr_fixed_4	Office Network.zr_mobile_1	Office Network.zr_mobile_1

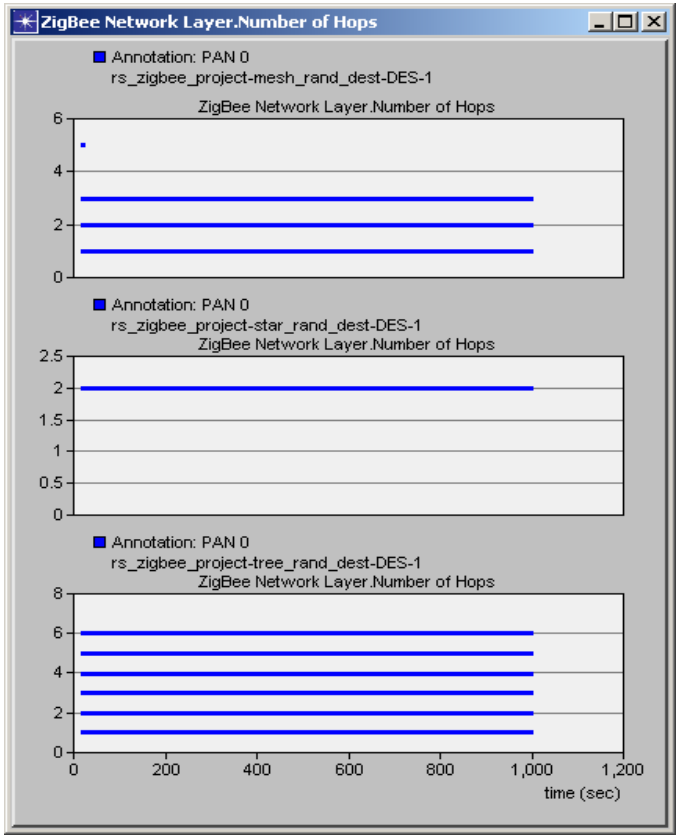
End-to-end delay

- Star and Mesh topologies have similar end-to-end delay in this simulation
- Tree topology has a higher end-to-end delay of 50% and it is increasing



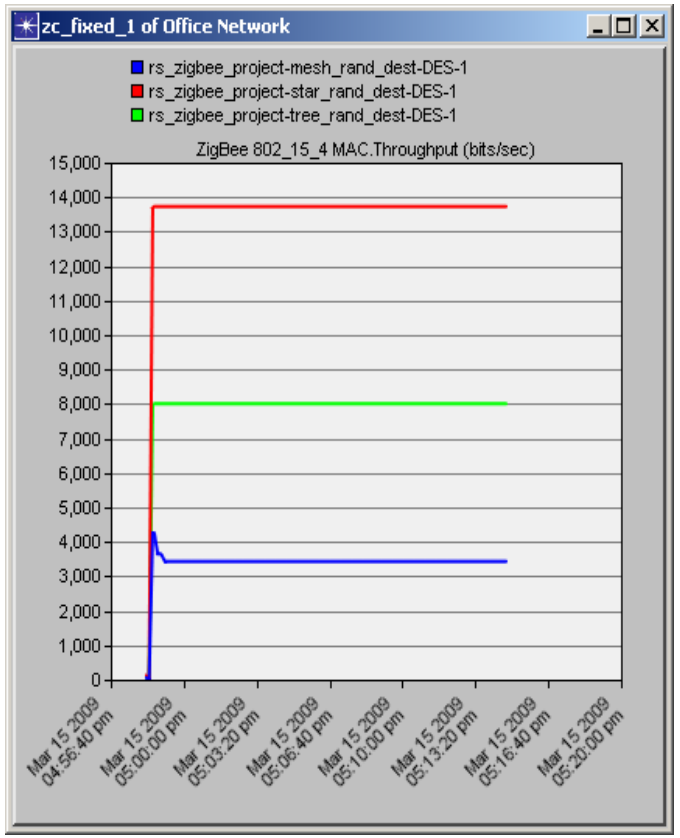
Number of hops

- Average number of hops for Mesh topology is the same as Star topology
- Tree topology has a higher average number of hops of 75%



Throughput - ZC

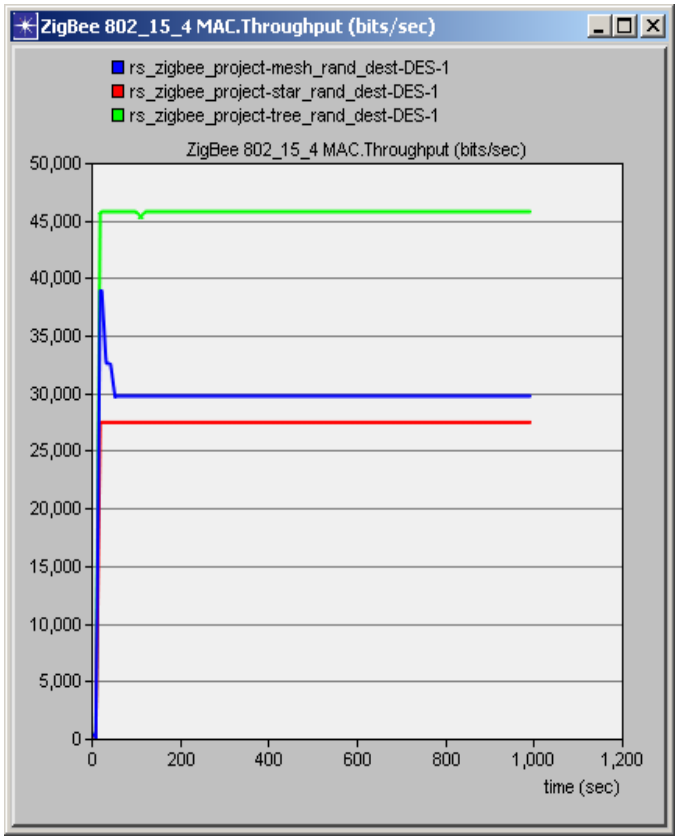
- The Coordinator in Star topology has the highest throughput (bits/sec)
- The Coordinator in Tree topology has the second highest throughput (bits/sec)
- The Coordinator in Mesh topology has the lowest throughput (bits/sec)



ZC: ZigBee Coordinator

Throughput - global

- Tree topology has the highest global throughput (bits/sec)
- Mesh topology has the second highest global throughput (bits/sec)
- Star topology has the lowest global throughput (bits/sec)



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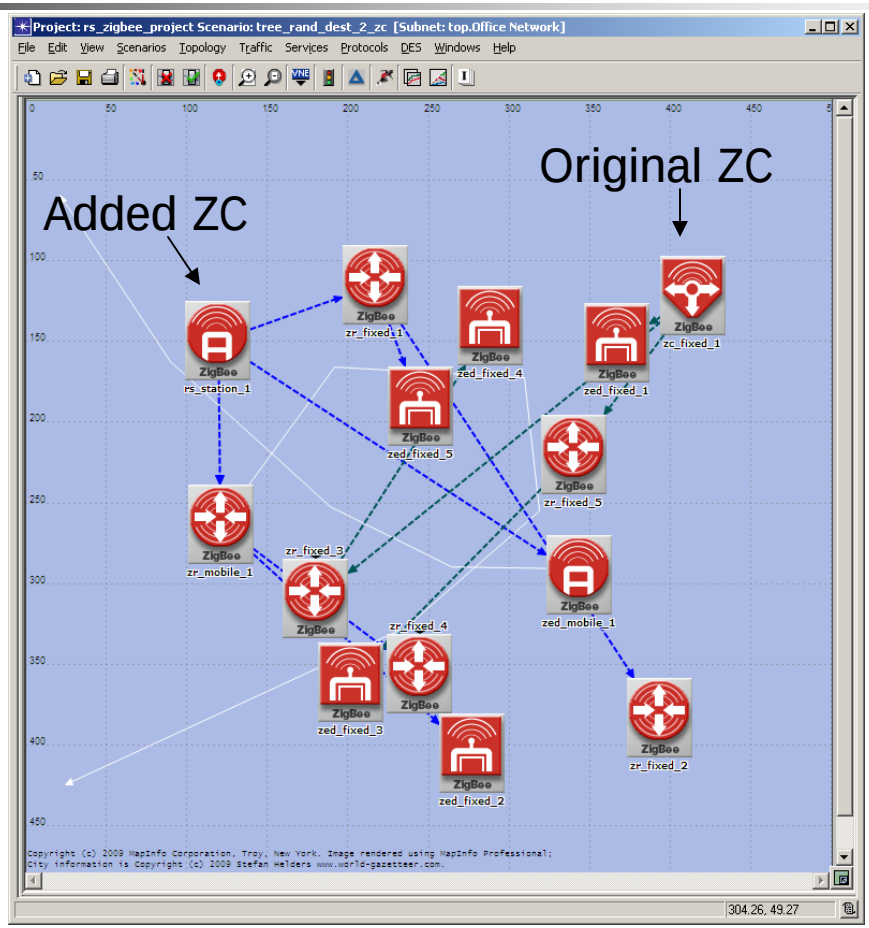
ZC: ZigBee Coordinator

Multiple ZC – tree topology



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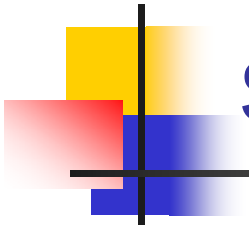


Simulation results

- End-to-end delay
- Throughput - ZC

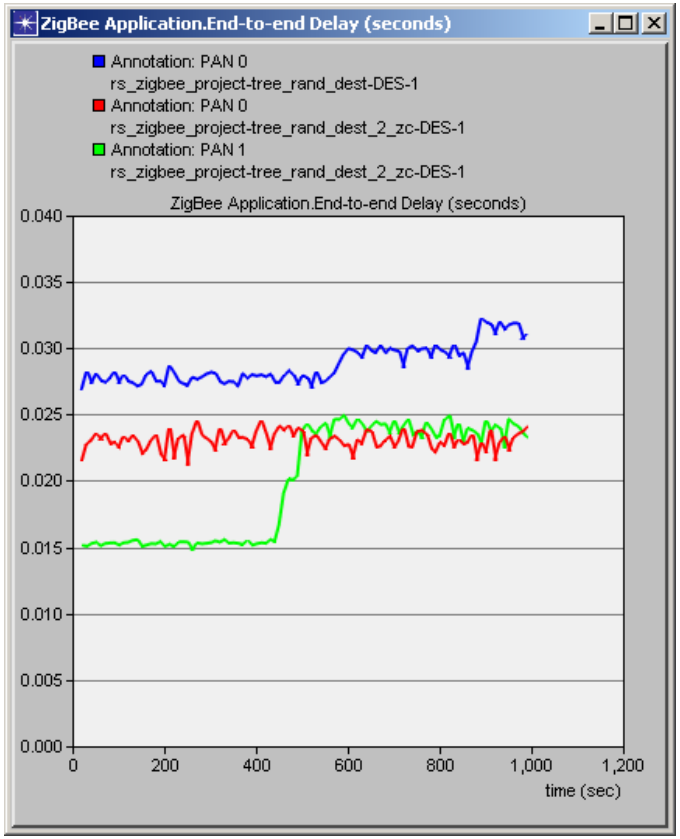
ZC: ZigBee Coordinator

End-to-end delay

- Ds_0: end-to-end delay of the network with a single PAN
- Dm_0: end-to-end delay of PAN_0 in the network with two PANs
- Dm_1: end-to-end delay of PAN_1 in the network with two PANs

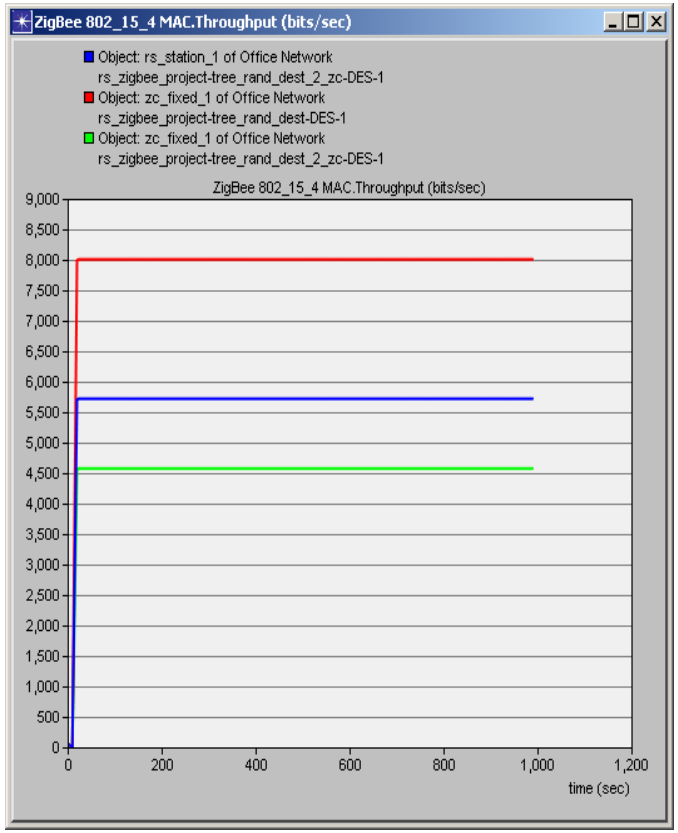
- Ds_0 > Dm_0
- Ds_0 > Dm_1
- Ds_0 < Dm_0 + Dm_1

PAN: Personal Area Network



Throughput - ZC

- Ts_0: throughput of ZC in the network with a single PAN
- Tm_0: throughput of ZC in PAN_0 of the network with two PANs
- Tm_1: throughput of ZC in PAN_1 of the network with two PANs
- (Ts_0 * 1.25) = Tm_1 + Tm_2



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Conclusions

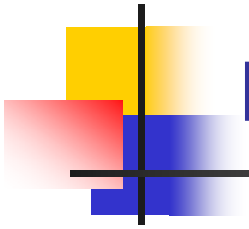
- End-to-end delay
  - Star and Mesh topologies are similar
  - Tree is higher
- Average number of hops
  - Star and Mesh topologies are similar
  - Tree is higher
- ZC throughput (bits/sec)
  - Star topology has the highest
  - Tree has the second highest
  - Mesh has the lowest
- Global throughput (bits/sec)
  - Tree topology has the highest
  - Mesh has the second highest
  - Star has the lowest

ZC: ZigBee Coordinator

Conclusions - single vs. multiple ZC

- End-to-end delay
  - The network with a single PAN has lower than the network with two PANs
- Throughput ZC
  - The network with a single PAN has lower than the network with two PANs

ZC: ZigBee Coordinator



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Unfinished work - simulation scenario and parameters

- Simulation scenario:
  - ZC failure and quick recovery using ZC backup (ZCB)
- Parameters:
  - 1,000 s simulated time
  - Destination: random
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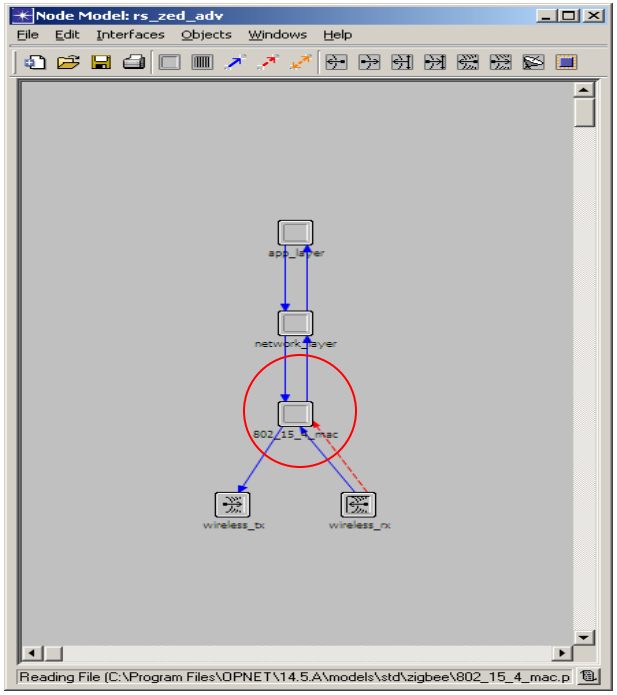
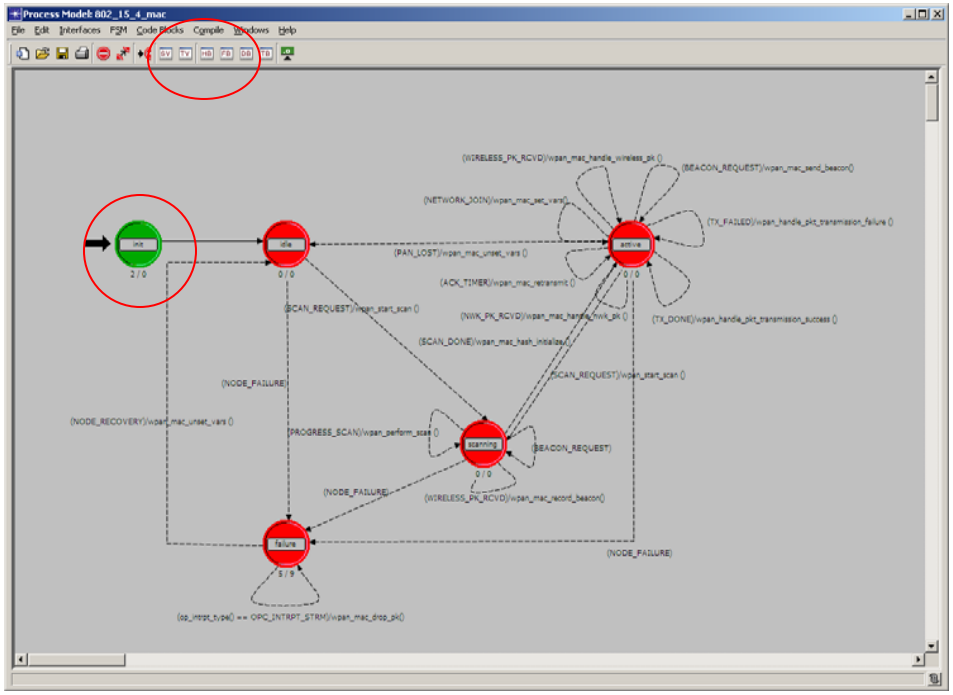
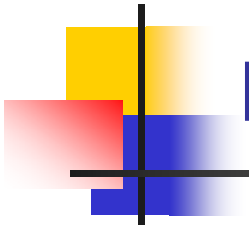




Unfinished work - implementation details

```
static void failNode(void * ptrVoid, int iCode);
void wpan_prj_init();
...
void wpan_prj_init() {

        double dInterruptTime = 100.0; // time is second that the interrupt is scheduled
        int iCode = 0; // verification code
        void * ptrVoid = 0; // data structure to send to the called function

        FIN (wpan_prj_init());
        dInterruptTime += op_sim_time();
        op_intrpt_schedule_call(dInterruptTime, iCode, failNode, ptrVoid);

        FOUT;
}

...
static void failNode(void * ptrVoid, int iCode)      {

        Objid iObjId;
        Objid iParentObjId;

        FIN (failNode);

        if ((0 == my_pan_id) && (0 == my_network_address) && (-1 == my_parent_address)) {
                printf("Node: Coordinator with PAN_ID: 0\n");
...
                op_ima_obj_attr_set(op_intrpt_source(), "condition", OPC_BOOLINT_DISABLED);
```



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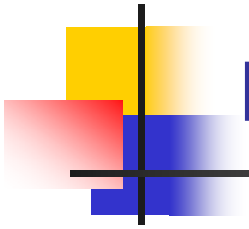

Future work

- Access to OPNET source code of the network and the application layers
- Complete ZC backup (ZCB) concept:
  - Monitor and mirror ZC data
  - Substitute ZC in case of failure
- Implement and analyze the concept in ns-2

ZCB: ZigBee Coordinator Backup

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