EE 662
Wireless Sensor Networks
Cluster-Tree Mesh Ad-Hoc Network
November 25
Implementation and Simulation

You have developed a self organizing cluster tree network protocol in the first assignment and reported your design in a design document. You have also been provided with a python based simulation platform that has been discussed in detail in class. In this assignment you are required to implement the protocol and run simulation to report the metrics listed in the following pages.

Implementation :

1- Design a neighbor discovery protocol and populate the neighbor table (more than one hop). You can initially develop a one hop neighbor table however final deliverable needs to include a multihop neighbor table populated by neighbor table sharing.
2- In your previous assignment you have developed a cluster tree network protocol and populated member networks, as well as members table. Both tables implemented in each clusterhead. The member networks table lists the networks below the cluster head, while members table lists the members of this cluster. Member networks table will need to be used in routing. The simulation model shared with you earlies does not implement routing. rather delivers packets to the destination directly. We need routing implemented in the simulation model. See item 3 below.
3- Implement Routing in your simulation platform
    a. Routing should use mesh routing in the local neighborhood and revert to tree when the local mesh routing fails.
    b. Report :
        i. Average time to join the network using simulation time. Each packet created (both control and data packets generated) will need to be timestamped. When the packet reaches final destination the time between receive time and packet creation time will need to be logged for measuring the delay within the network. Please note that the current system does take the processing time or transmission time. Models that considers these times will receive bonus points.
        ii. Implement packet tracing and record he path between any two network nodes when data packets are exchanged between random nodes.

4- Config parameters,
    a. Number of child nodes allowed for a cluster , by configuring the number of nodes in a cluster you can control the topology of the network.
    b. Tx Power of each cluster. For each cluster allow specification of a Tx Power between TxMin and TxMax. All nodes in a cluster will have the same power level. The system should also allow all nodes use the same power level.
    c. Packet loss ratio. In the current model channel is assumed to be perfect, all packets are delivered to destination. In your model you should allow packet loss rate to be specified. The model should consider packet loss rate when delivering packets.

5- In the current model the Clusters are overlapping by a large amount since cluster head of a new cluster is chosen among the nodes in an existing cluster. Develop a variation where the clusters overlap minimally and cluster heads communicate using a router. The model should allow cluster head role to move from one node to another.

6- The model should implement recovery of network from node and link failures. This will be tested by randomly killing a node after the simulation is started and recovering the node after some time. The events (orphan networks nodes, joining a network, role changes (nodes becoming cluster head) needs to be logged and reported.
    a. Time to recover
    b. Number of nodes orphan

7- Develop a cluster optimization protocol that will minimize
    a. The number of clusters and/or
    b. The energy consumed in the network (per packet energy consumption)

8- Develop an Energy Model where every nodes energy will be reduced by an amount equal to the energy required to transmit/receive a packet. When the power level of a node drops to a minimum specified, the node should be turned off. Please use the CC2420 radio for this estimation. We will test your protocol for network life. Your system should maximize the network life.

Energy Required to Transmit a Packet on a CC2420 Node

The energy required to transmit a packet on a TI/Chipcon CC2420 (2.4 GHz IEEE 802.15.4 radio) depends on the transmission (TX) power, packet length, and whether startup or turnaround time is included.

1. Basic Parameters

    - Data rate (R): 250 kbps → 4 μs per bit
    - Supply voltage (V): ≈ 3.0 V
    - TX current at 0 dBm: ≈ 17.4 mA → Power (P) ≈ 52.2 mW
    - PHY overhead: 6 bytes (4-byte preamble + 1-byte SFD + 1-byte PHR)

2. Energy Formula

Energy to transmit (E_{tx}) a packet with PSDU length N bytes (MAC frame length), excluding startup:

- $E_{tx} \approx P \times (8 \times (N + 6)) / R$
- $E_{tx} \approx (V \times I) \times (8 \times (N + 6)) / 250{,}000$

At V = 3.0 V and I = 17.4 mA:

- Energy per bit ≈ 0.208 μJ = Power in Watts (Joules/second) / Bit rate (bits/second) = Joules/bit
- Energy per byte ≈ 1.67 μJ
- Optional turnaround/PLL settling overhead ≈ 10 μJ

3. Example Energy Values (3.0 V, 0 dBm)

   At 0dBm CC2420 current is 17.4mA → Power = 52.2 mV
   PHY overhead = 6 bytes (4 bytes preamble, 1 byte SFD, 1 byte PHR)

   Energy per bit = 0.208 μJ. , per byte = 1.67 μJ

PSDU (MAC) Bytes (N)	Total Over-Air Bytes (N + 6)	Energy (μJ)
20	26	≈ 43 μJ
50	56	≈ 94 μJ
100	106	≈ 177 μJ
127	133	≈ 222 μJ

4. Dependence on TX Power

The CC2420’s TX current depends on output power:

Chipcon Products from Texas Instruments — CC2420

Parameter	Min.	Typ.	Max.	Unit	Condition / Note
Current Consumption, transmit mode:					
P = -25 dBm		8.5		mA	The output power is delivered differentially to a 50 Ω singled ended load through a balun, see also page 54.
P = -15 dBm		9.9		mA	
P = -10 dBm		11		mA	
P = −5 dBm		14		mA	
P = 0 dBm		17.4		mA	

Rx Current : 18.8 mA

Energy scales linearly with TX current. Lower output power reduces energy consumption proportionally.

Relating Transmission Energy to Battery Lifetime (Two AA Batteries)

The energy per packet can be related to battery lifetime by comparing the per-packet energy cost with the total energy available from the power source.

1. Battery Energy

For two AA alkaline batteries in series:
- Voltage ≈ 3.0 V
- Capacity ≈ 2000 mAh
- Total energy: 3.0 V × 2.0 Ah = 6.0 Wh = 21,600 J

2. Example Packet Energy

(CC2420 @ 0 dBm, 3.0 V):

- Energy per byte ≈ 1.67 µJ
- 50-byte packet → ≈ 94 µJ
- With overhead (startup/PLL): ≈ 104 µJ per packet (this is about 10 micro Amp due to RX/TX PLL turnaround setting which is 192 microsecond)

3. Packets Transmittable from Two AA Cells

Ignoring idle/sleep energy:
Packets = 21,600 J ÷ 1.04×10^{-4} J ≈ 2.08×10^{8} packets
If one packet is sent per second:
Lifetime ≈ 2.08×10^{8} s ≈ 6.6 years (theoretical upper bound)

4. Including Baseline Power Draw

Average power combines packet transmissions and baseline current draw:
P_avg = r × E_pkt + V × I_base
Lifetime = E_bat / P_avg

Example scenarios (V = 3.0 V, E_bat = 21,600 J, E_pkt = 1.04×10^{-4} J):

Packet Rate (r)	Baseline Current (I_base)	Average Power (P_avg, W)	Lifetime (s)	Lifetime (days)
1 pkt/min	100 µA	0.000302	2.5×10^{7}	≈ 291 days
1 pkt/s	500 µA	0.001604	1.35×10^{7}	≈ 156 days
1 pkt/s	5 mA	0.015104	1.43×10^{6}	≈ 16.6 days

5. Continuous Transmission Limit

If the CC2420 transmits continuously (I_TX ≈ 17.4 mA @ 0 dBm), the battery life is roughly:
Lifetime ≈ 2000 mAh ÷ 17.4 mA ≈ 115 hours ≈ 4.8 days.

6. Lifetime Formula Summary

To estimate your specific node lifetime:

1. Compute $E_{bat} = V \times Ah \times 3600$
2. Compute $E_{pkt} = (V \times I_{TX} \times 8 \times (N + 6)) / 250{,}000$
3. Choose your send rate (r) and baseline current (I_{base})
4. Lifetime = $E_{bat} / (r \times E_{pkt} + V \times I_{base})$