Wsn (4353201) - Problem Solver

Antigravity AI

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Contents

Appendix: Key Formulae

This appendix provides a quick reference to the key formulae and mathematical relationships discussed in this book, organized by unit.

Unit 1: Wireless Sensor Networks Basics

Node Deployment and Coverage

- **Node Density (λ):** The number of nodes per unit area.

$$\lambda = \frac{N}{A_{\text{total}}}$$

- **Total Area (A_{total}):**

$$A_{\text{total}} = \text{Length} \times \text{Width}$$

- **Sensing Area (A_{sense}):** Area covered by a sensor with sensing radius R_s.

$$A_{\text{sense}} = \pi \cdot R_s^2$$

- **Minimum Number of Nodes (N_{min}):** Minimum nodes required to cover the total area without overlap.

$$N_{\text{min}} = \frac{A_{\text{total}}}{A_{\text{sense}}}$$

- **Number of Neighbors ($N_{\text{neighbors}}$):** Expected number of nodes within the sensing range.

$$N_{\text{neighbors}} = \lambda \cdot A_{\text{sense}} = \frac{N \cdot \pi \cdot R_s^2}{A_{\text{total}}}$$

Data Transmission and Energy

- **Packet Length (L_{packet}):**

$$L_{\text{packet}} = L_{\text{payload}} + L_{\text{overhead}}$$

- **Transmission Time (T_{tx}):** Time required to transmit a packet at data rate R.

$$T_{\text{tx}} = \frac{L_{\text{packet}}}{R}$$

- **Energy per Cycle (E_{cycle}):** Total energy consumed in one active-sleep cycle.

$$E_{\text{cycle}} = E_{\text{tx}} + E_{\text{rx}} + E_{\text{idle}} + E_{\text{sleep}}$$

- **Average Power (P_{avg}):**

$$P_{\text{avg}} = \frac{E_{\text{cycle}}}{T_{\text{cycle}}}$$

- **Battery Energy (E_{battery}):** Energy stored in a battery with voltage V and capacity C.

$$E_{\text{battery}} = V \times C$$

- **Number of Cycles (N_{cycles}):** Total operating cycles before battery depletion.

$$N_{\text{cycles}} = \frac{E_{\text{battery}}}{E_{\text{cycle}}}$$

Unit 2: MAC and Routing Protocols

Energy Consumption Models

- **Energy to Receive ($E_{\mathbf{Rx}}$):** Energy consumed to receive a k-bit message.

$$E_{\text{Rx}}(k) = k \cdot E_{\text{elec}}$$

- **Energy to Transmit ($E_{\mathbf{Tx}}$):** Energy consumed to transmit k bits over distance d.

$$E_{\text{Tx}}(k, d) = \begin{cases} k \cdot E_{\text{elec}} + k \cdot \epsilon_{\text{fs}} \cdot d^2 & \text{if } d < d_0 \text{ (Free Space Model)} \\ k \cdot E_{\text{elec}} + k \cdot \epsilon_{\text{mp}} \cdot d^4 & \text{if } d \geq d_0 \text{ (Multipath Model)} \end{cases}$$

- **Crossover Distance (d_0):** Threshold distance between free space and multipath propagation models.

$$d_0 = \sqrt{\frac{\epsilon_{\text{fs}}}{\epsilon_{\text{mp}}}}$$

- **Energy per Frame ($E_{\mathbf{frame}}$):**

$$E_{\text{frame}} = (P_{\text{listen}} \times T_{\text{listen}}) + (P_{\text{sleep}} \times T_{\text{sleep}})$$

- **Total Energy Consumption ($E_{\mathbf{total}}$):**

$$E_{\text{total}} = \frac{T_{\text{total}}}{T_{\text{frame}}} \times E_{\text{frame}}$$

MAC Protocols and Timing

- **Frame Duration ($T_{\mathbf{frame}}$):**

$$T_{\text{frame}} = T_{\text{listen}} + T_{\text{sleep}}$$

- **Duty Cycle (D):** Percentage of time a node is active.

$$D = \left(\frac{T_{\text{listen}}}{T_{\text{frame}}}\right) \times 100\%$$

- **Contention Window (CW):**

$$CW = 2^c$$

- **Backoff Time:**

$$\text{Backoff Time} = R \times \text{Slot\_Time}$$

- **Maximum Backoff Time:**

$$\text{Max Backoff Time} = R_{\text{max}} \times \text{Slot\_Time}$$

Routing and Synchronization

- **LEACH Cluster Head Threshold ($T(n)$):** For probability P and current round r.

$$T(n) = \frac{P}{1 - P \times (r \bmod (1/P))}$$

- **Time Synchronization Offset (Δ):**

$$\Delta = \frac{(T_2 - T_1) - (T_4 - T_3)}{2}$$

- **Time Synchronization Delay (d):**

$$d = \frac{(T_4 - T_1) - (T_3 - T_2)}{2}$$

- **Trilateration Coordinates (x, y):** Intersection point of overlapping node ranges.

$$x = \frac{r_1^2 - r_2^2 + d^2}{2d}$$
$$y = \frac{r_1^2 - r_3^2 + i^2 + j^2 - 2ix}{2j}$$

Unit 3: Data Dissemination and Gathering

Performance Metrics

- **Transmission Time (T_t):**

$$T_t = \frac{L}{R}$$

- **Protocol Efficiency:** Percentage of payload P relative to total packet size L.

$$\text{Efficiency } \% = \left(\frac{P}{L}\right) \times 100\%$$

- **Throughput:** Effective data transfer rate.

$$\text{Throughput} = \frac{\text{Payload Size (bits)}}{T_{\text{total}}}$$

- **Total Daily Data:** Total amount of data generated by all nodes in one day.

$$\text{Total Daily Data} = N \times \text{Data per day}$$

Power and Lifetime

- **Average Power (P_{avg}):**

$$P_{\text{avg}} = \frac{E_{\text{cycle}}}{T_{\text{cycle}}}$$

- **Node Lifetime:** Node operational time given battery capacity and current draw.

$$\text{Lifetime (hours)} = \frac{\text{Battery Capacity (Ah)}}{\text{Average Current (A)}}$$

Unit 4: WSN Network Performance and Traffic

Network Traffic and Bandwidth

- **Packet Size (S_{packet}):**

$$S_{\text{packet}} = S_{\text{payload}} + S_{\text{overhead}}$$

- **Sensor Data Rate (R_{sensor}):**

$$R_{\text{sensor}} = S_{\text{packet}} \times f_{\text{packet}}$$

- **Total Data Rate (R_{total}):**

$$R_{\text{total}} = N \times R_{\text{sensor}}$$

- **Required Bandwidth (B_{req}):** Required bandwidth for a specified utilization factor U.

$$B_{\text{req}} = \frac{R_{\text{total}}}{U}$$

Delay and Latency

- **Transmission Delay (D_{trans}):**
$$D_{\text{trans}} = \frac{L}{R}$$
- **Propagation Delay (D_{prop}):**
$$D_{\text{prop}} = \frac{d}{s}$$
- **Total Link Delay (D_{link}):**
$$D_{\text{link}} = D_{\text{trans}} + D_{\text{prop}} + D_{\text{proc}} + D_{\text{queue}}$$
- **Total Network Delay (D_{total}):**
$$D_{\text{total}} = \sum D_{\text{link}}$$

Node Deployment and Lifetime

- **Sensor Coverage Area (A_{sensor}):**
$$A_{\text{sensor}} = \pi \cdot r^2$$
- **Minimum Nodes (N_{min}):**
$$N_{\text{min}} = \frac{A_{\text{total}}}{A_{\text{sensor}}}$$
- **Actual Nodes (N_{actual}):** Actual nodes deployed, accounting for overlap factor O.
$$N_{\text{actual}} = \lceil N_{\text{min}} \times O \rceil$$
- **Duty Cycle (D):** Ratio of active time to total cycle time.
$$D = \frac{T_{\text{active}}}{T_{\text{active}} + T_{\text{sleep}}}$$
- **Average Current (I_{avg}):**
$$I_{\text{avg}} = (D \times I_{\text{active}}) + ((1 - D) \times I_{\text{sleep}})$$
- **Battery Lifetime:**
$$\text{Life}_{\text{hours}} = \frac{C_{\text{battery}}}{I_{\text{avg}}}$$
$$\text{Life}_{\text{days}} = \frac{\text{Life}_{\text{hours}}}{24}$$
$$\text{Life}_{\text{years}} = \frac{\text{Life}_{\text{days}}}{365}$$

Unit 5: WSN Design and Reliability

System Reliability

- **Series Reliability (R_{series}):**
$$R_{\text{series}} = R_1 \times R_2 \times \cdots \times R_n$$
- **Parallel Reliability (R_{parallel}):**
$$R_{\text{parallel}} = 1 - [(1 - R_1) \times (1 - R_2) \times \cdots \times (1 - R_n)]$$
- **Total Reliability (R_{total}):**
$$R_{\text{total}} = R_{\text{mcu}} \times R_{\text{modem\_block}}$$

Grid Deployment

- **Effective Area for Grid Deployment ($A_{\text{effective}}$):** Coverage area of a node in a square grid with transmission radius r.

$$A_{\text{effective}} = 2r^2$$

- **Number of Nodes for Grid (N):**

$$N = \left\lceil \frac{A_{\text{total}}}{A_{\text{effective}}} \right\rceil = \left\lceil \frac{A_{\text{total}}}{2r^2} \right\rceil$$

Data, Latency, and Storage

- **Sensor Data Rate (R_{sensor}):** Based on sample size and sampling frequency.

$$R_{\text{sensor}} = D_{\text{sample}} \times f_{\text{sample}} \quad \text{(bytes/second)}$$

- **Total Data Rate (R_{total}):**

$$R_{\text{total}} = N \times R_{\text{sensor}} \quad \text{(bytes/second)}$$

- **Bandwidth with Overhead:**

$$\text{Bandwidth (bps)} = R_{\text{total}} \times 8 \times \left(1 + \frac{P_{\text{overhead}}}{100}\right)$$

- **Storage Requirement:**

$$\text{Storage} = R_{\text{total}} \times T_{\text{seconds}} \quad \text{(bytes)}$$

- **Transmission Latency (T_{trans}):**

$$T_{\text{trans}} = \frac{\text{Packet Size (bits)}}{\text{Data Rate (bps)}}$$

- **Propagation Latency (T_{prop}):**

$$T_{\text{prop}} = \frac{\text{Distance (m)}}{\text{Signal Propagation Speed (m/s)}}$$

- **Total Latency (L_{total}):**

$$L_{\text{total}} = T_{\text{proc}} + T_{\text{trans}} + T_{\text{prop}} + T_{\text{queue}}$$

Power and Lifetime (Detailed)

- **Average Current (I_{avg}):**

$$I_{\text{avg}} = \frac{(I_{\text{active}} \times T_{\text{active}}) + (I_{\text{sleep}} \times T_{\text{sleep}})}{T_{\text{total}}}$$

- **Lifetime in Hours (L_{hours}):** Given battery capacity C.

$$L_{\text{hours}} = \frac{C}{I_{\text{avg}}}$$

- **Lifetime in Days (L_{days}):**

$$L_{\text{days}} = \frac{L_{\text{hours}}}{24}$$