Wireless IoT technology

① LoRa / LoRaWAN

Range (km): {urban: 2~5, rural: 15} Speed: 50kbps power consumption: •••

Application: Precision farming, manufacturing automation, pipeline monitoring

② Sigfox

Range (km): {urban: 3~10, rural: 30~50} Speed: 300bps power consumption: •

Application: Predictive maintenance, capacity planning, demand forecasting

③ NB-IoT

Range (km): {urban: 1-5, rural: 10-15} Speed: 250kbps power consumption: •

Application: Electric metering, manufacturing automation, retail PoS, Emergency Command Center, GIS monitor center, DMA Pipe Network

↑WAN
↓WPAN

④ Zigbee

{Zigbee Router, Zigbee Coordinator, Zigbe Device}

Zigbee Device Objectives (ZDO)
↓
provides the interface between application objects, device profiles, and APS layer in Zigbee devices.

⑤ MQTT: Message Queuing Telemetry Transport

Features: Publish and subscribe to topics

3 quality of service:
- 0 Best effort to deliver a msg
- 1 Deliver at least once
- 2 Deliver exactly once

Application: Home Automation, Health care, Mobile phone apps, Industrial automation, Automotive

Edge Computing

Benefits and use cases

- Latency - extremly low latency is essential for near real-time control
- Bandwidth — limited bandwidth
- Connectivity - reduce cloud connectivity costs
- Keeps data private by doing more computations locally
- Time sensitive compute-intensive workloads

Energy Models

k = no. of bits E_{elec}: 50 nJ/bit E_{amp}: 100pJ/bit/m^2 → energy loss due to chanel tsn

Transmitter ⇒ $E_{Tx}(k,d) = E_{elec} * k + [E_{amp} * k * d^2]$

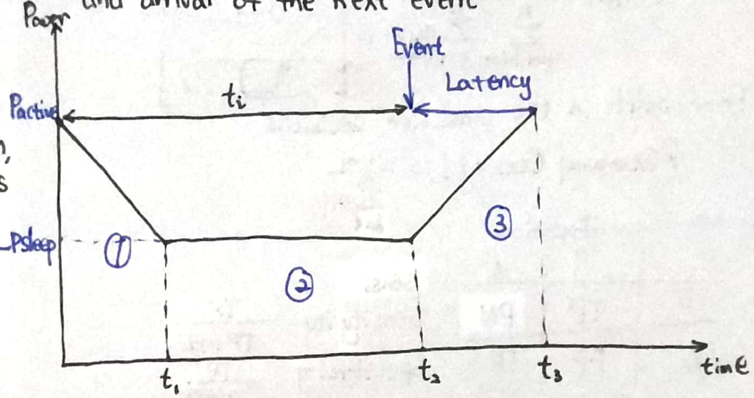
Receiver ⇒ $E_{Rx}(k,d) = E_{elec} * k$

• Start Up Energy

Energy consumption dominated by start-up transient when packet size is small.

• State transitions

t_i = time between end of processing of previous event and arrival of the next event

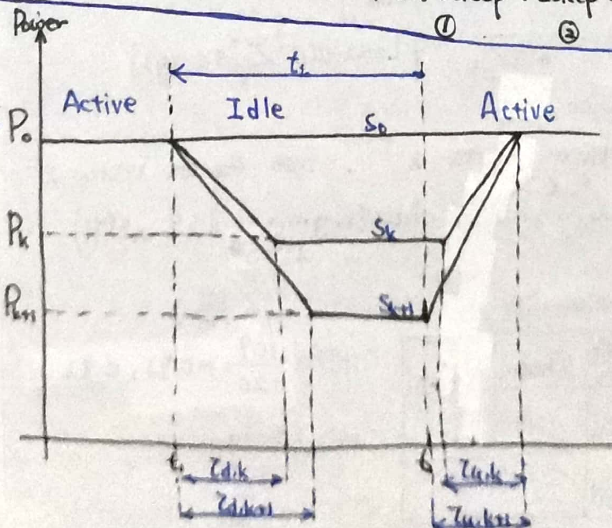


① $E_{act\to sleep} = (P_{active} + P_{sleep}) * \frac{t_1}{2}$

② $E_{sleep} = P_{sleep} * \frac{t_2 - t_1}{2}$

③ $E_{sleep\to active} = (P_{active} + P_{sleep}) * \frac{t_3 - t_2}{2}$

∴ Sleep if $P_{active} * t_i > \underset{①}{E_{act\to sleep}} + \underset{②}{E_{sleep}} + \underset{③}{E_{sleep\to active}}$



• Energy Savings E_s

$$E_{s,k} = (P_0 - P_k)t_i - \left[\frac{P_0 - P_k}{2}\right]\tau_{d,k} - \left[\frac{P_0 + P_k}{2}\right]\tau_{u,k}$$

Transition is only justified when $E_{s,k} > 0$

• Transition time threshold

$$T_{th,k} = \frac{1}{2}\left[\tau_{d,k} + \left(\frac{P_0 + P_k}{P_0 - P_k}\right)\tau_{u,k}\right]$$

Worthwhile going to mode k if $(t_i > T_{th,k})$ ⇒ $S_0 \to S_k$

States

Active(S_0), Ready(S_1), Monitor(S_2), Look(S_3), Sleep(S_4)

WSN Routing

- Minimum Transmission Energy (MTE) routing: neighbour selection.

For 3-nodes A, B, C, A would transmit to node C through B iff $E_{TX}(d=d_{AB}) + E_{TX}(d=d_{BC}) < E_{TX}(d=d_{AC})$

d_{AB}^2 d_{BC}^2 d_{AC}^2

LEACH

- The job of cluster head is to collect data from their surrounding nodes and pass it on to the base station.
- Cluster head role is rotated to share energy load
  Dynamic
- Cluster head receives the data and performs signal processing functions on the data and transmits data to the remote base station

The LEACH network has two phases

① Set-Up phase
- Cluster Heads (CH) are chosen.
- Nodes join clusters.

② The Steady-State Phase
- The cluster heads and clusters are maintained.
- Data is transmitted from nodes to CHs.
- CHs may do some processing and data aggregation before sending the data to the base station (BS)

- Each sensor node elects itself to be cluster head with a certain prob at the beginning of each round.
- Node have not already been cluster heads may become CH

Decision to be cluster heads

Threshold: $T(r) = \dfrac{P}{1 - P \times (r \bmod P^{-1})}$ $\forall$ nodes $\in G$

$T(r) = 0$ $\forall$ nodes $\notin G$

P is the cluster-head probability

G is the set of nodes that were't CHs previous rounds

$P = \dfrac{\text{no. of CH}}{\text{no. of nodes}} = \dfrac{k}{N}$

n is the random number between 0 and 1, if $n < T(r)$, then that node become cluster head. Each node will be cluster head once in an interval of $\frac{1}{P}$ rounds.

Nodes send data during their allocated time slot

Setup	Steady-state		
Clusters formed	Slot for node i	Slot for node i	...

TDMA Schedule

(this time can aggregate to BS)

Cluster members will send data according to DSSS code & a TDMA Schedule to minimize inter-cluster interference

Advantages of LEACH

① LEACH helps to balance the load in the networks as compared to direct transmission

② LEACH is completely distributed, requiring no control information from the base station

③ Nodes do not need global topology information

Disadvantages of LEACH

① Nodes must have data to send in the alloted time

② Bad clusters can be formed due to the random nature of cluster information

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Data fusion

Vairous forms of CSP

- Single Node, Multiple Modality (SN, MM)
  - No communication burden
- Multiple Node, Single Modality (MN, SN)
  - Higher communication burden
- Multiple Node, Multiple Modality (MN, MM)
  - Highest communication and computational burden

Classification.

For a $m \times m$ confusion matrix

- Probability of detection for class m

$$PD_m = \frac{n_{mm}}{\sum_{j=1}^{M} n_{mj}}$$

- Probability of false alarm for class m

$$PFA_m = \frac{\sum_{k=1, k\neq m} n_{km}}{\sum_{k=1, k\neq m}^{M} \sum_{j=1}^{M} n_{kj}}$$

- Prior belif in the classifier decisions

$$P(x \in w_m \mid C(x) = j) = \frac{n_{mj}}{\sum_{i=1}^{M} n_{ij}}$$

Binary Classification

	$\hat{P}$	$\hat{N}$
P	TP	FN
N	FP	TN

Percision $\dfrac{TP}{TP+FP}$

Sensitivity $\dfrac{TP}{TP+FN}$

Specificity $\dfrac{TN}{TN+FN}$

Accuracy $= \dfrac{TP+TN}{TP+TN+FP+FN}$

Gaussian Classifiers

mean vector $\mu_j = E_j[x]$, $\Sigma_j = E_j[(x-\mu_j)(x-\mu_j)^T]$

Likelihood function for class j

$$P(x \mid w_j) = \frac{1}{\pi^N |\Sigma_j|} \cdot \exp[-(x-\mu_j)^T \Sigma_j^{-1} (x-\mu_j)]$$

NN classifier

Training feature vector x^{cTr}, test feature vector x^c

$$C_{NN}(\overbrace{x_1, \dots, x_k}^{x^c}) = \text{class}\left(\underset{x^{cTr} \in S^{Tr}}{\arg\min} \|x^c - x^{cTr}\|\right)$$

Ex:

Gaussian classifier

	$C(x)$ / w_m	Wheeled	Tracked
120	Wheeled	109	11
120	Tracked	22	98

$PD = 0.91$, 0.82, avg $= 0.86$ ($\frac{109}{120}$)

$PFA = 0.18$, 0.09 ($\frac{22}{120}$)

Collaborative Signal & Information Processing (CSIP)

IDSQ: Information Driven Sensor Query

(Static case) ↑ without need to have the sensor data first

Measurement / Observation model

$z_i(t) = h(x(t), \lambda_i(t))$ ① $\lambda_i = [x_i, \sigma_i^2]^T$

$$z_i = \frac{a}{\|x_i - x\|^{\frac{\alpha}{2}}} + w_i$$

a is target amplitude

α is attenuation coefficie

Information Utility