a. Network Lifetime

Network lifetime in WSN refers to the duration of time the network remains operational before the energy of its nodes is exhausted. Since sensor nodes are usually battery-powered and deployed in remote or harsh environments, maximizing network lifetime is crucial. Strategies to prolong network lifetime include energy-efficient routing, data aggregation, sleep/wake scheduling, and energy harvesting techniques.

b. Energy Scavenging

Energy scavenging in WSN involves harnessing ambient energy (such as solar, thermal, or vibration energy) to power sensor nodes. This method helps to extend the lifetime of WSNs by reducing dependence on non-rechargeable batteries. Common energy scavenging methods in WSNs include photovoltaic cells (solar power), piezoelectric devices (vibration energy), and thermoelectric generators (temperature gradients).

c. Event Mobility

Event mobility refers to the movement of an event that is being monitored by a WSN. In applications like wildlife tracking, the object or event being sensed can move through the network. The challenge is for the WSN to adapt to this mobility, by dynamically selecting nodes near the event to collect data or adjusting routing paths to maintain efficient communication with mobile nodes.

d. Adaptive Fidelity provides trade-off between accuracy and energy efficiency. Indicate of node failure, energy consumption or scavenging rate.

Adaptive fidelity in WSNs refers to the dynamic adjustment of the quality or resolution of data collection based on the network's conditions and the importance of the sensed data. Nodes can reduce the frequency of sampling or the number of active nodes in the network to conserve energy when high fidelity is not required, and increase it when more detailed data is necessary.

e. Function Approximation and Edge Detection

Function approximation involves approximating sensed data to reduce the amount of transmitted information, thus saving energy and bandwidth. In edge detection, WSNs detect significant changes (edges) in the sensed environment, such as temperature or pressure gradients. Edge detection techniques are vital in reducing unnecessary data transmission, as only critical information is sent.

f. Frequency Stability

Frequency stability is crucial for maintaining reliable communication between sensor nodes in WSNs. Since sensor nodes often communicate using wireless protocols, maintaining stable radio frequency is essential to avoid communication failure, interference, or degradation. Methods to improve frequency stability include crystal oscillators and software-controlled frequency adjustments.

g. Dynamic Voltage Scaling (DVS)

Dynamic Voltage Scaling is a power management technique where the voltage and frequency of a processor or microcontroller in a WSN node are adjusted dynamically based on the required computational load. By lowering the voltage and frequency during periods of low activity, DVS helps reduce power consumption and prolong node battery life.

h. Carrier Sense Multiple Access (CSMA)

Carrier Sense Multiple Access is a protocol used to manage access to the shared wireless communication medium in WSNs. Before transmitting data, a node "listens" to the channel to check if it is free. If the channel is busy, the node waits for a random backoff time before attempting to transmit again. This reduces collisions and improves the efficiency of data transmission in the network.

i. Wakeup Radio

Wakeup radio systems are designed to minimize the energy consumption of sensor nodes by allowing nodes to remain in a low-power sleep mode until a signal is detected, "waking up" the node only when it is needed. This eliminates the need for nodes to periodically wake up and check for communication, significantly reducing idle listening and energy consumption.

j. Event-Based Programming

Event-based programming in WSN refers to programming models where actions are triggered by specific events, such as the detection of a particular environmental condition (e.g., temperature rise, motion detection). This approach allows nodes to remain inactive until a predefined event occurs, conserving energy and computational resources by avoiding unnecessary operations.

k. Split-Phase Programming

Split-phase programming is a technique used in event-driven systems like WSNs where operations that involve waiting (such as I/O tasks) are split into two phases: an initiation phase and a completion phase. The initiation phase triggers the operation, allowing the system to continue executing other tasks while waiting. The completion phase is called once the operation is done. This helps avoid blocking the system and improves responsiveness and energy efficiency.

l. Agent-Based Networking

Agent-based networking in WSNs refers to a decentralized model where autonomous agents (software entities) are deployed on sensor nodes to perform tasks such as data collection, processing, and decision-making. These agents can interact and collaborate to handle dynamic network conditions, enabling adaptability and reducing the need for central control. This approach is particularly useful in complex, large-scale, or dynamic WSNs.

m. WSN Tunnelling

WSN tunneling refers to the encapsulation of network traffic from one protocol within another, creating a "tunnel" between two points in the network. This is useful in WSNs when data needs to be routed across different network types or when secure communication channels are required. Tunneling can also be used to enable communication between WSNs and other network infrastructures, such as the Internet.

n. Communication vs Computation

In WSNs, there is often a trade-off between communication and computation. Communication (transmitting data between nodes) tends to be more energy-intensive than computation (processing data locally). Hence, reducing communication by performing more local computations (such as data aggregation or in-network processing) can conserve energy and prolong network lifetime. The challenge lies in balancing this trade-off for optimal energy efficiency.

o. Timer Interface

A timer interface in WSNs allows nodes to schedule tasks or events at specific times. Timers are essential for managing energy-efficient operations, such as putting the node into sleep mode, waking it up at intervals, or triggering periodic data collection. Timer interfaces can also be used for synchronizing communication schedules between nodes, enabling duty cycling and reducing idle listening.

p. Component-Based Programming

Component-based programming involves building WSN applications by composing reusable software components. Each component is responsible for a specific functionality, such as sensing, communication, or data processing. This modular approach makes it easier to develop, maintain, and adapt WSN applications by allowing developers to swap or upgrade individual components without affecting the entire system.

q. Centralized vs Distributed Network Paradigm

In a **centralized WSN**, a central node (or base station) collects and processes data from all the sensor nodes, making decisions and controlling the network. In a **distributed WSN**, decision-making and processing are spread across multiple nodes, with each node handling its data or collaborating with nearby nodes. Centralized systems are easier to manage but can suffer from bottlenecks and single points of failure. Distributed systems are more resilient and scalable but require more sophisticated algorithms for coordination.

r. Overlay Networks

An overlay network in WSNs is a virtual network built on top of the physical network to provide additional functionalities, such as routing, aggregation, or security. Overlay networks help abstract the complexity of the underlying physical network and allow for more flexible and adaptive network architectures, especially in large-scale or dynamic WSN environments.

s. Scalability in WSN

Scalability refers to the ability of a WSN to maintain performance and efficiency as the network size increases. A scalable WSN should be able to handle an increasing number of nodes, data traffic, and communication demands without significant degradation in performance. Strategies to improve scalability include hierarchical architectures, clustering, and data aggregation.

t. Robustness of WSN

Robustness in WSNs refers to the network's ability to maintain functionality in the face of failures, such as node malfunctions, communication disruptions, or environmental challenges. Techniques to enhance robustness include redundancy (deploying more nodes than necessary), fault-tolerant algorithms, adaptive routing protocols, and self-healing mechanisms that allow the network to reconfigure itself when parts of it fail.

u. Aggregation in In-Network Processing

In-network processing involves performing data aggregation and processing directly within the WSN, rather than transmitting all raw data to a central base station. Aggregation techniques (e.g., averaging, summing, or filtering data) help reduce the volume of transmitted data, thus conserving energy and bandwidth. This is especially useful in applications where nodes collect redundant or similar data, such as environmental monitoring.

v. Data-Centric vs Address-Centric Paradigm

In **data-centric** WSNs, data is addressed based on its content rather than the address of the node that produced it. This allows queries or tasks to be sent based on the type of data needed (e.g., temperature readings from a specific area), enhancing efficiency in querying and data dissemination. In contrast, **address-centric** WSNs rely on traditional addressing mechanisms where data is routed based on the address of the nodes, which is less flexible and scalable in dynamic environments.

w. Gateway in WSN

A gateway in WSN serves as a bridge between the WSN and external networks, such as the Internet or a local network. The gateway aggregates data from sensor nodes, translates protocols, and routes data to remote servers or applications. It can also serve as a control point, allowing users or administrators to send commands to the WSN, perform data processing, and manage the network.

x. Wave Propagation Phenomenon (Diffraction, Scattering, and Doppler Fading)

- **Diffraction**: Occurs when radio waves encounter an obstacle and bend around it, enabling communication even if a direct line-of-sight path is blocked.
- **Scattering**: Happens when radio waves hit small objects or rough surfaces, causing the signal to disperse in different directions. This is common in urban or forest environments.
- **Doppler Fading**: Results from relative motion between the transmitter and receiver, causing shifts in the signal frequency. This is particularly important in mobile WSNs.

y. Flat Fading vs Fast Fading

- **Flat Fading**: Affects all frequencies of the signal equally, causing the overall signal strength to fluctuate but without distorting the signal. It typically occurs in narrowband communication systems.
- **Fast Fading**: Results from rapid changes in the signal's amplitude and phase due to the movement of the transmitter or receiver relative to their environment. Fast fading occurs over short time scales and can severely degrade signal quality.

z. Co-Channel vs Adjacent Channel Interference

- **Co-Channel Interference**: Occurs when two or more devices transmit on the same frequency channel, leading to collisions and signal degradation. This is common in densely deployed WSNs using the same frequency band.
- **Adjacent Channel Interference**: Happens when transmissions from a neighboring frequency channel overlap and interfere with the target channel. It can result from insufficient filtering or poor channel separation.

- **Direct Sequence Spread Spectrum (DSSS)**: In DSSS, the original data signal is multiplied by a higher-rate pseudo-random noise (PN) code. This spreads the signal over a wider frequency band. DSSS provides resistance to interference and multipath fading, as the original signal can be reconstructed by correlating it with the same PN code at the receiver.

- **Frequency Hopping Spread Spectrum (FHSS)**: In FHSS, the signal hops between different frequency channels according to a predefined pseudo-random sequence. This makes FHSS more resilient to narrowband interference and eavesdropping, as the signal only stays on any given frequency for a short time before moving to another frequency.

cc. Carrier and Frame Synchronization

- **Carrier Synchronization**: In wireless communication, carrier synchronization refers to the process of aligning the frequency and phase of the receiver's carrier wave with the transmitter's carrier wave. Proper carrier synchronization is necessary to demodulate the received signal correctly.
- **Frame Synchronization**: Frame synchronization ensures that the receiver can correctly identify the boundaries of data frames in a continuous stream of bits. This is essential for extracting meaningful data from the incoming signal, and techniques like preambles or special synchronization patterns are used to achieve this.

dd. Equalization Techniques

Equalization techniques are used in communication systems to mitigate the effects of channel-induced distortions, such as multipath fading. Common equalization methods include:

- **Linear Equalization**: Applies a linear filter to the received signal to counteract inter-symbol interference (ISI).
- **Decision Feedback Equalization (DFE)**: Uses past decisions about received symbols to eliminate ISI in the current symbol.
- **Adaptive Equalization**: Continuously adjusts the equalizer settings based on the changing characteristics of the communication channel.

ee. Dynamic Modulation Scaling

Dynamic modulation scaling refers to the practice of adjusting the modulation scheme used in wireless communication dynamically, depending on the channel conditions. For instance, in good channel conditions, a higher-order modulation (e.g., 64-QAM) can be used for increased data rates. In poor conditions, the system can switch to a more robust modulation scheme (e.g., BPSK) to maintain reliable communication.

ff. Pure vs Slotted ALOHA

- **Pure ALOHA**: In this protocol, nodes transmit data whenever they have data to send, without any coordination. Collisions can occur if two nodes transmit at the same time, and the colliding data must be retransmitted after a random time. The throughput of pure ALOHA is low due to frequent collisions.
- **Slotted ALOHA**: In slotted ALOHA, time is divided into discrete time slots. Nodes can only begin transmitting at the start of a slot. This reduces the chance of collisions, improving throughput compared to pure ALOHA.

gg. Hidden vs Exposed Terminal Problem in CSMA

- **Hidden Terminal Problem**: Occurs when two nodes that are out of each other's communication range attempt to send data to a common receiver simultaneously, causing a collision at the receiver. The nodes are "hidden" from each other and unaware of each other's transmissions.
- **Exposed Terminal Problem**: Occurs when a node mistakenly refrains from transmitting because it senses another nearby transmission, even though its transmission would not interfere with the destination node. The node is "exposed" to unnecessary transmission restrictions.

hh. Idle Listening vs Collision Problem for MAC

- **Idle Listening**: Refers to the energy wasted when a node listens to the communication medium while no relevant communication is happening. This is a significant issue in WSNs, as it drains battery power unnecessarily.
- **Collision Problem**: Occurs when multiple nodes transmit simultaneously on the same communication medium, resulting in corrupted packets. This leads to retransmissions, increasing energy consumption and reducing network efficiency.

ii. Schedule-Based vs Contention-Based MAC Protocols

- **Schedule-Based MAC Protocols**: These protocols assign fixed time slots or schedules for each node to transmit. Examples include TDMA (Time Division Multiple Access). Such protocols avoid collisions and provide deterministic communication, but they are less flexible in dynamic environments.

- **Contention-Based MAC Protocols**: In these protocols, nodes compete for access to the communication medium (e.g., CSMA). These protocols are more flexible and adaptable to varying traffic conditions but may suffer from collisions and higher energy consumption due to idle listening.

jj. FEC vs ARQ Techniques

- **Forward Error Correction (FEC)**: In FEC, the sender adds redundant information to the transmitted data, allowing the receiver to detect and correct errors without needing retransmissions. FEC is useful in environments with high error rates but adds computational overhead and increases the amount of data transmitted.
- **Automatic Repeat Request (ARQ)**: In ARQ, the receiver checks for errors in the received data and requests the sender to retransmit any erroneous packets. ARQ requires a reliable communication link but avoids the additional overhead of FEC.

kk. Non-Persistent vs Persistent CSMA

- **Non-Persistent CSMA**: In this variant of CSMA, a node checks the medium before transmitting. If the medium is busy, the node waits for a random amount of time before trying again. This reduces the chance of collisions but can lead to underutilization of the medium.
- **Persistent CSMA**: In persistent CSMA, if the medium is busy, the node continuously senses the medium and transmits as soon as it becomes free. This increases the chance of collisions but ensures that the medium is utilized effectively.

ll. Periodic Wakeup vs Wakeup Radio

- **Periodic Wakeup**: In this strategy, nodes periodically wake up at predefined intervals to check if they need to transmit or receive data. This approach conserves energy by allowing the nodes to sleep most of the time but can lead to delays if a node is asleep when data is available.
- **Wakeup Radio**: A wakeup radio system employs a separate, ultra-low-power radio receiver that listens for a wakeup signal while the main radio is asleep. When the wakeup signal is received, the main radio is activated, reducing energy consumption without increasing latency as in periodic wakeup.

mm. STEM-B vs STEM-T

- **STEM-B (Sparsely Tuned Energy-Efficient Multihop – Beaconing)**: In STEM-B, nodes periodically send beacon signals to neighboring nodes to announce their availability for communication. It helps in discovering neighbors and establishing routes without keeping the radio on all the time.
- **STEM-T (STEM with Threshold)**: In STEM-T, nodes use a threshold mechanism to control when they should wake up for communication. The threshold is set based on specific parameters like traffic conditions or energy levels. It aims to further reduce energy consumption by limiting unnecessary communication.