ETX,ETT,WCETT

1. Introduction to Routing Metrics

- **Routing Metrics**: Used by routing protocols to determine the best path for data transmission in a network.
- **Purpose**: To optimize network performance by selecting paths based on specific criteria such as link quality, bandwidth, and latency.
- **Key Considerations**:
    - **Link Quality**: Reliability and stability of the communication link.
    - **Bandwidth**: Available data capacity of the link.
    - **Latency**: Time taken for data to travel from source to destination.

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2. ETX (Expected Transmission Count)

- **Overview**: ETX estimates the number of transmissions required to successfully deliver a packet over a link, including retransmissions.
- **Calculation**:
    - ETX = 1 / (df * dr)
        - df: Forward delivery ratio (probability of successful packet delivery).
        - dr: Reverse delivery ratio (probability of successful acknowledgment receipt).
- **Advantages**:
    - **Link Quality**: Provides a reliable measure of link quality.
    - **Efficiency**: Helps in selecting paths with fewer retransmissions.
- **Disadvantages**:
    - **Overhead**: Requires periodic measurement of delivery ratios.
    - **Latency**: Does not account for latency directly.

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3. ETT (Expected Transmission Time)

- **Overview**: ETT extends ETX by considering the bandwidth of the link, estimating the time required to transmit a packet.
- **Calculation**:
    - ETT = ETX * (S / B)
        - S: Packet size.
        - B: Bandwidth of the link.
- **Advantages**:
    - **Bandwidth Awareness**: Incorporates link bandwidth into the metric.
    - **Performance**: Helps in selecting paths with lower transmission times.

- **Disadvantages**:
    - **Complexity**: More complex to calculate than ETX.
    - **Overhead**: Requires knowledge of link bandwidth and packet size.

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4. WCETT (Weighted Cumulative ETT)

- **Overview**: WCETT is designed for multi-radio, multi-channel networks, combining ETT with channel diversity to avoid intra-flow interference.
- **Calculation**:
    - WCETT = max(X_j) + (1 - β) * Σ ETT_i
        - X_j: Sum of ETTs on channel j.
        - β: Weighting factor (0 ≤ β ≤ 1).
        - Σ ETT_i: Sum of ETTs for all links in the path.
- **Advantages**:
    - **Channel Diversity**: Reduces interference by balancing traffic across different channels.
    - **Performance**: Improves throughput and reduces latency in multi-radio networks.
- **Disadvantages**:
    - **Complexity**: More complex to calculate and implement.
    - **Parameter Tuning**: Requires careful selection of the weighting factor β.

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5. Comparison of ETX, ETT, and WCETT

- **ETX**:
    - Focuses on link quality and retransmissions.
    - Simple to calculate but does not consider bandwidth or latency.
- **ETT**:
    - Extends ETX by incorporating bandwidth.
    - More complex but provides better performance in bandwidth-sensitive applications.
- **WCETT**:
    - Designed for multi-radio, multi-channel networks.
    - Balances link quality, bandwidth, and channel diversity.
    - Most complex but offers the best performance in heterogeneous networks.

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6. Applications of ETX, ETT, and WCETT

- **Wireless Mesh Networks**:

    - Used to optimize routing in community networks, smart cities, and industrial automation.
- **Wireless Sensor Networks (WSNs)**:
    - Helps in selecting reliable and efficient paths for data collection and transmission.
- **Multi-Radio Networks**:
    - Enhances performance by reducing interference and balancing traffic across channels.

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7. Future Developments in Routing Metrics

- **Integration with AI**: Using machine learning to dynamically adjust routing metrics based on network conditions.
- **Energy Efficiency**: Developing metrics that consider energy consumption for battery-operated devices.
- **Security**: Incorporating security considerations into routing metrics to protect against attacks.
- **5G and Beyond**: Adapting routing metrics for next-generation networks with higher data rates and lower latency.

Air Time Metric

1. Introduction to Air Time Metric

- **Definition**: The Air Time Metric (ATM) is a routing metric used in wireless networks to estimate the amount of time (air time) required to transmit a packet over a link, considering factors like data rate, packet size, and overhead.
- **Purpose**: To optimize routing decisions by selecting paths that minimize the total air time, thereby improving network efficiency and performance.
- **Key Features**:
    - **Data Rate Awareness**: Incorporates the data rate of the link.
    - **Overhead Consideration**: Accounts for protocol overhead (e.g., MAC headers, ACKs).
    - **Link Quality**: Reflects the impact of link quality on transmission time.

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2. Calculation of Air Time Metric

- **Formula**:

$$\text{Air Time} = \left(\frac{O+S}{B}\right) \times \frac{1}{1-e}$$

  - O: Protocol overhead (in bits).
  - S: Packet size (in bits).
  - B: Data rate of the link (in bits per second).
  - e: Packet error rate (PER).
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- **Components**:
  - **Protocol Overhead (O)**: Includes MAC headers, preambles, and acknowledgments.
  - **Packet Size (S)**: Size of the data payload.
  - **Data Rate (B)**: Transmission rate of the link.
  - **Packet Error Rate (e)**: Probability of packet loss due to link errors.

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3. Advantages of Air Time Metric

- **Efficiency**: Helps in selecting paths that minimize transmission time, improving overall network efficiency.
- **Link Quality Awareness**: Incorporates packet error rate, reflecting the impact of link quality on transmission time.
- **Data Rate Awareness**: Considers the data rate of the link, making it suitable for heterogeneous networks with varying link speeds.

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4. Disadvantages of Air Time Metric

- **Complexity**: Requires accurate measurement of data rate, packet error rate, and protocol overhead.
- **Overhead**: Periodic measurement and updating of link parameters can introduce additional overhead.
- **Scalability**: May become complex to manage in large-scale networks with dynamic link conditions.

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5. Applications of Air Time Metric

- **Wireless Mesh Networks**:

    - Used to optimize routing in community networks, smart cities, and industrial automation.
- **Wireless Sensor Networks (WSNs)**:
    - Helps in selecting efficient paths for data collection and transmission.
- **Multi-Radio Networks**:
    - Enhances performance by considering data rates and link quality across different radios and channels.

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6. Comparison with Other Routing Metrics

- **ETX (Expected Transmission Count)**:
    - Focuses on the number of transmissions required for successful packet delivery.
    - Does not consider data rate or protocol overhead.
- **ETT (Expected Transmission Time)**:
    - Extends ETX by incorporating data rate.
    - Does not explicitly account for protocol overhead or packet error rate.
- **Air Time Metric**:
    - Provides a more comprehensive measure by including data rate, protocol overhead, and packet error rate.
    - More complex but offers better performance in heterogeneous networks.

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7. Future Developments in Air Time Metric

- **Integration with AI**: Using machine learning to dynamically adjust the air time metric based on network conditions.
- **Energy Efficiency**: Developing variants of the air time metric that consider energy consumption for battery-operated devices.
- **Security**: Incorporating security considerations into the air time metric to protect against attacks.
- **5G and Beyond**: Adapting the air time metric for next-generation networks with higher data rates and lower latency.

AODV, DSR, DSDV, and HWMP Routing Protocols

1. Introduction to Routing Protocols

- **Routing Protocols**: Algorithms used to determine the best path for data transmission in a network.
- **Purpose**: To ensure efficient and reliable communication between nodes in a network.
- **Key Considerations**:
  - **Scalability**: Ability to handle a large number of nodes.
  - **Efficiency**: Minimizing resource usage (e.g., bandwidth, energy).
  - **Reliability**: Ensuring data reaches its destination despite network changes.

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2. AODV (Ad hoc On-Demand Distance Vector)

- **Overview**: A reactive routing protocol that establishes routes only when needed.
- **Key Features**:
  - **Route Discovery**: Uses Route Request (RREQ) and Route Reply (RREP) messages to find routes.
  - **Route Maintenance**: Uses Route Error (RERR) messages to handle link failures.
  - **Sequence Numbers**: Ensures loop-free and up-to-date routes.
- **Advantages**:
  - **Low Overhead**: Routes are established only when needed.
  - **Scalability**: Suitable for large networks.
- **Disadvantages**:
  - **Latency**: Route discovery can introduce delays.
  - **Overhead**: Periodic route maintenance can consume resources.

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3. DSR (Dynamic Source Routing)

- **Overview**: A reactive routing protocol where the source node specifies the complete route in the packet header.
- **Key Features**:
  - **Route Discovery**: Uses Route Request (RREQ) and Route Reply (RREP) messages.
  - **Route Caching**: Nodes cache routes to reduce route discovery overhead.

- **Source Routing**: The source node specifies the entire route in the packet header.
- **Advantages**:
    - **Efficiency**: Reduces overhead by caching routes.
    - **Flexibility**: Adapts to network changes.
- **Disadvantages**:
    - **Overhead**: Large packet headers due to source routing.
    - **Scalability**: Limited by the size of route caches.

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4. DSDV (Destination-Sequenced Distance Vector)

- **Overview**: A proactive routing protocol that maintains routing tables with up-to-date routes.
- **Key Features**:
    - **Routing Tables**: Each node maintains a routing table with routes to all destinations.
    - **Sequence Numbers**: Ensures loop-free and up-to-date routes.
    - **Periodic Updates**: Nodes periodically broadcast their routing tables.
- **Advantages**:
    - **Low Latency**: Routes are always available.
    - **Simplicity**: Easy to implement.
- **Disadvantages**:
    - **Overhead**: High due to periodic updates.
    - **Scalability**: Limited by the size of routing tables.

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5. **HWMP (Hybrid Wireless Mesh Protocol)**

- **Overview**: A hybrid routing protocol used in wireless mesh networks, combining proactive and reactive elements.
- **Key Features**:
    - **Proactive Tree-Based Routing**: Maintains a tree structure for efficient routing within the mesh.
    - **Reactive On-Demand Routing**: Establishes routes on demand for external communication.
    - **Path Selection**: Uses metrics like airtime cost to select the best path.
- **Advantages**:
    - **Efficiency**: Combines the benefits of proactive and reactive routing.
    - **Scalability**: Suitable for large mesh networks.
- **Disadvantages**:

- **Complexity**: More complex to implement and manage.
- **Overhead**: Requires periodic updates and route discovery.

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6. Comparison of AODV, DSR, DSDV, and HWMP

- **AODV**:
  - Reactive, low overhead, suitable for large networks.
  - Latency due to route discovery.
- **DSR**:
  - Reactive, efficient route caching, flexible.
  - Overhead due to large packet headers.
- **DSDV**:
  - Proactive, low latency, simple.
  - High overhead due to periodic updates.
- **HWMP**:
  - Hybrid, efficient, scalable.
  - Complex to implement and manage.

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7. Applications of AODV, DSR, DSDV, and HWMP

- **AODV**:
  - Used in mobile ad hoc networks (MANETs) and wireless sensor networks (WSNs).
- **DSR**:
  - Suitable for small to medium-sized MANETs with dynamic topology.
- **DSDV**:
  - Used in stable networks with predictable traffic patterns.
- **HWMP**:
  - Ideal for wireless mesh networks in smart cities, community networks, and industrial automation.

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8. Future Developments in Routing Protocols

- **Integration with AI**: Using machine learning to optimize routing decisions based on network conditions.
- **Energy Efficiency**: Developing protocols that minimize energy consumption for battery-operated devices.
- **Security**: Incorporating robust security mechanisms to protect against attacks.
- **5G and Beyond**: Adapting routing protocols for next-generation networks with higher data rates and lower latency.

VANET Routing

Vehicular Ad Hoc Network (VANET) Routing

Vehicular Ad Hoc Networks (VANETs) are a type of Mobile Ad Hoc Network (MANET) designed for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication. Due to the high mobility of vehicles, VANET routing faces unique challenges such as frequent topology changes, high-speed nodes, and intermittent connectivity.

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1. Classification of VANET Routing Protocols

VANET routing protocols can be broadly categorized into three types:

A. Topology-Based Routing

These protocols use traditional routing tables and maintain end-to-end paths between nodes.

(i) Proactive Routing (Table-Driven)

- Maintains routing tables with up-to-date information about all nodes.
- **Examples:**
  - **DSDV (Destination-Sequenced Distance Vector)** – Uses sequence numbers to prevent routing loops.
  - **OLSR (Optimized Link State Routing)** – Uses link-state information to update routing tables.
- **Pros:** Low latency due to precomputed routes.
- **Cons:** High overhead due to frequent updates, making it inefficient for high-mobility environments like VANETs.

(ii) Reactive Routing (On-Demand)

- Routes are created only when needed.
- **Examples:**
  - **AODV (Ad hoc On-Demand Distance Vector)** – Establishes routes using RREQ and RREP messages.
  - **DSR (Dynamic Source Routing)** – Uses source routing and caching.
- **Pros:** Reduces overhead by not maintaining unnecessary routes.
- **Cons:** High delay during route discovery.

(iii) Hybrid Routing

- Combines proactive and reactive approaches.
- **Example: ZRP (Zone Routing Protocol)** – Uses proactive routing within a limited zone and reactive routing beyond that zone.

B. Position-Based Routing

Position-based routing uses **GPS coordinates** instead of routing tables. It is highly effective in VANETs due to the availability of GPS in modern vehicles.

(i) Greedy Forwarding

- Each node forwards packets to the neighbor closest to the destination.
- **Example: GPSR (Greedy Perimeter Stateless Routing)**

(ii) Predictive Routing

- Predicts vehicle movement based on speed and direction.
- **Example: CAR (Connectivity-Aware Routing)**

(iii) Delay-Tolerant Routing

- Used when network connectivity is intermittent.
- **Example: VADD (Vehicle-Assisted Data Delivery)**

Pros: Works well in high-mobility environments.
Cons: Requires accurate position information.

C. Cluster-Based Routing

- Groups vehicles into clusters to reduce overhead.
- **Example: COIN (Clustering for Open Inter-Vehicle Network)**

Pros: Reduces routing overhead and improves scalability.
Cons: Cluster maintenance adds extra complexity.

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2. Challenges in VANET Routing

- **Frequent Topology Changes:** Due to vehicle movement.
- **High Speed of Nodes:** Causes frequent disconnections.
- **Intermittent Connectivity:** Routes may break often.
- **Scalability Issues:** A large number of vehicles increases routing complexity.
- **Urban vs. Highway Scenarios:** Routing strategies need to adapt to different environments.

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3. Comparison of VANET Routing Protocols

Protocol Type	Example	Strengths	Weaknesses
Proactive (Table-Driven)	DSDV, OLSR	Low latency	High overhead
Reactive (On-Demand)	AODV, DSR	Low overhead	High delay during route discovery
Position-Based	GPSR, CAR	Efficient in high mobility	Requires GPS
Cluster-Based	COIN	Scalable, reduces overhead	Complex cluster management

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4. Summary

- **Topology-based protocols** (AODV, DSDV) work well in small-scale networks but struggle with high mobility.
- **Position-based protocols** (GPSR, CAR) are best suited for VANETs due to their ability to handle dynamic topology changes.
- **Cluster-based protocols** improve scalability but require extra cluster management overhead.