Part IV: Measures & indices

Introduction

- Understanding the performance, efficiency, and resilience of a network requires quantitative analysis through carefully designed **metrics** and **indices**. These tools provide insights into structural properties (e.g., redundancy), spatial efficiency (e.g., routing paths), and real-time performance (e.g., speed).
- By analyzing these metrics, network engineers can optimize designs (e.g., minimizing latency), diagnose bottlenecks (e.g., high betweenness centrality nodes), and balance cost vs. performance (e.g., Pi Index for infrastructure planning).
- Together, they form a framework for building robust, scalable, and high-performing networks.

Network metrics

Diameter: Longest shortest path between any two nodes.

- **Interpretation**: Indicates network "spread"; smaller = faster communication.
- **Formula**: Diameter = max(shortest paths between all node pairs).
- **Example**: A social network with a diameter of 6 means six degrees (steps) of separation.
- **Networking Use Case**: Optimizing data center topologies to minimize latency.

Network metrics

Density: Ratio of existing connections to possible connections.

- **Interpretation**: High density = highly interconnected; low = sparse.
- **Formula**: Density = $2E/N(N-1)$ (undirected).
- **Example**: A fully connected mesh network has density $D=1$.
- **Networking Use Case**: Designing IoT networks for energy efficiency (sparse) vs. redundancy (dense).

Network metrics

Cyclomatic number: Number of independent cycles (redundant paths).

- **Interpretation**: Higher values = more fault tolerance .
- **Formula**: Cyclomatic number = $E-N+P$ (E=edges, N=nodes, P=components).
- **Example**: A power grid with $C=10$ can survive 10 link failures.
- **Networking Use Case**: Assessing redundancy in ISP networks.

Network metrics

Average Path Length: Mean of all shortest paths between node pairs.

- **Interpretation**: Lower = more efficient communication.
- **Formula**: APL = 2∑ shortest paths /N(N-1).
- **Example**: A corporate LAN with APL=2.5 hops..
- **Networking Use Case**: Optimizing routing protocols (e.g., OSPF vs. BGP).

Network metrics

Betweeness Centrality: Number of shortest paths passing through a node/link.

- **Interpretation**: Higher = critical for network flow.
- **Formula**: Betweeness(v) = ∑ (paths through v/total paths).
- **Example**: A core router with high betweenness in an enterprise network.
- **Networking Use Case**: Identifying bottlenecks in data center traffic.

Network indices

Detour Index: Ratio of network path distance to straight-line distance.

- **Interpretation**: Values > 1 indicate inefficiency (detours).
- **Formula**: Detour index = network path / stright line.
- **Example**: A road network with average detour index 1.3.
- **Networking Use Case**: Evaluating routing efficiency in WANs.

Network indices

Eta Index: Average edge length in spatial networks.

- **Interpretation**: Higher = longer physical links.
- **Formula**: η = Total edge length / E.
- **Example**: A metro system with η = 2 km.
- **Networking Use Case**: Planning fiber-optic cable layouts.

Network indices

Gamma Index: Ratio of edges to maximum possible edges.

- **Interpretation**: $\gamma=1$ = fully connected.
- **Formula**: $\gamma = 2E/N(N-1)$.
- **Example**: A planar road network with $\gamma = 0.8$.
- **Networking Use Case**: Designing resilient cellular tower layouts.

Network indices

Alpha Index: Normalized measure of cycles in planar networks.

- **Interpretation**: $\alpha = 0$ (tree) to $\alpha = 1$ (fully triangulated).
- **Formula**: $\alpha = (E - N + P) / (2N - 5)$.
- **Example**: A city grid with $\alpha = 0.7$.
- **Networking Use Case**: Analyzing mesh Wi-Fi network resilience.

Network indices

Pi Index: Ratio of total network length to diameter.

- **Interpretation**: Higher = more infrastructure per unit span.
- **Formula**: π = Total edge length / Diameter.
- **Example**: A rail network with $\pi = 50$ (50 km track per 1 km diameter).
- **Networking Use Case**: Balancing cost vs. coverage in ISP networks.

Performance metrics

Latency: Time for data to travel between nodes.

- **Interpretation**: Lower = better real-time performance.
- **Formula**: Latency = Propagation Delay + Transmission Delay.
- **Example**: 50 ms latency in a VoIP (Voice over Internet Protocol) call.
- **Networking Use Case**: Optimizing gaming or video conferencing QoS.

Performance metrics

Bandwidth: Maximum data rate of a link.

- **Interpretation**: Higher = greater capacity.
- **Formula**: Bandwidth = Channel width x Modulation rate.
- **Example**: A 10 Gbps fiber-optic link.
- **Networking Use Case**: Planning network upgrades for 4K video streaming.

Performance metrics

Throughput: Actual data transfer rate.

- **Interpretation**: Higher = more capacity.
- **Formula**: Throughput = Data transfered / Time.
- **Example**: 100 Mbps throughput on a 1 Gbps link.
- **Networking Use Case**: Monitoring data center backbone utilization.

Performance metrics

Jitter: Variability in packet arrival times.

- **Interpretation**: Lower = smoother streaming.
- **Formula**: Jitter = $\sqrt{(\sum(D_i - Avg(Delay))^2/N)}$.
- **Example**: 10 ms jitter in a video stream.
- **Networking Use Case**: Ensuring quality in VoIP systems.

The end …