# Paper 3: Orchestrating End-to-End Slices in 5G Networks

## 1. Introduction

📌 What is this paper about?

Network slicing enables customized 5G services for different applications like:

• eMBB (Enhanced Mobile Broadband): High-speed internet for video streaming, AR/VR.

• URLLC (Ultra-Reliable Low Latency Communications): Low-latency for autonomous driving, remote surgery.

• mMTC (Massive Machine-Type Communications): Supports IoT devices with low power.

📌 Key Problem Addressed

• How to place Virtualized Network Functions (VNFs) efficiently in an E2E slice?

• How to minimize migration overhead when users move across the network?

• How to optimize resource utilization while ensuring QoS guarantees like latency and bandwidth?

📌 Solution Proposed

✅ MILP (Mixed Integer Linear Programming) model for optimal slice placement.

✅ Heuristic algorithm for scalability in large networks.

✅ Consideration of handover impacts to reduce VNF migrations.

## 2. Understanding Network Slicing in 5G

📌 What is a Network Slice?

A network slice is a virtual network instance running on the same physical infrastructure, customized for specific applications.

📌 Types of Network Slices:

1️⃣ eMBB: High-speed data (e.g., video streaming, AR/VR).

2️⃣ URLLC: Ultra-low latency (e.g., remote surgery, self-driving cars).

3️⃣ mMTC: Supports millions of IoT devices with low energy consumption.

📌 Components of an E2E Network Slice:

• RAN (Radio Access Network): Connects users to the network.

• Transport Network: Carries data between RAN and Core.

• 5GC (5G Core): Manages sessions, authentication, and traffic routing.

📌 Why SFC Placement Matters in Network Slicing?

✅ Minimize cost and latency.

✅ Ensure stability even when users move.

✅ Prevent network congestion and resource overload.

## 3. MILP-Based Optimization Model for E2E Slice Placement

📌 What does MILP do?

The MILP model finds the best possible VNF placement within a slice while minimizing:

1️⃣ VNF Placement Cost

2️⃣ Bandwidth Consumption

3️⃣ Handover Impact & Migration Cost

📌 Decision Variables:

• x\_{s,n} = 1 → If VNF s is placed at node n, otherwise 0.

• y\_{s,t} = 1 → If VNF s is migrated from node t, otherwise 0.

📌 Objective Function (Minimizing Cost & Migrations):

min Σ C\_n \* x\_{s,n} + Σ B\_l \* U\_l + Σ M\_t \* y\_{s,t}

📌 Constraints:

1️⃣ Each VNF must be placed exactly once: Σ x\_{s,n} = 1, ∀ s

2️⃣ Node Resource Capacity Constraints: Σ x\_{s,n} \* R\_s ≤ C\_n, ∀ n

3️⃣ Bandwidth Constraints: Σ U\_{s,l} ≤ B\_l, ∀ l

4️⃣ Latency Constraints: Σ L\_n \* x\_{s,n} ≤ L\_max

## 4. Numerical Example: Solving Slice Placement Using MILP

📌 Problem Setup:

• Two slices (Slice A and Slice B) need to be placed:

- Slice A: VNFs for Authentication (AMF), Session Management (SMF), User Plane Function (UPF).

- Slice B: VNFs for Access Control (ACF) and Firewall (FW).

📌 Latency values for each node:

• Edge Cloud = 5 ms

• Regional Cloud = 10 ms

• Central Cloud = 20 ms

📌 MILP Solution:

1️⃣ AMF is placed at Edge Cloud → Latency = 5 ms.

2️⃣ SMF is placed at Regional Cloud → Latency = 10 ms.

3️⃣ UPF is placed at Central Cloud → Latency = 20 ms.

✅ Total Latency = 35 ms (Optimal Solution)

📌 Problem? MILP is slow for large-scale networks.

## 5. Heuristic Approach for Faster Slice Placement

📌 Why Use a Heuristic?

• MILP is too slow for large-scale networks.

• A heuristic finds a near-optimal solution in seconds.

📌 Heuristic Strategy:

1️⃣ Sort slice requests by priority (e.g., latency-sensitive slices first).

2️⃣ Assign VNFs greedily to the lowest-latency node available.

3️⃣ Ensure network capacity is not exceeded.

📌 Heuristic Solution:

1️⃣ AMF is placed at Edge Cloud → Latency = 5 ms.

2️⃣ SMF is placed at Regional Cloud → Latency = 10 ms.

3️⃣ UPF is placed at Central Cloud → Latency = 20 ms.

✅ Fast computation but slightly suboptimal compared to MILP.

## 6. Key Takeaways from Paper 3

✅ MILP provides optimal VNF placement but is computationally expensive.

✅ Heuristic approaches offer a fast, near-optimal alternative.

✅ Balancing fronthaul and backhaul utilization is critical for performance.

✅ Minimizing VNF migrations reduces service disruptions.

✅ Network slicing improves resource efficiency in 5G networks.