Velsanet Matrix Architecture White Paper

1. Introduction

This section explains the foundational shift from packet-based networking to AI-native connectivity, where networks must support multi-agent, real-time multimodal processing. Velsanet introduces a matrix-based, semiconductor-inspired architecture enabling globalscale multi-layer interconnects.

Key components include:
• Single-layer matrix switching
• Eight-layer optical channel stacking
• Face-level matrix construction
• Combinatorial face-to-face connectivity
• Polyhedral 3D routing topologies
• Hyperparallel multi-channel E2E pathways

This document focuses exclusively on the physical, structural, and mathematical architecture of Velsanet's multi-layer matrix and polyhedral switching fabric.
The operational behavior of PAI, AAI, and AsAI — including intent processing, routing decisions, and network-level control — is explicitly outside the scope *of this paper and is addressed in the separate* Velsanet Network AI White Paper**.**

2. Semiconductor Origins of the Matrix Architecture

Modern semiconductors rely on crossbar switches, multi-metal-layer routing, parallel interconnects, and Network-on-Chip structures. Velsanet extends these principles globally, treating each node as a semiconductor tile and each polyhedron as a 3D routing entity.

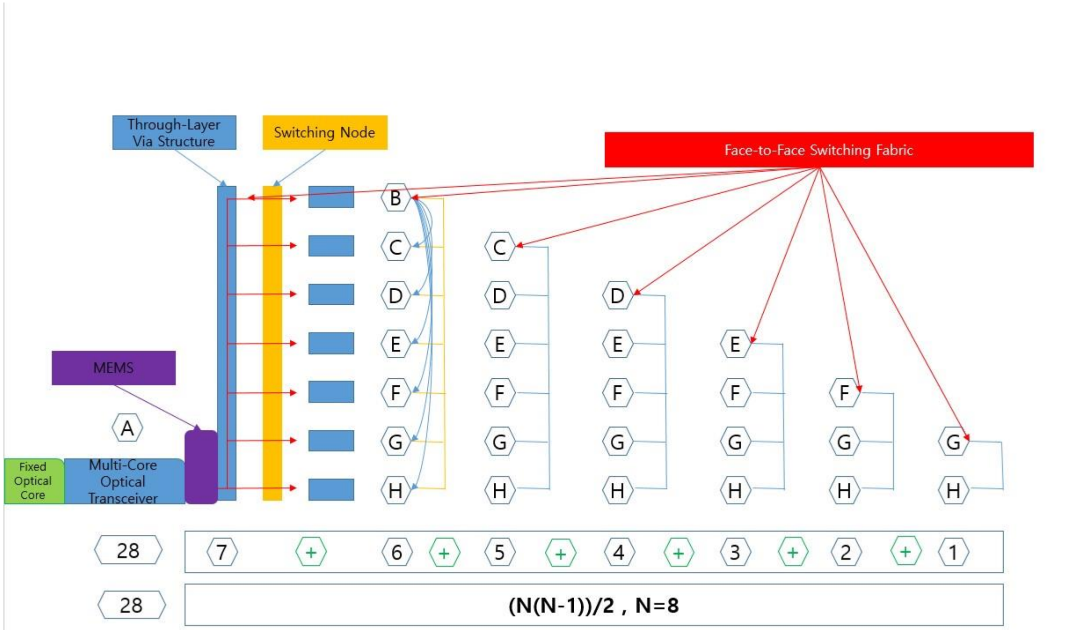

Figure 2. Semiconductor-Inspired Matrix Switching Architecture (N = 8 Case)

Use this description directly under the figure:

This diagram illustrates how a multi-core optical transceiver connects to a fixed optical core and routes signals through a through-layer via structure toward the switching node. Each vertical finger port serves as an ingress/egress access point to the Single-Layer Matrix (SLM), allowing directional selection as defined by the switching control logic.

The switching node then maps each input to one of eight output faces (B–H), producing the complete set of **$N(N-1)/2 = 28$** possible face-to-face switching paths.
These paths represent the fundamental connectivity required for constructing a polyhedral, multi-plane switching fabric, where each face can independently connect to all other faces.

This architecture demonstrates how semiconductor-style matrix switching—via structures, directional control, and cross-point activation—can be expanded directly into a networkscale matrix, forming the structural basis for Velsanet's E2E and parallel E2E optical pathways.

Velsanet employs MEMS-based micro-fabricated alignment fixtures for fiber-to-chip coupling.
These structures ensure that multi-core fibers are positioned accurately over the matrix input interfaces.
No MEMS switching, actuation, or beam steering is used within the matrix itself.

3. Single-Layer Matrix (SLM)

SLM is the atomic switching unit managing exactly one optical channel. It uses directional control and a single activated cross-point to generate deterministic E2E flows.

Mathematical definition:

SLM = 1 channel → 1 E2E path

3.1.1 Patent Foundation – Claim 1 (Ready for Insertion)

This subsection is intentionally prepared to allow direct insertion of Claim 1 from KR 102023-0056157.
Place the full text of Claim 1 here, followed by its interpretation and mapping to the SLM switching behavior.

▼ Suggested Structure:

Claim 1
A method of connecting ports through a matrix, the method comprising:

1. **receiving connection information of a subscriber port from a subscriber;**
2. **acquiring usage information of a transmission port;**
3. **selecting a front-side or back-side connection at the center of a contactcontrol line;** and
4. **controlling cross-points that form the matrix connection;** wherein the

   subscriber port and the transmission port are connected through the matrix.

• Step-by-step interpretation

Step 1 – Receiving connection information of the subscriber port
This step represents the arrival of an intent or connection request from an upstream entity. In a conventional system, this would correspond to a subscriber device or service endpoint requesting a path.
In Velsanet, this maps to an intent-driven request coming from PAI/AAI, which specifies **what** needs to be connected rather than a static address.

Step 2 – Acquiring usage information of the transmission port
Here, the system checks whether the requested transmission port is currently occupied, idle, or reserved.
This step ensures that no conflicting connection is created and that parallel paths can be safely instantiated.
In Velsanet, this corresponds to querying the **port state** (Idle / Reserved / Connected) inside the SLM.

Step 3 – Selecting front-side or back-side at the center of the contact-control line
This step defines the switching direction within the matrix: which side of the crossbar is treated as input and which as output for this connection instance.
Conceptually, it is a **direction selection** decision inside a symmetric switching fabric. In Velsanet, this abstracts to choosing the direction of flow across a layer in the 8-layer stack (e.g., ingress vs. egress within a face).

Step 4 – Controlling the cross-points to form the matrix connection
Finally, the relevant cross-points in the matrix are activated to establish the physical path. This is the moment where the abstract connection request becomes a concrete, deterministic E2E signal path.
In Velsanet, this is the execution phase where the SLM commits the connection on a specific layer/channel.

- Corresponding SLM operation mapping

Mapping to SLM and the Velsanet Switching Node

- **Input to the SLM (Claim 1 – Step 1)**
  The Single-Layer Matrix (SLM) receives an intent-based connection request from the upstream AI layer (PAI/AAI) or from a previous node.
  At this point, the SLM does **not** make any intelligent decision; it only accepts the request parameters (which port, which direction, which channel).
- **Port state evaluation (Claim 1 – Step 2)**
  The SLM consults its internal port state table (Idle / Reserved / Connected) to determine whether the requested transmission port can be used.
  This directly corresponds to "acquiring usage information of the transmission port" and is implemented as a simple state lookup rather than a complex algorithm.
- **Direction selection inside the switching node (Claim 1 – Step 3)**
  Within the SLM, the switching node selects the effective direction across the matrix layer – conceptually the "front" and "back" of the contact-control line.
  In practice, this is a **direction flag** that decides how the crossbar is traversed for this connection instance (e.g., ingress→egress or local loopback).
- **Physical commitment of the path (Claim 1 – Step 4)**
  Once the direction and availability are confirmed, the SLM activates the corresponding cross-points, forming a deterministic path through that layer. In the 8-layer stack, this action is performed per layer and can be repeated across multiple layers to support multi-channel and parallel E2E paths.

Role separation: AI vs. SLM

- The **AI layer (PAI/AAI/AsAI)** decides *what* to connect and *why* (intent, policy, role, service).
- The **SLM / switching node** only performs *how* to connect at the physical level:
  - check state
  - apply direction
  - toggle cross-points

- This strict separation of roles is exactly what Claim 1 formalizes at the matrix level and what Velsanet extends into a 3D polyhedral, multi-layer, multi-channel switching fabric.

4. Eight-Layer Matrix (8LM)

Optical transceivers provide 8 independent wavelength channels. Therefore, Velsanet stacks 8 SLMs vertically to form an Eight-Layer Matrix. Each Face = one 8LM.

4.1 Layer-1 Autonomous Optical Intelligence

Velsanet's Layer-1 switching fabric incorporates self-directed intelligence enabling autonomous link formation, evaluation, and adaptation.

4.1.1 Channel 1 as the Supervisory Signal

- Channel 1 monitors:
  - Port states
  - Directional availability
  - External link intentions
- It determines whether a structural link can be created.

4.1.2 Autonomous Path Formation

1. Direction is chosen through Channel 1 monitoring.
2. Matrix activation identifies an unused port in the intended face direction.
3. Multi-core optical activation creates either individual or parallel E2E.

4.1.3 Why This Matters

Layer-1 itself becomes:

- self-aware
- self-adjusting
- capable of synaptic construction without higher-layer AI involvement.

This is the world's first **optically intelligent physical layer**.

5. Face-to-Face Switching Fabric

5.1 Conceptual Overview

In a polyhedral network topology, every face must be capable of establishing a direct connection with every other face.
For a structure with **N faces**, this yields **N(N–1)/2** unique face-to-face connectivity pairs.

While the Single-Layer Matrix (SLM) enables signal routing within each layer, the **Face-toFace Switching Fabric** defines the higher-level logic that determines which faces connect, in which direction, and through which layer and port.

This section describes the switching-node behavior and the corresponding control-contact mechanism that physically activates the appropriate connection.

5.2 Switching Node Logic for Face-Level Connectivity

The switching node is responsible for interpreting the connection request between two faces and determining how that connection should be established within the fabric.

The switching node performs the following conceptual functions:

- **Connection Request Handling**
  Receives a request stating that Face A must connect to Face B.
  This request can originate from the upstream AI layer (AAI/AsAI) or another network node.
- **Ingress and Egress Determination**
  Identifies through which finger port and which layer the signal enters the face, and selects an appropriate exit path based on channel availability.
- **Face State Evaluation**
  Each face maintains an internal state table indicating whether its ports or layers are idle, reserved, or currently in use.
  This ensures collision-free physical connectivity.
- **Directional Selection**
  Determines whether the connection should be applied through the "front-side" or "back-side" of the switching structure.
  This corresponds directly to the direction-selection clause in Claim 1 of your divisional patent.
- **Connection Validation**
  Once the switching node decides the direction and layer, the fabric prepares for cross-point activation.

This process allows each face to dynamically choose a connection path without interfering with existing links.

5.3 Control Contact Line and Cross-Point Activation

The **control contact line** is the mechanism that enables physical activation of the matrix's cross-points.
It is the structural interface between the logical decision made by the switching node and the physical realization of the connection.

Its key responsibilities include:

- **Mapping ingress and egress ports**
  Determines which internal nodes of the SLM will form the connection between the two faces.
- **Assessing Port Availability**
  Verifies whether the desired physical ports or layers are idle or reserved. This prevents path conflicts and supports reservation-based scheduling.
- **Selecting the Appropriate Control Path**
  Based on ingress location, egress target, and selected direction, the control contact line identifies the correct cross-point within the 8-layer matrix.
- **Activating the Cross-Point**
  Physically enables the optical path by toggling the corresponding matrix connection. This action completes the deterministic link between the two faces.
- **Confirmation and Stabilization**
  Ensures the optical path is continuous and stable across the selected layer.

This mechanism is **directly inspired by semiconductor matrix-switching designs**, configured to work in an optical multi-layer environment.

5.4 Combined Face-to-Face Switching Operation

When two faces must be connected, the complete operation proceeds as follows:

1. A connection intent is generated (PAI/AAI/AsAI or upstream system).
2. The switching node interprets the face-pair requirement.
3. An available layer is selected from the 8-layer stack.
4. The control contact line identifies and prepares the appropriate cross-point.
5. The physical connection is established through cross-point activation.
6. The optical signal path is validated.
7. Additional layers can be activated for **parallel E2E** if needed.

Through these steps, the fabric achieves stable, multi-layer, parallel-capable connectivity among all faces of the polyhedral structure.

5.5 Significance for Velsanet Parallel E2E

Face-level switching is what transforms a polyhedral model into a **true multi-agent, multipath network substrate**.
By allowing each face to connect to all others across multiple layers, the architecture supports:

- deterministic E2E optical connections,
- simultaneous multi-channel communication,
- scalable distributed AI execution,
- dynamic and reconfigurable network topologies.

This is the foundation enabling Velsanet's **parallel E2E**, something fundamentally beyond packet-switched network capabilities.

6. Combinatorial Face-to-Face Connectivity

The number of unique face pairs follows:

C(N, 2) = N(N − 1) / 2

Examples:
Cube (6 faces) → 15 pairs
Octahedron (8 faces) → 28 pairs
Dodecahedron (12 faces) → 66 pairs
Icosahedron (20 faces) → 190 pairs

Internal matrix count:

8 × N(N − 1) / 2

However, this value has a deeper architectural meaning in Velsanet.

Each face represents an **independent 8-layer matrix (8LM)**, and each matrix can establish **one deterministic E2E optical path per layer**. Therefore, the real connectivity capacity is:

- **Geometric:** how many face pairs exist
- **Architectural:** how many internal matrices exist
- **Operational:** how many layers can be activated in parallel

Thus, Velsanet's connectivity is not merely combinatorial—it is **layer-multiplicative**.

6.1 Interpretation in the physical architecture

- A cube has 15 face pairs, but each pair is supported by 8 matrix layers → 120 internal switching surfaces.
- An octahedron has 28 pairs → 224 matrices.

- A dodecahedron has 66 pairs → 528 matrices.
- An icosahedron has 190 pairs → 1520 matrices.

This multiplication effect is what enables Velsanet to behave as a **3D optical switching organism**, rather than a traditional 2D graph.

7. Polyhedral Matrix Architecture

A polyhedral node is not a conceptual container but a **multi-layer, multi-face switching engine**.
Each face contains:

- one 8LM (Eight-Layer Matrix)
- directional switching capability
- N(N−1)/2 connection availability
- finger-port ingress/egress structure
- deterministic cross-point activation

When these are combined across all faces, the polyhedron becomes a **hyper-connected 3D router** that behaves fundamentally differently from packet routers.

Key characteristics added by this architecture:

- **Directional determinism**
  Each face knows exactly which other face it can reach and through which combination of layers.
- **Parallel path diversity**
  Since all 8 layers of each face pair can operate independently, the polyhedron supports **eight independent E2E flows per face pair**.

- **Geometric parallelism**
  Polyhedral structure allows natural spatial separation of E2E paths, eliminating contention found in packet networks.
- **3D-to-3D routing**
  A polyhedron connecting to another polyhedron forms a 3D mesh of multi-layer paths, enabling extremely dense optical routing.

In essence, the polyhedral architecture is the **physical substrate of Velsanet's hyperparallel network topology**.

7.1 Mapping of AI Layers to Neuron Architecture

Velsanet assigns AI functions to spatial layers based on their role in the network's cognitive hierarchy.

7.1.1 PAI — Sensory Neuron Layer

- Captures user intention
- Forms individual E2E
- Lowest spatial layer (Z-axis base)

7.1.2 AAI — Interpretive Neuron Layer

- Evaluates intent
- Coordinates link formation
- Manages inter-layer communication

7.1.3 AsAI — Executive Neuron Layer

- Executes actions
- Requires parallel E2E
- Top-layer neuron structure

7.1.4 Conceptual Summary

- Synapses = optical E2E
- Neurons = polyhedral nodes with x,y,z coordinates
- AI = functional roles assigned per layer

This transforms Velsanet into a **distributed optical-neural system**, not merely a network.

8.Formation of E2E Connectivity & Optical Synapse Model

E2E arises through SLM activation → 8LM bundling → face selection → matrix activation → output connection.

E2E formula:

E2E = SLM × 8 × Face-Pair Matrix

The formation of an E2E path in Velsanet is not a routing process— it is a **physical activation sequence** across the matrix layers.

The E2E path emerges through the following chain:

1. **SLM activation**
   One deterministic cross-point is toggled in a chosen layer.
2. **8LM bundling**
   The layer belongs to an 8LM, enabling up to 8 independent E2E paths in the same face.

3. **Face-pair selection**
   The switching node determines which face-to-face connection must be activated.
4. **Matrix activation**
   The corresponding face-pair matrix is selected from the N(N−1)/2 possible connections.
5. **Output commitment**
   The chosen face outputs the optical signal toward the next polyhedron in the network.

8.1 Optical Synapse Model

In Velsanet, the formation of an end-to-end (E2E) optical path is conceptualized as the creation of a *synapse* between two neurons in a spatially defined network.

- A synapse is established only when a **structural link** between two nodes is valid. (Face direction, layer position, and available port conditions)
- Once this structural alignment exists, **multiple optical cores** may be activated to construct an **associative parallel E2E path**.
- A single optical core → **individual E2E (single synapse)**
- Multiple optical cores → **parallel E2E (reinforced synaptic bundle)**

8.1.1 Synaptic Reinforcement & Decay

- Increasing the number of active optical cores = synaptic reinforcement
- Decreasing the number of cores = synaptic weakening
- No abrupt drop occurs; strength changes gradually.

This establishes Velsanet as a **physical optical neural substrate**, not a packet-based network.

9. Formation and Scaling of Parallel E2E

When multiple face-pairs activate simultaneously, parallel E2E reaches:

Parallel E2E_max = 8 × N(N − 1) / 2

Velsanet's parallel E2E capability is not a software construct but a **physical result of its multi-layer matrix architecture**.
Because each face-to-face connection has **8 independent layers**, multiple E2E paths can be established simultaneously without interference.

9.1 Independence of Layers

Each E2E path is allocated to a distinct layer in the 8LM structure:

- Layer 1 → PAI-to-AAI

- Layer 3 → AAI-to-AsAI
- Layer 5 → AsAI-to-Service Node
- Layer 6 → External E2E connection

Since layers are physically separate optical surfaces, there is:

- no packet collision
- no arbitration
- no bandwidth sharing
- no queuing delay

Each AI request obtains a dedicated optical highway.

9.2 Deterministic Parallelism

Parallel E2E is deterministic because **the control logic evaluates all 8 layers simultaneously**. This allows:

- conflict-free scheduling
- guaranteed latency
- predictable E2E formation
- isolation of multi-agent workloads

Traditional networks attempt parallelism through VLANs, QoS, slicing, or virtual routing, but all of them still share the same switching fabric.
Velsanet avoids this limitation by **physically separating E2E paths in hardware**.

9.3 Multi-Agent Execution Model

Modern AI systems operate as multi-agent ecosystems (PAI, AAI, AsAI, task agents). Parallel E2E gives each agent its own channel:

- No waiting for network resources

- No interference between agents
- Real-time coordination
- Instantaneous intent execution

Thus, Velsanet is not just a network—it is a **hardware execution substrate for distributed intelligence**.

9.4 Parallel E2E Scaling

Parallelism increases in three dimensions:

(1) Per Face-Pair

8 parallel paths exist because each 8LM has 8 layers. Each layer represents **one independent E2E link**.

(2) Per Polyhedron

A polyhedron has multiple face pairs:

- 15 in a cube
- 28 in an octahedron
- 66 in a dodecahedron
- 190 in an icosahedron

Thus, one node alone provides **hundreds to thousands of independent E2E pathways**.

(3) Across the Network

When polyhedra interconnect:

The network becomes a lattice of multi-layer optical corridors.

This is the structural basis of a **planet-scale parallel network**.

9.5 Architectural Implications

- AI inference becomes parallel by design
- Large-scale multi-agent workloads run without congestion
- Network behaves more like a multi-core CPU than a packet router
- Latency remains stable regardless of traffic load
- Intelligence flows continuously across the network

Parallel E2E is the key differentiator between:

- **Velsanet = physical parallelism**
- **Internet = logical serialization**