The Forgotten Boundary: A Layer-Span × Underlay–Overlay Taxonomy and Gap Matrix for Multi-Layer Network Orchestration

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Coordination across network layers is an old problem, and five research literatures address it with no shared vocabulary. From 2003 one of them formalised the interaction between overlay routing and underlay traffic engineering as a non-cooperative game, establishing that independent layers settle into a stable but sub-optimal equilibrium and that one-way awareness has a ceiling. One of those results goes further, reporting that greater visibility can make outcomes worse. In parallel the IETF standardised an interface for exposing underlay information to applications, and continued that work into 2024. An application-aware multilayer literature drove requirements from the application down to the optical layer without engaging the virtualisation boundary, and deterministic networking attacked the same problem under a latency bound at the link layer. Software-defined, intent-based and 6G orchestration frameworks now span more layers and domains than their predecessors while largely dropping the boundary question. We survey 119 papers spanning 2003 to 2026, of which 82 propose or position a mechanism and carry the analysis, and organise them on two axes no existing survey combines: the span of layers a mechanism coordinates, and whether it treats the network as underlay only, overlay only, overlay aware of underlay, or jointly. Span and boundary treatment do not co-occur. All 20 jointly coordinating mechanisms operate between the data link and application layers, and every span reaching the optical layer or crossing radio, transport and core segments has none. Over time the two move in

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opposite directions: wide-span mechanisms rise from 5 of 15 pre-2012 papers to 27 of 47 today while boundary engagement falls from 13 of 15 to 20 of 47. Engagement tracks the coordination formalism rather than the period, since every paper formulating coordination as a negotiation or around a shared information substrate engages the boundary and none driven by an intent-based closed loop treats it jointly. Joint work is a simulation literature: 17 of its 20 mechanisms are evaluated in simulation, against 1 production deployment in the whole mechanism corpus. We identify the results the current literature has left behind and state what a boundary-aware orchestrator has to provide.

Keywords: Multi-layer orchestration, underlay–overlay coordination, network virtualisation, taxonomy, literature survey.

1 Introduction: five traditions, one boundary

Networks carry logical networks over physical ones: a virtual private network over a routed substrate, a content overlay over an operator's traffic engineering, a 5G slice over a shared transport segment. Coordinating behaviour across that boundary is an old problem, and orchestration platforms now span more layers and more administrative domains than their predecessors. Whether they engage the boundary is a separate question.

Five vocabularies make the material hard to read as a body of work. In one literature the word layer names protocol levels from data link to application, in a second the optical through IP transport levels, and in a third the management tiers. Overlay and underlay name a virtualisation relationship in one literature and a spectrum access mode in another. These literatures developed largely apart, and questions settled in one are still posed as open in another: [1], read in full, names cross-layer orchestration among the open challenges of its own area without surveying it.

Existing surveys organise this material on other axes. [2] organise network function virtualisation by architectural component, [3] by enabling technology, [4] by intent lifecycle stage, and [5] by domain tier crossed with resource-management function. Multilayer and multidomain transport orchestration is covered by [6], which stops at the network layer. Cross-layer design in the wireless protocol stack, a different technical sense of the term, is surveyed by [7] and [8]. None of them crosses the two. Table 1 records what each organises on and what it leaves undone.

This survey organises the material on two axes at once: the span of layers a mechanism coordinates, and how it treats the boundary between a carried logical network and its carrier, from not engaged through one-way awareness to a joint two-way treatment. Cross-tabulation produces a matrix whose empty cells are the agenda.

Four contributions follow. The first is a taxonomy of layer span crossed with underlay and overlay role, with written placement rules. Under it sits a screened corpus of 119 papers spanning 2003 to 2026 with per-paper provenance, and over the 82 mechanism papers in that corpus, a gap matrix. The fourth is an inventory of results the older literature established and the current one restates as open.

Table 1: Competing surveys, ordered by citation count, with the axis each organises on and what it leaves undone. These 26 are cited individually; 11 further survey rows in the corpus are group-cited through them. No incumbent cross-tabulates layer span against underlay–overlay role. *Src* records how each row was read: `ft` = full text, `abs` = abstract only. On an `abs` row the last column states what the abstract does not indicate, not what the survey demonstrably omits. Citation counts are those recorded during corpus construction and are not a live count.

Survey	Year	Cites	Src	Its organising axis	What it does not do
[2]	2015	1907	ft	Architectural component: NFVI, VNF and MANO, plus lifecycle and business roles	Uses neither layer span nor the underlay-overlay distinction as an axis
[7]	2005	1121	abs	Types of cross-layer interaction in the wireless PHY, MAC and network stack	A different sense of cross-layer; no carried-network and carrier distinction
[3]	2019	809	abs	Enabling technology: SDN, NFV and MEC, for single- and multi-domain slicing	Organises by technology rather than by layer span or boundary role
[9]	2014	381	abs	A layered taxonomy of SDN research: infrastructure, control and application tiers	Layered here means SDN's own three tiers, not protocol layers
[4]	2023	351	abs	Intent lifecycle stage: expression, translation, activation and assurance	No layer-span axis and no underlay-overlay axis
[10]	2016	315	abs	Infrastructure, control and application tiers of software-defined optical networks	Scoped to optical and SDN; does not extend above the network layer
[11]	2018	305	abs	Hybrid SDN and legacy coexistence: controllers, protocols, traffic engineering	The abstract does not indicate an overlay or upper-layer axis
[12]	2008	292	abs	Traffic-engineering routing: unicast and multicast, intra- and inter-domain, IP and MPLS	Treats overlay interaction in one section rather than as an axis, and stops at the network layer
[8]	2008	205	abs	Cross-layer proposals for 3G and beyond, by functional entity and signalling	The wireless mobile stack, not the virtualisation boundary
[13]	2018	149	abs	Network service orchestration by function, enabling technology and standardisation	Axis is technology and domain, not layer span crossed with boundary role
[14]	2020	112	ft	Multi-cloud orchestration frameworks by cloud feature and application feature	Network-blind: no layer or boundary axis, and network treated only tangentially
[15]	2017	93	abs	Standards body: SDN, NFV and ABNO standardisation efforts	Axis is the standards organisation, not layer span or boundary role
[6]	2018	76	abs	Multidomain and multilayer optical transport orchestration	Multilayer here stops at the network layer and does not reach above it

Table 1: Competing surveys (continued).

Survey	Year	Cites	Src	Its organising axis	What it does not do
[16]	2024	72	abs	5G and TSN integration, by technology pair and integration mechanism	One technology pair rather than layer span across traditions
[5]	2024	71	ft	Domain tier crossed with resource-management function	States explicitly that it uses no underlay-overlay dichotomy
[17]	2026	38	abs	6G system segment crossed with intent lifecycle	Segment-based rather than protocol-layer span, and no boundary axis
[18]	2024	38	ft	Graph-learning and reinforcement-learning families crossed with RAN, transport and core	Functional segments rather than protocol layers, and no boundary axis
[1]	2025	32	ft	Technology pillar, application domain and challenge category for AI-native 6G	Names cross-layer orchestration as an open challenge without surveying it
[19]	2024	14	ft	SD-WAN research in four directions: traffic engineering, systems, orchestration, security	Underlay and overlay appear once, as a measured quantity, never as an axis
[20]	2025	10	abs	Quad view: organisational, functional, cognitive and system architecture	Axis is the architectural view, not layer span or boundary role
[21]	2026	9	abs	Network function and domain: RAN, transport, core and IoT	Segment-based, with no underlay-overlay axis
[22]	2018	6	abs	Peer-to-peer overlay-to-underlay mapping: probing, provider-assisted and middleware selection	Has the boundary axis, but only for content overlays, and no layer span
[23]	2009	4	abs	Overlay routing organised at the network and transport layers	No cross-tabulation with boundary role, and neither the link layer nor above transport
[24]	2025	3	ft	SD-WAN functional feature and control-plane architecture	Names the overlay-underlay split and spans L2 to L7, but never crosses the two
[25]	2010	2	abs	Models of overlay-to-overlay and overlay-to-IP interaction, with avoidance guidelines	A book-chapter review: no taxonomy and no gap matrix
[26]	2024	1	abs	Architecture paradigms for application-to-network integration	Covers the application-network axis rather than the overlay-underlay boundary

2 Terminology: three senses of ”layer”, two of overlay/underlay

Three incompatible senses of the word layer appear in this corpus, and a survey that does not separate them will be read as a duplicate of whichever literature the reader knows.

Protocol stack is the first sense, running from the data link layer to the application layer. Cloud-native and service-chaining work uses it, and this survey adopts it as the default. A second sense is the transport hierarchy, from the optical layer through Ethernet and IP. Optical and transport-network researchers call work on that hierarchy multilayer, and it stops at the network layer: [27] is the clean example, and [6] survey the same range.

Third is the management tier: business support, operations support and network operations functions, or the virtual infrastructure manager, controller and orchestrator stack. [28] call coordination between these tiers cross-layer and [29] call it multi-layer orchestration. Neither means protocol layers.

Overlay and underlay carry two senses. In network virtualisation, an overlay is a carried logical network and an underlay is the network carrying it, which is the sense used throughout this survey. In cognitive radio, overlay and underlay name spectrum access modes, a homonym with no relation to virtualisation, and [30] survey that sense, which is excluded here. Wireless cross-layer design, in which physical, medium access and network layers are jointly optimised inside one stack, is a separate literature surveyed by [7], [8] and critiqued by [31]. It is cited for disambiguation and is not surveyed.

3 Method: sources, criteria, screening, taxonomy construction

We searched with two scholarly connectors, Consensus and an OpenAlex-backed service, and used targeted web search and direct retrieval for standards documents. Queries ran in eleven snowball rounds across distinct vocabularies: the interaction between overlay routing and traffic engineering, application-aware multilayer optimisation, segment routing, deterministic networking, and information exposure from operator to application. Two rounds returned connector failures, and both are recorded as failures rather than routed around.

A record was included if it proposes, evaluates or reviews a mechanism that coordinates behaviour across two or more network layers, where layer means a protocol level or the virtualisation relationship between a carried logical network and a carrying one. Records were excluded for using those terms in a different technical sense, for being off topic, for venue quality, for not being peer-reviewed research, or for having no English abstract. Table 2 summarises the categories. Each included record was coded on the six axes of Section 4 and revised across four passes. A blind re-code of a ten per cent sample disagreed on 3 of 9 records, which is why the two axes re-

Table 2: Screening outcome by category. Group entries cover more than one record; the per-entry detail is in the screening log. Counts are regenerated from the corpus and the log, not transcribed.

Disposition	Entries
Included	**119**
competing surveys and reviews	37
mechanism and position papers	82
Excluded, by reason	**18**
predatory or low quality venue	4
off topic	3
not peer reviewed research	3
standards document retained as background	3
non English no english abstract	2
term used in different technical sense	1
off topic orthogonal axis	1
off topic lexical drift	1

sponsible carry written placement rules, under which 8 records were re-coded. That figure is the disagreement before the rules existed. No second blind re-code was run after them, so it reads as the reason for the rules rather than as a measure of the coding that followed.

Screening included 119 records, 37 of them competing surveys or reviews and 82 mechanism or position papers, published between 2003 and 2026, with searching stopped on 2026-08-29. Exclusions are logged individually: 18 entries, two of which cover groups of records rather than single ones, four for venue quality; three as off topic; three as not peer-reviewed research; three as standards documents kept as background rather than coded; two for having no English abstract; one for using the terms in a different technical sense; one as belonging to an orthogonal axis; and one as lexical drift off the field. Of the 119 records included, 14 were read in full text and 105 in abstract; none rests on metadata alone.

Provenance is reported because it bounds what the comparison tables may claim. Where a record was read in abstract only, this survey states what the abstract does not indicate, never that the work does not do something.

4 The taxonomy: two axes and their placement rules

Two primary axes and four descriptive ones make up the taxonomy, listed with their value counts in Table 3.

Layer span is the first axis: which layers the mechanism itself acts on. Its placement rule is to code the layers the mechanism acts on, not the layers the paper mentions. Segment-based spans from the 5G and 6G literature, covering radio access, transport and core, are held as a separate value rather than mapped onto protocol

Table 3: The six coding axes, their value counts over the whole corpus, and the largest bin as a share of it. The first two are the primary axes of the taxonomy; the other four are descriptive. Every axis discriminates: none holds a single value.

Axis	Values	Most common value	Share
layer span	11	L3-L7-service	24%
underlay overlay	5	not-engaged	53%
coordination mechanism	12	intent-based-closed-loop	16%
domain scope	4	multi-domain-federated	51%
evaluation maturity	4	conceptual	46%
era	3	intent-AI(2020-2026)	58%

layers, because forcing them onto a protocol range invents precision the papers do not have.

Underlay and overlay role is the second axis, with five values. A mechanism is not engaged if the paper never distinguishes a carried logical network from a carrying one. It is underlay-only if it acts in the carrying substrate and the paper also names a carried construct such as a tenant network, a virtual private network or a slice. The mirror case is overlay-only. A mechanism is aware if the overlay adapts to the underlay while the underlay does not change, and joint if both sides adapt or a single optimisation ranges over both. Aware against joint is a one-way against two-way distinction, and the underlay-only rule was sharpened after the consistency re-code.

In construction the two axes are close to orthogonal. In the data they are not, which is the finding reported in Section 10. Four descriptive axes, covering coordination mechanism, domain scope, evaluation maturity and era, are used for grouping rather than for the central claim.

5 Tradition I: overlay and underlay coordination

Oldest of the five, this tradition treats the boundary directly, and it is the only one in which every paper does so. [32] posed the problem: overlays that probe the Internet independently duplicate work and see it poorly, and the answer proposed there was a shared routing underlay the substrate exposes for querying. A two-player non-cooperative game is how [33] formalised the interaction between overlay routing and underlay traffic engineering, proving existence, uniqueness and global stability

of its Nash equilibrium. [34] united transport-layer congestion control with network-layer routing and proved near-optimal aggregate utility.

Several results from this tradition constrain what a boundary-aware orchestrator can promise. [35] found that independent layers recover from failures quickly but sub-optimally, which places a ceiling on one-way awareness. Separating server selection from traffic engineering yields sub-optimal equilibria, [36] showed, and additional visibility can make outcomes worse. Joint optimisation fares no better in [37]: history-based placement and traffic engineering together often underperformed simple unplanned strategies. Exchanging classified metrics beats exposing topology, [38] argued. [39] bounded overlay selfishness through traffic-engineering awareness, and [40] let one layer predict the other's response under incomplete information.

Its reach extends to application overlays. [41] proposed an operator-provided oracle ranking peers by underlay proximity, [42] reached joint optimality while bounding what each side reveals, and [43] studied joint reconfiguration of content mapping and operator topology. Many overlays over shared underlays are treated as a coalitional game by [44] and [45], using Shapley-value and Stackelberg formulations as governance mechanisms.

What the tradition does not settle is scale. Its formulations range over one substrate and few overlays, and [46], [47], [48] and [49] still operate at that scale.

6 Tradition II: application and transport integration

No tradition in the corpus spans more layers than this one, from the optical layer to the application, and none engages the boundary less. [50] argued that optimising jointly over packet and transport resources while taking application requirements into account reduces capital expenditure, and [51] stated that multi-layer transport networks lack coordination between their IP and optical layers. The mechanisms drive requirements downward. An application declares what it needs, an orchestrator allocates across packet and optical resources, and the allocation is revised as demand changes. For six of these seven papers the abstract does not indicate that a carried logical network is distinguished from a carrying one. The exception is [52], which observes that the network and application layers are decoupled and carries application information in the packet header to close that gap.

What the tradition does not settle is who adapts. Its transport substrate is optimised on behalf of applications, and the applications are not modelled as adapting in return, so the wide layer span buys no two-way treatment.

7 Tradition III: information exposure and ALTO

This third tradition answers the exposure problem that [32] and [41] posed, and it answers as a standard rather than as a mechanism. [53] framed the requirement that led to the Application-Layer Traffic Optimization protocol, specified in (**rfc7285**): a

network exposes cost and topology maps, and applications choose peers and paths against them. Every paper here engages the boundary, and all but one do so in one direction by design, because exposure informs the overlay without obliging the underlay to change. Work continues. [55] derives network and cost maps from measurement instead of operator disclosure, [56] benchmarked a prototype against classical peer selection, and [57] frames the protocol as a settlement of the tussle between applications and providers. Standardisation continued into 2024 [58].

What the tradition does not settle is reciprocity. An exposed map lets an overlay adapt, and gives the underlay no corresponding way to respond.

8 Tradition IV: deterministic networking

At the link and network layers the fourth tradition coordinates against a latency bound rather than a cost objective, and [59] integrates time-sensitive networking with container orchestration by separating operational and information-technology data paths, making it the one paper here that distinguishes a carried construct from its carrier. For the other four the abstract does not indicate that distinction: they coordinate controllers across technology domains, harmonise shapers with non-deterministic neighbours, or allocate flows under a latency constraint. All of it stays inside the substrate.

What the tradition does not settle is whether a virtualised tenant can inherit a bound established in the substrate beneath it.

9 Tradition V: modern orchestration

Largest in the corpus, the fifth tradition also spans the most layers and domains. It covers software-defined and virtualised service orchestration together with intent-based and zero-touch management, and its newest members orchestrate end to end across radio access, transport and core segments. [60] presented orchestration architectures for multilayer and multidomain transport, [61] set out the open problems for next-generation service orchestration, and [62] proposed end-to-end intent-based networking integrated with zero-touch control across layers and segments. Each node's protocol stack is reconfigured by [63], which goes further still.

Boundary engagement in this tradition stands at 14 of 38. Where mechanisms cross the segment boundary of the 5G and 6G literature the figure is lower still, and the abstracts do not indicate that a carried logical network is distinguished from a carrying one. [64] is among the exceptions, carrying segment-routing state into the mobile core data plane. Naming the gap from the other side, [65] finds that software-defined control does not reach the physical and medium access layers. Nor is the pattern new: [66] optimises across administrative boundaries without treating a carried construct at all.

What changed over the three periods is the composition of the field rather than the position of any tradition in it. Tradition I supplied 12 of the 15 mechanism papers

Table 4: The five traditions side by side, over the 82 mechanism papers. Membership is derived from the corpus by a written rule rather than assigned by hand, so every row regenerates. *Span* and *formalism* give the most common value in the tradition with its count, and *eng.* counts any distinction between a carried and a carrying network.

Tradition	*n*	Years	Dominant span	Dominant formalism	Eng.	Joint	Strongest eval.
Overlay-underlay coordination	24	2003–2024	L3-L4-overlay-routing (15)	game theoretic negotiation (12)	24	17	simulation (21)
Application-transport integration	7	2016–2022	L0-L7-app-to-optical (7)	algorithmic optimization (4)	1	0	simulation (4)
ALTO information exposure	8	2009–2024	L3-L7-service (8)	shared information substrate (6)	8	1	simulation (4)
Deterministic networking	5	2021–2024	L2-L3-network (4)	policy enforcement (1)	1	0	testbed prototype (3)
Modern orchestration	38	2005–2026	RAN-TN-CN-segment (8)	intent based closed loop (11)	14	2	testbed prototype (21)

published before 2012, then 7 of 20, then 5 of 47, while Tradition V ran the other way, at 2, then 6, then 30. Table 4 sets the five traditions side by side. Boundary-treating work did not stop and did not change its mind. It was outgrown, and the discontinuity of Section 10 follows from that.

What Tradition V does not settle is the boundary itself, which is the subject of Section 10.

10 The gap matrix and what it shows

Table 5 cross-tabulates layer span against underlay and overlay role over the 82 mechanism papers. One column needs care before the patterns are read off it. Of the 34 papers in the not-engaged column, 2 were read in full text and 32 in abstract, so that column mixes work that demonstrably does not treat the boundary with work whose abstract is silent on it; 7 of the 82 mechanism papers were read in full. The engaged columns carry the argument, and a paper reaches them only by stating the distinction positively, which an abstract can establish. Three patterns then fall out.

First, boundary treatment and layer span do not co-occur. Every one of the 20 mechanisms that treats the boundary jointly sits inside the band from the data link layer to the application layer: 10 in overlay routing, 7 at the service layer, 3 at the network layer. Every span that reaches below the network layer or crosses the segment structure of mobile networks has none. Counting them: 0 of 7 for the optical-to-network span, 0 of 7 for application-to-optical, 0 of 6 for the full stack, and 0 of 8 for radio-transport-core, which does not engage the boundary at all. Mechanisms that span the most layers do the least across the boundary between them.

Second, there is a discontinuity over time. A paper counts as engaging the boundary when it treats it in both directions, whether by one-way awareness or jointly.

Table 5: The gap matrix: layer span against underlay–overlay role, over the 82 mechanism and position papers. Competing surveys are excluded so that no cell is filled by a paper that only describes the area. A zero means no paper *in this corpus* landed in that cell; it is not a claim that none exists.

Layer span	joint	aware	ov. only	ul. only	not eng.	total
L3-L7-service	7	9	2	**0**	5	23
L3-L4-overlay-routing	10	5	**0**	**0**	**0**	15
L2-L3-network	3	3	**0**	**0**	5	11
RAN-TN-CN-segment	**0**	**0**	**0**	**0**	8	8
L0-L3-transport	**0**	**0**	**0**	4	3	7
L0-L7-app-to-optical	**0**	1	**0**	**0**	6	7
L2-L7-full-stack	**0**	3	**0**	**0**	3	6
L1-L3-wireless-stack	**0**	**0**	**0**	**0**	2	2
non-OSI-mgmt-tier	**0**	**0**	**0**	**0**	1	1
RAN-only	**0**	**0**	**0**	**0**	1	1
L2-L4-wan-overlay	**0**	1	**0**	**0**	**0**	1
total	20	22	2	4	34	82

On that definition engagement falls from 13 of 15 pre-2012 mechanisms to 9 of 20 in the software-defined era and 20 of 47 in the intent and machine-learning era. We state the definition because the alternatives differ: counting any distinction between carried and carrying network gives a shallower fall, counting only joint treatment a steeper one.

Boundary-engaged work in the modern tradition is small and recent. [67] verifies overlay and underlay control planes together on a deployed national network, [68] provisions both an underlay and its overlay from agents on each router, and [69], [70], [71] and [72] carry overlay state that is aware of the substrate beneath it.

Third, the two trends run in opposite directions. A span counts as wide when the mechanism acts across five or more protocol layers, or across network segments rather than protocol layers at all. On that rule wide-span mechanisms rise from 5 of 15 papers before 2012 to 12 of 20 and then 27 of 47, while two-way engagement falls over the same periods, and Figure 1 plots both shares. Conditioning on span sharpens it: every wide-span mechanism published before 2012 treated the boundary in both directions, 5 of 5, against 4 of 12 in the software-defined era and 11 of 27 now.

11 What predicts boundary engagement

Era does not determine whether a paper engages the boundary. The formalism it works in does. Table 6 crosses the coordination formalism coded for each mechanism paper against its boundary role, and the two axes separate cleanly.

Two formalisms always engage. All 12 papers formulating the problem as a nego-

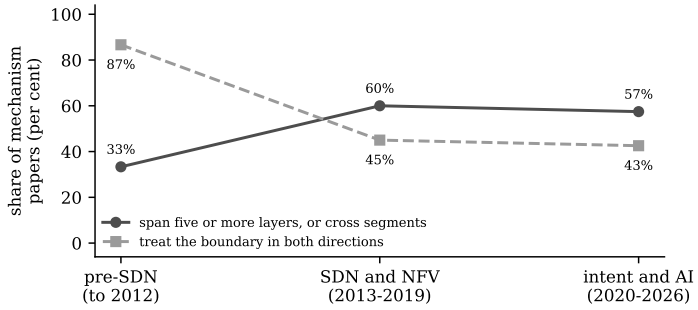


Figure 1: The two halves of the discontinuity, over the mechanism papers. The share spanning five or more protocol layers or crossing network segments rises; the share treating the underlay–overlay boundary in both directions falls.

tiation between self-interested layers treat the boundary, and 10 of 12 treat it jointly. All 14 built around a shared information substrate treat it as well, 4 jointly and 10 through one-way awareness. Neither formalism has a single paper that ignores the boundary, which follows from what they are: a negotiation needs two parties, and an information substrate needs something on each side of the interface to publish and to read.

Two formalisms almost never engage. Of the 11 papers driven by an intent-based closed loop, 10 do not distinguish a carried logical network from a carrying one and none treats the two jointly. The 6 papers driven by machine learning contain no joint treatment either. These are the formalisms the recent literature is built on, and they express the network as one object to be optimised toward a declared objective. That framing has no place to put a second party with its own objective, which is what the boundary is.

Behind the discontinuity of Section 10 sits a mechanism rather than lost interest: the field adopted formalisms in which the boundary cannot be stated, and the two that can state it are the two the current literature does not use.

One axis that looks as though it explains the pattern does not. Multi-domain scope is often assumed to force boundary awareness, but the corpus gives 21 of 39 multi-domain mechanisms engaging the boundary against 23 of 39 single-domain ones. Crossing administrative boundaries and crossing the virtualisation boundary are independent here.

12 How much of this has been built

Table 7 crosses boundary role against the strongest form of evaluation each paper reports, and across all 82 mechanism papers it finds exactly 1 reported production deployment.

Joint treatments are a simulation literature. Of the 20 mechanisms that treat the

Table 6: Coordination formalism against underlay–overlay role, over the 82 mechanism papers. Every paper working in game-theoretic negotiation or on a shared information substrate engages the boundary; no paper working in an intent-based closed loop treats it jointly.

Coordination formalism	**joint**	**aware**	**ov. only**	**ul. only**	**not eng.**	**total**
shared information substrate	4	10	**0**	**0**	**0**	14
algorithmic optimization	4	2	**0**	**0**	7	13
game theoretic negotiation	10	2	**0**	**0**	**0**	12
intent based closed loop	**0**	**0**	**0**	1	10	11
hierarchical federated orchestrator	**0**	2	**0**	1	5	8
centralized SDN controller	**0**	1	1	**0**	5	7
ML AI driven	**0**	2	**0**	**0**	4	6
standards based general	**0**	**0**	**0**	2	2	4
policy enforcement	**0**	2	1	**0**	**0**	3
autonomous agent provisioning	1	1	**0**	**0**	**0**	2
ensemble verification	1	**0**	**0**	**0**	**0**	1
cross layer protocol design	**0**	**0**	**0**	**0**	1	1
total	20	22	2	4	34	82

boundary jointly, 17 report simulation, 1 reports a testbed prototype, 1 is conceptual and 1 reports deployment. That single deployment is [67], whose authors report running a control plane verifier over a national research network and finding 22 misconfigurations. Every other result the joint literature offers rests on simulated topologies and traffic. That includes the equilibrium and ceiling results of Section 13.

What has been built instead is one-way awareness. Of the 22 mechanisms that make an overlay aware of its underlay, 11 report a testbed prototype, the highest prototype share of any boundary role. Mechanisms that ignore the boundary are the least evaluated: 13 of 34 report no evaluation at all.

Read together with Section 11 this gives the agenda its shape. Formalisms that can express the boundary produce results in simulation, and the systems that get built express at most half of it. The recovered results of Section 13 have never been tested at the scale at which orchestration platforms now operate, and the one paper in this corpus that verifies both layers on a real network does so as a checking problem rather than a coordination one.

Hold the maturity column loosely. It records the strongest evaluation a paper reports, and for the 105 records read in abstract only it records what the abstract claims.

Table 7: Strongest form of evaluation reported, against underlay–overlay role, over the 82 mechanism papers. The values are those coded in the corpus: a conceptual paper reports no evaluation, and the deployment column requires the authors to report operation on a production network.

Boundary role	concept.	simul.	testbed	deployed	total
joint	1	17	1	1	20
aware	3	8	11	**0**	22
ov. only	1	**0**	1	**0**	2
ul. only	1	**0**	3	**0**	4
not eng.	13	9	12	**0**	34
total	19	34	28	1	82

13 Recovered results: what the modern tradition can reuse

Four results established in Tradition I bear directly on assumptions made in Tradition V.

Oscillation between layers is structural rather than incidental. [33] reported a unique, globally stable Nash equilibrium for the interaction, which means an orchestrator treating layer conflict as a tuning problem solves the wrong problem.

One-way awareness has a ceiling. [35] reported that independently recovering layers converge quickly to a worse outcome, which bounds what an underlay-aware overlay achieves without a cooperating substrate.

More visibility can be worse than less. [36] reported that partial cooperation between server selection and traffic engineering produced outcomes worse than no cooperation. That runs against the assumption that a global cross-layer view always improves matters.

Joint optimisation is not free. [37] reported that history-based joint optimisation of content placement and traffic engineering often underperformed simple unplanned strategies, and [38] argued that exchanging classified metrics achieves more than exposing topology.

All five works were read in abstract only, because their publishers refuse automated retrieval. Each statement above is what the authors reported, not a verified reproduction. Table 8 audits the works that were read in full text, separating what each reports from what it does not measure.

Whether the later literature has taken these results up is a question this survey answers only indirectly, because the corpus records bibliographic metadata and coding rather than citation links. Two pieces of evidence bear on it. Figure 2 plots how often four of the works were cited each year, and OpenAlex records none for two of them after 2018 and 2022, over a period in which the orchestration literature grew from 20 to 47 mechanism papers in this corpus alone. Separately, the problems are still

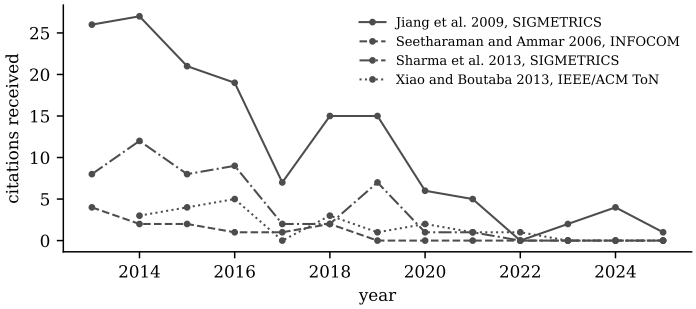


Figure 2: Citations received per year by four of the works carrying the recovered results. Source: OpenAlex, retrieved 30 August 2026; these are not counts over the corpus. Liu et al. (2005) is omitted because OpenAlex holds no indexed record for it.

posed as open by people working in the later tradition: [73], read in full, names the binding from the service layer down to the underlay as future work, and [65] reports the corresponding gap at the lower layers. We do not claim that the later work fails to cite the earlier. We observe that the earlier results stopped accumulating citations while the questions they answer were being restated.

14 Open problems

Seven problems follow from the sections above, each stated so that a study can settle it.

Four of them are about reach. Can a joint treatment of the boundary be made to hold at the scale Tradition I never reached, over many overlays and many administrative domains rather than one substrate and a few overlays? Does span itself force one-way coordination, or can a wide-span mechanism, from the optical layer upward, carry a two-way boundary treatment? Is a reciprocal exposure interface possible, one in which a substrate both informs an overlay and receives something it can act on? Can a latency bound established in a substrate be inherited by a tenant carried over it?

Two are about evidence. Does the negative result on joint optimisation survive at current traffic volumes, or was it an artefact of the workloads available when it was measured? Second, can a boundary-aware mechanism be deployed rather than simulated? The equilibrium and ceiling results rest on simulated topologies, and a deployment that reproduced or refuted one of them is worth more than another simulation.

One question the rest of the agenda depends on remains. Can an intent-based or learned controller be given a formalism that admits a second party with its own objective? Formalisms carrying boundary treatment and those carrying the current literature are disjoint.

Table 8: Evidence audit over the 14 works read in full text. The last column is the one that earns the citations, and it is why this table is restricted to full-text rows: an abstract cannot establish what a paper did not measure. *Legend:* `no` = the work does not do this, asserted only where the full text was read; `n/i` = not indicated by the abstract; `--` = the axis does not apply.

Work	What the full text establishes	Reported	Not measured
[2]	Organises network function virtualisation by architectural component and lifecycle	–	Uses neither layer span nor the underlay-overlay distinction anywhere
[74]	Maps tenant virtual infrastructure onto multi-technology optical domains	~100 ms setup, optical testbed	No underlay-overlay vocabulary, nothing above the network layer, and scaling not established
[27]	Optical through IP orchestration behind one control-orchestration abstraction	Blocking probability, multi-domain testbed	No underlay-overlay vocabulary and nothing above the network layer
[14]	Classifies multi-cloud orchestration by cloud and application feature	–	No layer or boundary axis, and network orchestration only in passing
[75]	Low-latency service and segment routing as a repeated game between two layers	Unstable after 100 rounds, simulated topology	Packet reordering under multipath and large segment counts, both deferred
[76]	Six hierarchical closed loops coordinated by intent delegation and escalation	None; conceptual	No underlay-overlay vocabulary, and no implementation, which the authors leave to further work
[77]	Service chaining on Kubernetes through a network service mesh at L2 and L3	None reported	No coordination with any physical underlay, and no quantitative evaluation at all
[78]	A closed loop with deep reinforcement learning for O-RAN slice allocation	37 ms against a 20 ms target, testbed	No underlay-overlay vocabulary, one radio domain only, and the core left as future work
[73]	Replaces the Kubernetes IP-in-IP overlay with a segment-routing overlay	TCP ~2 Gb/s, UDP ~1 Gb/s	Binding high-level Kubernetes models to segment-routing capabilities, named as future work
[5]	Domain tier crossed with resource-management function	–	States explicitly that it uses no underlay-overlay dichotomy
[19]	SD-WAN research in four directions, from traffic engineering to security	–	No systematic treatment of underlay-overlay coordination and no layer-span taxonomy

Table 8: Evidence audit (continued).

Work	What the full text establishes	Reported	Not measured
[18]	Graph-learning and reinforcement-learning families crossed with network domains	–	No layer-span axis and no underlay-overlay axis
[24]	Separates overlay control from underlay transport across L2 to L7 mechanisms	Review; no measurements	No cross-tabulation of span against boundary role, and no gap matrix
[1]	AI-native 6G by technology pillar, application domain and challenge	–	No underlay-overlay vocabulary; organises by pillar rather than by layer span

15 Threats to validity

Three limits bound what this survey establishes. Only 14 of the 119 included records were read in full text, because three publishers refuse automated retrieval, so every other statement about a paper reports what its abstract indicates rather than what the work demonstrably omits. The empty cells of the gap matrix are relative to this corpus and are not claims that no such work exists; one such cell was broken during construction and the claim was restated rather than defended. The corpus records bibliographic metadata and coding, not citation links, so no claim here rests on which work cites which. Searching reached saturation three times and was overturned three times by a query in an adjacent vocabulary, so the corpus is bounded by vocabulary rather than by field, with in-network computing and programmable data planes untried.

16 Conclusion

Five research traditions have approached the same coordination boundary with incompatible vocabulary and little contact between them. Set out on layer span and underlay and overlay role, the 119 papers show that the two do not co-occur: the mechanisms that treat the boundary in both directions operate over narrow spans, and the mechanisms that span the widest range of layers and domains largely do not treat the boundary at all. The tradition that treats it has not stopped. It was outgrown. Two of the results it established stopped accumulating citations years ago, while the questions they answer were still being written down as open.

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