

TECHNICAL WHITE PAPER

AION ENTERPRISE ACADEMIC

VERSION A / SCHOOLS, COLLEGES & UNIVERSITIES

Hybrid Cloud-Edge Timing & Intelligent Node Orchestration for Distributed Digital Signage



PRECISION TIMING / INDEPENDENT NODE CONTROL / LOCAL RESILIENCE

01 / EXECUTIVE OVERVIEW

A new layer of intelligence

A vendor-independent infrastructure designed to complement established digital signage ecosystems.

Aion Enterprise Academic is a proposed hybrid cloud-edge timing and orchestration platform for organizations that require distributed displays to operate as coordinated yet independently programmable endpoints.

Its purpose extends beyond showing an accurate clock. It is designed to combine authoritative network time, location-specific scheduling, individual display control, continuous timing diagnostics and resilience during internet outages.

THREE COORDINATED CAPABILITIES

TIME AUTHORITY

Local GNSS-referenced timing, NTP service and optional PTP distribution.

ZONE CONTROL

Independent calendars, countdowns, behavior profiles and location-based policies.

NODE AUTONOMY

Each display executes cached events against its own synchronized local clock.

THE OPERATING PRINCIPLE

Centralize the time authority and management policies.
Distribute execution intelligence to every display node.

BUILT FOR ORGANIZATIONS THAT CANNOT PAUSE

- Schools, colleges and universities coordinating hallway countdowns, lecture sessions and building schedules.
- Corporate, healthcare and industrial sites operating synchronized displays and localized time-driven workflows.
- Signage providers extending an existing CMS with timing, node control and offline execution - without replacing authoring tools.

02 / THE OPERATIONAL GAP

Beyond conventional signage

Content synchronization, clock synchronization and visible presentation timing are related - but different.

A traditional content management system excels at designing layouts, distributing media and deciding which playlist should run. It does not necessarily maintain a shared clock across players or guarantee that geographically separated displays will execute a transition at the same instant.

CONVENTIONAL SIGNAGE

Content, playlists, publishing and screen management.

AION OPERATIONS LAYER

Time authority, node schedules, calibrated clocks and local timed execution.

FOUR REQUIREMENTS THAT CHANGE THE DESIGN

Independent endpoints

Two displays can share a campus while operating different schedules or timers.

Predictable transitions

A node executes a preloaded event at an absolute deadline, not upon packet arrival.

Measured clock quality

Offset, RTT, jitter and clock health are monitored continuously.

No cloud dependency

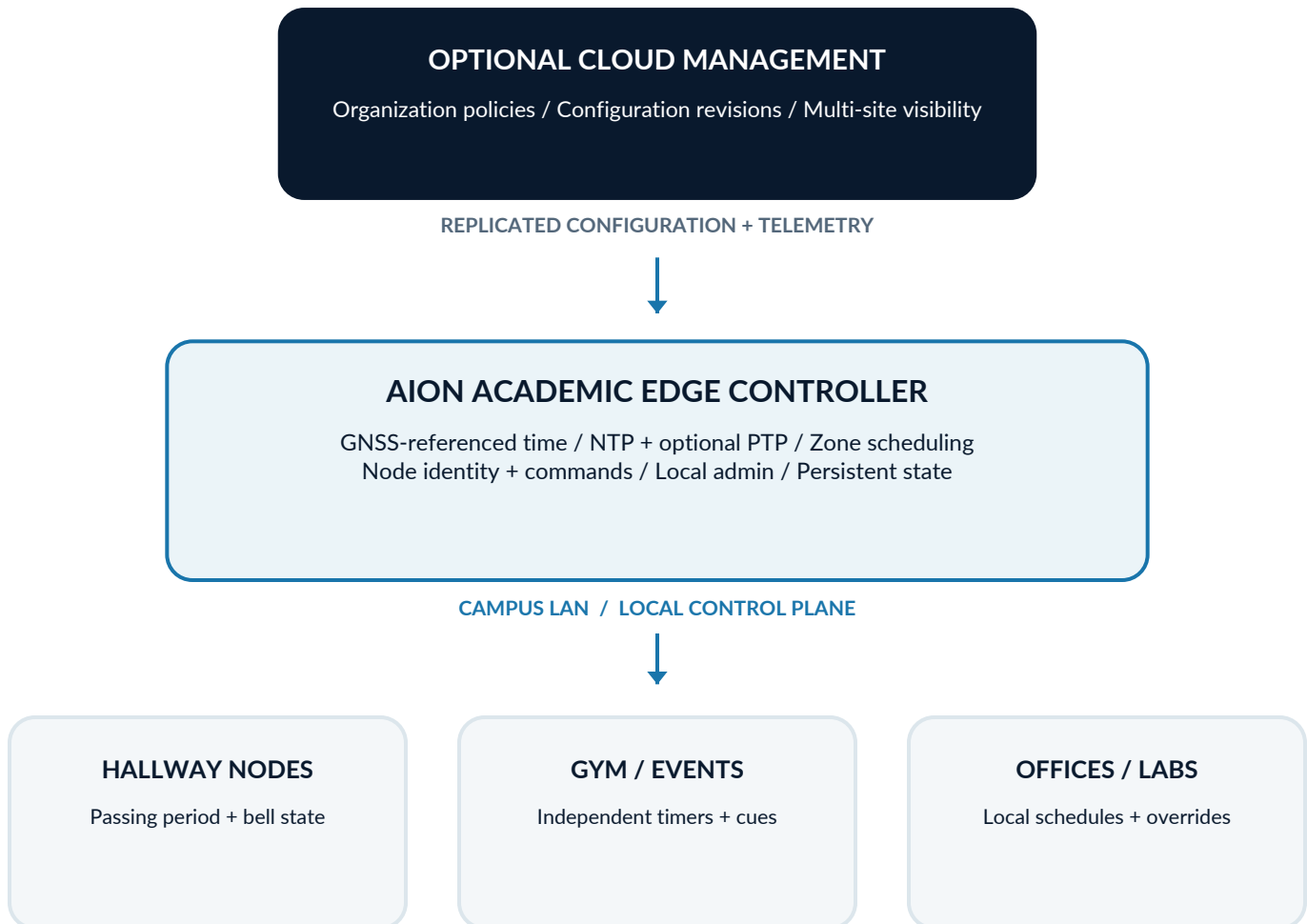
Timing and operational control continue on the intranet when the WAN is unavailable.

Design boundary: synchronized software clocks do not automatically imply frame-perfect visible output. Rendering cadence and physical display latency remain separate considerations.

03 / PLATFORM ARCHITECTURE

Hybrid by design

Cloud management is optional. Local timing and control remain authoritative.



Data plane: Each endpoint maintains a calibrated time reference and locally executes scheduled behavior.

Control plane: The campus Edge Controller distributes policies, future event deadlines and commands.

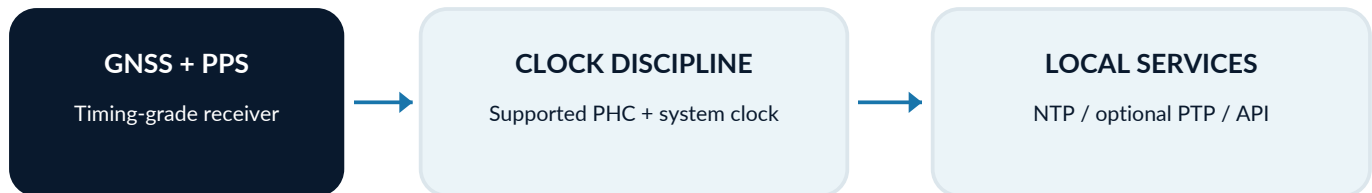
Management plane: Optional cloud services replicate non-real-time configuration and fleet telemetry.

Existing signage platforms remain responsible for visual layouts, decoding, playback and presentation. Aion does not need to replace the content management system.

04 / TIMING FOUNDATION

One authoritative clock

The architecture separates physical time distribution from zone-specific timers and schedule state.



A timing-grade GNSS receiver and hardware pulse-per-second reference provide a stable local source. Suitable NIC timestamping, clock-discipline mechanisms and Linux services then establish an authoritative clock for the site. The exact PHC discipline path must be validated on the selected hardware.

THREE NODE SYNCHRONIZATION PATHS

STANDARD NTP / SNTP

General-purpose Android, Linux, Windows and hardware signage players. Preferred default.

APPLICATION-LEVEL CLOCK

Browsers or restricted players use four-timestamp exchanges to calibrate an internal monotonic timebase.

NATIVE PTP

Optional precision clients with compatible stacks and networks; tighter clock alignment where needed.

Critical distinction: All nodes receive legitimate reference time. A classroom countdown or paused gym timer is an application-level state derived from the clock - it must never alter the NTP/PTP time distributed to other devices.

Offline timing: GNSS lock permits local operation without internet. Holdover accuracy following GNSS loss is hardware-dependent and must be reported rather than assumed.

05 / SYNCHRONIZATION QUALITY

From clock to glass

A display can know the correct time yet still paint a frame late. The two problems require different measurements.

01**CLOCK OFFSET**

NTP, PTP or four-timestamp client calibration.

02**EVENT EXECUTION**

Preloaded deadlines computed against local monotonic time.

03**PRESENTATION**

Render scheduling + device-specific output behavior.

RETAIN AND EVOLVE THE AION TCV MEASUREMENT SYSTEM

Aion's existing browser display code performs repeated four-timestamp communication measurements and estimates clock offset and network round-trip time. It also samples rendering-scheduling delay with `requestAnimationFrame()`. Enterprise Academic can adapt these techniques into a reusable node clock and telemetry model.

LOCAL EVENT EXECUTION

$$\text{remaining} = \text{deadlineUtc} - \text{calibratedNowUtc}$$

Events arrive ahead of time. Their network arrival delay does not dictate the countdown boundary, provided the schedule reaches the client before execution.

QUALITY METRICS AVAILABLE TO ADMINISTRATION**Clock offset**

Estimated difference from local authority

Round-trip delay

Time to complete a measurement exchange

Jitter / drift

Variability and stability across samples

Render cadence

Observed opportunities to update the display

Engineering caveat: browser frame callbacks estimate application scheduling latency, not the exact moment physical pixels illuminate. True display-output alignment must be tested using supported presentation APIs or calibrated external measurements.

06 / INTELLIGENT ENDPOINTS

Each display is a node

A persistent identity and local execution capability turn a screen into a managed operational endpoint.

AION NODE RUNTIME

Identity / Calibrated clock / Schedule cache

Operational state + countdown engine

Command + event subscriptions

Health metrics + sync confidence

A NODE KNOWS...

- Where it belongs
- What it is allowed to do
- Which schedule is active
- What to do if disconnected
- How accurate its clock is

AN INTENTIONAL NODE LIFE CYCLE

1

ENROLL

Securely identify player and capabilities.

2

ASSIGN

Map campus, zone and behavior policy.

3

PRELOAD

Cache signed configuration and upcoming events.

4

EXECUTE

Run local deadlines on calibrated time.

5

OBSERVE

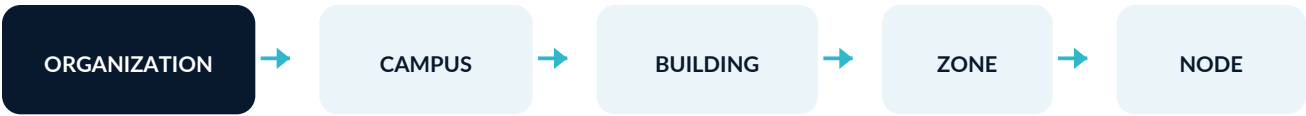
Report sync, health and last execution state.

The Node Runtime is an integration component, not a replacement content player. Compatible signage software decides how events become on-screen layouts, colors, animation or media playback.

07 / HIERARCHY AND POLICY

Zones without clock drift

Independent behavior does not require independent physical time sources.



Schedules, policies and permissions can be inherited down the hierarchy. A node may receive its building's normal academic timetable while a permitted local override changes an auditorium or athletic display independently.

SCHEDULE RESOLUTION - EVALUATED LOCALLY

- 01

AUTHORIZED CRITICAL OVERRIDE
Highest-priority institutional information; scope and expiry controlled.
- 02

AUTHORIZED LOCAL OVERRIDE
Temporary node or zone-specific instruction.
- 03

SPECIAL-EVENT CALENDAR
Exam day, assembly, special program or event.
- 04

RECURRING SCHEDULE
Normal academic day, A/B day or rotation.
- 05

FALLBACK BEHAVIOR
Defined default when no valid schedule applies.

Timing invariant: bell schedules, timers, local time zones and content offsets are all application data. The underlying time service remains correct and common to all participating nodes.

08 / EDUCATION USE CASE

A campus passing period

One schedule can drive synchronized corridor countdowns while other spaces operate independently.

WEST CAMPUS / BUILDING A

ILLUSTRATIVE

TIME TO NEXT CLASS

03:42

CURRENT: PASSING PERIOD

TARGET: 10:45:00 LOCAL

HALLWAY A1

03:42

Passing countdown

HALLWAY A2

03:42

Same absolute deadline

GYMNASIUM

12:00

Independent local timer

HOW THE EVENT IS COORDINATED

- 01 CALCULATE

Edge evaluates local calendar and converts deadline to UTC.
- 02 DISTRIBUTE

Each affected node caches the event before it is due.
- 03 EXECUTE

Every node renders locally from calibrated time; no per-second server tick required.
- 04 RECOVER

After reconnect, the node computes current state instead of replaying expired events.

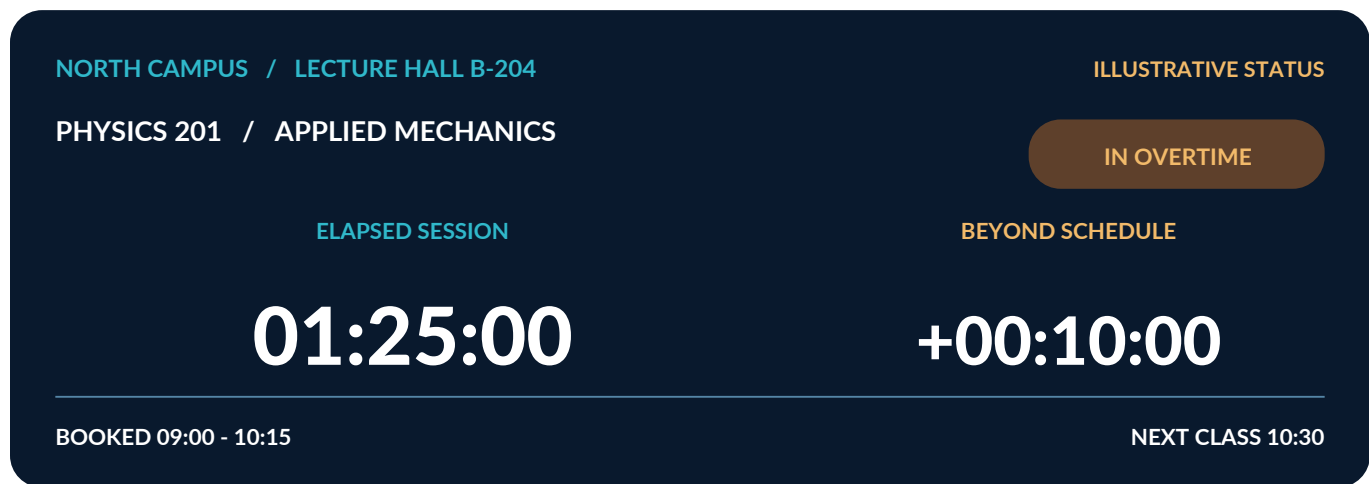
K-12 timetables can include rotating days, lunch waves, examinations and local exceptions. Colleges and universities also require room-session intelligence; the following sections address lecture timing, overruns and faculty controls. Display examples are illustrative.

09 / UNIVERSITY USE CASE

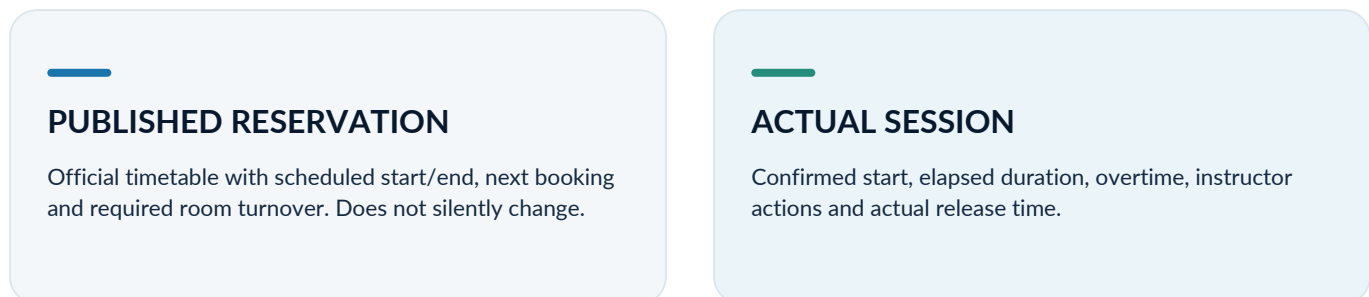
Lecture halls know the clock

Colleges and universities need to distinguish scheduled reservations from the lecture actually in progress.

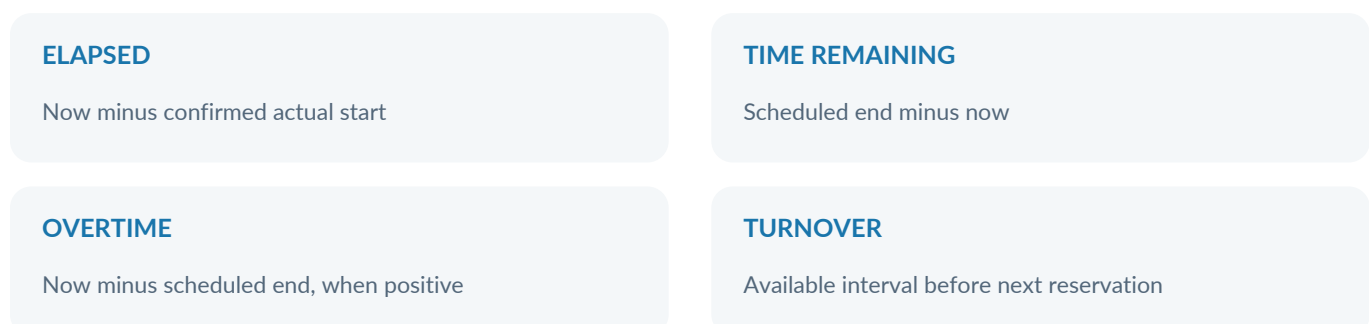
The proposed Room Session Manager coordinates current and upcoming lectures, elapsed time, scheduled finish, authorized extensions and room turnover. Hallway signage, an instructor display and an administrative dashboard can present different views of the same room state.



TWO INDEPENDENT TIMELINES



DERIVED ROOM AND SESSION INDICATORS

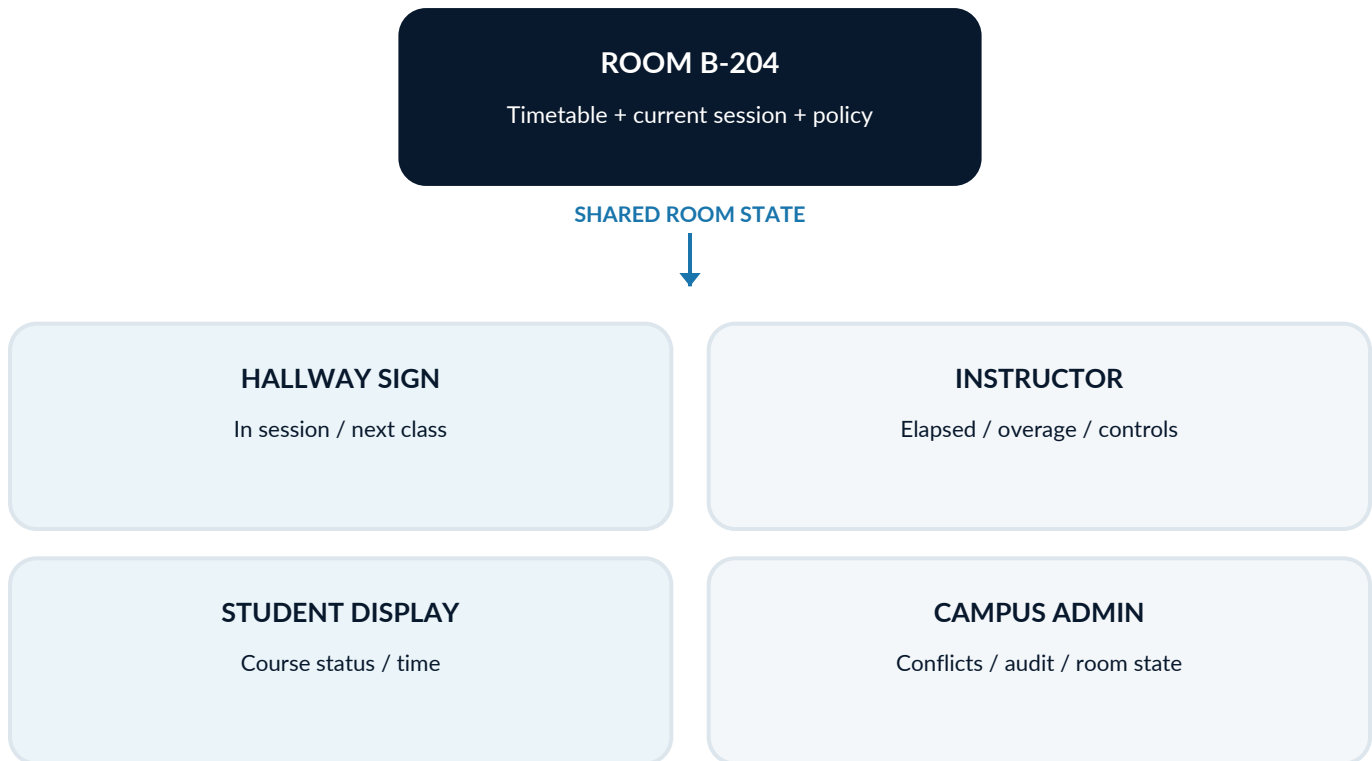


Truthful room status: a timetable entry alone does not prove occupancy. Public signage should say "Scheduled" until an authorized start/check-in or approved room-system integration establishes that a session is actually in progress.

10 / ROOM SESSION MODEL

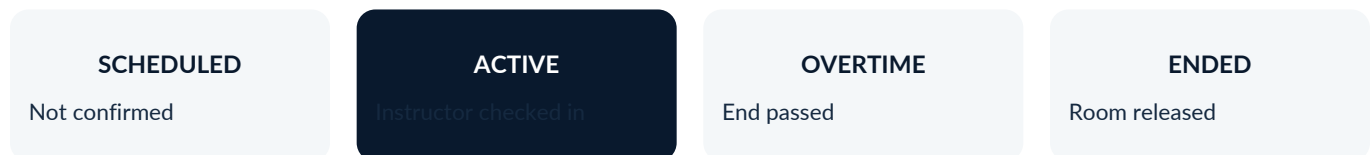
One session. Many node views.

Rooms, sessions and displays are related entities - a room is not simply another display zone.



EXPLICIT SESSION STATE AND IDENTITY

Each room has reservations, enrolled nodes and a control policy. Each session records a booking reference, scheduled interval, actual start/end, authorized operator, current state and revision history. Nodes subscribe to relevant state without owning the reservation.



ACADEMIC CALENDAR AND EVENT SOURCES

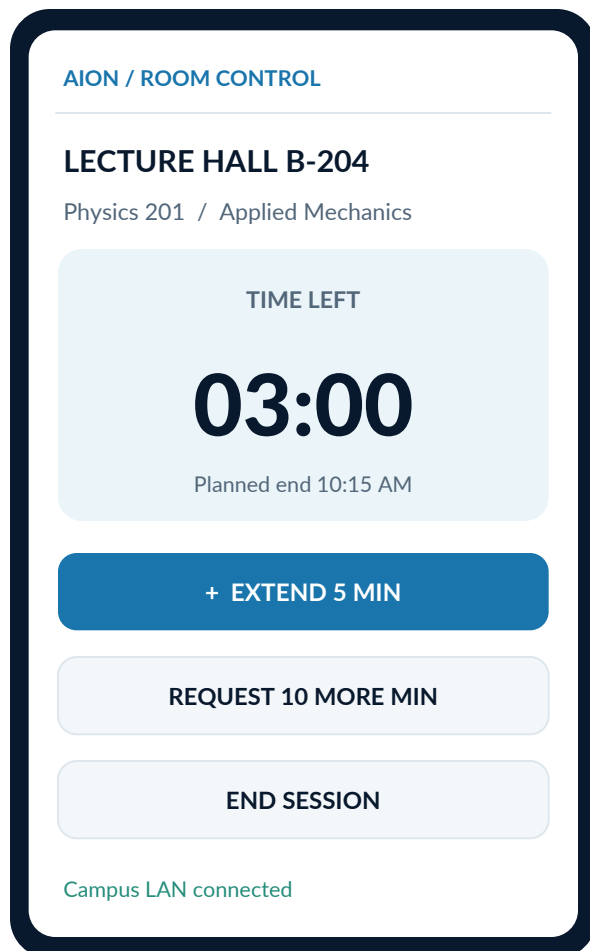
Version A is designed for rotating school days and also for university semesters, course meetings, exam periods, room changes, guest seminars and departmental events. A future importer may ingest supported calendar feeds or institutional room-booking APIs, with explicit reconciliation and provenance.

Start and occupancy policy: universities can use authenticated instructor check-in, a permitted local room controller or a verified room-management integration. A scheduled reservation is never silently treated as evidence that the class physically started.

11 / FACULTY EXPERIENCE

Two taps, not a control room

A room-specific interface gives authorized teachers and professors only the controls they actually need.



THREE ACCESS MODES

QR / MOBILE WEB

Scan a room code to open the local responsive page. Instructor authentication is still required.

ROOM TOUCHSCREEN

A 5-7 inch panel at the lectern can expose permitted actions after badge or PIN access.

EXISTING AV PANEL

Where supported, integrate the same room actions into the classroom projector/audio control UI.

A SECURE, ROOM-SPECIFIC WORKFLOW

- A QR code identifies the room; it never grants control without authenticated authorization.
- Assigned instructors can start/end a session and request an extension within configured limits.
- An institutional SSO integration can identify faculty, with approved local login fallback for WAN outages.

For K-12, teacher actions can be limited to classroom timers while school bells remain under campus control. For universities, professors may receive greater authority for their booked lecture hall.

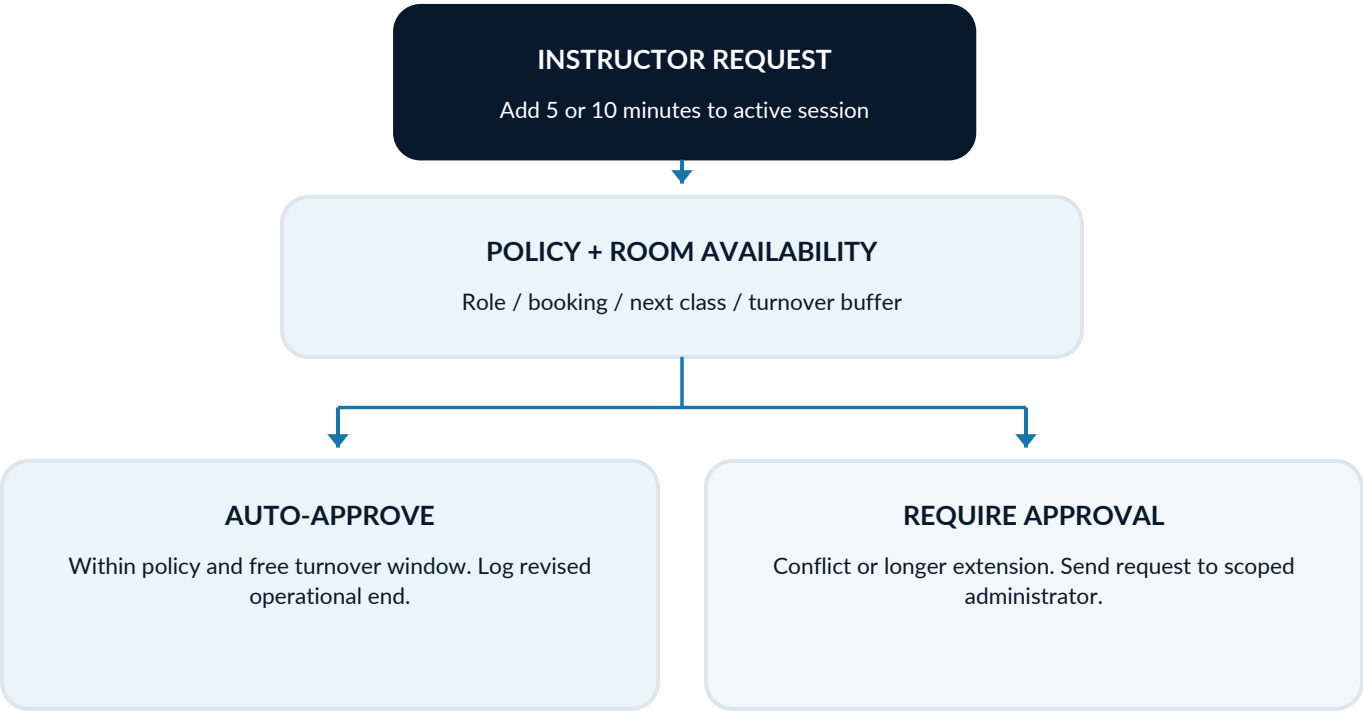
12 / EXTENSIONS AND AUTHORITY

Overtime without surprises

A live session may run past its planned end; that must not silently rewrite the university booking system.

An active lecture can automatically enter an Overtime state at the scheduled end, without instructor intervention. Overtime reflects actual activity; a reservation extension is a separate authorized action.

DECISION FLOW FOR AN EXTENSION REQUEST



WHO CAN DO WHAT? / POLICY-CONTROLLED

ACTION	INSTRUCTOR	DEPT ADMIN	CAMPUS
Start/end own assigned session	Yes	Yes	Yes
Extend inside free buffer	By policy	Yes	Yes
Approve a booking conflict	No	Scoped	Yes
Change campus-wide bell schedule	No	No	Yes

Local operation and presentation: Instructor actions use the campus LAN and are logged for later cloud reconciliation. Authorized faculty may also select approved display modes such as Lecture in Progress, Break, Exam in Progress or Session Ended; the signage provider renders each layout.

17 / RESILIENCE

The internet is optional

Local timekeeping, administration and scheduled node behavior are designed to continue without public cloud reachability.

OFFLINE FIRST

The local Edge Controller retains complete active schedules and policies. Nodes maintain enough cached state to execute already approved events if the Edge becomes temporarily unreachable.

EXPECTED RECOVERY BEHAVIOR

PUBLIC INTERNET LOST

Edge operates on LAN; local admins continue changing schedules and nodes.

CLOUD MANAGEMENT DOWN

Local policies and execution remain available; replication queues changes.

EDGE TEMPORARILY DOWN

Cached node events continue with degrading clock confidence as applicable.

NODE RESTARTED

Node reloads state, re-calibrates and evaluates what schedule is active now.

GNSS REFERENCE LOST

Timing enters defined holdover/degraded state; accuracy depends on oscillator.

CONNECTIVITY RESTORED

Reconcile versions, refresh state and discard or account for expired commands.

Third-party boundary: offline orchestration can only guarantee the parts Aion controls. A signage player with mandatory cloud license checks, remote assets or cloud-only administration may impose additional dependencies that require validation.

14 / OPEN INTEGRATION

Designed for signage providers

Aion owns authoritative time and operational state. Existing CMS and player software own presentation and media.

AION OPERATIONS

Clock sync, zone policies, event deadlines, local control and telemetry.

SIGNAGE PRESENTATION

Layouts, media playback, visual transitions, templates and player support.

THREE INTEGRATION TIERS

01 / WEB COMPONENT

Embed an Aion-hosted local clock/countdown inside a compatible web region. Fastest proof of concept.

02 / NODE SDK

Integrate synchronization, schedules and telemetry in an Android, desktop or other native player.

03 / CLOUD FEDERATION

Coordinate device/site records and non-real-time policy deployment across management systems.

EXAMPLE EVENT CONTRACT - PROPOSED, NOT AN EXISTING PUBLIC API

```
{
  "nodeGroup": "west-campus-hallway",
  "event": "passing-period",
  "startUtc": "2026-10-20T14:40:00Z",
  "endUtc": "2026-10-20T14:45:00Z",
  "presentation": "countdown",
  "revision": 104
}
```

Local interfaces may include authenticated HTTPS/REST endpoints and WebSocket or SignalR event delivery. SDK availability, payload shape, security controls and compatibility commitments will be defined during Enterprise Academic implementation.

15 / SECURITY AND GOVERNANCE

Control with clear boundaries

Academic session overrides and node commands require scoped faculty and administrative authority.

SECURE ENROLLMENT

Unique node identity, authenticated provisioning, revocation and trusted software updates.

SCOPED AUTHORITY

Campus, building, zone and node permissions with recorded override origin.

SEGMENTED NETWORKS

Control access to timing and administration with approved LAN/VLAN policies.

AUDIT + RECONCILIATION

Revised configurations, expiration-aware commands and explicit conflict rules.

OPERATIONAL POLICY EXAMPLES

- A professor can control an assigned room session but cannot alter the campus bell schedule or another course booking.
- A department administrator can approve a lecture extension when it does not violate authorized room-turnover rules.
- A node coming online after an outage resolves the current desired state instead of replaying stale transitions.
- A locally authorized instructor control must not require a cloud identity service during a WAN outage.

SAFETY AND COMPLIANCE

Aion Enterprise Academic is an operational information and orchestration platform. Fire alarms, evacuation systems, access control and other life-safety applications require appropriately certified equipment and separately validated interfaces. Display overrides alone are not a life-safety system.

16 / DEPLOYMENT FLEXIBILITY

One platform, several footprints

The same timing, room-session and node orchestration services serve local or hybrid deployments.

DEDICATED APPLIANCE GNSS receiver, NTP/PTP service, local database and resilient hardware.	FIT Campuses requiring local reference and continuity.
SOFTWARE EDGE Install on approved local server/VM with defined timing reference.	FIT Sites using suitable existing IT infrastructure.
HYBRID MULTI-SITE Independent campus Edge Controllers with cloud policy/telemetry synchronization.	FIT School districts and distributed institutions.
FULLY ON-PREMISES Local management and execution; no runtime public internet requirement.	FIT Isolated or regulated networks.

AN INTENTIONAL PRODUCT-FAMILY DISTINCTION

VERSION A / ACADEMIC	Campus timing + intelligent nodes
VERSION B / BROADCAST	ST 2110 + broadcast timecode

Version A does not require the broadcast-focused ST 2110 processing paths or hardware LTC/IRIG subprocessors. Shared timing architecture does not imply identical hardware specifications.

17 / ENGINEERING STATUS

What exists. What comes next.

A clear separation between existing Aion technology and Enterprise Academic development avoids overstating product readiness.

EXISTING AION FOUNDATION

- GNSS/PTP timing code and operational monitoring
- Browser/Android TCV client experience
- Network round-trip and clock-offset estimation
- Display rendering-scheduling diagnostics

PROPOSED ENTERPRISE ACADEMIC WORK

- Multi-campus, zone, room, academic session and intelligent-node data models
- Academic calendars, lecturer overrides, room conflict policy and local execution
- Provider-facing integration SDK and authenticated node API
- Optional cloud/Edge configuration replication and reconciliation

VALIDATION SEQUENCE

01	LOCAL EDGE	NTP service, datastore, local admin and baseline security.
02	ROOM + NODE PILOT	Two hallways, a lecture hall and a local instructor control.
03	PLAYER INTEGRATION	Embedded web reference, then native SDK on suitable hardware.
04	OFFLINE TEST	Cut WAN, run a faculty extension, restart displays, restore state.
05	MEASURE + SCALE	Clock offset, event deadlines, physical transitions and fleet load.

Performance position: synchronization and end-to-end visible alignment depend on network topology, operating system, player and panel hardware. Public accuracy targets will follow representative measurements, not assumptions.

APPENDIX A / EXPLORATORY R&D

Sports timing & event intelligence

An optional extension of Aion Enterprise Academic, inspired by earlier Aion sports-timing concepts.

Institutional athletic programs introduce a new application for the same authoritative clock, intelligent-node model and locally controlled event engine. Aion could evolve from coordinating scheduled display events to also timestamping measured physical events at practice facilities, competition venues and campus athletic centers.

CONCEPT UNDER EVALUATION

Combine a synchronized high-speed camera, a 2D LiDAR sensing plane and AI-assisted motion analysis to propose event times for review by authorized officials.

ORIGIN IN EARLIER AION SPORTS-TIMING WORK

Earlier Aion planning described a 100 fps camera paired with 2D LiDAR for AI-assisted finish-line detection, together with tablet-based official controls and TCV-driven public timing displays. This appendix places that concept within the new Academic architecture; it does not represent a completed or certified sports-officiating product.

POTENTIAL APPLICATIONS

TRACK & FIELD

Crossing detection, elapsed race clocks, reviewable finish events and spectator boards.

AQUATICS

Lap/finish candidates using sport-specific water-safe camera and sensing geometry.

COURT / FIELD

Practice drills, reaction timers and selected motion-triggered events.

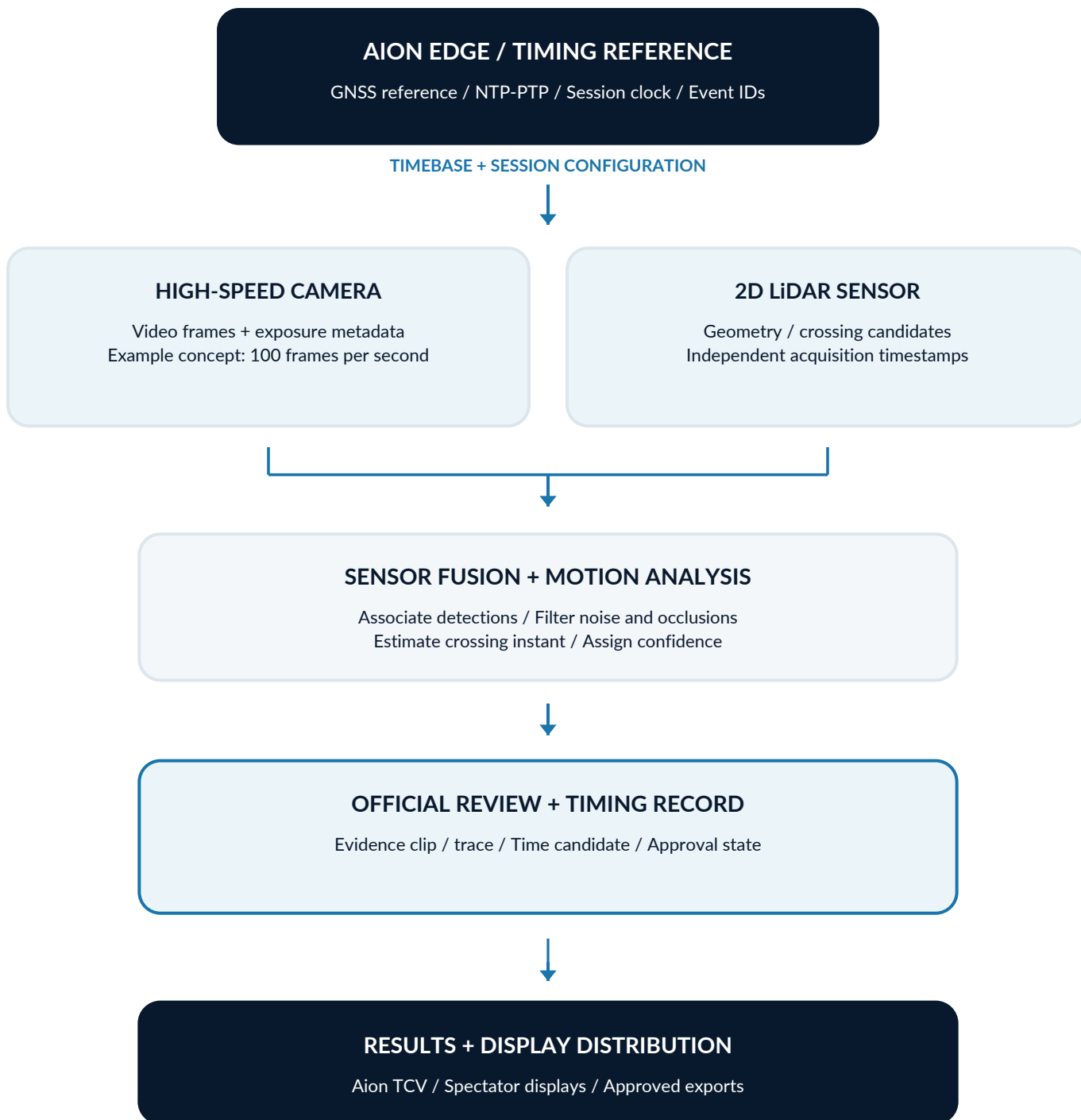
WHAT IS SHARED WITH ENTERPRISE ACADEMIC

- Aion Edge remains the facility time authority, providing a common UTC-aligned timeline and local orchestration.
- Sensor controllers become specialized nodes with calibration profiles, health monitoring, event history and local APIs.
- Authorized officials control sessions from tablets; results and clocks can be distributed to compatible TCV or third-party signage clients.
- Campus and cloud dashboards provide optional administration and reporting; live event capture stays on the intranet.

APPENDIX A / SENSOR FUSION

A common clock for every sensor

Synchronized acquisition timestamps come first; AI helps interpret measurements after capture.



Illustrative integration: the event collector retains original sensor timestamps and evidence before any display or results publication. AI output alone does not establish an official event time.

APPENDIX A / METROLOGY

Timing an observed crossing

A synchronized clock is necessary; a traceable sensor-acquisition timestamp is equally important.

Event accuracy must be evaluated as the sum of several error sources, not equated to clock synchronization alone. The acquisition method, optics, geometric setup, sensor cadence and analysis model can dominate the result even when the Edge clock is highly stable.

WHERE UNCERTAINTY ENTERS

REFERENCE CLOCK

GNSS discipline, timestamp synchronization and drift during holdover.

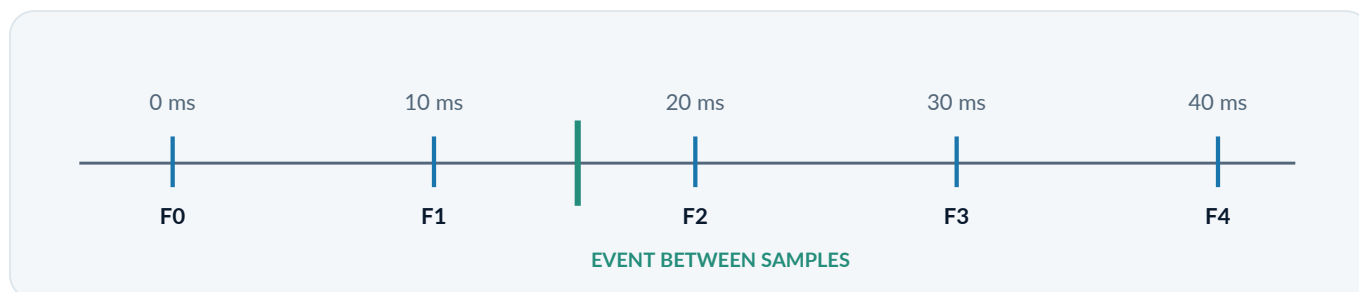
SENSOR CAPTURE

Exposure/readout, LiDAR scan phase and trigger acquisition delay.

INTERPRETATION

Motion models, occlusion, geometry and athlete/target identification.

AN ILLUSTRATIVE CAMERA SAMPLING INTERVAL



At 100 frames per second, consecutive frames are nominally separated by 10 ms. A model may interpolate the instant at which a target crossed a calibrated plane, but such estimates require uncertainty bounds and validation against a trusted reference. A 2D LiDAR sensor introduces its own scan cadence and geometry-dependent sampling uncertainty.

DESIGN CHOICES THAT MERIT VALIDATION

- Prefer global-shutter capture and verified acquisition/trigger timestamps where suitable; generic frame-arrival times include software and transport delay.
- For strict event timing, evaluate direct PPS/trigger synchronization or supported PTP hardware timestamping rather than assuming application-level NTP is sufficient.
- Calibrate sensor position, crossing plane, lane geometry and all offsets. Keep the original observations alongside each proposed result.
- Report uncertainty and ambiguous detections explicitly, and allow officials to inspect synchronized video and LiDAR evidence.

APPENDIX A / OPERATIONS & VALIDATION

Assist officials. Preserve evidence.

The sensing system proposes detections; event rules and authorized review determine reportable results.

PROPOSED COMPETITION WORKFLOW

01

CONFIGURE

Official chooses sport, venue, event, timing rule and calibrated sensor zone.

02

SYNCHRONIZE

Edge confirms device lock and sensor acquisition timebase.

03

CAPTURE

Camera and LiDAR record motion with source timestamps.

04

REVIEW

AI filters noise and proposes a crossing; official reviews evidence.

05

PUBLISH

Approved result is logged, displayed and exported through authorized interfaces.

REQUIRED INTEGRITY AND VALIDATION CONTROLS

- **Auditability:** retain original frame/LiDAR records, calibration version, timestamps, review decisions and immutable result revisions.
- **Reliability:** test multi-athlete crossings, occlusion, changing lighting, reflective surfaces, lane geometry and network loss.
- **Human authority:** provide manual correction, rejection and clear confidence/uncertainty information; do not silently auto-certify results.
- **Sport-specific design:** track finishes, pool touches and basketball movement require different sensor geometry and officiating rules.

DEVELOPMENT STATUS / IMPORTANT BOUNDARY

AI-assisted sports detection is a future research addendum, separate from the initial Enterprise Academic release. Use in sanctioned competition would require sport-specific validation, calibration procedures and acceptance by the relevant governing authority. No certified accuracy or officiating status is claimed.

TIME THAT EVERY NODE CAN TRUST.

A vendor-independent timing and operational intelligence layer for distributed digital signage.

INTEGRATION & ENTERPRISE INQUIRIES

Digital signage software developers, display manufacturers, systems integrators and institutional technology teams are invited to discuss pilot integrations and deployment requirements.

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DOCUMENT STATUS / PUBLIC TECHNICAL CONCEPT - OCTOBER 2026 / v1.2

Enterprise Academic zone orchestration, academic sessions, cloud federation and integration APIs are proposed. Sports timing sensor fusion and AI-assisted detection are exploratory R&D; only. Existing Aion technology provides the starting foundation. Final hardware, performance, availability and supported-platform specifications are subject to verification. Enterprise Broadcast is a separate product configuration.