Technical White Paper

Unified Ethernet Backbone: How Single Pair Ethernet (T1L | T1S) Drives Efficiency in Building Automation

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1 Abstract

Modern building automation systems (BAS) face a widening gap between increasing intelligence and aging physical infrastructures. While modern HVAC and fire-safety sensors demand high-frequency data streaming and millisecond-level response times, the legacy serial networks used to transport this data are struggling with bandwidth bottlenecks, high latency, and complex multi-conductor wiring. This whitepaper identifies the critical risks associated with these legacy architectures and proposes a scalable answer: single-pair Ethernet (T1L and T1S). By analyzing the technical advantages of T1L for long-reach HVAC control and T1S for deterministic fire-safety loops, this document demonstrates how engineers can potentially reduce cabling costs by up to 50% while providing a native IP-based foundation. The result is a unified, secure, and potentially future-proofed building architecture that improves energy performance and life-safety compliance through the power of Ethernet.

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2 Introduction

Legacy cabling and protocols in building automation struggle to meet the current demands of modern HVAC optimization (requiring dense sensor data) and critical fire safety systems (demanding deterministic performance and reliability), leading to potentially higher costs, complexity, and risk.

A strategic, layered adoption of Ethernet technologies can help provide a future-proof foundation for a unified network topology. This adoption includes standard Ethernet for backbone or high-bandwidth needs, single pair Ethernet (SPE) for more cost-effective sensor connectivity, SPE long reach Ethernet (T1L, IEEE 802.3cg) for extended-distance PoDL applications, and Ethernet single pair multidrop (T1S, IEEE 802.3ch) for lower-cost sensor networks.

This white paper explores how adopting emerging Ethernet technologies such as T1L and T1S Ethernet, in combination with the commonly used standard Ethernet backbone, transforms building automation from an aggregation of siloed, limited systems into a unified, high-bandwidth, and efficient platform to meet the imperatives of fast, reliable data, and overall system efficiency.

3 The Current Landscape in Building Automation

3.1 Evolution of Building Intelligence

For the past five decades, the philosophy of building automation has shifted from *simple automation* to *intelligent orchestration*. However, while the logic and sensing capabilities of HVAC and fire-safety systems have evolved exponentially, the physical infrastructure used to transport the data of these systems has remained largely stagnant.

- **The Era of Discrete Control (1970s–1980s):** Building systems were primarily mechanical. HVAC consisted of simple thermostat-to-relay connections, and fire-safety was comprised of hard-wired, point-to-point alarm loops. Data requirements were negligible, the *intelligence* was local and analog.
- **The Rise of Digital Fieldbuses (1990s–2000s):** As building management systems (BMS) emerged, digital intelligence was introduced. Variable air volume (VAV) controllers, complex PID loops for thermal comfort, and addressable smoke detectors were added. To manage these additions, low-speed, serial fieldbuses (RS-485, BACnet MS/TP, LonWorks) were adopted. These additions worked well for the limited telemetry of the time, but were designed for small, periodic data packets, not continuous streams.
- **The Data Imperative and Sensor Explosion (2010s–Today):** This is now the so-called *Data Imperative* era. Modern HVAC systems no longer just manage temperature; HVAC systems also manage indoor air quality (IAQ), CO^2 levels, humidity, occupancy, and airflow turbulence. Fire-safety has moved beyond simple smoke detection to include multi-criteria sensors, flame detection, and even video-based smoke analysis.

Efficiency is key in both HVAC and fire-safety systems. Inefficient systems contribute to higher operational costs and reduced reliability, which is why modern HVAC systems rely heavily on punctual data flow to manage a myriad of control loops across all subsystems and maintain a relatively good coefficient of performance (COP) to achieve the most efficient system possible.

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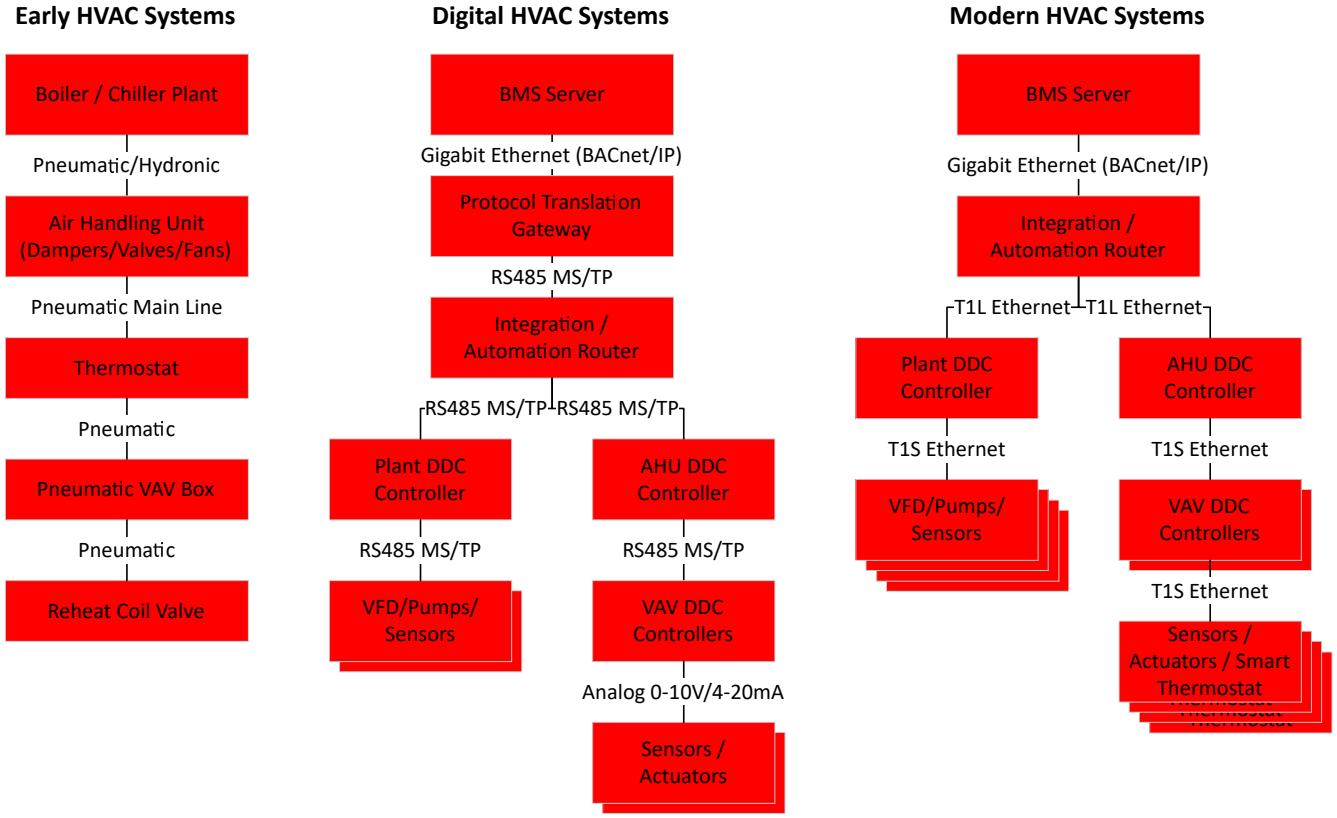


Figure 3-1. HVAC Systems Evolution

3.2 The Breaking Point

The explosion of data points and the requirement for real-time response have created a fundamental mismatch between the intelligence at the edge and the capacity of the wiring. This mismatch creates three critical risks:

- **The Bandwidth Bottleneck (The Data Choke)**: Legacy serial networks are commonly referred to as *choking* on modern data. As high-resolution sensors are added for energy auditing and predictive maintenance, the low-bandwidth fieldbuses suffer from high latency and packet collision. In HVAC, this choking results in sluggish control loops. In fire-safety, choking creates risks of delayed critical alarm signals.
- **The Complexity and Cost Trap**: To increase intelligence, engineers are often forced to pull massive, expensive, multi-conductor cable bundles to accommodate power and communication. This increases labor, material costs, and the physical footprint of conduits, making retrofits in existing buildings prohibitively expensive.
- **The Fragmentation of Intelligence (The Silo Problem)**: Since legacy fieldbuses cannot natively *speak* IP, every subsystem (HVAC, fire, lighting) requires an individual proprietary gateway. This requirement creates data silos where the fire-safety system cannot easily communicate with the HVAC system to trigger smoke-purging ventilation modes, and therefore, a gap in integrated life-safety responses.

The industry is at a crossroad, continue to patch aging, low-speed serial networks, or fundamentally upgrade the *nervous system* of the building. Adopting single-pair Ethernet (T1L and T1S) offers a path for alleviating these growing risks. By transitioning to an entirely Ethernet-based physical layer, the system moves from a fragmented, low-speed architecture to a unified, high-bandwidth, and deterministic ecosystem. This transition not only fixes the wiring issue, but also unlocks the ability to implement true closed-loop intelligence and integrated life-safety that legacy systems simply cannot support.

4 Unified Ethernet Ecosystem

4.1 The Architecture: From Core to Edge

To resolve the tension between increasing data demands and aging infrastructure, building automation must undergo a paradigm shift—the migration from fragmented serial fieldbuses to a unified, IP-based single-pair

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Ethernet (SPE) architecture. The proposed answer is not replacement of certain network elements, but instead an evolution of the network reach. A modern, future-proof building uses a hierarchical Ethernet architecture:

- **The IP Backbone (The Core)**: High speed, multi-pair gigabit Ethernet acts as the robust *highway* for the data in the building, connecting building management system (BMS), cloud servers, and floor-level distribution switches.
- **The SPE Extension (The Edge)**: T1L and T1S Ethernet act as the *capillaries* that extend this network architecture directly to the most granular devices. Instead of going through a gateway that translates IP to a slow serial protocol, the data flows smoothly from the sensor to the core, and visa-versa, as standard Ethernet packets.

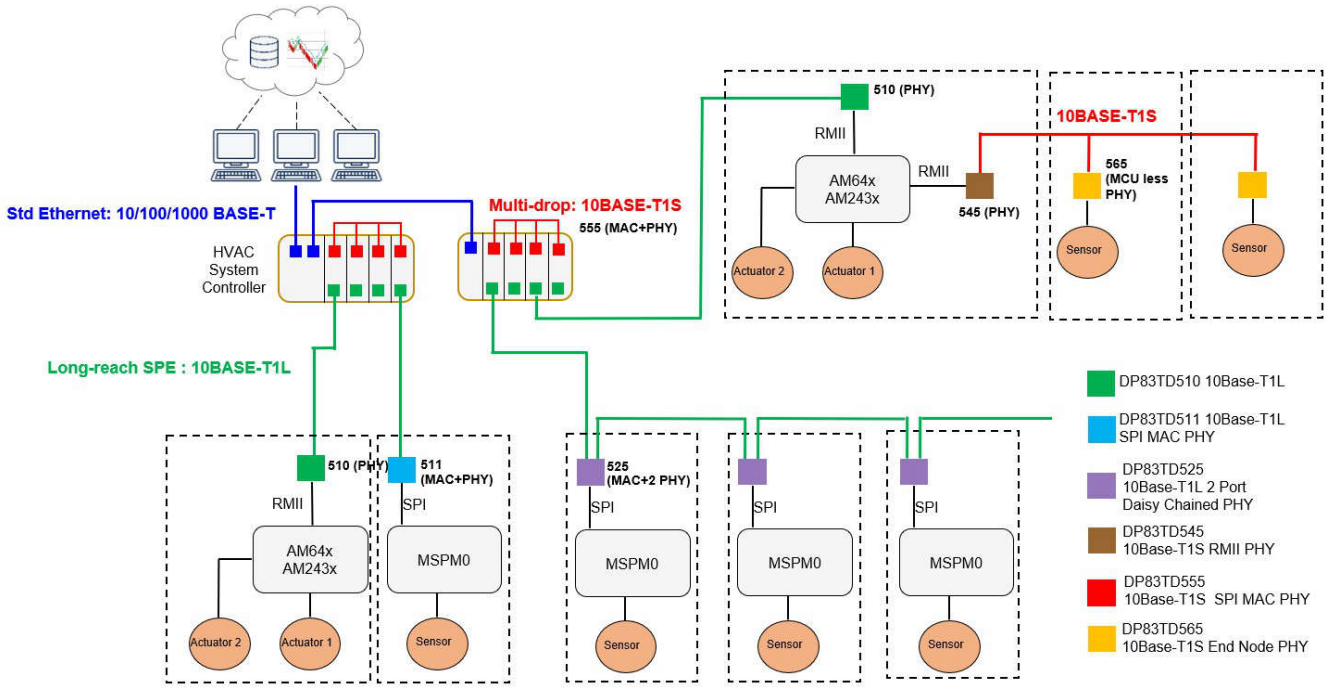


Figure 4-1. Proposed System Architecture

4.2 Closing the Gaps: T1L and T1S

By implementing single pair Ethernet, the specific technical voids left by legacy systems address:

- **The Long Reach Intelligence Layer (10BASE-T1L)**: T1L is designed to replace long-distance, low-speed serial links such as RS-485 or M-Bus. Traditional HVAC systems often struggle with large payload transfers, firmware updates, high latency, and ground loops which can lead to communication failures. With a range of up to 2km and 10Mbps throughput, T1L Ethernet eliminates this bandwidth ceiling for devices located far from the controller (VAV boxes, outdoor environmental sensors, remote HVAC dampers, and so forth). The added isolation on the analog front end breaks ground loops entirely, making communication more robust against electrical interference, while the added PoDL support can be leveraged, eliminating the need for separate power lines. The expanded array of cable diagnostic features offered by T1L PHYs also enables real-time cable monitoring, predictive cable health checks, and easy debugs using remote fault detection features. Tunable terminations also allow for using existing cable infrastructure for communication and power.
- **The Multidrop Intelligence Layer (10BASE-T1S)**: T1S is designed to replace short-range, localized fieldbuses such as CAN and LIN. Similarly to T1L, T1S Ethernet offers increased bandwidth, vastly improved robustness, and PoDL support, while also adding the option of multidrop Ethernet. Traditional multidrop systems rely on controller-target polling or CSMA/CD token-passing, both of which degrade heavily under higher traffic conditions. Data collisions, indeterministic timing, and token timeout loops are common symptoms when multiple smart controllers try to communicate simultaneously. T1S introduces physical layer collision avoidance (PLCA), which utilizes a round-robin method to eliminate data collisions entirely by assigning each node on the bus a unique ID and transmit opportunity, providing deterministic latency and equal opportunities for each node to communicate irrespective of network congestion.

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Together, T1L and T1S act as the bridge between the high-speed Ethernet backbone and the low-speed Edge devices. A bi-product of this integration is that the whole network architecture, from the backbone to the edge, supports native IP, which means fewer gateways, less translation, and fewer points of failure. Each and every sensor or device can be programmed to a particular IP address, making accessing all the devices on the network much easier.

5 Benefits and Results

The migration from fragmented, legacy fieldbus architectures (RS-485, CAN, LonWorks, and so forth) to a unified Ethernet backbone is not simply a cabling upgrade, but a fundamental shift in the economics, capability and future-readiness of building infrastructure. Legacy serial buses impose hard physical limits on the data rate, distance, and determinism that modern building analytics and life-safety systems cannot tolerate.

Table 5-1. Legacy Protocols vs Ethernet IP

Capability	Legacy Architectures	Unified Ethernet Architecture	Result
Bandwidth | Telemetry Granularity	• Speeds ranging from a few Kbps to a few Mbps shared across dozens of devices • Polling intervals are typically large, with only current values transmitted	• Speeds from 10Mbps (T1L/T1S) to gigabit (Gbps+) • Streaming telemetry at 10Hz-100Hz • Full waveform captures (vibration, pressure, transients, and so forth)	• Higher granularity in collected data allows for predictive maintenance in critical systems like VAV dampers, AHU fans, and so forth. • Higher throughput allows for faster reaction to environmental changes, leading to energy savings
Determinism and Control Latency	• Controller-target polling adds significant latency, while CSMA/CR can be unreliable at higher node counts and potentially delay transmission indefinitely in some cases	• Time sensitive networking adds support for deterministic latency with minimal jitter • Transmits packet in multi-node systems within the allotted time using PLCA	• Allows for more reliable, resilient, and time-sensitive PID loop networks • Every sensor or node has the opportunity to transmit critical data
Network Topology	• A single point of failure breaks the network in daisy-chain topologies and isolates all downstream devices	• Multiple different topologies (Star, Ring, Bus) and protocols (HSR, MRP, and so forth) can be used • Offers redundancy against single point failures	• Increased reliability in case of failures for life-critical systems such as fire-safety loops, and so forth
Protocol Interoperability	• The system consists of siloed stacks of BACnet MS/TP, Modbus RTU, LonTalk, proprietary protocols, and so forth • Gateways are required at multiple points for IT/OT convergence	• Brings native IP stack to the edge using BACnet IP, Modbus TCP, MQTT, and so forth. • Zero gateways required • Cloud talks directly to edge devices like VAV boxes	• Future proofing systems by bringing *intelligence* to the edge by unifying system network architecture • No *translation* required between different subsystems
Cabling and Wiring	• Uses multi-conductor bundles, sending power and data separately • No standardized cables or connectors	• Standardized cables and connectors. • Sends power and data over the same cable using PoDL	• Significant reduction in cable weight and wiring complexity • Tunable termination allows for retrofitting existing infrastructure

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6 Conclusion

The ultimate result of adopting T1L (for distributed intelligence), T1S (for deterministic local multidrop networks and fire safety loops), and standard Ethernet (For backbone or cloud connectivity) is the elimination of fragmented building management systems.

In legacy systems, HVAC runs on one bus, fire runs on another, and each requires multiple gateways for protocol translation, where data is trapped. Under these conditions, real-time analytics and debugs are next to impossible. Using an all Ethernet architecture, one cable sends both power and data, and one protocol is spread from cloud to the edge. Under these conditions, the cloud interacts with all edge devices from a single IP-based dashboard. This change is not merely a networking change, but enabling architecture for an autonomous, self-optimizing building automation system. A system where subsystems have no need for competing priorities, but are instead integrated into the same intelligent network fabric.

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