Global Prior Art Search Analysis: Microsecond Temporal Fragmentation of Digital Communications

Search reveals significant technical gap in microsecond temporal fragmentation

After conducting an extensive global prior art search across patent databases, academic literature, and technical standards, the research reveals a clear technical gap in the specific area of microsecond temporal fragmentation of digital communications. While numerous related technologies exist in Time-Sensitive Networking (TSN), precision timing protocols, and deterministic networking, Semiconductor Engineering TTTECH no prior art directly describes the claimed invention's specific approach to fragmenting data across microsecond temporal windows. B&R Industrial Automation

Patent landscape analysis across major jurisdictions

The comprehensive patent search across USPTO, EPO, JPO, KIPO, CNIPA, and WIPO databases identified several categories of related prior art, but critically, none that specifically address microsecond temporal fragmentation as defined in the invention.

Closest USPTO prior art includes US10511455B1 (Xilinx, 2017) describing time-sensitive networking control circuitry with sub-microsecond timing precision. This patent focuses on gate control circuits and cycle timer mechanisms for TSN applications, achieving clock-cycle level precision. However, it controls the timing of complete packets through gates rather than fragmenting data across temporal windows. Similarly, US10511403B2 (General Electric, 2017) addresses microsecond-level clock drift and variance in TSN networks, mentioning "clock error mean is one microsecond, variance is two microseconds," but focuses on synchronization and guard band allocation rather than data fragmentation.

International patent searches revealed extensive work in TSN and ultra-low latency communications. Nokia's US20200304429A1 monitors timing mismatches in TSN queues with 200-500 microsecond round-trip budgets for Cloud Radio Access Networks. Ericsson's US11265805B2 implements TSN over 5G with 1 microsecond jitter tolerance. Advanced Micro Devices' US10743269B2 describes coordinated timing synchronization with microsecond-level precision. Yet none of these patents fragment data into microsecond-sized temporal windows or assign fragments to specific transmission slots.

The **technical gap identified** is substantial: while existing patents address microsecond-precision timing control, network synchronization, and temporal scheduling of complete packets, no patents specifically describe fragmenting digital data across 1-999 microsecond temporal windows with fragment-to-temporal-window assignment and microsecond-precision fragment transmission control.

Academic literature demonstrates timing capabilities but not fragmentation methods

Academic research from 2015-2025 shows remarkable progress in achieving microsecond and even nanosecond-level timing precision, yet lacks specific work on temporal fragmentation as claimed.

Sub-microsecond achievements include groundbreaking work from the FooDog research team (ArXiv 2024) achieving end-to-end jitter under 150 nanoseconds in TSN systems, representing a 96% reduction in memory usage while maintaining sub-microsecond performance. Their period-wise and stream-wise Gate Control List structure approaches temporal scheduling but doesn't fragment individual data units. OpenTSN demonstrations achieve synchronization precision under 32 nanoseconds with FPGA-based prototypes showing microsecond-level transmission jitter for unicast and multicast traffic.

Time-aware scheduling research extensively covers IEEE 802.1Qbv implementations. Craciunas et al. (RTNS 2016) presented SMT-based synthesis for microsecond-precision scheduling with over 200 citations, establishing time-division scheduling with microsecond granularity. The Time-sensitive Software-defined Network (TSSDN) achieves deterministic end-to-end delays of 14 microseconds with bounded jitter of 7 microseconds through user-space packet processing and hardware-triggered interrupts.

Despite these advances, **no academic papers describe** the specific technique of fragmenting data across microsecond temporal windows, assigning fragments to transmission windows, or controlling individual fragment transmission timing. The literature focuses on scheduling complete packets, frames, or flows rather than fragmenting data units across temporal boundaries.

Technical standards provide infrastructure but not fragmentation specifications

Analysis of technical standards reveals sophisticated timing infrastructure that could support temporal fragmentation but doesn't specify such mechanisms.

IEEE 802.1AS-2020 provides sub-microsecond precision synchronization as the foundation for TSN applications, enabling coordinated time-based scheduling across network devices. PubMed Central Wikipedia **IEEE 802.1Qbv** (Time-Aware Shaper) implements time-gated queues with microsecond-granularity time slots and Gate Control Lists specifying exact transmission times. Wikipedia Semiconductor Engineering However, these standards schedule complete frames within temporal windows rather than fragmenting data across windows. arXiv

IEEE 1588-2019 PTP achieves sub-microsecond synchronization accuracy with hardware timestamping typically providing 100 nanosecond accuracy. Wikipedia +4 **IETF RFC 8655** (DetNet Architecture) ensures bounded end-to-end latency with minimal jitter for synchronous flows RFC Editor but focuses on resource allocation for complete DetNet flows rather than temporal fragmentation. IETF

Industrial protocols demonstrate microsecond capabilities: **PROFINET IRT** achieves cycle times down to 31.25 microseconds with sub-microsecond jitter, using bandwidth reservation and time-slot scheduling. profinet +4 **EtherCAT** provides distributed clock synchronization with typically sub-100 nanosecond accuracy. Wikipedia +4 Yet these protocols process complete frames within cycles rather than fragmenting across temporal boundaries.

Application domains show timing precision without temporal fragmentation

High-frequency trading exploits microsecond timing differently

HFT systems demonstrate the commercial value of microsecond timing but use fundamentally different approaches. AMD/Xilinx FPGA solutions achieve **13.9 nanosecond actionable latency** in trading systems, while Network-1's patent portfolio covers FPGA clock domain management where "the difference between success and failure may be measured in nanoseconds."

MiFID II regulations mandate 100 microsecond accuracy with 1 microsecond granularity for algorithmic trading. NASDAQ's infrastructure provides sub-50 microsecond round-trip latency. IEX's famous "speed bump" uses a 38-mile fiber optic coil creating a deterministic 350-microsecond delay. However, **all these systems optimize end-to-end latency** rather than fragmenting data across temporal windows.

Industrial control focuses on deterministic cycles

Industrial systems achieve remarkable timing precision through different mechanisms. PROFINET IRT fragments large TCP/IP frames across multiple cycles but uses cycle-based rather than microsecond-window fragmentation. Machinebuilding +2 EtherCAT processes data "on the fly" with hardware-only delays using a summing frame approach. ethercat +2 SERCOS III provides sub-microsecond synchronization with cycle times from 31.25 microseconds to 65 milliseconds using time-triggered communication with allocated time slots. Wikipedia +2

Tesla's Hardware Link Timer patent (WO2024039794A1, 2024) achieves single-digit microsecond latency through hardware state machines, demonstrating cutting-edge timing control for AI computing clusters. Google Patents Yet none implement the specific temporal fragmentation approach claimed.

Medical and automotive safety-critical timing

Medical devices achieve microsecond precision for patient safety. Pacesetter's implantable device patent uses 976.5625 microsecond binary count resolution with dual-timer architecture. Google Patents ZOLL Medical implements sub-microsecond synchronization using IEEE 1588 PTP for ECG synchronization and defibrillator coordination.

Automotive TSN achieves ±500 nanosecond worst-case accuracy for ADAS systems. (Semiconductor Engineering) (Justia Patents) The Microsecond Bus (μSB) transmits 16 bits per microsecond for motor control. C-V2X requires 0.1 microsecond measurement precision with 10-nanosecond network latency for vehicle-to-vehicle communication. These applications require precise timing but don't fragment data across temporal windows.

Novelty assessment and patentability analysis

Clear novelty over prior art

The invention demonstrates **strong novelty** in three key aspects:

1. Microsecond temporal fragmentation (1-999 μs): No prior art fragments digital data specifically into microsecond-sized temporal windows. Existing systems schedule complete packets, use cycle-based fragmentation (millisecond scale), or optimize latency without fragmentation.

2. Fragment-to-temporal-window assignment: The concept of assigning individual data fragments to specific microsecond transmission windows is absent from prior art. TSN assigns complete frames to time slots, while industrial protocols use fixed cycle assignments. (IEEE Xplore)

3. Microsecond-precision fragment transmission control: Controlling when individual fragments transmit with microsecond precision for security, bandwidth optimization, or coordination purposes represents a novel application not found in existing patents or literature.

Non-obviousness analysis

The invention appears **non-obvious** because combining existing elements wouldn't naturally lead to this solution. While TSN provides microsecond timing infrastructure (IEEE Xplore) and frame preemption allows interrupting transmissions, (IEEE Xplore) neither suggests fragmenting data across microsecond windows. (Iebmedia) (Iebmedia) Industrial protocols fragment across cycles (typically milliseconds) for different purposes. (Wikipedia) (PI North America) HFT systems minimize latency rather than intentionally fragmenting data. (B&R Industrial Automation) (B&R Industrial Automation) The specific temporal fragmentation approach for security and coordination represents an inventive step beyond existing art.

Industrial applicability across multiple domains

The invention demonstrates **broad industrial applicability**:

- **Financial trading:** Enhanced security through temporal distribution of sensitive trading data
- **Industrial control:** Precise coordination of distributed manufacturing systems
- **Autonomous vehicles:** Temporal isolation of critical sensor data from non-critical communications
- **Medical devices:** Secure, coordinated transmission of patient monitoring data

- **5G/6G networks:** Bandwidth optimization through temporal multiplexing

Potential challenges and mitigation strategies

Possible obviousness arguments

Examiners might argue the invention combines known elements (TSN timing + fragmentation + scheduling). **Mitigation:** Emphasize the specific microsecond scale (1-999 μs) and novel purpose (security/coordination through temporal distribution) not suggested by prior art. Document unexpected benefits like improved security through temporal obfuscation.

Standard-essential patent considerations

Some claims might overlap with TSN standards implementation. **Mitigation:** Focus claims on the novel temporal fragmentation method rather than underlying timing infrastructure. Differentiate from standard TSN frame scheduling.

Prior art from China and Japan

Language barriers may have limited search completeness. **Mitigation:** Consider supplemental searches with native language keywords. File continuation applications as new prior art emerges.

Strategic recommendations for patent filing

Claim construction strategy

Independent claims should emphasize:

1. The specific microsecond temporal window range (1-999 microseconds)
2. The fragmentation method creating fragments sized to fit temporal windows
3. The assignment algorithm mapping fragments to specific temporal windows
4. The transmission control ensuring microsecond-precision timing

Dependent claims should cover:

- Specific applications (HFT, industrial, medical, automotive)
- Security implementations through temporal distribution
- Bandwidth optimization methods
- Integration with existing standards (TSN, PTP)
- Hardware acceleration implementations

Geographic filing priorities

Tier 1 priorities:

- United States (largest market, strong enforcement)
- European Union (covers major industrial markets)
- China (manufacturing hub, growing innovation)

Tier 2 priorities:

- Japan (strong automotive/industrial sectors)
- South Korea (semiconductor/telecommunications)
- United Kingdom (financial services)

Continuation and divisional strategy

File the initial application broadly, then pursue divisionals for:

- Method claims (temporal fragmentation process)
- System claims (apparatus implementing the method)
- Industry-specific applications
- Security-focused implementations

Consider continuation-in-part applications as the technology develops to capture improvements and new applications.

Conclusion: Strong patentability with strategic opportunities

The comprehensive prior art search reveals that microsecond temporal fragmentation of digital communications represents a **significant technical gap** in the current patent landscape. While extensive prior art exists in related areas of precision timing, deterministic networking, and packet scheduling, the specific invention of fragmenting data across 1-999 microsecond temporal windows with precise fragment-to-window assignment and transmission control appears to be novel and non-obvious. B&R Industrial Automation B&R Industrial Automation

The invention addresses real industrial needs across multiple high-value sectors including financial trading, industrial automation, autonomous vehicles, and medical devices. The absence of direct prior art, combined with broad applicability and technical merit, suggests **strong potential for obtaining broad patent protection**. Strategic claim construction focusing on the specific temporal fragmentation method, microsecond scale, and novel applications should overcome potential obviousness arguments while maximizing commercial value. Wikipedia

Rapid filing is recommended given the active development in related TSN and precision timing technologies. The patent application should emphasize the inventive step of temporal fragmentation for security and coordination purposes, differentiating from existing latency optimization and packet scheduling approaches. With proper claim construction and prosecution strategy, this invention has excellent prospects for establishing valuable intellectual property protection in the emerging field of microsecond-precision temporal communications.