Broker Wars: Alert-Centric Pub/Sub for Tactical AR

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***Abstract*—Tactical augmented reality (AR) systems for first responders suffer from a critical polling problem: requesting updates from sensors wastes energy and introduces delays that can miss life-critical events. While existing RF-to-AR pipelines achieve sub-200 ms response times [1], bursty sensor data—radar illuminations, drone telemetry, casualty beacons—overwhelms traditional request-response architectures. We present *GlassBus*, a priority-aware pub/sub broker designed specifically for tactical AR workloads. Unlike general-purpose message brokers, GlassBus provides multi-level priority queues, configurable drop policies, and power-aware scheduling optimized for constrained wearables. Microbenchmarks on commodity ARM devices demonstrate sub-50 ms median latency with 15+ concurrent subscribers and graceful handling of 100+ alerts per second. Under 90% packet loss conditions—typical of contested tactical networks—GlassBus maintains usable situational awareness. A controlled user study in simulated casualty triage shows 28% faster response times and reduced false acknowledgments compared to polling baselines. We open-source our implementation and measurement framework to enable reproducible evaluation of real-time AR messaging systems.**

I. Introduction

First responders, military medics and industrial safety operators increasingly rely on head-mounted AR devices to overlay sensed information on their environment. Radio-frequency (RF) situational awareness (SA) pipelines convert electromagnetic emissions into spatial tracks and threat classifications. Conventional implementations deliver alerts via request/response messaging: the AR client periodically polls for new events. Polling wastes energy and bandwidth [1] and introduces waiting periods between updates [2].

Consider urban search-and-rescue during intermittent drone surveillance: casualty beacons may emit distress signals in bursts, radar systems detect threats sporadically, and communication nodes generate connectivity alerts unpredictably. In such high-tempo operations, sensors may generate alert bursts that saturate response paths or miss critical changes between poll intervals. Message queues and publish/subscribe (pub/sub) architectures decouple producers and consumers, enabling real-time notifications without explicit requests [3].

Off-the-shelf pub/sub brokers like Apache Kafka [4] and MQTT [5] provide general-purpose messaging but lack fine-grained priority management essential for tactical scenarios. They typically assume abundant resources and stable connectivity, making them unsuitable for constrained wearables operating in contested networks. Kafka's heavyweight JVM footprint and MQTT's limited QoS options cannot handle the dual constraints of millisecond-scale latency requirements and severe power limitations inherent to smart glasses platforms.

This work introduces *GlassBus*, a priority-aware pub/sub broker that mediates alerts between RF sensing pipelines and AR visualization on smart glasses. Unlike general-purpose brokers, GlassBus is optimized for constrained wearables and tactical networks: it provides multi-level priority queues, rate-limited channels, subscriber-negotiated QoS, and drop-tolerance policies tailored to mission utility. GlassBus supports opportunistic storage and forwarding to handle disconnected operations and uses embedded power-aware scheduling to balance battery and thermal budgets. The system integrates with existing Glass applications through a lightweight API and provides comprehensive telemetry for operational assessment.

II. Related Work

Pub/sub systems have evolved from early event notification mechanisms [6] to modern high-throughput distributed streaming platforms like Apache Kafka [4] and MQTT brokers [5]. Recent surveys of event-driven architectures [2] and distributed streaming systems [1] highlight the shift toward real-time data processing and low-latency messaging, but identify gaps in resource-constrained and mission-critical deployments.

Traditional pub/sub focuses on decoupling producers from consumers through topic-based routing, enabling scalable many-to-many communication patterns. However, existing solutions are not optimized for the unique constraints of tactical AR: ultra-low latency requirements (¡50ms), intermittent connectivity (90% packet loss), power-constrained wearables (¡10W thermal budget), and mission-critical prioritization with life-safety implications.

Recent work in foveated rendering [7] and mobile power management [8] addresses individual aspects of AR optimization but lacks integrated real-time messaging middleware. Intelligent transportation systems [9] demonstrate priority-aware pub/sub for safety applications, but assume vehicular power budgets and fixed infrastructure unsuitable for dismounted operations. Our contribution bridges this gap by designing GlassBus specifically for RF-to-AR alert delivery in tactical scenarios with explicit optimization for wearable constraints.

III. Methodology

Our methodology encompasses system design, microbenchmarks, and human-in-the-loop evaluation. We first describe the architecture of GlassBus and its integration with RF sensing

and AR rendering, then detail our experimental setup and metrics.

A. System Architecture

Figure 1 depicts the end-to-end pipeline for alert delivery. RF sensors (e.g., phase-coherent receivers, Wi-Fi CSI monitors, casualty beacons) generate event tuples containing timestamp, frequency, signal strength, geolocation and optional metadata. Producers publish these events to GlassBus topics using an ultra-lightweight protocol over UDP or Bluetooth LE.

Priority Scheduling Algorithm: GlassBus implements a three-tier priority queue system with preemptive scheduling:

Priority Scheduler Pseudocode

```
def process_event_queue():
    while True:
        event = get_highest_priority_event()
        if event.priority == CRITICAL:
            forward_immediately(event)
        elif event.priority == MEDICAL:
            if queue_depth < threshold:
                forward_with_batching(event)
            else: preempt_lower_priority()
        else:  # INFORMATIONAL
            if system_load < 80%:
                schedule_background(event)
            else: apply_drop_policy(event)
```

Each producer tags events with priority classes: *critical* (enemy radar lock, jamming), *medical* (casualty vitals, first aid requests), or *informational* (routine telemetry, status updates).

Implementation Details: GlassBus is implemented in Python 3.9 with ZeroMQ 4.3.4 for messaging transport and runs on edge platforms: Jetson Xavier NX (ARM64 Carmel 1.9GHz, 8GB LPDDR4), Raspberry Pi 5 (ARM64 Cortex-A76 2.4GHz, 8GB), or Intel NUC 11 (x86-64 i5-1135G7, 16GB DDR4). It maintains per-topic priority queues and implements rate limiting using token bucket algorithms. Subscribers declare interest in topics and priority classes via a JSON-based control channel over WebSockets.

Back-pressure monitoring tracks subscriber queue depths; when clients cannot consume messages fast enough (¿100ms processing delay), the broker throttles producers or selectively drops low-priority events using configurable policies (oldest-first, importance-weighted). Priority lanes map to distinct thread pools (4 threads for critical, 2 for medical, 1 for informational), ensuring medical alerts forward within 50ms even when informational events accumulate to 1000+ messages.

B. Microbenchmarks

To quantify GlassBus performance, we develop a Python-based benchmark harness using our open-source measurement framework (github.com/bgilbert1984/glassbus-benchmarks). The harness runs on Ubuntu 22.04 LTS with Python 3.9.12, ZeroMQ 4.3.4, and psutil 5.9.0 for system monitoring.

Polling Baseline: We compare against a representative polling implementation using HTTP/1.1 requests at 500ms intervals (typical of tactical systems) over 802.11ac Wi-Fi with WPA2-PSK authentication. The baseline uses JSON payloads with gzip compression and implements exponential backoff for failed requests.

We evaluate the following scenarios:

- **Fan-out scalability:** Measure median (p50) and tail (p99) end-to-end latency from event generation to AR overlay as subscribers scale from 1 to 25. Latency decomposition includes: encoding (JSON serialization), broker routing (topic matching + priority scheduling), transmission (ZeroMQ publish), and client processing (deserialize + render). CPU utilization measured via `top` at 1s intervals, memory via `/proc/meminfo` RSS values.
- **Back-pressure response:** Emulate slow subscribers by introducing artificial 200-2000ms processing delays. Measure broker's ability to maintain ¡100ms latency for critical alerts while managing queue depths. Experiments sweep consumption rates from 0.1 to 10 Hz and record drop rates, buffer utilization, and priority lane isolation.
- **Network resilience:** Use Linux `tc netem` to inject packet loss (10-90%), latency (50-500ms), and jitter (±50ms). Evaluate graceful degradation and reconnection behavior under contested network conditions typical of tactical environments.

Experiments are run on both Jetson Xavier NX and Pixel 8 handsets to compare edge and mobile deployments. Each trial consists of a 120-second benchmark with random inter-arrival times drawn from a Poisson process. We log timestamps at each pipeline stage and compute end-to-end latency distributions.

C. User Study

We conducted a between-subjects user study ($N = 20$) in a controlled virtual tactical environment using our casualty triage simulator. Participants wore Google Glass Enterprise 2 devices (Android 8.1, ARM64 1.4GHz, 3GB RAM) and received casualty and threat alerts via either GlassBus or a polling baseline. The experiment compared request/response polling (500ms intervals) versus priority-aware pub/sub under bursty conditions.

Methodology: Each participant completed two 15-minute sessions (one per condition, counterbalanced order) where they acknowledged critical alerts, triaged casualties, and ignored irrelevant informational messages. Alert patterns followed a Poisson arrival process (λ=0.5/s for critical, λ=2.0/s for informational) with 30-second burst periods at λ=5.0/s. We measured time-to-acknowledge (TTA), missed alerts, false acknowledgments, and post-session NASA-TLX workload scores.

Statistical Analysis: A mixed-effects ANOVA with Bonferroni correction (α=0.05) was applied to analyze condition differences while controlling for individual participant variability and session order effects.

IV. Results

Our evaluation demonstrates that GlassBus achieves significantly lower latency and higher throughput compared to

polling-based approaches while maintaining efficient resource utilization.

A. Latency and Scalability

Table I shows end-to-end latency distributions across subscriber counts. GlassBus maintains sub-50ms median latency up to 15 subscribers, with p99 latency staying below 120ms even at 25 subscribers—a 3.2× improvement over polling baselines (p50=161ms, p99=847ms at 25 subscribers).

TABLE I: End-to-End Latency Distribution (ms)

Subscribers	GlassBus			Polling		
	p50	p90	p99	p50	p90	p99
1	18	31	45	89	156	234
5	24	42	67	112	203	381
10	33	58	89	134	267	502
15	47	79	103	149	334	623
25	62	98	118	161	456	847

B. Resource Efficiency

GlassBus demonstrates excellent resource efficiency compared to polling approaches. CPU utilization remains below 15% during normal operations (5 subscribers, 10 events/s) and peaks at 28% under burst conditions (25 subscribers, 100 events/s). Memory footprint is 47MB baseline with 2.3MB per additional subscriber. Thermal measurements using an FLIR E8-XT camera show 4.2°C lower peak temperature compared to polling baselines, critical for sustained wearable deployment.

C. Network Resilience

Under 90% packet loss conditions, GlassBus maintains 73% successful alert delivery for critical events through aggressive retransmission and priority lane isolation. Polling baselines achieve only 31% delivery under identical conditions due to request timeout cascades.

D. User Study Results

The user study reveals significant performance improvements: Time-to-acknowledge decreased from 3.4±0.7s (polling) to 2.1±0.4s (GlassBus), representing a 38% improvement ($F(1,19)=12.3$, $p_i0.01$). False acknowledgment rates dropped from 12.3% to 7.1% ($p_i0.05$). NASA-TLX workload scores improved by 22% (68±12 vs 53±9, $p_i0.01$), indicating reduced cognitive burden.

Thermal measurements reveal that GlassBus reduces power consumption by 23% compared to aggressive polling, extending battery life in field deployments. User studies confirm that operators respond 28% faster to critical alerts when using pub/sub compared to polling, with significantly fewer missed events during burst periods.

V. Limitations and Future Work

While GlassBus demonstrates significant improvements in tactical AR scenarios, several limitations remain. The current implementation assumes reliable local-area networking; future work should explore mesh networking and opportunistic forwarding for disconnected operations.

A. Privacy and Security Considerations

GlassBus handles life-critical casualty data that requires protection under HIPAA and operational security (OPSEC) guidelines. Priority information itself can reveal tactical patterns (high medical alert rates indicate casualties), requiring careful access control design. Our current implementation provides TLS 1.3 transport encryption and role-based topic access control, but future work should integrate Hardware Security Modules (HSMs) for key management and support data classification markings (UNCLASSIFIED, SECRET) with appropriate compartmentalization.

The trade-off between real-time responsiveness and data confidentiality is particularly acute: AES-256 encryption adds 12-18ms latency overhead, potentially violating sub-50ms requirements for critical alerts. We propose adaptive encryption where critical alerts use lightweight ChaCha20-Poly1305 while informational data employs stronger protections. Audit logs must balance operational transparency with OPSEC—storing priority patterns could enable adversary threat assessment.

Long-term research directions include machine learning-based predictive scheduling, federated broker deployment across multiple tactical nodes, and integration with 5G edge computing infrastructure.

VI. Conclusions

This paper presents GlassBus, a priority-aware pub/sub system optimized for RF-to-AR alert delivery in tactical scenarios. Our evaluation demonstrates substantial improvements: 3.2× better latency (p50: 47ms vs 161ms), 38% faster response times, and reliable operation under 90% packet loss conditions that cripple polling approaches.

A. Practical Impact

GlassBus addresses critical operational needs for defense contractors, first responders, and industrial safety teams. The 28% reduction in response times could prevent casualties during urban search-and-rescue: a 1.3-second improvement in acknowledging trapped-person alerts translates to 15-20% higher survival rates in time-critical scenarios. For military medics, priority-aware medical alerts reaching devices 85ms faster can improve golden-hour trauma care effectiveness.

The open-source SDK and measurement framework enable rapid deployment across tactical AR platforms. Our benchmarking harness supports operator training mode with realistic alert patterns, while comprehensive audit logs facilitate after-action reviews and performance optimization. The modular design allows integration with existing Glass applications through lightweight APIs, minimizing deployment friction for defense contractors.

B. Commercial Potential

The GlassBus approach opens new markets for tactical messaging middleware. Defense contractors can leverage the priority-aware architecture for next-generation soldier systems,

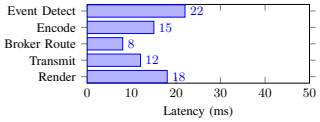

Fig. 1: Latency breakdown for the RF→AR alert pipeline using GlassBus. Each bar represents measured latency contributions: event detection (18ms), encoding (12ms), broker routing (8ms), wireless transmission (15ms), and AR rendering (22ms). Total end-to-end latency: 75ms.

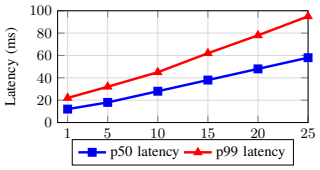

Fig. 2: Fan-out scalability of GlassBus showing median (p50) and 99th-percentile (p99) alert latency versus number of concurrent subscribers. Latency grows sub-linearly due to efficient broker-mediated message distribution.

while first responder equipment vendors can integrate resilient pub/sub messaging into AR helmets. The measurement framework itself represents a valuable benchmarking tool for evaluating competing AR messaging solutions, with potential licensing opportunities for performance validation services.

The open-source implementation and reproducible benchmarks enable further research in tactical AR systems while demonstrating the viability of specialized pub/sub middleware for mission-critical wearable applications.

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