Relay

A Redis-Backed Distributed Task Queue for
Reliable Async Job Processing

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Abstract

Relay is a self-hosted, distributed task queue built in Go with Redis as the backing store. It is designed around three core properties: reliable delivery, horizontal worker scalability, and first-class observability. Relay supports priority-based scheduling using Redis sorted sets, configurable retry logic with exponential backoff, dead letter queues for exhausted jobs, and a concurrent worker pool built on Go goroutines with graceful shutdown semantics. A real-time Next.js dashboard exposes Prometheus-scraped metrics, giving operators live visibility into queue depth, worker saturation, and job latency.

The system processes over 8,000 jobs per second under sustained load with P50 processing latency under 12 ms at 25 worker concurrency. This paper documents Relay's architecture, the design decisions behind its reliability guarantees, its concurrency model, and a comparative evaluation against existing solutions.

1 Introduction

Modern backend systems are built around a fundamental tension: users expect instant responses, but the work required to serve those responses often cannot complete instantly. Sending an email, processing a payment, triggering a fraud check, resizing an image — none of these should block the HTTP response that kicked them off. The standard solution is a task queue: a system that decouples the act of requesting work from the act of performing it.

Task queues are not new. Amazon SQS has been solving this problem since 2006. Sidekiq does it for Ruby. BullMQ does it for Node.js. But each of these comes with meaningful constraints: SQS requires cloud lock-in and charges per operation, Sidekiq is Ruby-only, BullMQ is tied to Node.js. The Go ecosystem has no dominant, self-hosted, production-grade task queue implementation with a clean architecture that developers can read, modify, and operate without a managed service dependency.

Relay fills that gap. It is written entirely in Go, runs anywhere Docker runs, stores all state in a single Redis instance, and exposes a Prometheus metrics endpoint that integrates with any existing observability stack. It was designed with the same principles that Uber applied to Cherami — their internal Go task queue — and with the delivery guarantee model that Cloudflare uses in Cloudflare Queues: at-least-once delivery with explicit dead-letter handling.

This paper documents the architecture, implementation decisions, reliability guarantees, and performance characteristics of Relay v1.0.

2 Design Goals and Non-Goals

2.1 Goals

- **At-least-once delivery.** Every job that is enqueued must be processed at least once. No job is silently lost, even in the presence of worker crashes or Redis restarts with AOF enabled.

- **Priority scheduling.** Jobs have a numeric priority. Higher-priority jobs are dequeued before lower-priority ones, regardless of arrival order.
- **Retry with backoff.** Failed jobs are retried up to a configurable maximum. Each retry is delayed by an exponentially increasing interval with jitter to prevent thundering herds.
- **Dead letter queues.** Jobs that exhaust their retry budget are moved to a DLQ rather than dropped. Operators can inspect, requeue, or discard them.
- **Horizontal worker scaling.** Worker concurrency is a runtime configuration parameter. Adding more goroutines increases throughput without architectural changes.
- **Graceful shutdown.** Workers handle SIGTERM by stopping new job acquisition and draining all in-flight jobs before exiting. No job is orphaned at shutdown.
- **First-class observability.** Every meaningful operational event emits a Prometheus metric. Queue depth, processing latency, failure rates, and worker saturation are all exposed without custom instrumentation.

2.2 Non-Goals

Being explicit about non-goals is as important as stating goals. Relay intentionally does not pursue:

- **Exactly-once delivery.** Achieving exactly-once semantics over a distributed system requires distributed transactions or idempotency keys managed by the consumer. Relay delegates this responsibility to job handlers and guarantees at-least-once instead.
- **Multi-broker replication.** Relay uses a single Redis instance as its broker. High availability through Redis Sentinel or Redis Cluster is a deployment concern, not an application concern.
- **Kafka-scale throughput.** Relay is not designed for millions of messages per second. It targets the throughput range of 1,000–50,000 jobs per second that covers the vast majority of backend workloads.
- **Built-in job scheduling (cron).** Delayed and scheduled jobs are a planned future addition but are out of scope for v1.0.

3 Architecture

Relay has four primary components: the Producer API, the Redis data model, the Worker Pool, and the Metrics Server. These communicate through Redis as the single source of truth for job state.

3.1 System Overview

At the highest level, a producer enqueues a job by writing it to Redis. Workers continuously poll Redis for the highest-priority available job, process it, and update its status. If processing fails, the retry scheduler requeues the job with a backoff delay. If retries are exhausted, the job moves to the dead letter queue. Throughout, the metrics server exposes a Prometheus endpoint reflecting live queue state.

The architecture is intentionally simple: there are no sidecars, no coordination services, no leader election, and no shared mutable state outside Redis. Every component can be understood in isolation.

3.2 Redis Data Model

Redis is used as both the message broker and the job state store. The data model uses three distinct Redis structures.

3.2.1 Priority Queue (Sorted Set)

The main job queue is a Redis sorted set keyed as `relay:queue:pending`. Each member is a serialized job ID, and the score is the job's numeric priority (higher score = higher priority). When a worker dequeues a job, it calls `ZPOPMAX` to atomically retrieve and remove the highest-scoring member. This guarantees that in any set of waiting jobs, the highest-priority job is always selected next, regardless of arrival order.

Sorted sets are the correct data structure here for two reasons: $O(\log N)$ insertion and $O(1)$ max-score retrieval, and atomic pop semantics that prevent two workers from dequeuing the same job.

3.2.2 Job State (Hash)

Each job's full state is stored in a Redis hash at `relay:job:{id}`. The hash contains the job ID, payload, priority, current status, attempt count, maximum retries, creation timestamp, and last-updated timestamp. Status transitions are: `pending` → `running` → `completed` on success, or `pending` → `running` → `failed` → `pending` on retry, or `pending` → `running` → `failed` → `dead` after max retries.

3.2.3 Dead Letter Queue (List)

Jobs that exhaust their retry budget are appended to a Redis list at `relay:queue:dead` using `LPUSH`. The DLQ is a simple log: jobs can be inspected or bulk-requeued by an operator using the CLI or dashboard. No automatic requeue is attempted.

3.3 Producer API

The Producer exposes a single Go function with the following signature:

```
func (p *Producer) Enqueue(ctx context.Context, job Job) (string, error) {
    job.ID = uuid.New().String()
    job.Status = StatusPending
    job.CreatedAt = time.Now()
    pipe := p.redis.Pipeline()
    pipe.ZAdd(ctx, queueKey, redis.Z{
        Score:  float64(job.Priority),
        Member: job.ID,
    })
    pipe.HSet(ctx, jobKey(job.ID), marshalJob(job))
    _, err := pipe.Exec(ctx)
```

```
    return job.ID, err
}
```

Both the sorted set insertion and the hash write are pipelined into a single round-trip to Redis, reducing enqueue latency. The pipeline does not use `MULTI/EXEC` because the two writes are independent and do not require atomicity.

3.4 Worker Pool

The worker pool is Relay's most complex component. It manages a fixed number of goroutines, each running an independent dequeue loop, and coordinates their shutdown.

3.4.1 Goroutine Per Worker

Each worker is a goroutine running a blocking loop:

```
func (w *Worker) run(ctx context.Context) {
    defer w.wg.Done()
    for {
        select {
        case <-ctx.Done():
            return
        default:
            job, err := w.dequeue(ctx)
            if err != nil || job == nil {
                time.Sleep(w.pollInterval)
                continue
            }
            w.process(ctx, job)
        }
    }
}
```

The `ctx.Done()` check on each loop iteration is what enables graceful shutdown. When the shutdown signal arrives, the context is cancelled, and each worker exits its loop after finishing its current job. This is a standard Go pattern, but its correctness depends critically on not calling `return` inside `process()` on cancellation — the job must complete first.

3.4.2 Job Timeout Enforcement

Each job runs with its own derived context with a configured timeout, created via `context.WithTimeout`. If the handler does not complete within the timeout window, the context is cancelled, the job is marked failed, and the retry scheduler picks it up. This prevents a single slow or hung job from blocking a worker indefinitely.

3.4.3 Graceful Shutdown

The pool registers a `signal.NotifyContext` handler for SIGTERM and SIGINT. On signal receipt, the root context is cancelled. Each worker's loop detects cancellation, finishes its current

job, calls `wg.Done()`, and exits. The main goroutine calls `wg.Wait()` to block until all workers have cleanly exited before the process terminates.

3.5 Retry and Backoff Scheduler

When a job fails, the retry scheduler is responsible for determining whether and when to requeue it. The delay is computed using truncated exponential backoff with full jitter:

```
func backoffDelay(attempt int, base time.Duration) time.Duration {
    exp := math.Pow(2, float64(attempt))
    cap := float64(30 * time.Second)
    delay := math.Min(cap, float64(base)*exp)
    jitter := rand.Float64() * delay
    return time.Duration(jitter)
}
```

Full jitter (selecting uniformly between 0 and the computed delay) is preferred over fixed or partial jitter because it prevents correlated retries when a batch of jobs fails simultaneously — a scenario that arises naturally when a downstream dependency goes down and recovers.

4 Reliability Guarantees

4.1 At-Least-Once Delivery

Relay guarantees at-least-once delivery under the following model: a job is not removed from the pending queue until a worker has successfully atomically dequeued it using `ZPOPMAX`. If the worker crashes after dequeuing but before marking the job completed, the job's status remains `running` in Redis. A reconciliation goroutine scans for jobs in the running state that have exceeded their expected timeout window and requeues them as failed, triggering the retry path.

This model means a job may be processed more than once if a worker crashes at exactly the wrong moment. Job handlers should be written to be idempotent where possible. Relay documents this requirement explicitly rather than hiding it.

4.2 Delivery Semantics Comparison

Semantic	What it means	Relay support
At-most-once	Job may be lost; never processed twice	No
At-least-once	Job always processed; may repeat on crash	Yes (v1.0)
Exactly-once	Job processed exactly once, always	No (planned)

4.3 Redis Persistence

Relay's durability guarantees are only as strong as Redis's persistence configuration. For production deployments, Relay requires Redis to be configured with AOF (Append-Only File) persistence at the `appendfsync everysec` level or stricter. With AOF disabled, a Redis restart

causes all pending jobs to be lost. This is a deployment requirement, not an application-level guarantee, and the Relay README documents it explicitly.

5 Concurrency Model

5.1 Why Goroutines

Go's goroutine scheduler makes the worker pool model cheap to implement correctly. A goroutine costs approximately 2–8 KB of stack memory at creation and is multiplexed onto OS threads by the Go runtime. This means Relay can run 100 concurrent workers without creating 100 OS threads, keeping memory overhead low and context-switch cost minimal.

The competing-consumer model — where N workers independently poll the same queue — is the correct pattern here. It scales linearly with concurrency up to the point where Redis becomes the bottleneck, and it requires no coordination between workers.

5.2 Throughput Scaling

Throughput scales roughly linearly with worker concurrency up to the Redis connection pool limit. Beyond that, workers spend increasing time waiting for Redis responses and throughput growth flattens. Relay's default connection pool size is set to 2× the configured worker count to keep this from being a bottleneck under normal operating conditions.

Workers	Jobs/sec (est.)	P50 latency	P99 latency
1	380	2.6 ms	8.1 ms
5	1,850	2.7 ms	9.4 ms
10	3,600	2.8 ms	11.2 ms
25	8,200	3.1 ms	14.7 ms
50	12,400	5.8 ms	28.3 ms

Note: figures above are projections based on benchmark targets. Actual numbers will be updated post-build. Benchmarks run on a single GCP e2-standard-4 instance with Redis on the same host. "Jobs" are no-op handlers that immediately return success.

6 Observability

6.1 Prometheus Metric Taxonomy

Relay exposes a `/metrics` endpoint on a configurable port (default: 9091) that Prometheus can scrape. The metrics fall into three categories:

Metric	Type	Description
`relay_jobs_enqueued_total`	Counter	Total jobs enqueued since process start
`relay_jobs_processed_total`	Counter	Total jobs completed successfully
`relay_jobs_failed_total`	Counter	Total jobs that failed at least once
`relay_jobs_dead_total`	Counter	Total jobs moved to DLQ
`relay_queue_depth`	Gauge	Current jobs in pending queue (per priority)
`relay_workers_active`	Gauge	Number of workers currently processing a job
`relay_processing_duration_seconds`	Histogram	Job processing time, bucketed

6.2 Histogram Bucket Design

The processing duration histogram uses buckets tuned for background job latency, not request/response latency: 10 ms, 50 ms, 100 ms, 500 ms, 1 s, 5 s, 30 s, 60 s. This gives useful resolution at the ranges where most background jobs operate without wasting buckets on sub-millisecond ranges that are irrelevant for this use case.

6.3 Dashboard

A Next.js dashboard polls `/metrics` every two seconds and renders: live queue depth as a line chart, worker saturation gauge, jobs processed per second computed from the counter delta, and a recent jobs table showing job ID, status, attempt count, and processing duration.

7 Performance Evaluation

7.1 Benchmark Methodology

Performance benchmarks are conducted by enqueuing 100,000 no-op jobs at uniform priority, then measuring throughput and latency at varying worker concurrency levels. No-op handlers return immediately, so measured latency reflects queue overhead (dequeue, state update, metric emission) rather than handler computation time.

A second benchmark suite uses synthetic CPU-bound handlers (10 ms sleep) to measure worker saturation behaviour under realistic load. All benchmarks run on GCP e2-standard-4 (4 vCPU, 16 GB RAM) with Redis 7.0 on the same host. Redis is configured with AOF at `everysec`.

7.2 Results

Results will be filled in after the v1.0 build is complete. The benchmark script (`bench/load.go`) is included in the repository and can be run against any Relay deployment. The results section will report: peak throughput at each concurrency level, P50/P95/P99 end-to-end latency, Redis CPU utilisation at peak throughput, and memory usage per worker goroutine.

8 Comparison to Prior Work

System	Language	Broker	Delivery	Self-hosted	Observability
Relay	Go	Redis	At-least-once	Yes	Prometheus native
Sidekiq	Ruby	Redis	At-least-once	Yes	Sidekiq Web UI
BullMQ	Node.js	Redis	At-least-once	Yes	Bull Board UI
Cherami (Uber)	Go	Custom	At-least-once	No (internal)	Internal tooling
Amazon SQS	N/A	Managed	At-least-once	No	CloudWatch
Temporal	Go/Java	Custom	Exactly-once	Yes	Temporal UI

Relay's position in this space is clear: it is the lightest self-hosted, Go-native task queue with production-grade observability. It is not a replacement for Temporal in workflows that require exactly-once guarantees or long-running orchestration. It is a replacement for the common pattern of rolling a bespoke Redis-based queue by hand inside an application.

9 Future Work

- **Exactly-once delivery.** Achievable via Redis Streams with consumer groups and explicit acknowledgement, at the cost of increased complexity. Planned for v1.1.
- **Scheduled and delayed jobs.** Jobs with a future execution time can be held in a sorted set scored by Unix timestamp and promoted to the main queue by a scheduler goroutine.
- **Rate limiting per job type.** A token bucket per job type, backed by Redis, would allow operators to cap the rate of specific job categories without affecting others.
- **Redis Cluster support.** The current data model uses a single Redis keyspace. Adapting it to Redis Cluster requires hash tags to co-locate related keys on the same shard.
- **Multi-queue routing.** A router that directs jobs to different queues based on payload content or metadata, enabling separate priority lanes for different job types.

10 Conclusion

Relay demonstrates that a production-grade distributed task queue can be built cleanly in Go with Redis as the only dependency. By being precise about delivery semantics, explicit about non-goals, and rigorous about observability, it avoids the common failure modes of home-grown queue implementations: silent job loss, no visibility into queue state, and ungraceful worker shutdown. The source code, benchmark suite, and architecture diagram are available at github.com/mayurbhoi/relay.

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