Kafka Producers: Complete Developer Guide

A comprehensive refresher on Apache Kafka Producers, designed for both beginners and experienced developers. This README covers producer basics, partitioning strategies, reliability features, and real-world applications with detailed Java examples.

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Producer Basics

KafkaProducer API

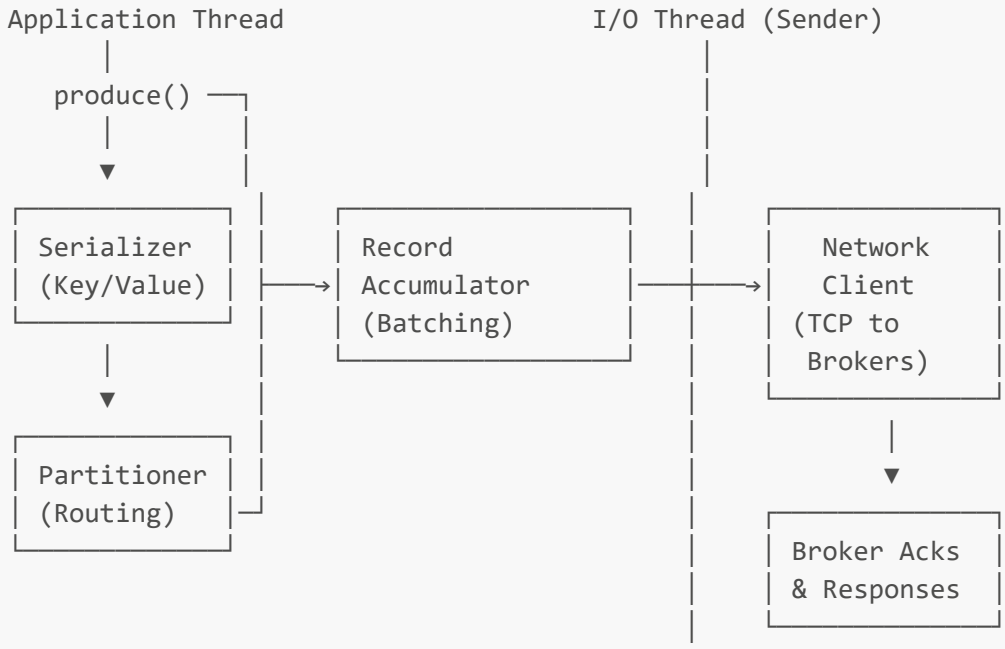
Simple Explanation

The KafkaProducer is the client API that applications use to publish records to Kafka topics. It's thread-safe and designed for high throughput with batching and asynchronous operations.

Problem It Solves

- **High Throughput**: Batches multiple messages for efficient network utilization
- **Fault Tolerance**: Handles retries and failures automatically
- **Scalability**: Distributes messages across topic partitions
- **Performance**: Asynchronous operations don't block application threads

Internal Architecture



Core Producer Configuration

```
Properties props = new Properties();

// Connection settings
props.put(ProducerConfig.BOOTSTRAP_SERVERS_CONFIG, "localhost:9092");
props.put(ProducerConfig.CLIENT_ID_CONFIG, "my-producer");

// Serialization
props.put(ProducerConfig.KEY_SERIALIZER_CLASS_CONFIG,
    "org.apache.kafka.common.serialization.StringSerializer");
props.put(ProducerConfig.VALUE_SERIALIZER_CLASS_CONFIG,
    "org.apache.kafka.common.serialization.StringSerializer");

// Performance & Batching
props.put(ProducerConfig.BATCH_SIZE_CONFIG, 16384);        // 16KB batches
props.put(ProducerConfig.LINGER_MS_CONFIG, 5);             // Wait 5ms for batch
props.put(ProducerConfig.COMPRESSION_TYPE_CONFIG, "gzip"); // Compress batches

// Reliability
props.put(ProducerConfig.ACKS_CONFIG, "all");              // Wait for all
replicas
props.put(ProducerConfig.RETRIES_CONFIG, Integer.MAX_VALUE); // Retry forever
props.put(ProducerConfig.ENABLE_IDEMPOTENCE_CONFIG, true);  // Prevent duplicates
```

Asynchronous vs Synchronous Send

Asynchronous Send (Recommended)

```
import org.apache.kafka.clients.producer.*;
import org.apache.kafka.common.serialization.StringSerializer;
import java.util.Properties;
import java.util.concurrent.Future;

public class AsyncProducerExample {
    private static final String TOPIC = "user-events";

    public static void main(String[] args) {
        Properties props = createProducerConfig();

        try (KafkaProducer<String, String> producer = new KafkaProducer<>(props))
{

            for (int i = 0; i < 1000; i++) {
                String key = "user-" + i;
                String value = "login-event-" + System.currentTimeMillis();

                ProducerRecord<String, String> record =
                    new ProducerRecord<>(TOPIC, key, value);

                // Asynchronous send with callback
                producer.send(record, new Callback() {
                    @Override
                    public void onCompletion(RecordMetadata metadata, Exception
exception) {
                        if (exception != null) {
                            System.err.println("Failed to send record: " +
exception.getMessage());
                            // Implement retry logic or dead letter queue
                        } else {
                            System.out.printf("Sent record to partition %d, offset
%d, timestamp %d%n",
                                metadata.partition(), metadata.offset(),
metadata.timestamp());
                        }
                    }
                });

                // Don't block - continue sending more records
            }

            // Ensure all records are sent before closing
            producer.flush();

        } catch (Exception e) {
            System.err.println("Producer failed: " + e.getMessage());
        }
    }

    private static Properties createProducerConfig() {
        Properties props = new Properties();
        props.put(ProducerConfig.BOOTSTRAP_SERVERS_CONFIG, "localhost:9092");
```

```
        props.put(ProducerConfig.KEY_SERIALIZER_CLASS_CONFIG,
StringSerializer.class);
        props.put(ProducerConfig.VALUE_SERIALIZER_CLASS_CONFIG,
StringSerializer.class);

        // High-throughput settings
        props.put(ProducerConfig.BATCH_SIZE_CONFIG, 16384);
        props.put(ProducerConfig.LINGER_MS_CONFIG, 5);
        props.put(ProducerConfig.COMPRESSION_TYPE_CONFIG, "gzip");
        props.put(ProducerConfig.ACKS_CONFIG, "1");

        return props;
    }
}
```

Advantages:

- ☑ **High Throughput**: Non-blocking sends allow batching
- ☑ **Better Resource Utilization**: Application thread doesn't wait
- ☑ **Scalability**: Can send thousands of messages per second

Trade-offs:

- ⚠ **Complexity**: Need to handle callbacks for error handling
- ⚠ **Memory Usage**: Messages buffered in memory until sent

Synchronous Send (Use Sparingly)

```
public class SyncProducerExample {
    public static void main(String[] args) {
        Properties props = createProducerConfig();

        try (KafkaProducer<String, String> producer = new KafkaProducer<>(props))
{

            for (int i = 0; i < 10; i++) {
                ProducerRecord<String, String> record =
                    new ProducerRecord<>("critical-events", "key-" + i, "critical-
data-" + i);

                try {
                    // Synchronous send - blocks until complete
                    RecordMetadata metadata = producer.send(record).get();
                    System.out.printf("Sent record synchronously to partition %d,
offset %d%n",
                        metadata.partition(), metadata.offset());

                } catch (Exception e) {
                    System.err.println("Failed to send record synchronously: " +
e.getMessage());
                    // Handle error immediately
```

```
                    break;
                }
            }
        }
    }
}
```

When to Use:

- 🎯 **Critical Messages**: When you need immediate confirmation
- 🎯 **Error Handling**: When you must handle failures immediately
- 🎯 **Ordering**: When strict order is required (with max.in.flight.requests=1)

Trade-offs:

- ❌ **Low Throughput**: Blocks on every send
- ❌ **Poor Performance**: No batching benefits
- ❌ **Latency**: Application waits for network round trips

ProducerConfig Deep Dive

Core Configuration Parameters

```
public class ProducerConfigExample {
    public static Properties createProductionConfig() {
        Properties props = new Properties();

        // === CONNECTION SETTINGS ===
        props.put(ProducerConfig.BOOTSTRAP_SERVERS_CONFIG,
            "broker1:9092,broker2:9092,broker3:9092");
        props.put(ProducerConfig.CLIENT_ID_CONFIG, "payment-service-producer");

        // === SERIALIZATION ===
        props.put(ProducerConfig.KEY_SERIALIZER_CLASS_CONFIG,
            "org.apache.kafka.common.serialization.StringSerializer");
        props.put(ProducerConfig.VALUE_SERIALIZER_CLASS_CONFIG,
            "org.apache.kafka.connect.json.JsonSerializer"); // For JSON payloads

        // === RELIABILITY SETTINGS ===
        props.put(ProducerConfig.ACKS_CONFIG, "all");              // Wait for all
in-sync replicas
        props.put(ProducerConfig.RETRIES_CONFIG, Integer.MAX_VALUE); // Retry
indefinitely
        props.put(ProducerConfig.RETRY_BACKOFF_MS_CONFIG, 100);     // Wait 100ms
between retries
        props.put(ProducerConfig.REQUEST_TIMEOUT_MS_CONFIG, 30000); // 30s request
timeout
        props.put(ProducerConfig.DELIVERY_TIMEOUT_MS_CONFIG, 120000); // 2min
total timeout

        // === IDEMPOTENCE & ORDERING ===
```

```
        props.put(ProducerConfig.ENABLE_IDEMPOTENCE_CONFIG, true);  // Prevent
duplicates
        props.put(ProducerConfig.MAX_IN_FLIGHT_REQUESTS_PER_CONNECTION, 5); //
Default with idempotence

        // === BATCHING & PERFORMANCE ===
        props.put(ProducerConfig.BATCH_SIZE_CONFIG, 32768);          // 32KB
batches
        props.put(ProducerConfig.LINGER_MS_CONFIG, 10);              // Wait 10ms
to fill batch
        props.put(ProducerConfig.COMPRESSION_TYPE_CONFIG, "gzip");  // Compress
data
        props.put(ProducerConfig.BUFFER_MEMORY_CONFIG, 67108864);    // 64MB total
buffer

        // === NETWORK SETTINGS ===
        props.put(ProducerConfig.SEND_BUFFER_CONFIG, 131072);        // 128KB TCP
send buffer
        props.put(ProducerConfig.RECEIVE_BUFFER_CONFIG, 65536);      // 64KB TCP
receive buffer

        return props;
    }
}
```

Configuration Trade-offs

Parameter	Higher Value	Lower Value
batch.size	↑ Throughput, ↑ Latency, ↑ Memory	↓ Latency, ↓ Throughput, ↓ Memory
linger.ms	↑ Batching efficiency, ↑ Latency	↓ Latency, ↓ Batching
acks	↑ Durability, ↓ Throughput	↓ Durability, ↑ Throughput
retries	↑ Reliability, ↑ Latency	↓ Reliability, ↓ Latency
buffer.memory	↑ Buffering capacity, ↑ Memory usage	↓ Memory, may block sends

Environment-Specific Configurations

```
public class EnvironmentConfigs {

    // Development - Low latency, simple debugging
    public static Properties developmentConfig() {
        Properties props = new Properties();
        props.put(ProducerConfig.BOOTSTRAP_SERVERS_CONFIG, "localhost:9092");
        props.put(ProducerConfig.ACKS_CONFIG, "1");                    // Leader
only
        props.put(ProducerConfig.RETRIES_CONFIG, 3);                   // Limited
retries
        props.put(ProducerConfig.LINGER_MS_CONFIG, 0);                 // No
```

```
batching delay
        props.put(ProducerConfig.ENABLE_IDEMPOTENCE_CONFIG, false);    //
Simplicity
        return props;
    }

    // Production - High reliability and performance
    public static Properties productionConfig() {
        Properties props = new Properties();
        props.put(ProducerConfig.BOOTSTRAP_SERVERS_CONFIG,
            "prod-broker1:9092,prod-broker2:9092,prod-broker3:9092");
        props.put(ProducerConfig.ACKS_CONFIG, "all");                   // Maximum
durability
        props.put(ProducerConfig.RETRIES_CONFIG, Integer.MAX_VALUE);    // Retry
forever
        props.put(ProducerConfig.LINGER_MS_CONFIG, 10);                 // Optimize
batching
        props.put(ProducerConfig.BATCH_SIZE_CONFIG, 32768);             // Larger
batches
        props.put(ProducerConfig.COMPRESSION_TYPE_CONFIG, "gzip");      // Reduce
bandwidth
        props.put(ProducerConfig.ENABLE_IDEMPOTENCE_CONFIG, true);      // Exactly-
once
        return props;
    }

    // High-throughput - Maximum performance
    public static Properties highThroughputConfig() {
        Properties props = new Properties();
        props.put(ProducerConfig.BOOTSTRAP_SERVERS_CONFIG, "localhost:9092");
        props.put(ProducerConfig.ACKS_CONFIG, "0");                     // Fire and
forget
        props.put(ProducerConfig.LINGER_MS_CONFIG, 100);                //
Aggressive batching
        props.put(ProducerConfig.BATCH_SIZE_CONFIG, 65536);             // 64KB
batches
        props.put(ProducerConfig.COMPRESSION_TYPE_CONFIG, "lz4");       // Fast
compression
        props.put(ProducerConfig.BUFFER_MEMORY_CONFIG, 134217728);      // 128MB
buffer
        return props;
    }
}
```

Partitioning & Ordering

Default Partitioner

How Default Partitioner Works

```
Partitioning Logic:

1. If record has a key:
   partition = hash(key) % num_partitions

2. If record has no key:
   partition = round-robin (sticky partitioner in Kafka 2.4+)

Examples:
Topic: "orders" (3 partitions)

Key-based:
"user123" → hash("user123") % 3 = 1 → Partition 1
"user456" → hash("user456") % 3 = 0 → Partition 0
"user789" → hash("user789") % 3 = 2 → Partition 2

No key:
null → Round-robin → Partition 0, 1, 2, 0, 1, 2...
```

Default Partitioner Java Example

```
import org.apache.kafka.clients.producer.*;
import java.util.Properties;

public class DefaultPartitionerExample {

    public static void main(String[] args) {
        Properties props = new Properties();
        props.put(ProducerConfig.BOOTSTRAP_SERVERS_CONFIG, "localhost:9092");
        props.put(ProducerConfig.KEY_SERIALIZER_CLASS_CONFIG,
            "org.apache.kafka.common.serialization.StringSerializer");
        props.put(ProducerConfig.VALUE_SERIALIZER_CLASS_CONFIG,
            "org.apache.kafka.common.serialization.StringSerializer");

        try (KafkaProducer<String, String> producer = new KafkaProducer<>(props))
{

            // Key-based partitioning - all messages for same user go to same
partition
            sendWithKey(producer, "user123", "User 123 placed order #1");
            sendWithKey(producer, "user123", "User 123 placed order #2");  // Same
partition
            sendWithKey(producer, "user456", "User 456 placed order #1");  //
Different partition

            // Round-robin partitioning - no key
            sendWithoutKey(producer, "Anonymous order #1");
            sendWithoutKey(producer, "Anonymous order #2");
            sendWithoutKey(producer, "Anonymous order #3");
```

```
        } catch (Exception e) {
            e.printStackTrace();
        }
    }

    private static void sendWithKey(KafkaProducer<String, String> producer,
                                    String key, String value) {
        ProducerRecord<String, String> record =
            new ProducerRecord<>("orders", key, value);

        producer.send(record, (metadata, exception) -> {
            if (exception == null) {
                System.out.printf("Key: %s → Partition: %d, Offset: %d%n",
                    key, metadata.partition(), metadata.offset());
            }
        });
    }

    private static void sendWithoutKey(KafkaProducer<String, String> producer,
String value) {
        ProducerRecord<String, String> record =
            new ProducerRecord<>("orders", null, value);

        producer.send(record, (metadata, exception) -> {
            if (exception == null) {
                System.out.printf("No key → Partition: %d, Offset: %d%n",
                    metadata.partition(), metadata.offset());
            }
        });
    }
}
```

Sticky Partitioner (Kafka 2.4+)

Problem with Old Round-Robin:

- Poor batching efficiency when no key provided
- Each message could go to different partition, reducing batch effectiveness

Sticky Partitioner Solution:

```
// Old behavior (pre-2.4):
// msg1 → partition 0, msg2 → partition 1, msg3 → partition 2, msg4 → partition
0...

// Sticky partitioner (2.4+):
// msg1-10 → partition 0, msg11-20 → partition 1, msg21-30 → partition 2...
// Sticks to partition until batch is sent, then switches
```

Custom Partitioner

When to Use Custom Partitioner

- 🎯 **Business Logic**: Route messages based on business rules
- 🎯 **Load Balancing**: Custom distribution strategies
- 🎯 **Data Locality**: Keep related data together
- 🎯 **Performance**: Optimize for specific access patterns

Custom Partitioner Implementation

```
import org.apache.kafka.clients.producer.Partitioner;
import org.apache.kafka.common.Cluster;
import org.apache.kafka.common.PartitionInfo;
import java.util.List;
import java.util.Map;

// Route VIP customers to specific partition for priority processing
public class VipCustomerPartitioner implements Partitioner {

    private static final int VIP_PARTITION = 0;  // Dedicate partition 0 for VIP
customers

    @Override
    public int partition(String topic, Object key, byte[] keyBytes,
                         Object value, byte[] valueBytes, Cluster cluster) {

        List<PartitionInfo> partitions = cluster.partitionsForTopic(topic);
        int numPartitions = partitions.size();

        if (key == null) {
            // No key - use round-robin for remaining partitions
            return (int) (Math.random() * (numPartitions - 1)) + 1;
        }

        String keyStr = key.toString();

        // VIP customers go to partition 0
        if (keyStr.startsWith("vip-")) {
            return VIP_PARTITION;
        }

        // Premium customers get better partitions (1-2)
        if (keyStr.startsWith("premium-")) {
            return (keyStr.hashCode() & Integer.MAX_VALUE) % 2 + 1;
        }

        // Regular customers use remaining partitions (3+)
        if (numPartitions > 3) {
            return (keyStr.hashCode() & Integer.MAX_VALUE) % (numPartitions - 3) +
3;
        }

        // Fallback to default behavior
```

```
        return (keyStr.hashCode() & Integer.MAX_VALUE) % numPartitions;
    }

    @Override
    public void close() {
        // Cleanup resources if needed
    }

    @Override
    public void configure(Map<String, ?> configs) {
        // Configuration if needed
    }
}

// Geographic partitioner - route by region
public class GeographicPartitioner implements Partitioner {

    @Override
    public int partition(String topic, Object key, byte[] keyBytes,
                         Object value, byte[] valueBytes, Cluster cluster) {

        if (key == null) {
            return 0; // Default partition
        }

        String keyStr = key.toString();
        int numPartitions = cluster.partitionsForTopic(topic).size();

        // Extract region from key (format: "region-user-id")
        String[] parts = keyStr.split("-");
        if (parts.length >= 2) {
            String region = parts[0].toLowerCase();

            switch (region) {
                case "us": return 0;
                case "eu": return 1;
                case "asia": return 2;
                case "latam": return 3;
                default:
                    return (keyStr.hashCode() & Integer.MAX_VALUE) %
numPartitions;
            }
        }

        return (keyStr.hashCode() & Integer.MAX_VALUE) % numPartitions;
    }

    @Override
    public void close() {}

    @Override
    public void configure(Map<String, ?> configs) {}
}
```

Using Custom Partitioner

```
public class CustomPartitionerExample {

    public static void main(String[] args) {
        Properties props = new Properties();
        props.put(ProducerConfig.BOOTSTRAP_SERVERS_CONFIG, "localhost:9092");
        props.put(ProducerConfig.KEY_SERIALIZER_CLASS_CONFIG,
            "org.apache.kafka.common.serialization.StringSerializer");
        props.put(ProducerConfig.VALUE_SERIALIZER_CLASS_CONFIG,
            "org.apache.kafka.common.serialization.StringSerializer");

        // Configure custom partitioner
        props.put(ProducerConfig.PARTITIONER_CLASS_CONFIG,
            "com.example.VipCustomerPartitioner");

        try (KafkaProducer<String, String> producer = new KafkaProducer<>(props))
{

            // VIP customer - goes to partition 0
            sendMessage(producer, "vip-customer-001", "VIP order: $10000");

            // Premium customer - goes to partition 1-2
            sendMessage(producer, "premium-customer-123", "Premium order: $1000");

            // Regular customer - goes to partition 3+
            sendMessage(producer, "regular-customer-456", "Regular order: $100");

            // Geographic routing
            sendMessage(producer, "us-customer-789", "US order");
            sendMessage(producer, "eu-customer-321", "European order");
            sendMessage(producer, "asia-customer-654", "Asian order");

        } catch (Exception e) {
            e.printStackTrace();
        }
    }

    private static void sendMessage(KafkaProducer<String, String> producer,
                                    String key, String value) {
        ProducerRecord<String, String> record =
            new ProducerRecord<>("customer-orders", key, value);

        producer.send(record, (metadata, exception) -> {
            if (exception == null) {
                System.out.printf("Key: %s → Partition: %d (Custom Logic)%n",
                    key, metadata.partition());
            } else {
                System.err.println("Failed to send: " + exception.getMessage());
            }
        });
```

```
    }
}
```

Ordering Guarantees

Single Partition Ordering

```
Single Partition = Total Order

Partition 0:
┌─────┬─────┬─────┬─────┬─────┐
│ M1  │ M2  │ M3  │ M4  │ M5  │
└─────┴─────┴─────┴─────┴─────┘
  ↑                       ↑
offset 0               offset 4

Consumer reads: M1, M2, M3, M4, M5 (always same order)
```

```
// Ensuring single partition for ordering
public class OrderedMessagesExample {

    public static void main(String[] args) {
        Properties props = createProducerConfig();

        try (KafkaProducer<String, String> producer = new KafkaProducer<>(props))
{

            String userId = "user123";  // Same key = same partition

            // These messages will be ordered within the partition
            sendOrderedMessage(producer, userId, "User created account");
            sendOrderedMessage(producer, userId, "User verified email");
            sendOrderedMessage(producer, userId, "User updated profile");
            sendOrderedMessage(producer, userId, "User made first purchase");

            producer.flush(); // Ensure all sent

        } catch (Exception e) {
            e.printStackTrace();
        }
    }

    private static void sendOrderedMessage(KafkaProducer<String, String> producer,
                                           String userId, String event) {
        ProducerRecord<String, String> record =
            new ProducerRecord<>("user-events", userId, event);

        // For strict ordering, consider using synchronous send
        try {
```

```
            RecordMetadata metadata = producer.send(record).get();
            System.out.printf("Ordered event for %s: %s → Partition %d, Offset
%d%n",
                userId, event, metadata.partition(), metadata.offset());
        } catch (Exception e) {
            System.err.println("Failed to send ordered message: " +
e.getMessage());
        }
    }

    private static Properties createProducerConfig() {
        Properties props = new Properties();
        props.put(ProducerConfig.BOOTSTRAP_SERVERS_CONFIG, "localhost:9092");
        props.put(ProducerConfig.KEY_SERIALIZER_CLASS_CONFIG,
            "org.apache.kafka.common.serialization.StringSerializer");
        props.put(ProducerConfig.VALUE_SERIALIZER_CLASS_CONFIG,
            "org.apache.kafka.common.serialization.StringSerializer");

        // Settings for strict ordering
        props.put(ProducerConfig.MAX_IN_FLIGHT_REQUESTS_PER_CONNECTION, 1);
        props.put(ProducerConfig.RETRIES_CONFIG, Integer.MAX_VALUE);
        props.put(ProducerConfig.ACKS_CONFIG, "all");

        return props;
    }
}
```

Multiple Partitions - No Global Order

```
Multiple Partitions = No Global Order

Partition 0: [M1, M3, M5] ← User A events
Partition 1: [M2, M4, M6] ← User B events

Consumer Group:
Consumer 1 reads P0: M1, M3, M5
Consumer 2 reads P1: M2, M4, M6

Global consumption order could be: M1, M2, M3, M4, M5, M6
                                OR: M2, M1, M4, M3, M6, M5
                                OR: Any interleaving!
```

Ordering Configuration Trade-offs

Configuration	Ordering Guarantee	Performance Impact
`max.in.flight.requests=1`	☑ Strict per partition	❌ Lower throughput

Configuration	Ordering Guarantee	Performance Impact
`max.in.flight.requests=5` + `enable.idempotence=true`	☑ Order preserved with retries	★ Good throughput
`max.in.flight.requests=5` + `enable.idempotence=false`	✗ May reorder on retry	★★ Higher throughput

🛡 Reliability

Idempotent Producer

Problem It Solves

Producer Retry Duplication:

```
Without Idempotence:
1. Producer sends message M1
2. Broker receives M1, but ACK is lost
3. Producer retries, sends M1 again
4. Result: M1 appears twice in log

With Idempotence:
1. Producer sends M1 with sequence number
2. Broker receives M1, but ACK is lost
3. Producer retries M1 with same sequence number
4. Broker recognizes duplicate, ignores retry
5. Result: M1 appears once in log
```

Internal Mechanism

```
Idempotent Producer Internals:

Producer ID (PID): Unique producer identifier
Sequence Number: Per-partition counter starting from 0

Message Format:
┌──────────┬──────────────┬──────────────┬─────────────────┐
│ PID      │ Epoch        │ Sequence     │ Message         │
│ 12345    │ 0            │ 0            │ "Hello"         │
└──────────┴──────────────┴──────────────┴─────────────────┘

Broker State:
Partition 0: Last seen (PID=12345, Epoch=0, Seq=2)
Partition 1: Last seen (PID=12345, Epoch=0, Seq=5)
```

Idempotent Producer Java Example

```
import org.apache.kafka.clients.producer.*;
import java.util.Properties;
import java.util.concurrent.ExecutionException;

public class IdempotentProducerExample {

    public static void main(String[] args) {
        Properties props = createIdempotentProducerConfig();

        try (KafkaProducer<String, String> producer = new KafkaProducer<>(props))
{

            // Simulate sending critical financial transactions
            for (int i = 0; i < 10; i++) {
                String transactionId = "txn-" + i;
                String transactionData = String.format(
                    "Transfer $%.2f from account A to account B",
                    1000.0 + (i * 100));

                sendIdempotentMessage(producer, transactionId, transactionData);
            }

            // Force any buffered messages to be sent
            producer.flush();

        } catch (Exception e) {
            System.err.println("Idempotent producer failed: " + e.getMessage());
            e.printStackTrace();
        }
    }

    private static void sendIdempotentMessage(KafkaProducer<String, String>
producer,
                                              String key, String value) {
        ProducerRecord<String, String> record =
            new ProducerRecord<>("financial-transactions", key, value);

        producer.send(record, new Callback() {
            @Override
            public void onCompletion(RecordMetadata metadata, Exception exception)
{
                if (exception != null) {
                    if (exception instanceof
org.apache.kafka.common.errors.OutOfOrderSequenceException) {
                        System.err.println("Out of order sequence - this shouldn't
happen with idempotence!");
                    } else if (exception instanceof
org.apache.kafka.common.errors.DuplicateSequenceNumberException) {
                        System.out.println("Duplicate detected and handled by
broker");
```

```
                    } else {
                        System.err.println("Send failed: " +
exception.getMessage());
                    }
                } else {
                    System.out.printf("Idempotent send: %s → P%d:O%d%n",
                        key, metadata.partition(), metadata.offset());
                }
            }
        });
    }

    private static Properties createIdempotentProducerConfig() {
        Properties props = new Properties();

        // Basic configuration
        props.put(ProducerConfig.BOOTSTRAP_SERVERS_CONFIG, "localhost:9092");
        props.put(ProducerConfig.KEY_SERIALIZER_CLASS_CONFIG,
            "org.apache.kafka.common.serialization.StringSerializer");
        props.put(ProducerConfig.VALUE_SERIALIZER_CLASS_CONFIG,
            "org.apache.kafka.common.serialization.StringSerializer");

        // Idempotence configuration (Kafka 3.0+ defaults)
        props.put(ProducerConfig.ENABLE_IDEMPOTENCE_CONFIG, true);

        // Required settings for idempotence
        props.put(ProducerConfig.ACKS_CONFIG, "all");               // Must wait
for all replicas
        props.put(ProducerConfig.RETRIES_CONFIG, Integer.MAX_VALUE); // Must
enable retries
        props.put(ProducerConfig.MAX_IN_FLIGHT_REQUESTS_PER_CONNECTION, 5); // Max
5 for idempotence

        // Additional reliability
        props.put(ProducerConfig.RETRY_BACKOFF_MS_CONFIG, 100);
        props.put(ProducerConfig.REQUEST_TIMEOUT_MS_CONFIG, 30000);

        return props;
    }
}
```

Idempotence Limitations & Considerations

```
public class IdempotenceLimitations {

    public void demonstrateLimitations() {
        // 1. Producer restart loses PID - can't prevent duplicates across
restarts
        System.out.println("Limitation 1: Producer restart breaks idempotence");

        // 2. Only works within producer session
```

```
        System.out.println("Limitation 2: Only prevents retries within same
producer instance");

        // 3. Only prevents duplicates from producer retries, not application
retries
        System.out.println("Limitation 3: Application-level retries can still
create duplicates");
    }

    // For cross-session idempotence, use transactional producer
    public Properties transactionalConfig() {
        Properties props = new Properties();
        props.put(ProducerConfig.BOOTSTRAP_SERVERS_CONFIG, "localhost:9092");
        props.put(ProducerConfig.KEY_SERIALIZER_CLASS_CONFIG,
            "org.apache.kafka.common.serialization.StringSerializer");
        props.put(ProducerConfig.VALUE_SERIALIZER_CLASS_CONFIG,
            "org.apache.kafka.common.serialization.StringSerializer");

        // Transactional settings
        props.put(ProducerConfig.TRANSACTIONAL_ID_CONFIG, "payment-processor-1");
        props.put(ProducerConfig.ENABLE_IDEMPOTENCE_CONFIG, true); //
Automatically true
        props.put(ProducerConfig.ACKS_CONFIG, "all");

        return props;
    }
}
```

Transactional Producer

Problem It Solves

- **Exactly-Once Processing**: Guaranteed exactly-once semantics across producer restarts
- **Atomic Multi-Topic Writes**: All messages in transaction committed together
- **Read Committed**: Consumers only see committed messages

Transactional Producer Architecture

```
Transactional Producer Flow:

1. Producer gets Transaction Coordinator assignment
2. Producer begins transaction
3. Producer sends messages to multiple topics/partitions
4. Producer commits transaction
5. Transaction Coordinator marks all messages as committed
6. Consumers with isolation.level=read_committed see messages

Transaction Log:
┌──────────────┬──────────────┬──────────────┬──────────────┐
│ TXN_ID       │ Status       │ Partitions   │ Timestamp    │
```

```
├──────────────┼──────────────┼──────────────┼──────────────┤
│ payment-1    │ ONGOING      │ orders:0     │ 1693875600   │
│              │              │ inventory:1  │              │
│ payment-1    │ COMMITTED    │ orders:0     │ 1693875605   │
│              │              │ inventory:1  │              │
└──────────────┴──────────────┴──────────────┴──────────────┘
```

Comprehensive Transactional Producer Example

```
import org.apache.kafka.clients.producer.*;
import org.apache.kafka.common.errors.ProducerFencedException;
import org.apache.kafka.common.errors.OutOfOrderSequenceException;
import org.apache.kafka.common.errors.AuthorizationException;
import java.util.Properties;

public class TransactionalProducerExample {

    private static final String ORDERS_TOPIC = "orders";
    private static final String INVENTORY_TOPIC = "inventory";
    private static final String PAYMENTS_TOPIC = "payments";

    public static void main(String[] args) {
        Properties props = createTransactionalProducerConfig();

        KafkaProducer<String, String> producer = new KafkaProducer<>(props);

        // Initialize transactions
        producer.initTransactions();

        try {
            // Process multiple orders atomically
            for (int i = 0; i < 5; i++) {
                processOrderTransactionally(producer, "order-" + i, i * 100.0);
            }

        } catch (Exception e) {
            System.err.println("Transactional processing failed: " +
e.getMessage());
        } finally {
            producer.close();
        }
    }

    private static void processOrderTransactionally(KafkaProducer<String, String>
producer,
                                                    String orderId, double amount)
{
        try {
            // Begin transaction
            producer.beginTransaction();
```

```
            // Send order creation event
            ProducerRecord<String, String> orderRecord = new ProducerRecord<>(
                ORDERS_TOPIC, orderId,
                String.format("Order created: %s, amount: $%.2f", orderId,
amount));
            producer.send(orderRecord);

            // Reserve inventory
            ProducerRecord<String, String> inventoryRecord = new ProducerRecord<>(
                INVENTORY_TOPIC, orderId,
                String.format("Inventory reserved for order: %s", orderId));
            producer.send(inventoryRecord);

            // Process payment
            ProducerRecord<String, String> paymentRecord = new ProducerRecord<>(
                PAYMENTS_TOPIC, orderId,
                String.format("Payment processed: %s, amount: $%.2f", orderId,
amount));
            producer.send(paymentRecord);

            // Simulate business logic that might fail
            if (orderId.equals("order-3")) {
                throw new RuntimeException("Payment processor temporarily
unavailable");
            }

            // Commit transaction - all messages become visible atomically
            producer.commitTransaction();
            System.out.println("Transaction committed successfully for " +
orderId);

        } catch (ProducerFencedException e) {
            // Another producer with same transactional.id is active
            System.err.println("Producer fenced: " + e.getMessage());
            producer.close();
        } catch (OutOfOrderSequenceException | AuthorizationException e) {
            // Unrecoverable errors
            System.err.println("Unrecoverable error: " + e.getMessage());
            producer.close();
        } catch (Exception e) {
            // Abort transaction on any error
            System.err.println("Transaction failed for " + orderId + ": " +
e.getMessage());
            try {
                producer.abortTransaction();
                System.out.println("Transaction aborted for " + orderId);
            } catch (Exception abortEx) {
                System.err.println("Failed to abort transaction: " +
abortEx.getMessage());
            }
        }
    }

    private static Properties createTransactionalProducerConfig() {
```

```
        Properties props = new Properties();

        // Basic configuration
        props.put(ProducerConfig.BOOTSTRAP_SERVERS_CONFIG, "localhost:9092");
        props.put(ProducerConfig.KEY_SERIALIZER_CLASS_CONFIG,
            "org.apache.kafka.common.serialization.StringSerializer");
        props.put(ProducerConfig.VALUE_SERIALIZER_CLASS_CONFIG,
            "org.apache.kafka.common.serialization.StringSerializer");

        // Transactional configuration
        props.put(ProducerConfig.TRANSACTIONAL_ID_CONFIG, "order-processor-1");

        // These are automatically set with transactional.id
        // props.put(ProducerConfig.ENABLE_IDEMPOTENCE_CONFIG, true);
        // props.put(ProducerConfig.ACKS_CONFIG, "all");
        // props.put(ProducerConfig.RETRIES_CONFIG, Integer.MAX_VALUE);

        // Performance settings
        props.put(ProducerConfig.BATCH_SIZE_CONFIG, 16384);
        props.put(ProducerConfig.LINGER_MS_CONFIG, 5);

        return props;
    }
}
```

Transactional Consumer (Read Committed)

```
import org.apache.kafka.clients.consumer.*;
import java.time.Duration;
import java.util.Arrays;
import java.util.Properties;

public class TransactionalConsumerExample {

    public static void main(String[] args) {
        Properties props = createTransactionalConsumerConfig();

        try (KafkaConsumer<String, String> consumer = new KafkaConsumer<>(props))
{
            consumer.subscribe(Arrays.asList("orders", "inventory", "payments"));

            while (true) {
                ConsumerRecords<String, String> records =
consumer.poll(Duration.ofMillis(1000));

                for (ConsumerRecord<String, String> record : records) {
                    // Only see committed messages due to
isolation.level=read_committed
                    System.out.printf("Consumed committed record: topic=%s,
key=%s, value=%s, " +
                        "partition=%d, offset=%d%n",
```

```
                        record.topic(), record.key(), record.value(),
                        record.partition(), record.offset());
                }

                // Commit offsets
                consumer.commitSync();
            }
        }
    }

    private static Properties createTransactionalConsumerConfig() {
        Properties props = new Properties();
        props.put(ConsumerConfig.BOOTSTRAP_SERVERS_CONFIG, "localhost:9092");
        props.put(ConsumerConfig.GROUP_ID_CONFIG, "transactional-consumer-group");
        props.put(ConsumerConfig.KEY_DESERIALIZER_CLASS_CONFIG,
            "org.apache.kafka.common.serialization.StringDeserializer");
        props.put(ConsumerConfig.VALUE_DESERIALIZER_CLASS_CONFIG,
            "org.apache.kafka.common.serialization.StringDeserializer");

        // Only read committed messages (default is read_uncommitted)
        props.put(ConsumerConfig.ISOLATION_LEVEL_CONFIG, "read_committed");

        props.put(ConsumerConfig.AUTO_OFFSET_RESET_CONFIG, "earliest");
        props.put(ConsumerConfig.ENABLE_AUTO_COMMIT_CONFIG, false);

        return props;
    }
}
```

Delivery Semantics

At-Most-Once (Fire and Forget)

```
public class AtMostOnceProducer {

    public static Properties createConfig() {
        Properties props = new Properties();
        props.put(ProducerConfig.BOOTSTRAP_SERVERS_CONFIG, "localhost:9092");
        props.put(ProducerConfig.KEY_SERIALIZER_CLASS_CONFIG,
            "org.apache.kafka.common.serialization.StringSerializer");
        props.put(ProducerConfig.VALUE_SERIALIZER_CLASS_CONFIG,
            "org.apache.kafka.common.serialization.StringSerializer");

        // At-most-once settings - fire and forget
        props.put(ProducerConfig.ACKS_CONFIG, "0");           // Don't wait for
ack
        props.put(ProducerConfig.RETRIES_CONFIG, 0);          // No retries
        props.put(ProducerConfig.ENABLE_IDEMPOTENCE_CONFIG, false);

        return props;
    }
```

```
    public static void main(String[] args) {
        Properties props = createConfig();

        try (KafkaProducer<String, String> producer = new KafkaProducer<>(props))
{
            for (int i = 0; i < 100; i++) {
                ProducerRecord<String, String> record =
                    new ProducerRecord<>("metrics", "sensor-" + i, "temperature:"
+ (20 + i));

                // Fire and forget - don't care about result
                producer.send(record);
            }
        }

        System.out.println("Messages sent (at-most-once) - some may be lost, none
duplicated");
    }
}
```

At-Least-Once (Standard Retry)

```
public class AtLeastOnceProducer {

    public static Properties createConfig() {
        Properties props = new Properties();
        props.put(ProducerConfig.BOOTSTRAP_SERVERS_CONFIG, "localhost:9092");
        props.put(ProducerConfig.KEY_SERIALIZER_CLASS_CONFIG,
            "org.apache.kafka.common.serialization.StringSerializer");
        props.put(ProducerConfig.VALUE_SERIALIZER_CLASS_CONFIG,
            "org.apache.kafka.common.serialization.StringSerializer");

        // At-least-once settings
        props.put(ProducerConfig.ACKS_CONFIG, "all");         // Wait for all
replicas
        props.put(ProducerConfig.RETRIES_CONFIG, Integer.MAX_VALUE); // Retry on
failure
        props.put(ProducerConfig.ENABLE_IDEMPOTENCE_CONFIG, false); // Allow
duplicates

        return props;
    }

    public static void main(String[] args) {
        Properties props = createConfig();

        try (KafkaProducer<String, String> producer = new KafkaProducer<>(props))
{
            for (int i = 0; i < 100; i++) {
                ProducerRecord<String, String> record =
```

```
                    new ProducerRecord<>("events", "event-" + i, "data-" + i);

                producer.send(record, (metadata, exception) -> {
                    if (exception != null) {
                        System.err.println("Failed after retries: " +
exception.getMessage());
                    } else {
                        System.out.printf("Sent: partition=%d, offset=%d%n",
                            metadata.partition(), metadata.offset());
                    }
                });
            }
        }

        System.out.println("Messages sent (at-least-once) - none lost, duplicates
possible");
    }
}
```

Exactly-Once (Idempotent/Transactional)

```
public class ExactlyOnceProducer {

    // Exactly-once with idempotence (single producer session)
    public static Properties createIdempotentConfig() {
        Properties props = new Properties();
        props.put(ProducerConfig.BOOTSTRAP_SERVERS_CONFIG, "localhost:9092");
        props.put(ProducerConfig.KEY_SERIALIZER_CLASS_CONFIG,
            "org.apache.kafka.common.serialization.StringSerializer");
        props.put(ProducerConfig.VALUE_SERIALIZER_CLASS_CONFIG,
            "org.apache.kafka.common.serialization.StringSerializer");

        // Exactly-once within producer session
        props.put(ProducerConfig.ENABLE_IDEMPOTENCE_CONFIG, true);
        // Other settings automatically configured: acks=all, retries=MAX,
max.in.flight=5

        return props;
    }

    // Exactly-once across restarts (transactional)
    public static Properties createTransactionalConfig() {
        Properties props = new Properties();
        props.put(ProducerConfig.BOOTSTRAP_SERVERS_CONFIG, "localhost:9092");
        props.put(ProducerConfig.KEY_SERIALIZER_CLASS_CONFIG,
            "org.apache.kafka.common.serialization.StringSerializer");
        props.put(ProducerConfig.VALUE_SERIALIZER_CLASS_CONFIG,
            "org.apache.kafka.common.serialization.StringSerializer");

        // Exactly-once across producer restarts
        props.put(ProducerConfig.TRANSACTIONAL_ID_CONFIG, "exactly-once-
```

```
producer");
        // Idempotence automatically enabled

        return props;
    }

    public static void main(String[] args) {
        // Example with transactional exactly-once
        Properties props = createTransactionalConfig();

        KafkaProducer<String, String> producer = new KafkaProducer<>(props);
        producer.initTransactions();

        try {
            producer.beginTransaction();

            for (int i = 0; i < 10; i++) {
                ProducerRecord<String, String> record =
                    new ProducerRecord<>("financial-events", "txn-" + i,
                        "amount:" + (1000.0 * i));
                producer.send(record);
            }

            producer.commitTransaction();
            System.out.println("Transaction committed - exactly-once guarantee");

        } catch (Exception e) {
            producer.abortTransaction();
            System.err.println("Transaction aborted: " + e.getMessage());
        } finally {
            producer.close();
        }
    }
}
```

Comprehensive Java Examples

Complete Producer Application

```
import org.apache.kafka.clients.producer.*;
import org.apache.kafka.common.serialization.StringSerializer;
import com.fasterxml.jackson.databind.ObjectMapper;
import com.fasterxml.jackson.core.JsonProcessingException;

import java.util.Properties;
import java.util.concurrent.CountDownLatch;
import java.util.concurrent.ExecutorService;
import java.util.concurrent.Executors;
import java.util.concurrent.atomic.AtomicInteger;
```

```
/**
 * Production-ready Kafka Producer with error handling, metrics, and monitoring
 */
public class ProductionKafkaProducerExample {

    private final KafkaProducer<String, String> producer;
    private final ObjectMapper objectMapper;
    private final AtomicInteger successCount = new AtomicInteger(0);
    private final AtomicInteger errorCount = new AtomicInteger(0);

    public ProductionKafkaProducerExample(Properties config) {
        this.producer = new KafkaProducer<>(config);
        this.objectMapper = new ObjectMapper();
    }

    public static void main(String[] args) {
        Properties config = createProductionConfig();
        ProductionKafkaProducerExample producerApp =
            new ProductionKafkaProducerExample(config);

        // Simulate high-throughput application
        producerApp.runHighThroughputTest();

        // Cleanup
        producerApp.close();
    }

    private static Properties createProductionConfig() {
        Properties props = new Properties();

        // Cluster connection
        props.put(ProducerConfig.BOOTSTRAP_SERVERS_CONFIG,
            "broker1:9092,broker2:9092,broker3:9092");
        props.put(ProducerConfig.CLIENT_ID_CONFIG, "order-service-producer-v1.0");

        // Serialization
        props.put(ProducerConfig.KEY_SERIALIZER_CLASS_CONFIG,
StringSerializer.class);
        props.put(ProducerConfig.VALUE_SERIALIZER_CLASS_CONFIG,
StringSerializer.class);

        // Reliability - exactly-once
        props.put(ProducerConfig.ENABLE_IDEMPOTENCE_CONFIG, true);
        props.put(ProducerConfig.ACKS_CONFIG, "all");
        props.put(ProducerConfig.RETRIES_CONFIG, Integer.MAX_VALUE);
        props.put(ProducerConfig.RETRY_BACKOFF_MS_CONFIG, 100);

        // Performance optimization
        props.put(ProducerConfig.BATCH_SIZE_CONFIG, 32768);      // 32KB batches
        props.put(ProducerConfig.LINGER_MS_CONFIG, 20);          // 20ms batching
window
        props.put(ProducerConfig.COMPRESSION_TYPE_CONFIG, "gzip"); // Compression
        props.put(ProducerConfig.BUFFER_MEMORY_CONFIG, 67108864); // 64MB buffer
```

```
        // Timeouts
        props.put(ProducerConfig.REQUEST_TIMEOUT_MS_CONFIG, 30000);
        props.put(ProducerConfig.DELIVERY_TIMEOUT_MS_CONFIG, 120000);

        return props;
    }

    public void runHighThroughputTest() {
        int numThreads = 4;
        int messagesPerThread = 1000;
        CountDownLatch latch = new CountDownLatch(numThreads);
        ExecutorService executor = Executors.newFixedThreadPool(numThreads);

        long startTime = System.currentTimeMillis();

        for (int t = 0; t < numThreads; t++) {
            final int threadId = t;
            executor.submit(() -> {
                try {
                    for (int i = 0; i < messagesPerThread; i++) {
                        sendOrderEvent(threadId, i);
                    }
                } finally {
                    latch.countDown();
                }
            });
        }

        try {
            latch.await(); // Wait for all threads to complete
            producer.flush(); // Ensure all messages are sent

            long duration = System.currentTimeMillis() - startTime;

            System.out.printf("Performance Results:%n");
            System.out.printf("Total messages: %d%n", numThreads *
messagesPerThread);
            System.out.printf("Successful: %d%n", successCount.get());
            System.out.printf("Errors: %d%n", errorCount.get());
            System.out.printf("Duration: %d ms%n", duration);
            System.out.printf("Throughput: %.2f messages/sec%n",
                (numThreads * messagesPerThread * 1000.0) / duration);

        } catch (InterruptedException e) {
            Thread.currentThread().interrupt();
        } finally {
            executor.shutdown();
        }
    }

    private void sendOrderEvent(int threadId, int messageId) {
        try {
            // Create order event object
            OrderEvent orderEvent = new OrderEvent(
```

```
                "order-" + threadId + "-" + messageId,
                "user-" + (messageId % 100),
                100.0 + (messageId % 500),
                System.currentTimeMillis()
            );

            String key = orderEvent.getUserId(); // Partition by user
            String value = objectMapper.writeValueAsString(orderEvent);

            ProducerRecord<String, String> record =
                new ProducerRecord<>("order-events", key, value);

            // Add headers for tracing/monitoring
            record.headers().add("source-service", "order-service".getBytes());
            record.headers().add("thread-id",
String.valueOf(threadId).getBytes());

            // Send asynchronously with callback
            producer.send(record, new Callback() {
                @Override
                public void onCompletion(RecordMetadata metadata, Exception
exception) {
                    if (exception == null) {
                        successCount.incrementAndGet();
                        if (messageId % 100 == 0) {
                            System.out.printf("Thread %d sent message %d to
partition %d%n",
                                threadId, messageId, metadata.partition());
                        }
                    } else {
                        errorCount.incrementAndGet();
                        System.err.printf("Thread %d failed to send message %d:
%s%n",
                            threadId, messageId, exception.getMessage());

                        // Handle different exception types
                        handleProducerException(exception, orderEvent);
                    }
                }
            });

        } catch (JsonProcessingException e) {
            System.err.println("JSON serialization error: " + e.getMessage());
            errorCount.incrementAndGet();
        }
    }

    private void handleProducerException(Exception exception, OrderEvent
orderEvent) {
        if (exception instanceof
org.apache.kafka.common.errors.RetriableException) {
            // Will be retried automatically by producer
            System.out.println("Retriable error - producer will retry: " +
exception.getMessage());
```

```
        } else if (exception instanceof
org.apache.kafka.common.errors.RecordTooLargeException) {
            // Message too large - need to handle specially
            System.err.println("Message too large, sending to DLQ: " +
orderEvent.getOrderId());
            // Send to dead letter queue or break into smaller messages
        } else {
            // Other non-retriable errors
            System.err.println("Non-retriable error: " + exception.getMessage());
            // Could send to DLQ or alert monitoring system
        }
    }

    public void close() {
        if (producer != null) {
            producer.close();
        }
    }

    // Data class for order events
    static class OrderEvent {
        private String orderId;
        private String userId;
        private double amount;
        private long timestamp;

        public OrderEvent(String orderId, String userId, double amount, long
timestamp) {
            this.orderId = orderId;
            this.userId = userId;
            this.amount = amount;
            this.timestamp = timestamp;
        }

        // Getters for JSON serialization
        public String getOrderId() { return orderId; }
        public String getUserId() { return userId; }
        public double getAmount() { return amount; }
        public long getTimestamp() { return timestamp; }
    }
}
```

Producer with Custom Serializer

```
import org.apache.kafka.common.serialization.Serializer;
import com.fasterxml.jackson.databind.ObjectMapper;
import java.util.Map;

// Custom JSON serializer for complex objects
public class JsonSerializer<T> implements Serializer<T> {
    private final ObjectMapper objectMapper = new ObjectMapper();
```

```
    @Override
    public void configure(Map<String, ?> configs, boolean isKey) {
        // Configuration if needed
    }

    @Override
    public byte[] serialize(String topic, T data) {
        try {
            return objectMapper.writeValueAsBytes(data);
        } catch (Exception e) {
            throw new RuntimeException("Error serializing JSON", e);
        }
    }

    @Override
    public void close() {
        // Cleanup if needed
    }
}

// Usage with custom serializer
public class CustomSerializerExample {

    public static void main(String[] args) {
        Properties props = new Properties();
        props.put(ProducerConfig.BOOTSTRAP_SERVERS_CONFIG, "localhost:9092");
        props.put(ProducerConfig.KEY_SERIALIZER_CLASS_CONFIG,
StringSerializer.class);
        props.put(ProducerConfig.VALUE_SERIALIZER_CLASS_CONFIG,
JsonSerializer.class);

        try (KafkaProducer<String, OrderEvent> producer = new KafkaProducer<>
(props)) {
            OrderEvent order = new OrderEvent("order-123", "user-456", 999.99,
System.currentTimeMillis());

            ProducerRecord<String, OrderEvent> record =
                new ProducerRecord<>("orders", order.getUserId(), order);

            producer.send(record, (metadata, exception) -> {
                if (exception == null) {
                    System.out.println("Custom serialized object sent
successfully");
                } else {
                    System.err.println("Failed to send: " +
exception.getMessage());
                }
            });
        }
    }
}
```

⚖️ Comparisons & Trade-offs

Delivery Semantics Comparison

Delivery Semantic	Configuration	Guarantees	Performance	Use Cases
At-Most-Once	`acks=0`, `retries=0`	Messages may be lost, never duplicated	★★★ Highest throughput	Metrics, logs, non-critical data
At-Least-Once	`acks=all`, `retries>0`, no idempotence	No data loss, duplicates possible	★★ Good performance	Event streaming, analytics
Exactly-Once	`enable.idempotence=true` or transactional	No loss, no duplicates	★ Higher latency	Financial systems, critical data

Producer Configuration Trade-offs

Parameter	Higher Value Impact	Lower Value Impact	Recommendation
`batch.size`	↑ Throughput, ↑ Latency, ↑ Memory	↓ Latency, ↓ Throughput	16KB-32KB for most use cases
`linger.ms`	↑ Batching, ↑ Latency	↓ Latency, ↓ Batching	5-20ms for balanced performance
`acks`	↑ Durability, ↓ Throughput	↓ Durability, ↑ Throughput	`all` for production systems
`compression.type`	↓ Bandwidth, ↑ CPU	↑ Bandwidth, ↓ CPU	`gzip` for bandwidth, `lz4` for speed

Partitioning Strategy Comparison

Strategy	Advantages	Disadvantages	When to Use
Key-based	Data locality, ordering per key	Uneven distribution if keys skewed	User events, entity updates
Round-robin	Even distribution	No data locality	Logs, metrics without keys
Custom	Business-specific optimization	Implementation complexity	Geographic routing, priority queues

🚨 Common Pitfalls & Best Practices

1. Configuration Mistakes

❌ Blocking the Application Thread

```
// DON'T - Synchronous sends hurt performance
for (int i = 0; i < 10000; i++) {
    try {
        producer.send(record).get(); // Blocks on every send!
    } catch (Exception e) {
        // Handle error
    }
}
```

```
// DO - Use async sends with callbacks
for (int i = 0; i < 10000; i++) {
    producer.send(record, (metadata, exception) -> {
        if (exception != null) {
            // Handle error asynchronously
            handleError(exception);
        }
    });
}
producer.flush(); // Wait for all sends to complete
```

❌ Ignoring Producer Exceptions

```
// DON'T - Fire and forget without error handling
producer.send(record);
```

```
// DO - Always handle exceptions
producer.send(record, new Callback() {
    @Override
    public void onCompletion(RecordMetadata metadata, Exception exception) {
        if (exception != null) {
            if (exception instanceof RetriableException) {
                // Will be retried automatically
                logger.warn("Retriable error: {}", exception.getMessage());
            } else {
                // Non-retriable - handle immediately
                logger.error("Failed to send message", exception);
                sendToDeadLetterQueue(record);
            }
        }
    }
});
```

2. Memory and Resource Issues

❌ Unbounded Producer Memory Usage

```
// DON'T - Can cause OutOfMemoryError
Properties props = new Properties();
props.put(ProducerConfig.BUFFER_MEMORY_CONFIG, Long.MAX_VALUE); // Dangerous!
props.put(ProducerConfig.BATCH_SIZE_CONFIG, 1048576); // 1MB batches
props.put(ProducerConfig.LINGER_MS_CONFIG, 60000); // Wait 60 seconds
```

```
// DO - Set reasonable limits
Properties props = new Properties();
props.put(ProducerConfig.BUFFER_MEMORY_CONFIG, 67108864); // 64MB limit
props.put(ProducerConfig.BATCH_SIZE_CONFIG, 16384); // 16KB batches
props.put(ProducerConfig.LINGER_MS_CONFIG, 100); // 100ms max wait
props.put(ProducerConfig.MAX_BLOCK_MS_CONFIG, 5000); // Block max 5s when buffer
full
```

❌ Producer Resource Leaks

```
// DON'T - Forget to close producer
public void sendMessage(String message) {
    KafkaProducer<String, String> producer = new KafkaProducer<>(props);
    producer.send(new ProducerRecord<>("topic", message));
    // Producer not closed - resource leak!
}
```

```
// DO - Use try-with-resources or proper cleanup
private final KafkaProducer<String, String> producer; // Shared instance

public void sendMessage(String message) {
    producer.send(new ProducerRecord<>("topic", message));
}

@PreDestroy
public void cleanup() {
    if (producer != null) {
        producer.close(Duration.ofSeconds(10)); // Graceful close
    }
}
```

3. Ordering and Idempotence Issues

❌ Losing Message Order on Retries

```
// DON'T - Can reorder messages on retry
Properties props = new Properties();
props.put(ProducerConfig.MAX_IN_FLIGHT_REQUESTS_PER_CONNECTION, 10);
props.put(ProducerConfig.RETRIES_CONFIG, 3);
props.put(ProducerConfig.ENABLE_IDEMPOTENCE_CONFIG, false);
```

```
// DO - Enable idempotence for ordering guarantees
Properties props = new Properties();
props.put(ProducerConfig.ENABLE_IDEMPOTENCE_CONFIG, true);
// Automatically sets: acks=all, retries=MAX_VALUE, max.in.flight.requests=5
```

4. Performance Anti-patterns

❌ Creating New Producer Per Message

```
// DON'T - Very expensive
public void sendMessage(String message) {
    Properties props = createProducerConfig();
    try (KafkaProducer<String, String> producer = new KafkaProducer<>(props)) {
        producer.send(new ProducerRecord<>("topic", message));
    } // Producer closed after every message!
}
```

```
// DO - Reuse producer instances
@Component
public class MessageService {
    private final KafkaProducer<String, String> producer;

    public MessageService() {
        this.producer = new KafkaProducer<>(createProducerConfig());
    }

    public void sendMessage(String message) {
        producer.send(new ProducerRecord<>("topic", message));
    }

    @PreDestroy
    public void close() {
        producer.close();
    }
}
```

Best Practices Summary

☑ Producer Configuration Best Practices

1. **Enable idempotence** by default (`enable.idempotence=true`)
2. **Use appropriate** `acks` setting (`all` for production)
3. **Set reasonable timeouts** (`request.timeout.ms=30000`)
4. **Configure proper batching** (`batch.size=16384`, `linger.ms=5-20`)
5. **Use compression** (`compression.type=gzip` or `lz4`)

☑ Application Best Practices

1. **Reuse producer instances** - they're thread-safe
2. **Handle exceptions properly** - distinguish retriable vs non-retriable
3. **Use async sends** - don't block application threads
4. **Monitor metrics** - track success rate, latency, errors
5. **Implement circuit breakers** - handle prolonged failures gracefully

☑ Operational Best Practices

1. **Monitor producer metrics** - `record-send-rate`, `record-error-rate`
2. **Set up alerting** - on error rates, buffer exhaustion
3. **Plan for backpressure** - handle when Kafka is slow/down
4. **Test failure scenarios** - broker failures, network partitions
5. **Capacity planning** - monitor throughput trends

🌍 Real-World Use Cases

1. E-commerce Order Processing

```
@Service
public class OrderService {
    private final KafkaProducer<String, OrderEvent> producer;

    @Transactional
    public void processOrder(Order order) {
        // Save to database
        orderRepository.save(order);

        // Publish event for downstream services
        OrderEvent event = new OrderEvent(order.getId(), order.getUserId(),
            order.getAmount(), OrderStatus.CREATED);

        ProducerRecord<String, OrderEvent> record =
            new ProducerRecord<>("order-events", order.getUserId(), event);

        producer.send(record, (metadata, exception) -> {
            if (exception != null) {
                // Compensating action or alert
```

```
                logger.error("Failed to publish order event", exception);
                orderEventFailureHandler.handle(order, exception);
            }
        });
    }
}
```

Why Kafka for Orders:

- **Decoupling**: Order service doesn't depend on inventory, payment services
- **Reliability**: Events are persisted and can be replayed
- **Scalability**: Multiple consumers can handle different aspects

2. Real-time Analytics and Monitoring

```
@Component
public class MetricsProducer {
    private final KafkaProducer<String, MetricEvent> producer;

    @Scheduled(fixedDelay = 1000) // Every second
    public void publishSystemMetrics() {
        // CPU usage
        double cpuUsage = systemMonitor.getCpuUsage();
        publishMetric("system.cpu.usage", cpuUsage, "percentage");

        // Memory usage
        long memoryUsed = systemMonitor.getMemoryUsed();
        publishMetric("system.memory.used", memoryUsed, "bytes");

        // Request rate
        double requestRate = applicationMonitor.getRequestRate();
        publishMetric("app.requests.rate", requestRate, "requests/sec");
    }

    private void publishMetric(String metricName, double value, String unit) {
        MetricEvent event = new MetricEvent(metricName, value, unit,
            System.currentTimeMillis(), "hostname");

        // Partition by metric name for consistent routing
        ProducerRecord<String, MetricEvent> record =
            new ProducerRecord<>("system-metrics", metricName, event);

        producer.send(record); // Fire and forget for metrics
    }
}
```

Configuration for High-Volume Metrics:

```
Properties metricsProducerConfig() {
    Properties props = new Properties();
    props.put(ProducerConfig.BOOTSTRAP_SERVERS_CONFIG, "localhost:9092");

    // Optimize for throughput over reliability
    props.put(ProducerConfig.ACKS_CONFIG, "1"); // Leader ack only
    props.put(ProducerConfig.BATCH_SIZE_CONFIG, 65536); // 64KB batches
    props.put(ProducerConfig.LINGER_MS_CONFIG, 100); // Wait 100ms for batch
    props.put(ProducerConfig.COMPRESSION_TYPE_CONFIG, "lz4"); // Fast compression

    return props;
}
```

3. Financial Transaction Processing

```
@Service
public class PaymentProcessor {
    private final KafkaProducer<String, PaymentEvent> producer;

    @Transactional
    public void processPayment(PaymentRequest request) {
        try {
            // Initialize transaction
            producer.initTransactions();
            producer.beginTransaction();

            // Validate payment
            PaymentValidation validation = paymentValidator.validate(request);
            if (!validation.isValid()) {
                throw new PaymentValidationException(validation.getErrors());
            }

            // Process payment with external service
            PaymentResult result = externalPaymentService.processPayment(request);

            // Record events atomically
            PaymentEvent event = new PaymentEvent(request.getPaymentId(),
                result.getStatus(), request.getAmount(),
System.currentTimeMillis());

            producer.send(new ProducerRecord<>("payment-events",
                request.getPaymentId(), event));

            // Update account balance event
            AccountEvent accountEvent = new AccountEvent(request.getAccountId(),
                AccountEventType.DEBIT, request.getAmount());

            producer.send(new ProducerRecord<>("account-events",
                request.getAccountId(), accountEvent));
```

```
            // Commit transaction
            producer.commitTransaction();

        } catch (Exception e) {
            producer.abortTransaction();
            throw new PaymentProcessingException("Payment failed", e);
        }
    }
}
```

Transactional Configuration:

```
Properties transactionalConfig() {
    Properties props = new Properties();
    props.put(ProducerConfig.BOOTSTRAP_SERVERS_CONFIG, "localhost:9092");
    props.put(ProducerConfig.TRANSACTIONAL_ID_CONFIG, "payment-processor-1");
    // Exactly-once semantics automatically configured
    return props;
}
```

4. IoT Sensor Data Streaming

```
@Service
public class IoTDataProducer {
    private final KafkaProducer<String, SensorReading> producer;

    public void publishSensorReading(String sensorId, SensorReading reading) {
        // Custom partitioner routes by geographic region
        ProducerRecord<String, SensorReading> record =
            new ProducerRecord<>("sensor-data", sensorId, reading);

        // Add metadata headers
        record.headers().add("sensor-type", reading.getSensorType().getBytes());
        record.headers().add("location", reading.getLocation().getBytes());
        record.headers().add("timestamp",
            String.valueOf(reading.getTimestamp()).getBytes());

        producer.send(record, (metadata, exception) -> {
            if (exception != null) {
                // Log error but don't fail - sensor data is high volume
                logger.warn("Failed to send sensor reading for {}: {}",
                    sensorId, exception.getMessage());

                // Could implement local buffering or retry queue
                sensorFailureBuffer.add(record);
            }
        });
    }
}
```

5. Log Aggregation from Microservices

```
@Component
public class StructuredLogger {
    private final KafkaProducer<String, LogEvent> producer;

    public void logEvent(String service, LogLevel level, String message,
                         Map<String, Object> context) {
        LogEvent event = LogEvent.builder()
            .service(service)
            .level(level)
            .message(message)
            .context(context)
            .timestamp(System.currentTimeMillis())
            .hostname(getHostname())
            .build();

        // Partition by service for consistent routing
        ProducerRecord<String, LogEvent> record =
            new ProducerRecord<>("application-logs", service, event);

        producer.send(record); // Async - don't slow down application
    }
}

// Usage in application code
@RestController
public class UserController {

    @Autowired
    private StructuredLogger logger;

    @PostMapping("/users")
    public ResponseEntity<User> createUser(@RequestBody CreateUserRequest request)
{
        Map<String, Object> context = Map.of(
            "userId", request.getUserId(),
            "email", request.getEmail(),
            "source", "web-app"
        );

        logger.logEvent("user-service", LogLevel.INFO,
            "Creating new user", context);

        // ... business logic ...

        return ResponseEntity.ok(user);
    }
}
```

Version Highlights

Kafka 4.0 (September 2025) - Current Latest

- ✨ **Default KRaft Mode**: ZooKeeper completely removed
- ✨ **New Consumer Protocol (KIP-848)**: Faster rebalancing, better partition assignment
- ✨ **Enhanced Producer Batching**: Improved sticky partitioner performance
- ✨ **Java 17+ Required**: For brokers (Java 11+ for clients)

Kafka 3.x Series Producer Features

- **3.6** (Oct 2023): Producer metrics improvements, better error reporting
- **3.5** (Jun 2023): Enhanced idempotent producer stability
- **3.4** (Feb 2023): Improved transactional producer performance
- **3.3** (Oct 2022): Producer client optimizations for KRaft
- **3.2** (May 2022): Better producer error handling and retry logic
- **3.1** (Jan 2022): Producer connection pooling improvements
- **3.0** (Sep 2021): **Idempotence enabled by default**, improved batching

Key Producer Evolution

Version	Producer Feature	Impact
4.0	Enhanced batching algorithms	Better throughput
3.0	Idempotence by default	Exactly-once semantics out-of-box
2.8	Producer improvements for KRaft	Better metadata handling
2.4	Sticky partitioner	Better batching for null keys
2.1	Zstandard compression	Better compression ratios
1.1	Headers support	Metadata in messages
0.11	**Idempotent producer**	Exactly-once semantics
0.10	Message timestamps	Time-based operations
0.9	Producer rewrite	Much better performance

Current Recommendations (2025)

```
// Modern Kafka 4.0 producer configuration
public static Properties modernProducerConfig() {
    Properties props = new Properties();
    props.put(ProducerConfig.BOOTSTRAP_SERVERS_CONFIG, "localhost:9092");
    props.put(ProducerConfig.KEY_SERIALIZER_CLASS_CONFIG, StringSerializer.class);
    props.put(ProducerConfig.VALUE_SERIALIZER_CLASS_CONFIG,
StringSerializer.class);

    // Kafka 4.0 best practices
    props.put(ProducerConfig.ENABLE_IDEMPOTENCE_CONFIG, true); // Default since
```

```
3.0
    props.put(ProducerConfig.ACKS_CONFIG, "all");              // Strong
durability
    props.put(ProducerConfig.COMPRESSION_TYPE_CONFIG, "zstd");  // Best
compression (2.1+)

    // Optimized batching (improvements in 4.0)
    props.put(ProducerConfig.BATCH_SIZE_CONFIG, 32768);        // 32KB
    props.put(ProducerConfig.LINGER_MS_CONFIG, 10);            // 10ms

    return props;
}
```

🔗 Additional Resources

📚 Official Documentation

- Kafka Producer API Documentation
- Producer Configuration Reference
- Kafka Improvement Proposals - Producers

🎓 Learning Resources

- Confluent Producer Tutorial
- Apache Kafka: Producer Deep Dive
- Kafka Producer Best Practices

🔧 Tools & Monitoring

- JMX Metrics for Producers
- Kafka Producer Performance Testing

🐛 Troubleshooting

- Producer Error Handling
- Common Producer Issues

Last Updated: September 2025
Kafka Version: 4.0.0
Java Compatibility: 11+ (clients), 17+ (recommended)

> 💡 **Pro Tip**: Start with idempotence enabled and `acks=all` for reliability, then optimize for performance based on your specific use case requirements.