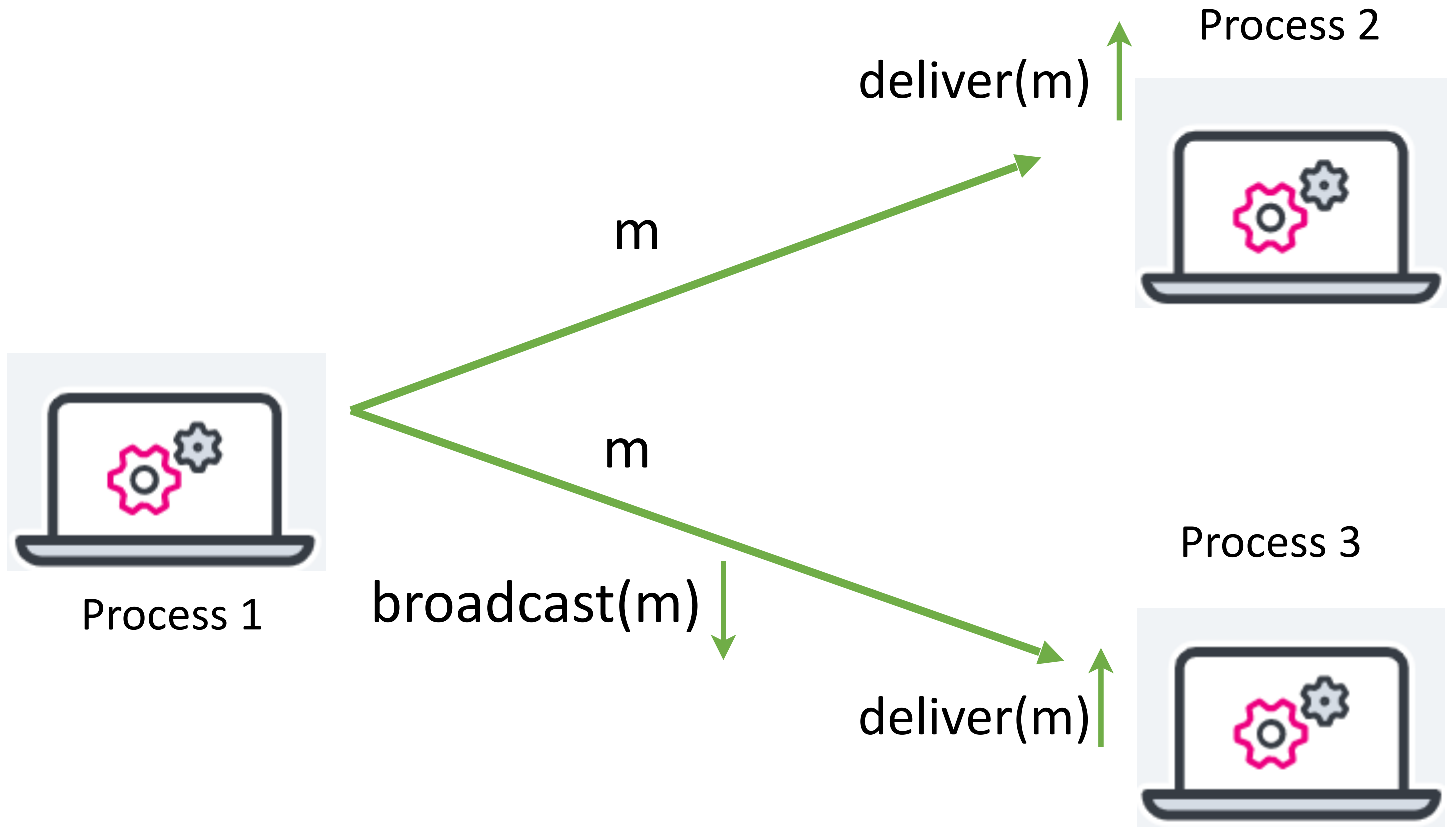
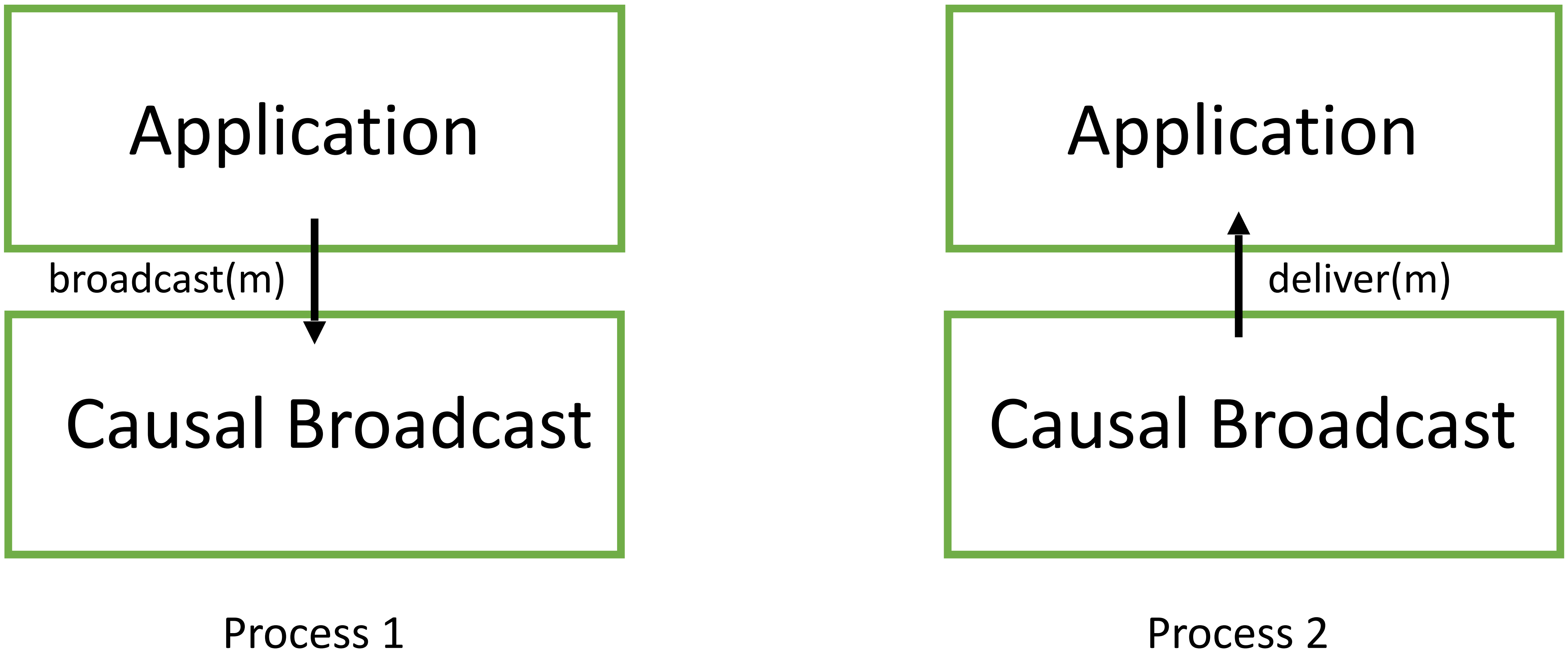
Causal Broadcast

Mohsen Lesani

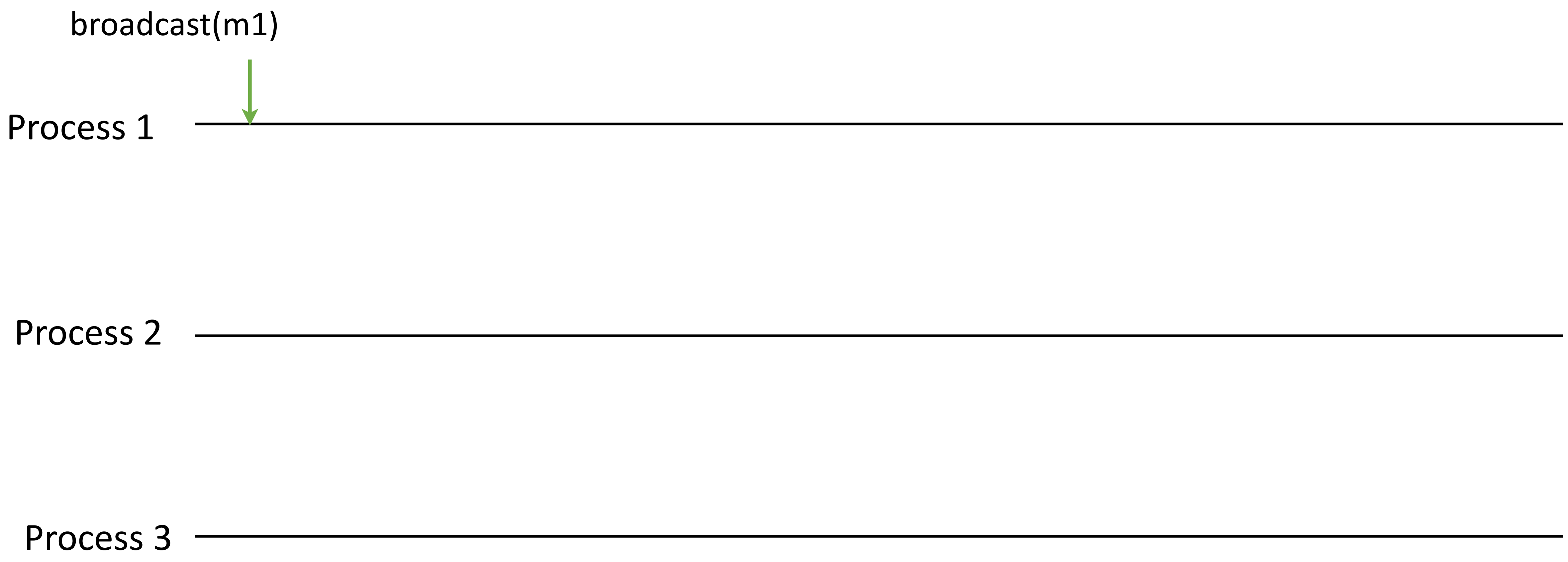
Broadcast Abstraction



Modular Design



Broadcast Execution Diagram



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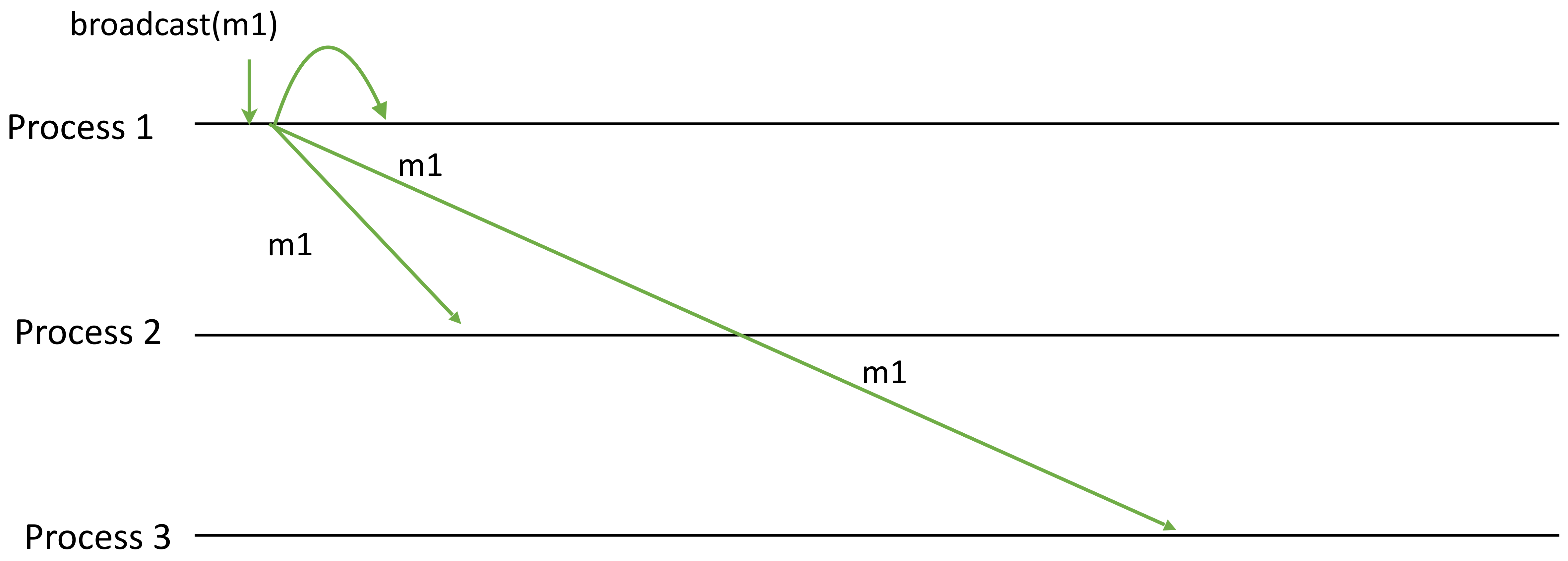

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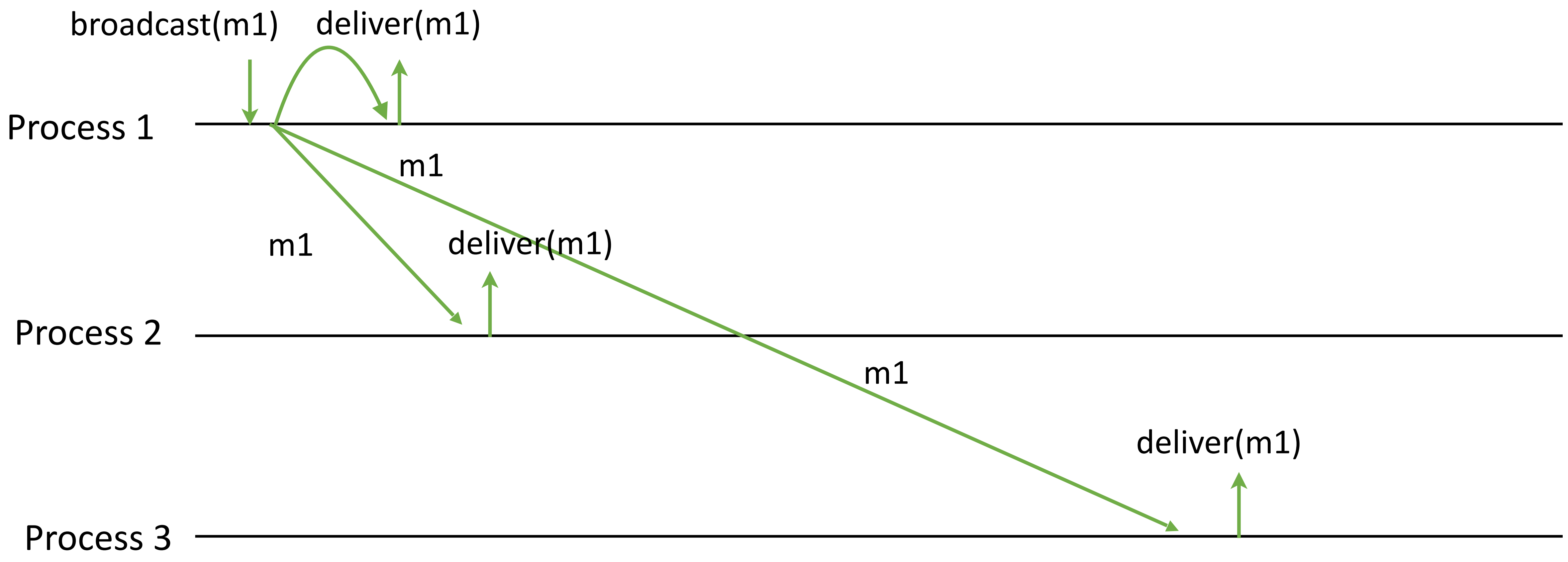

Overview

- **Motivation: why causal broadcast?**
- Properties of causal broadcast
- Protocols

Intuition

- So far, we did not consider ordering among messages; In particular, we considered messages to be independent
- Two messages from the same process might not be delivered in the order they were broadcast
- A message m1 that causes a message m2 might be delivered by some process after m2
- Consider a news or social network where every new event contains a reference to the event that caused it.

Photo and Comment

Hey, check out my cool picture.

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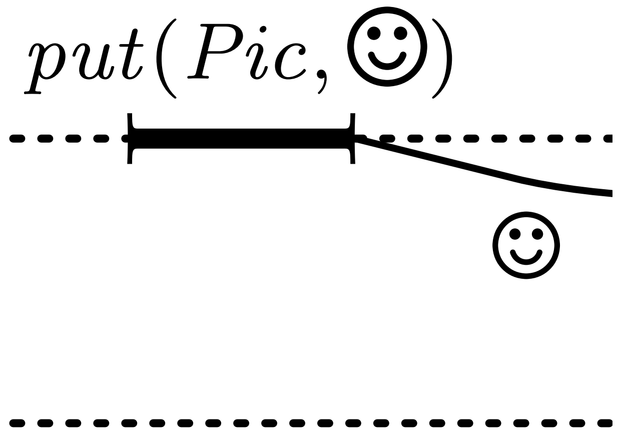

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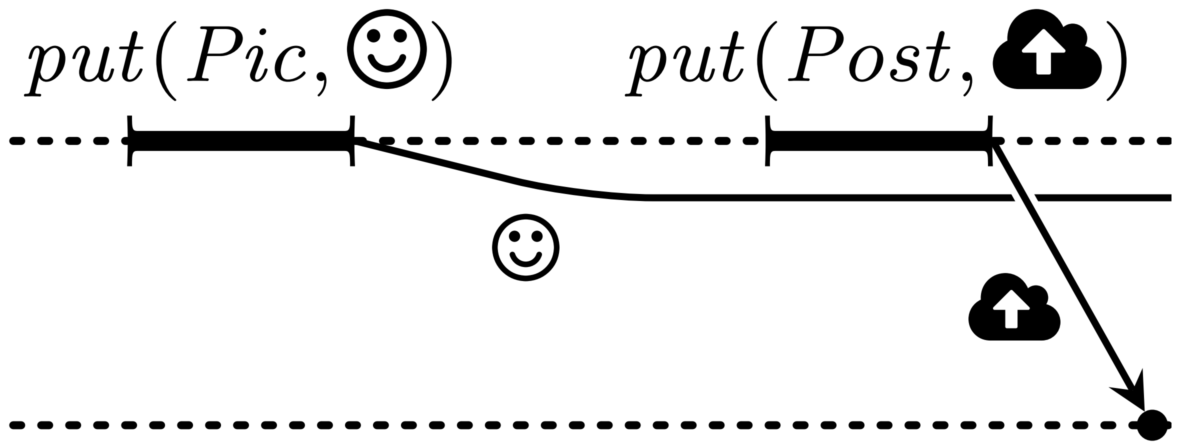

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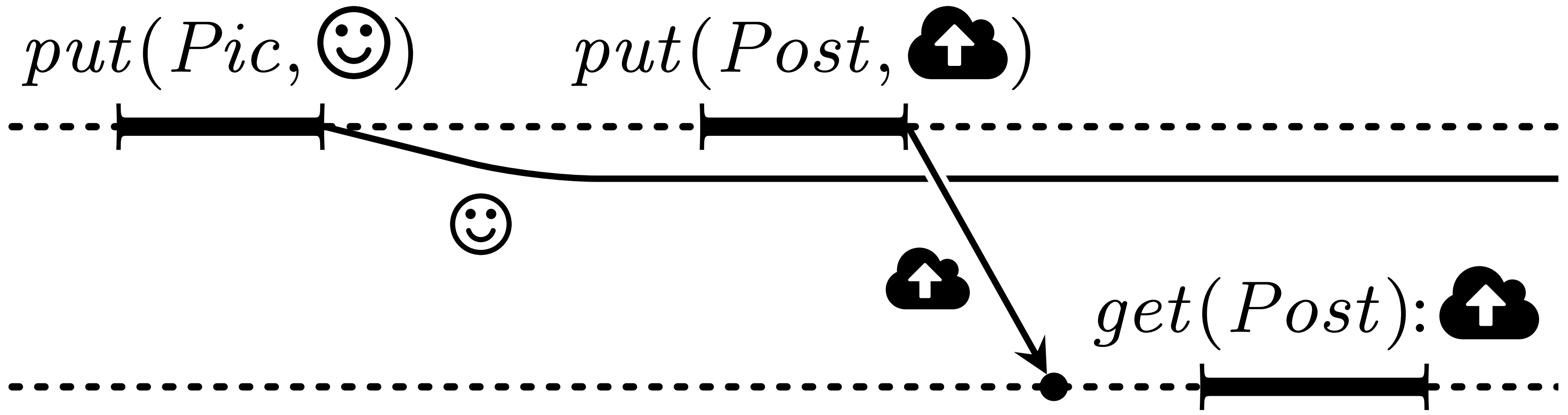

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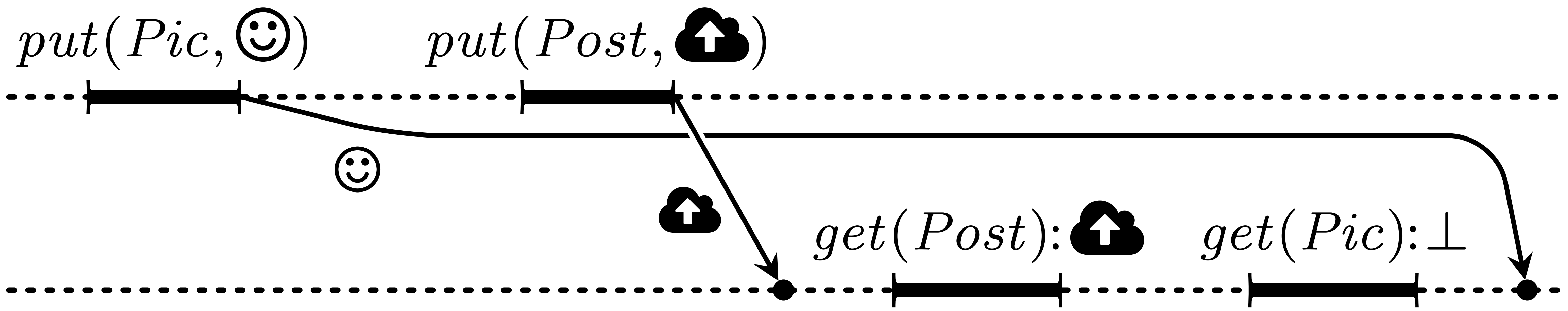
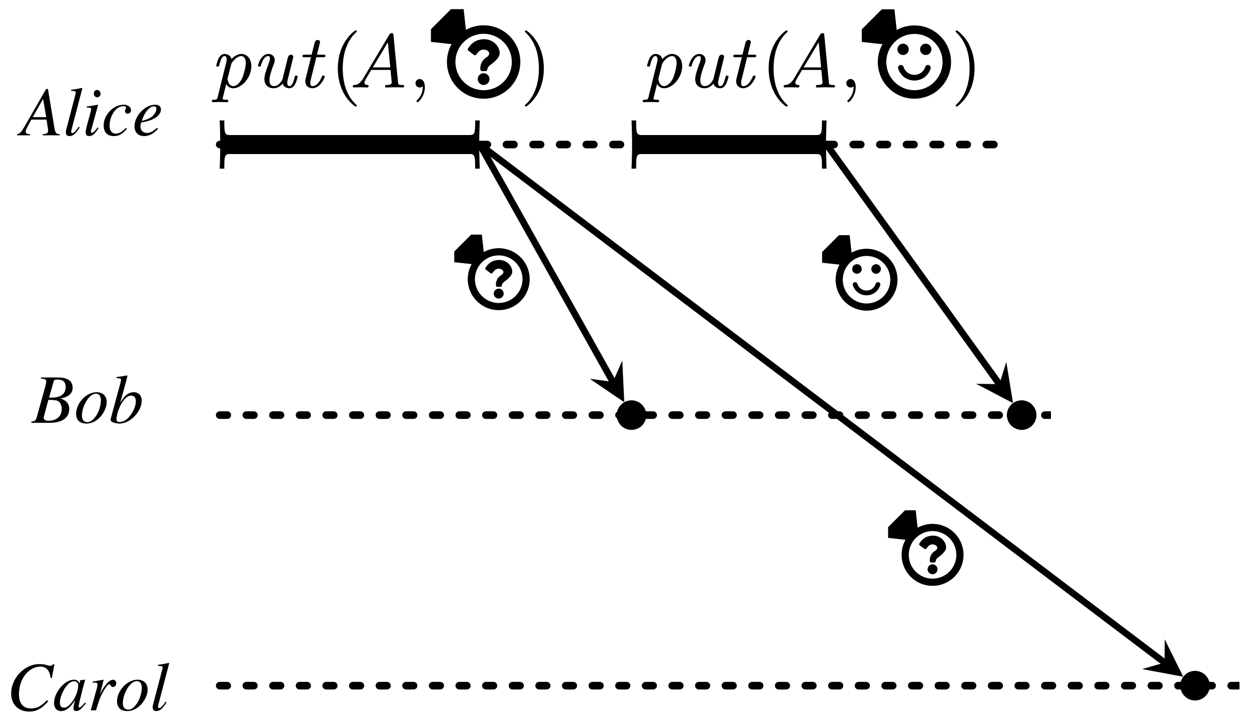


Lost Ring



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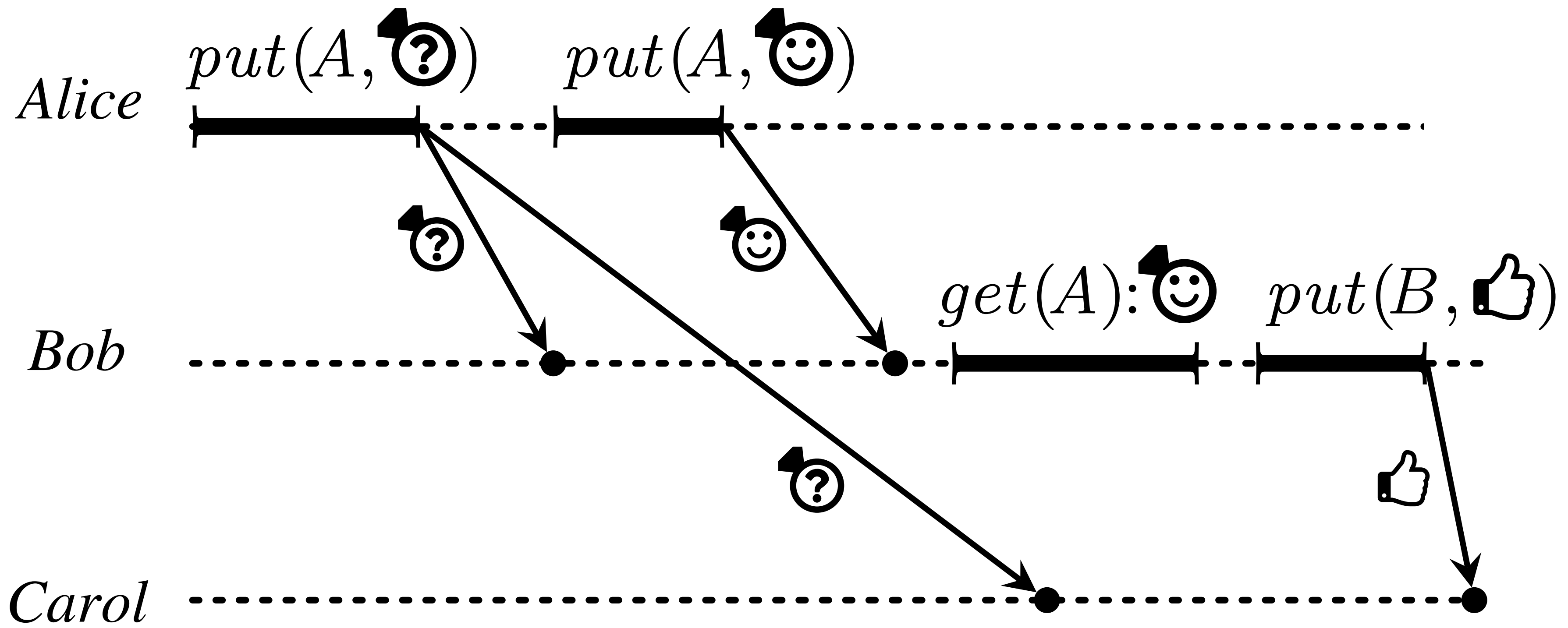

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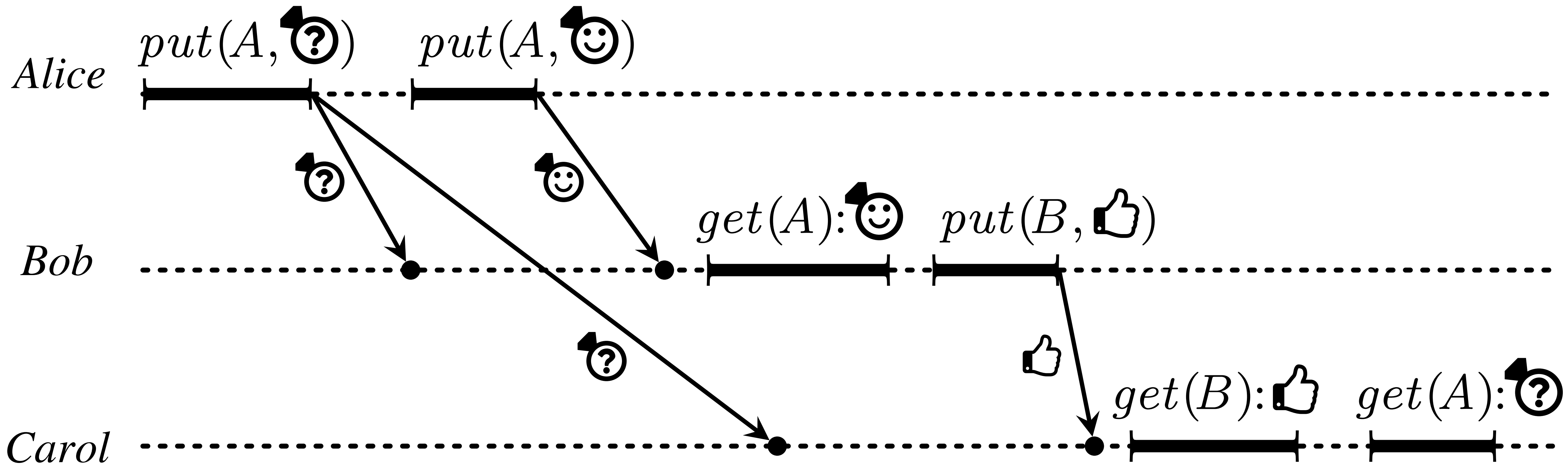


Overview

- Motivation: why causal broadcast?
- **Properties of causal broadcast**
- Protocols

Causal Order Property

If any process pi delivers a message m2,
then pi must have delivered every message m1 that m2 is **dependent** on.

Causal Relation (Dependency)

Let m1 and m2 be any two messages.
m1 < m2 (m1 is causally before m2, or m2 depends on m1) iff

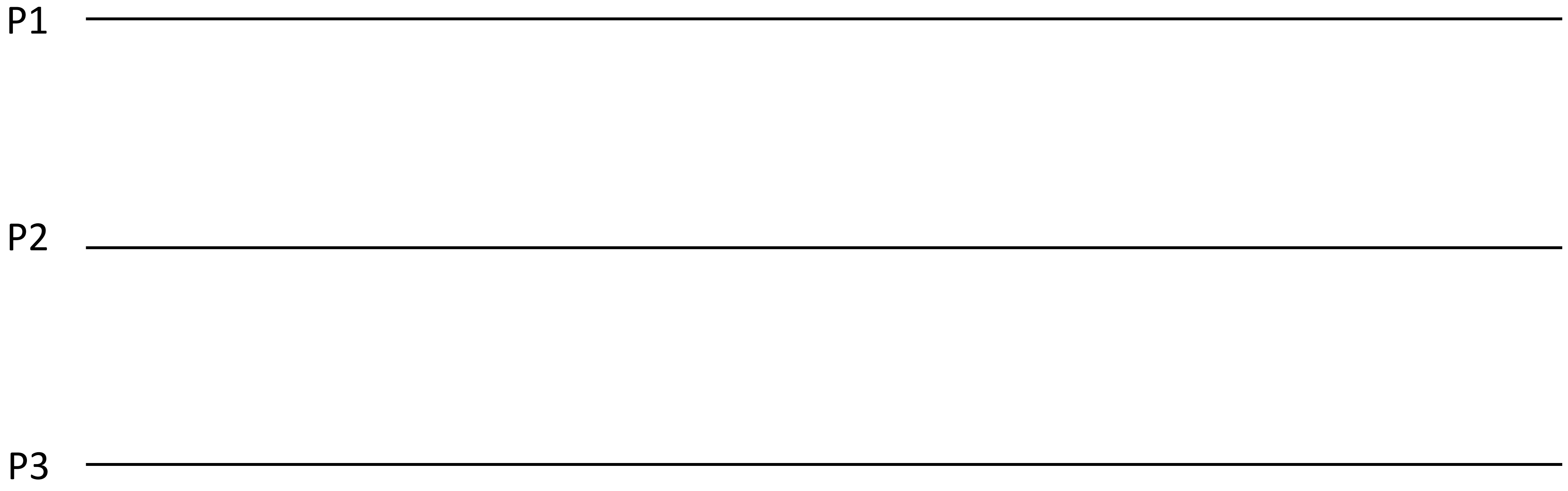
- **FIFO order:**
  A process pi broadcasts m1 before broadcasting m2.

- …

- …

Example 1: FIFO Order

If a process pi broadcasts m1 before broadcasting m2 then m1 < m2.



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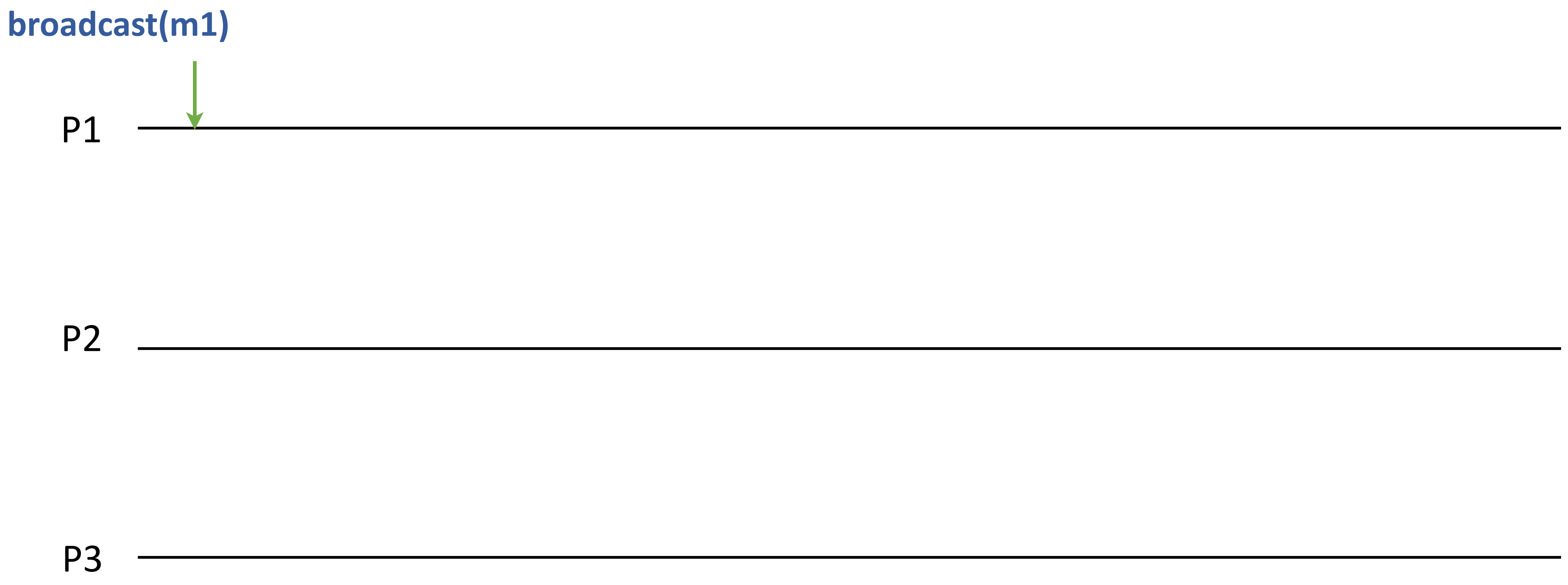

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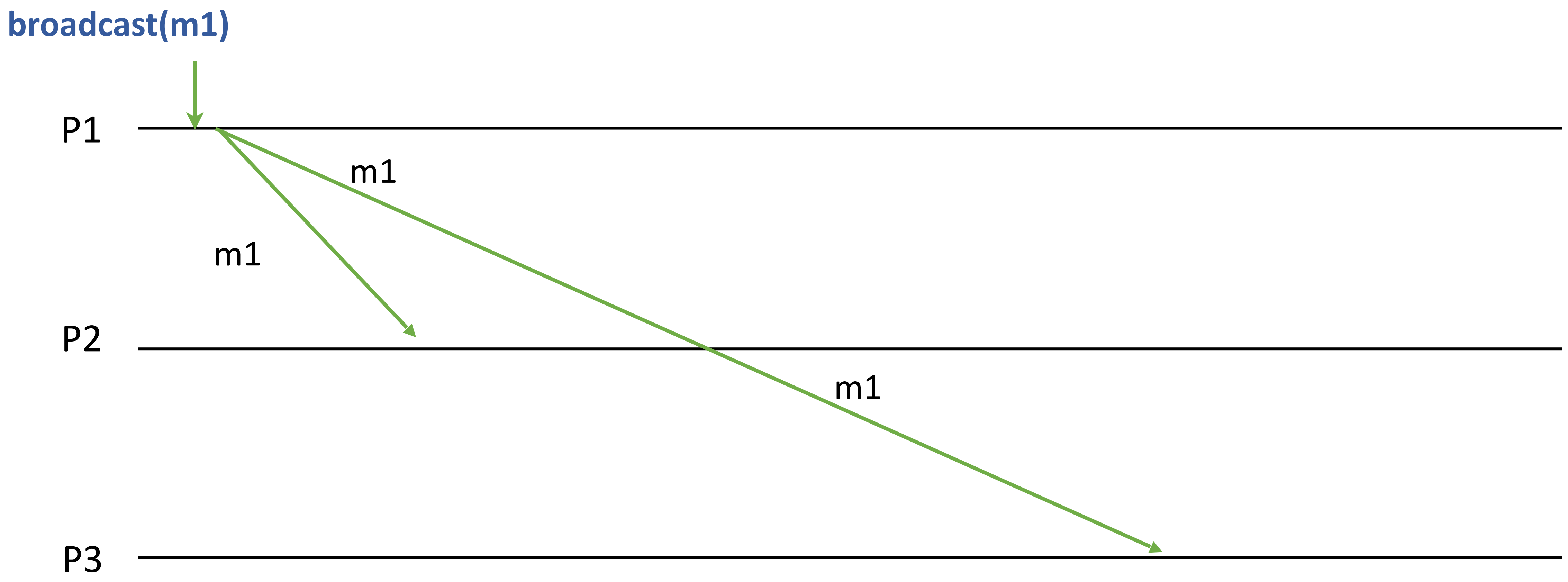

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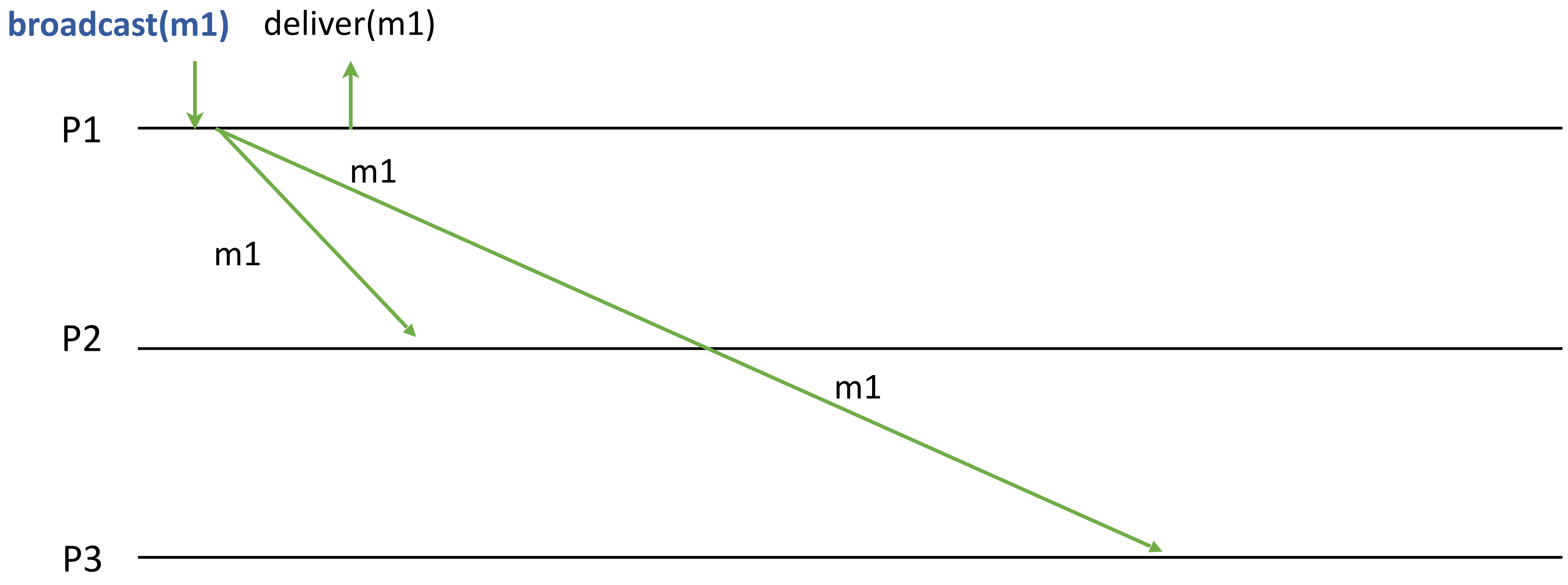

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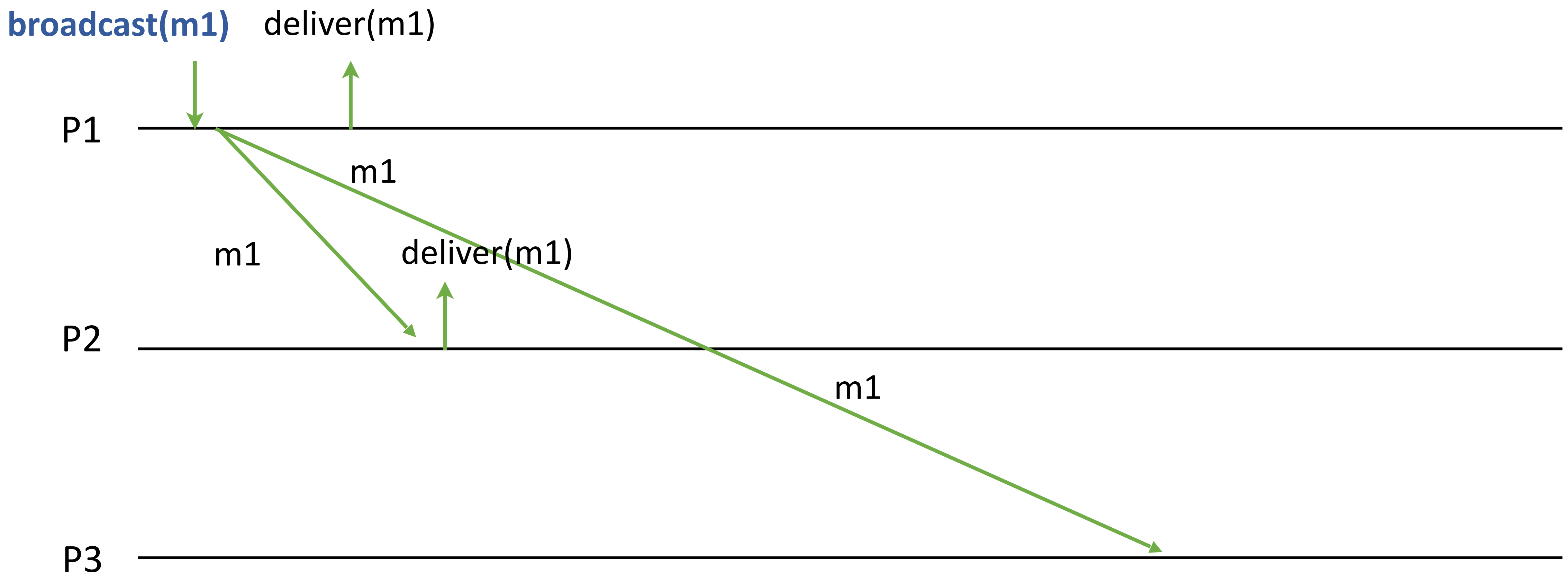

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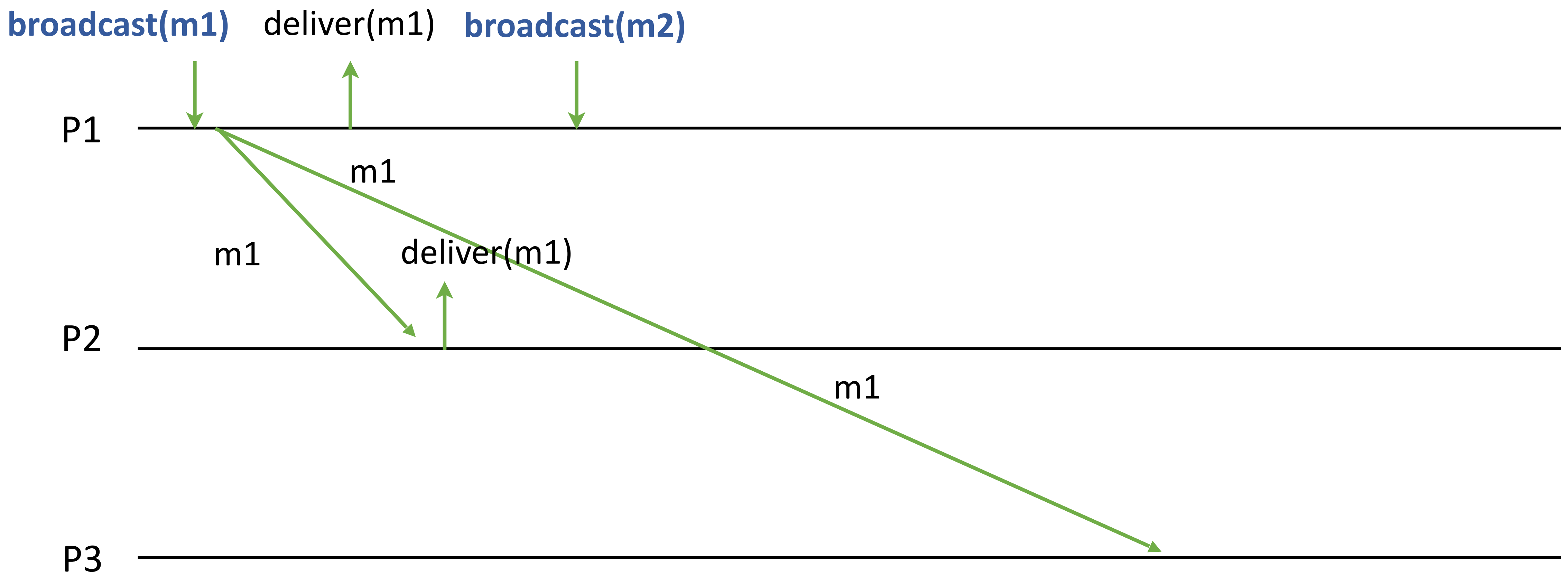

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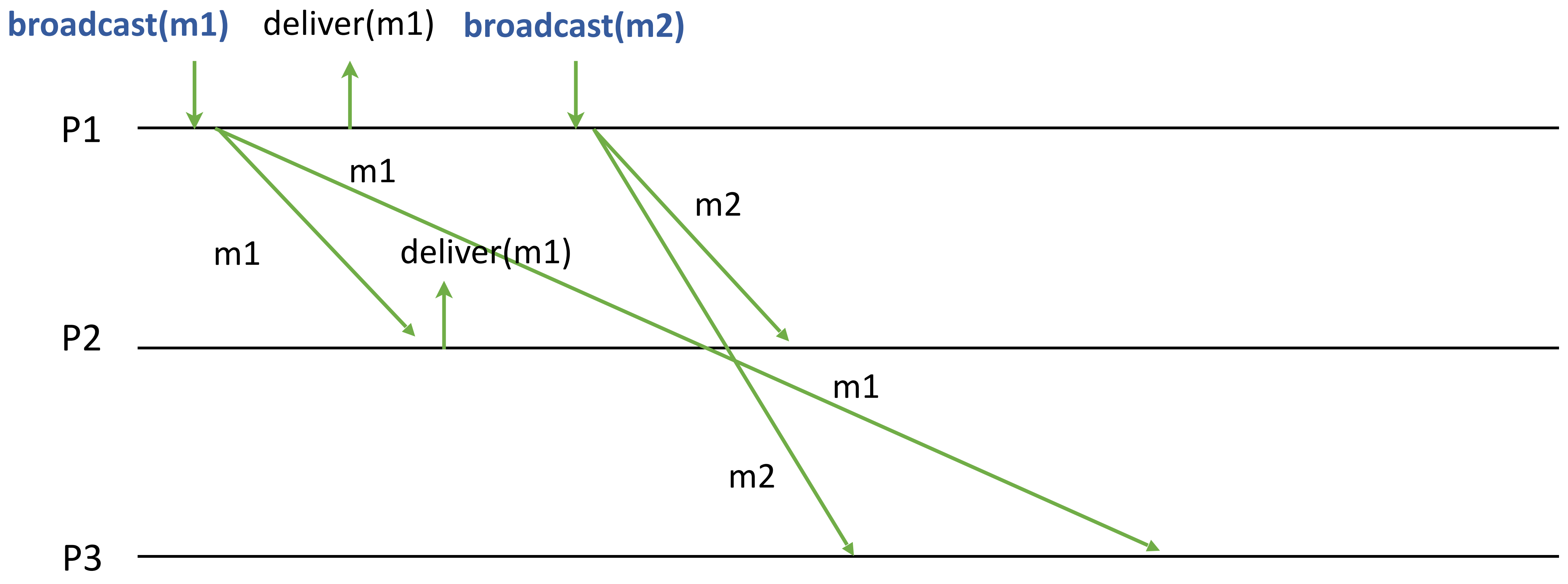

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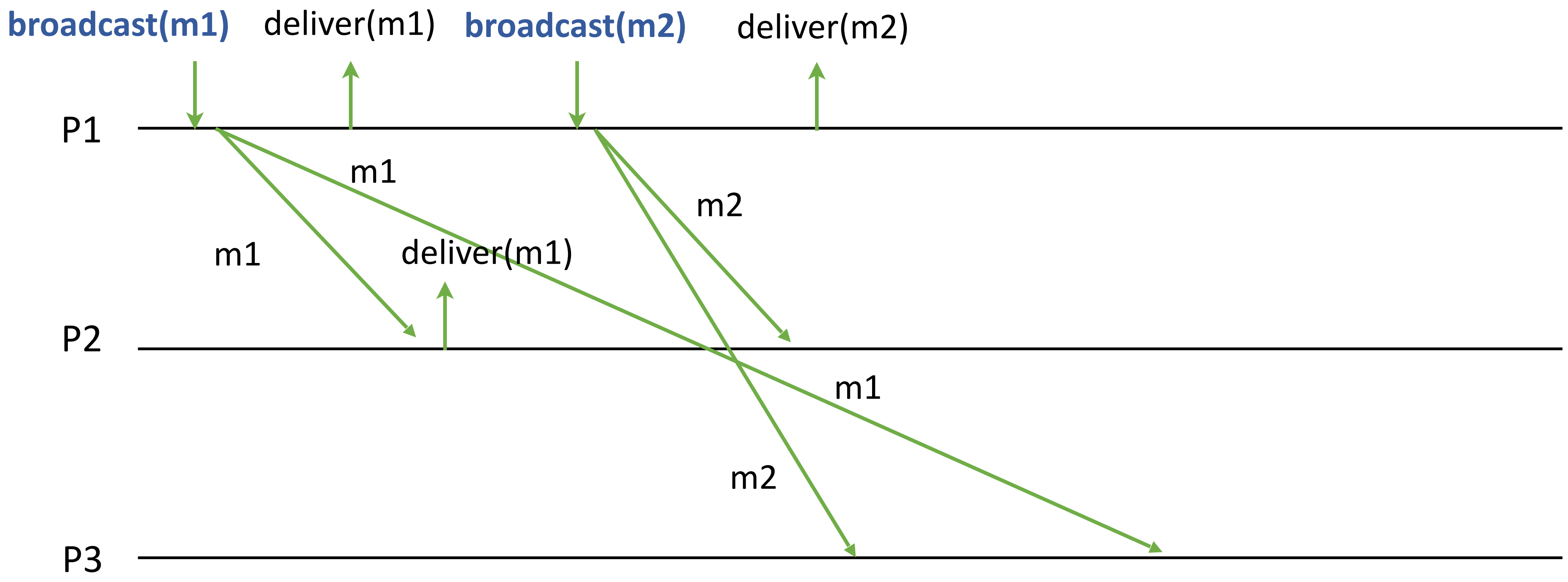

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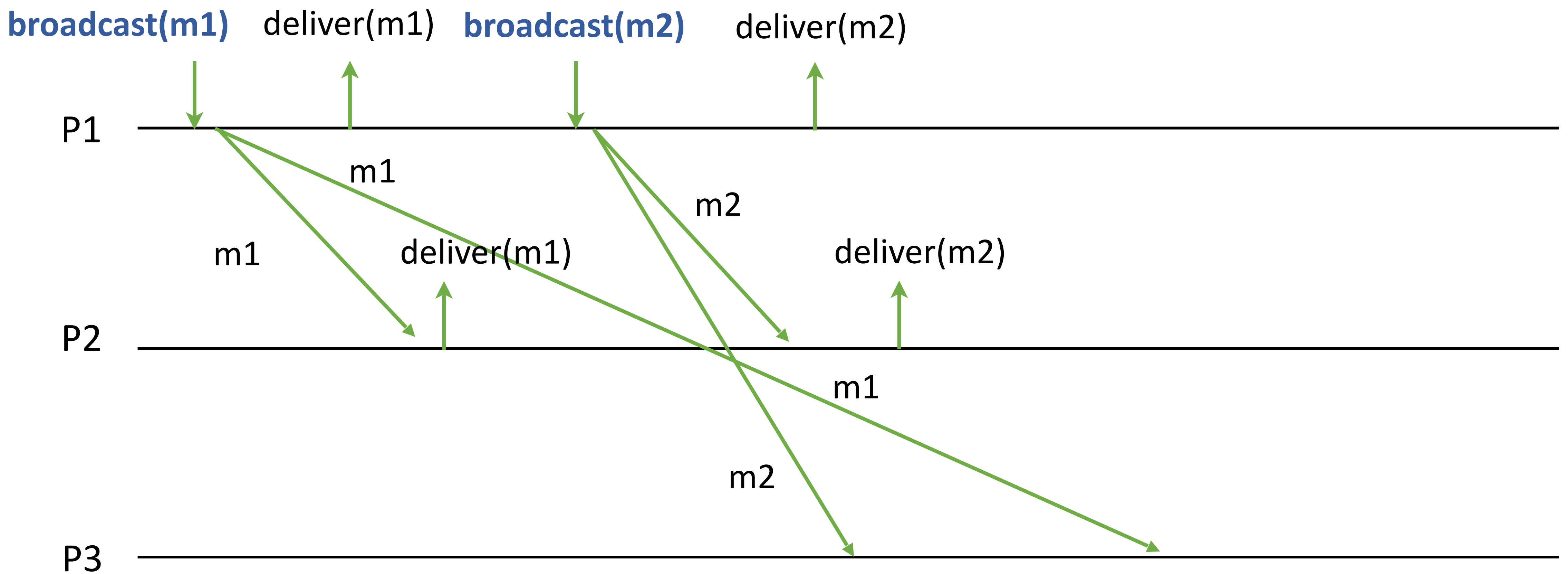

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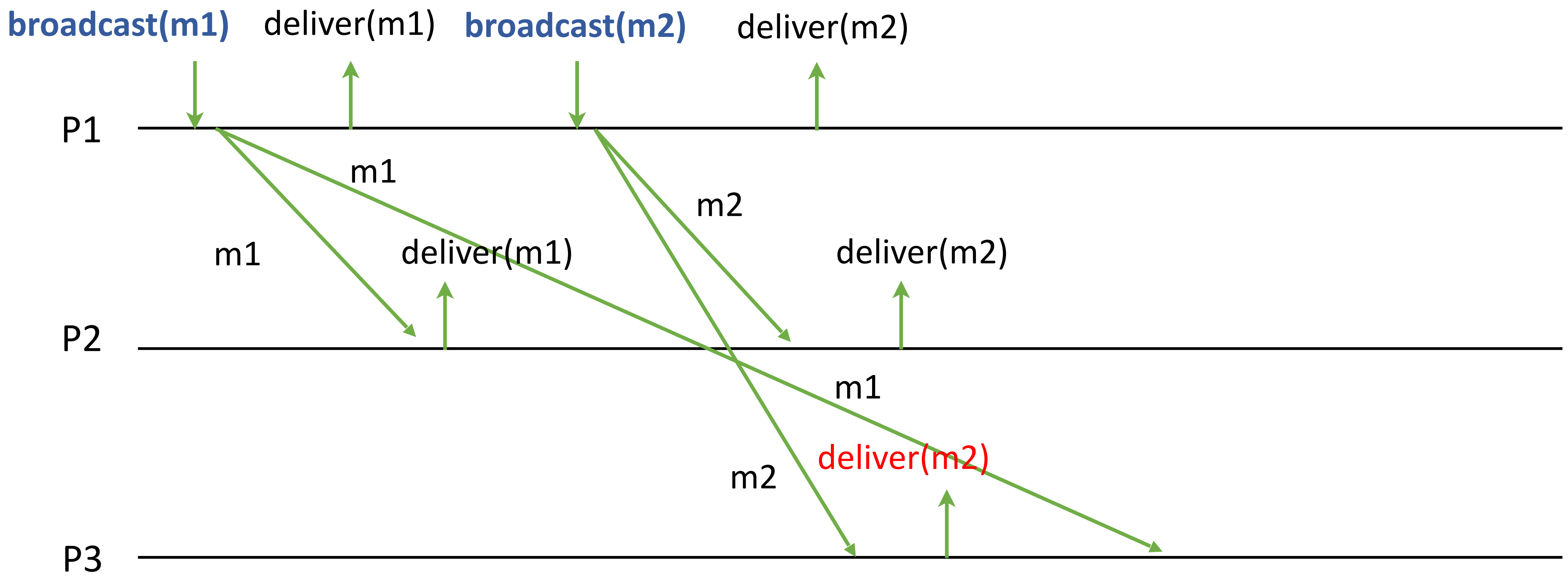

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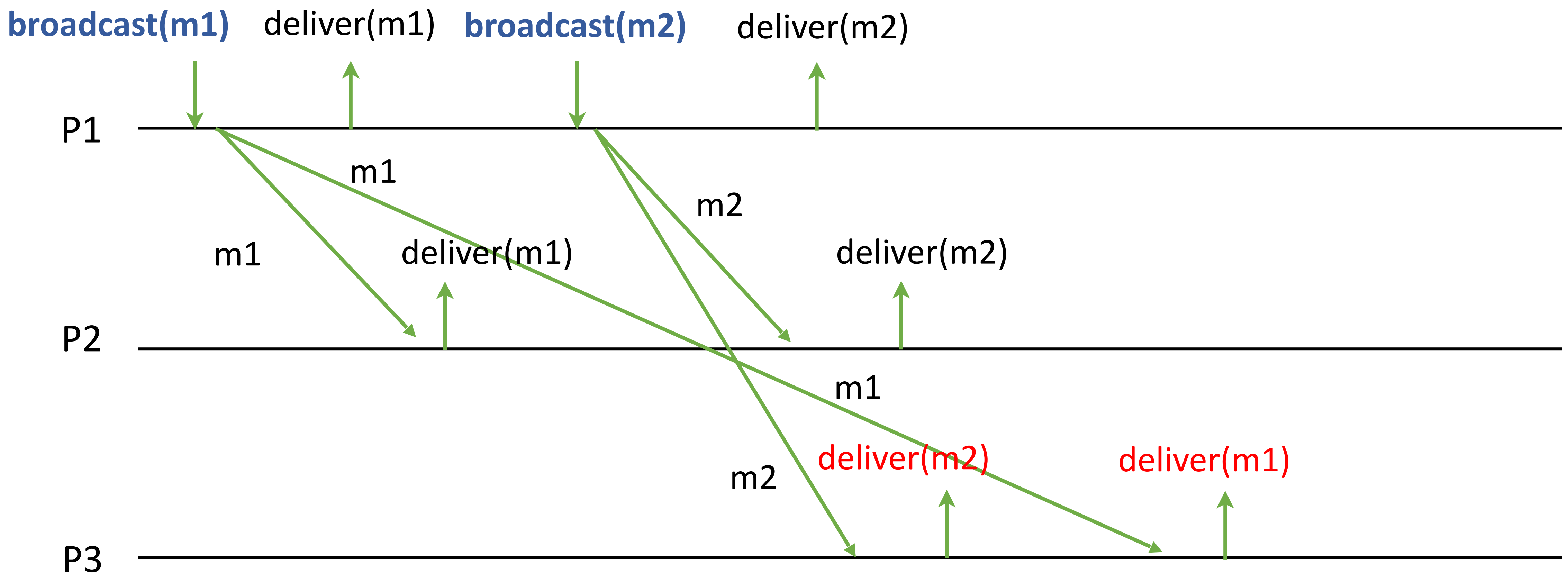

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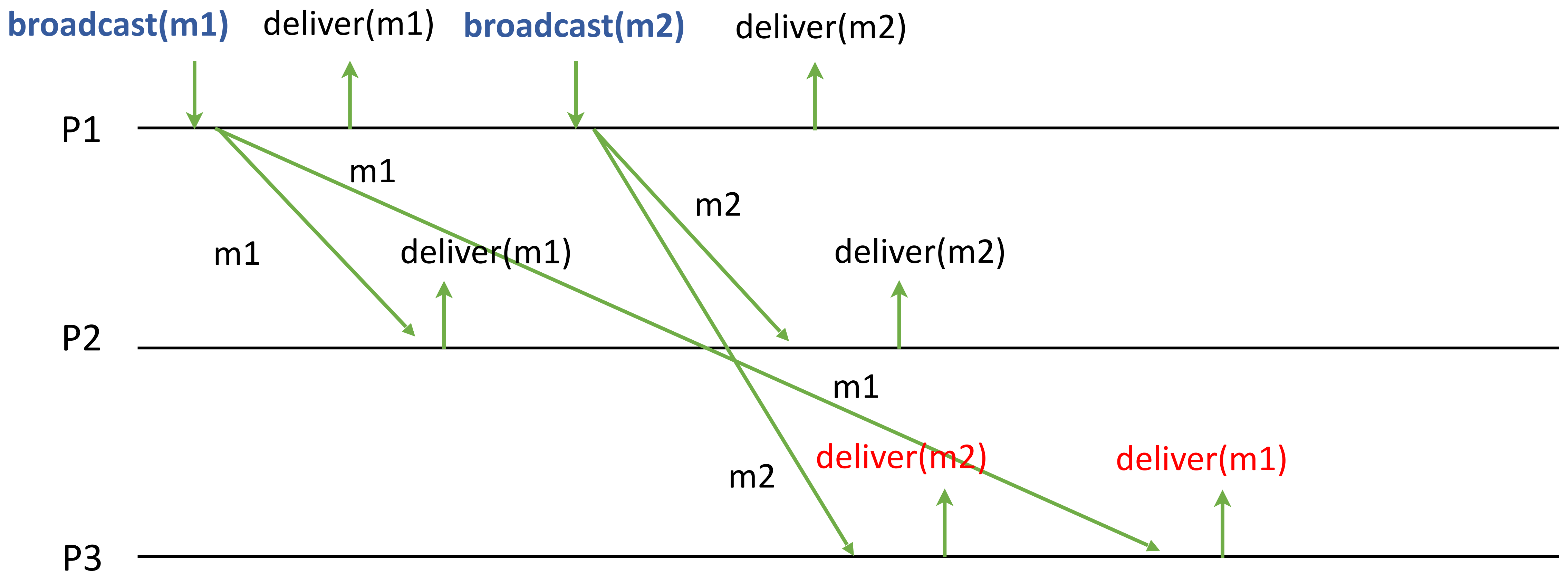

FIFO order of p1, m1 < m2, is not preserved.

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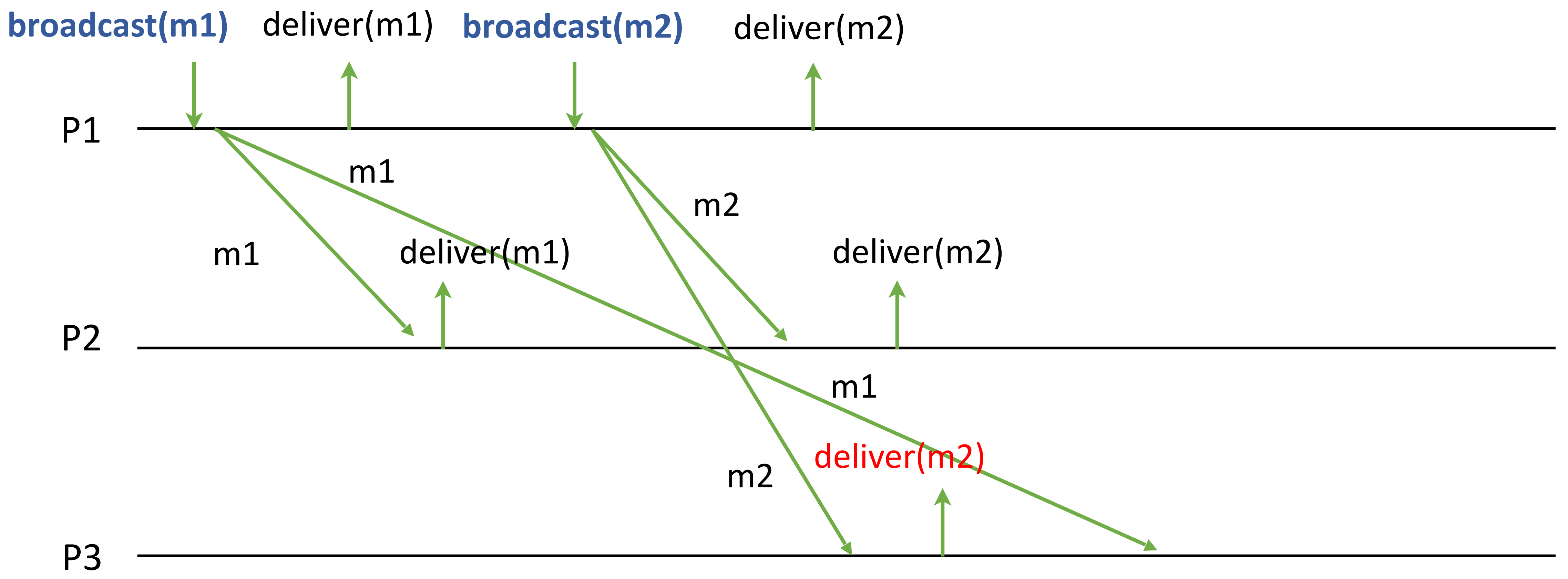

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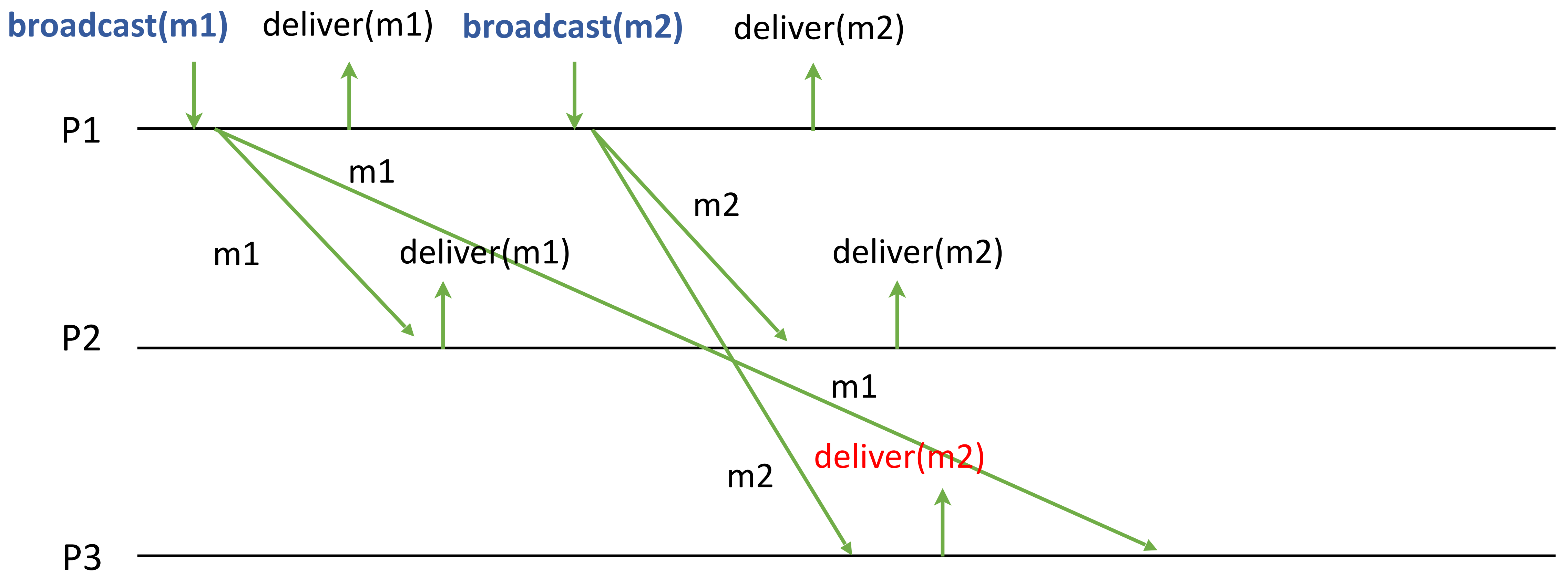


m2 delivered but m1 not delivered.
FIFO order of p1, m1 < m2, is not preserved.

Causal Relation (Dependency)

Let m1 and m2 be any two messages.
m1 < m2 (m1 is causally before m2, or m2 depends on m1) iff

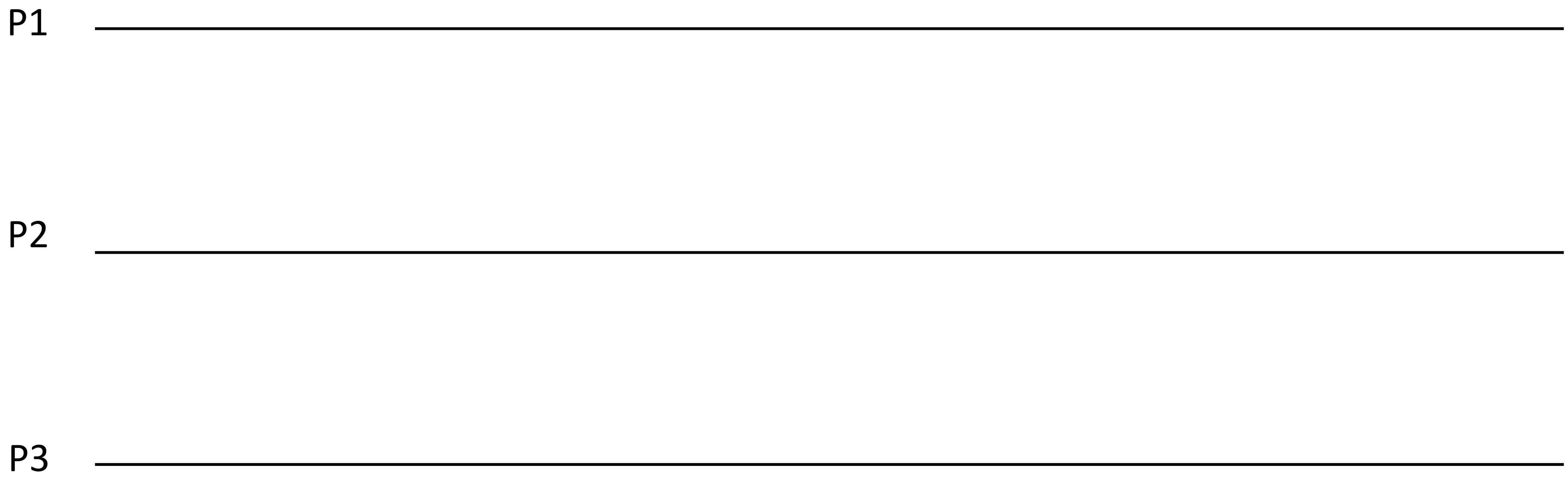
- **FIFO order:**
  A process pi broadcasts m1 before broadcasting m2.

- **InOut order:**
  A process pi delivers m1 and then broadcasts m2.

- …

Example 2: InOut Order

If a process pi delivers m1 and then broadcasts m2 then then m1 < m2.



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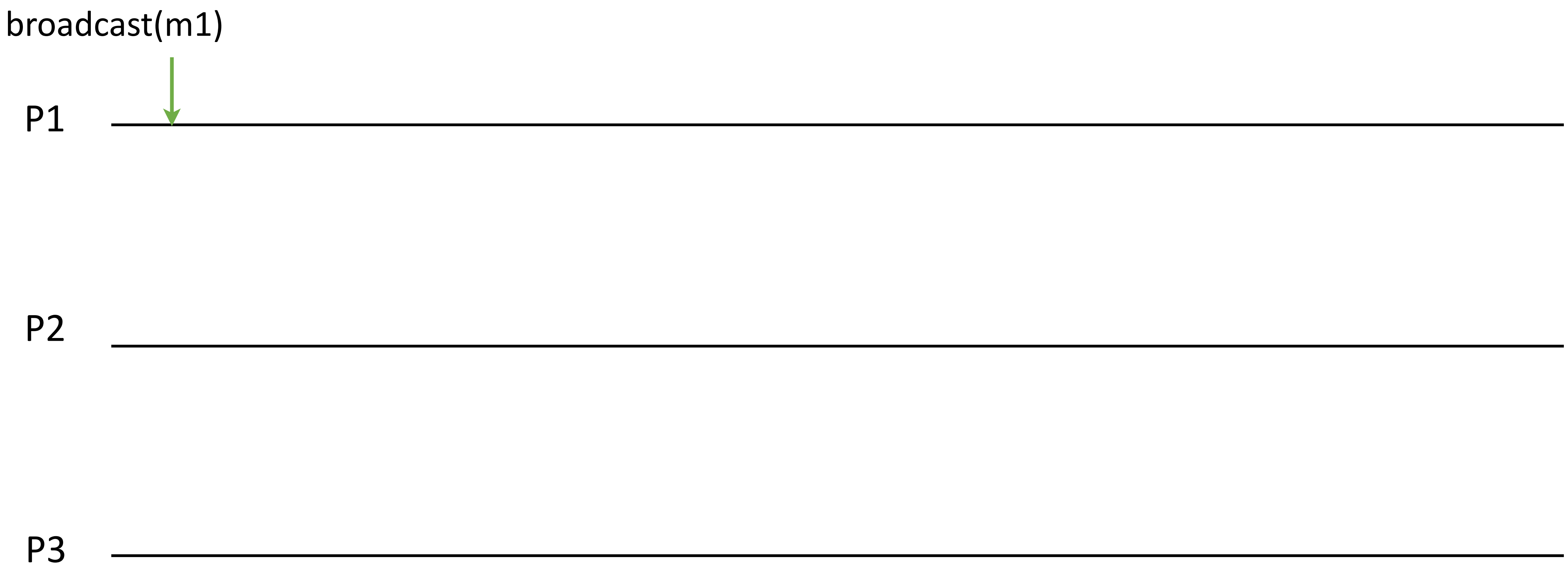

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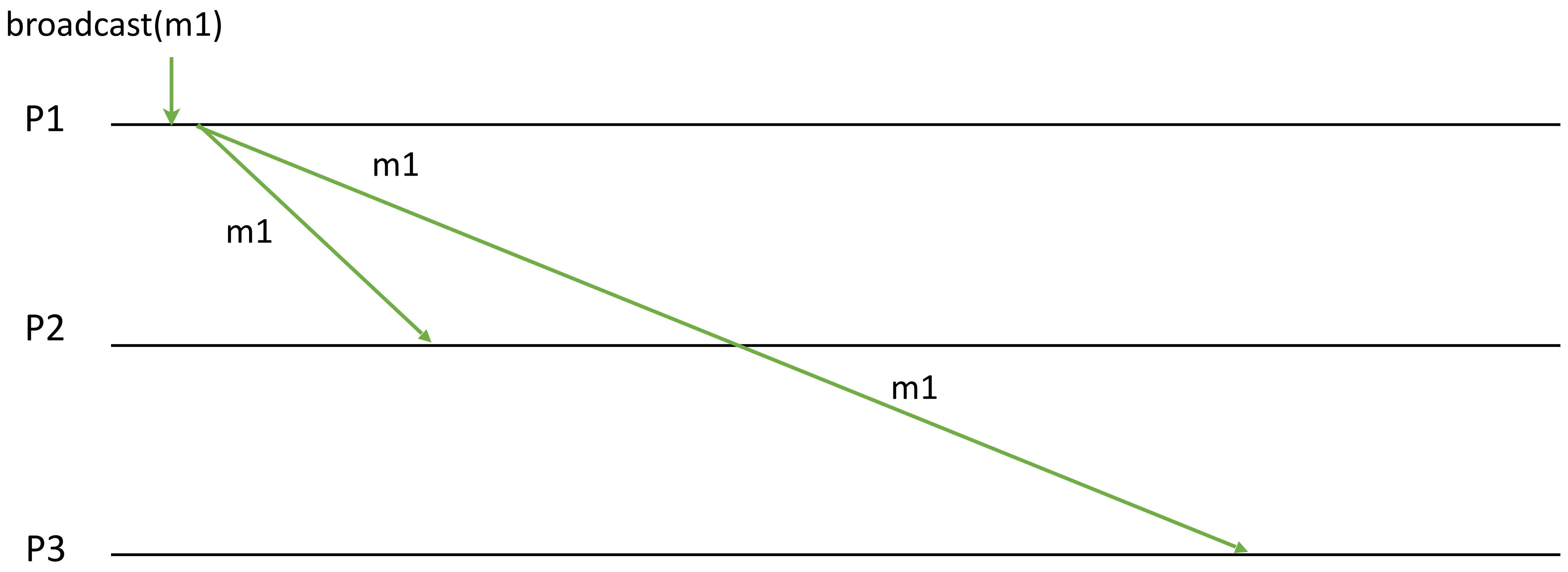

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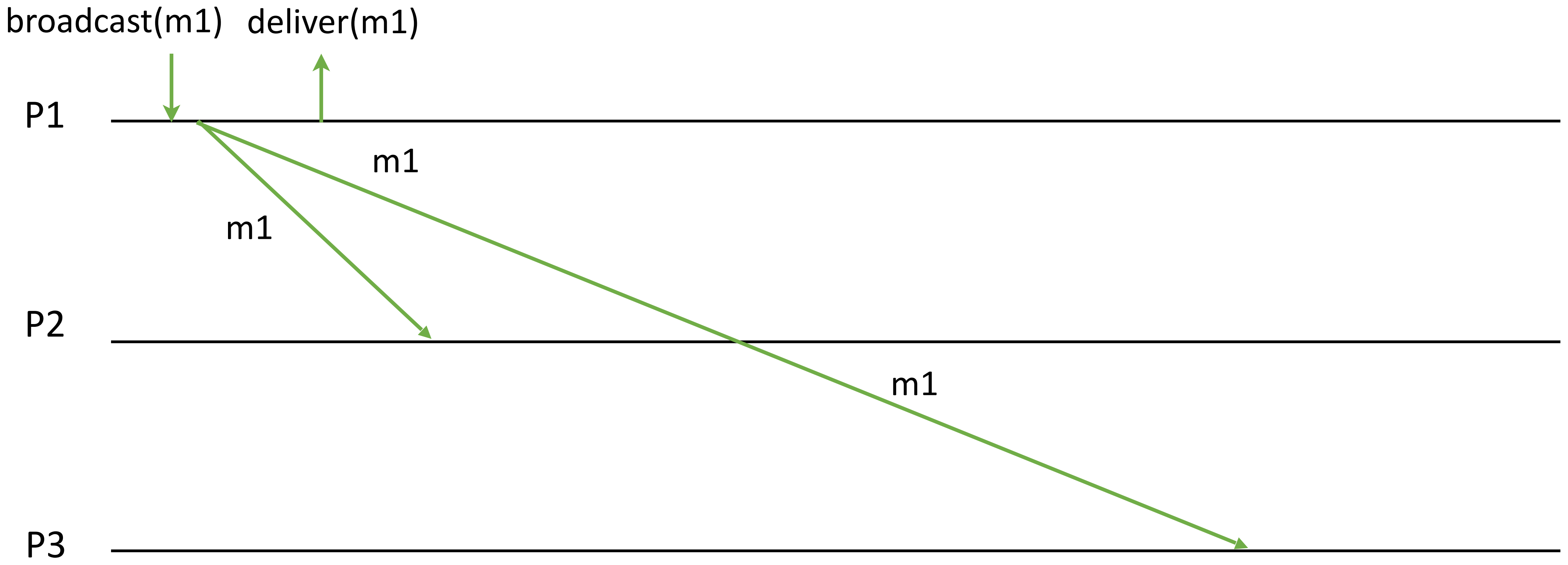

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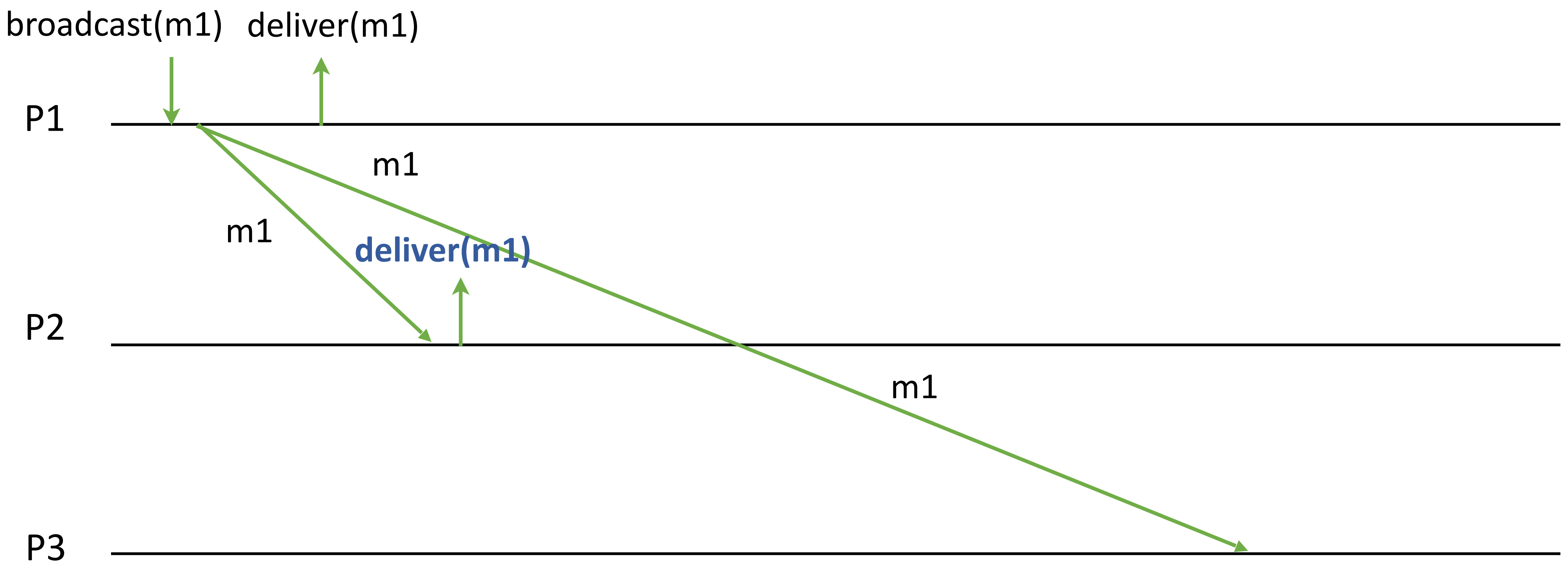

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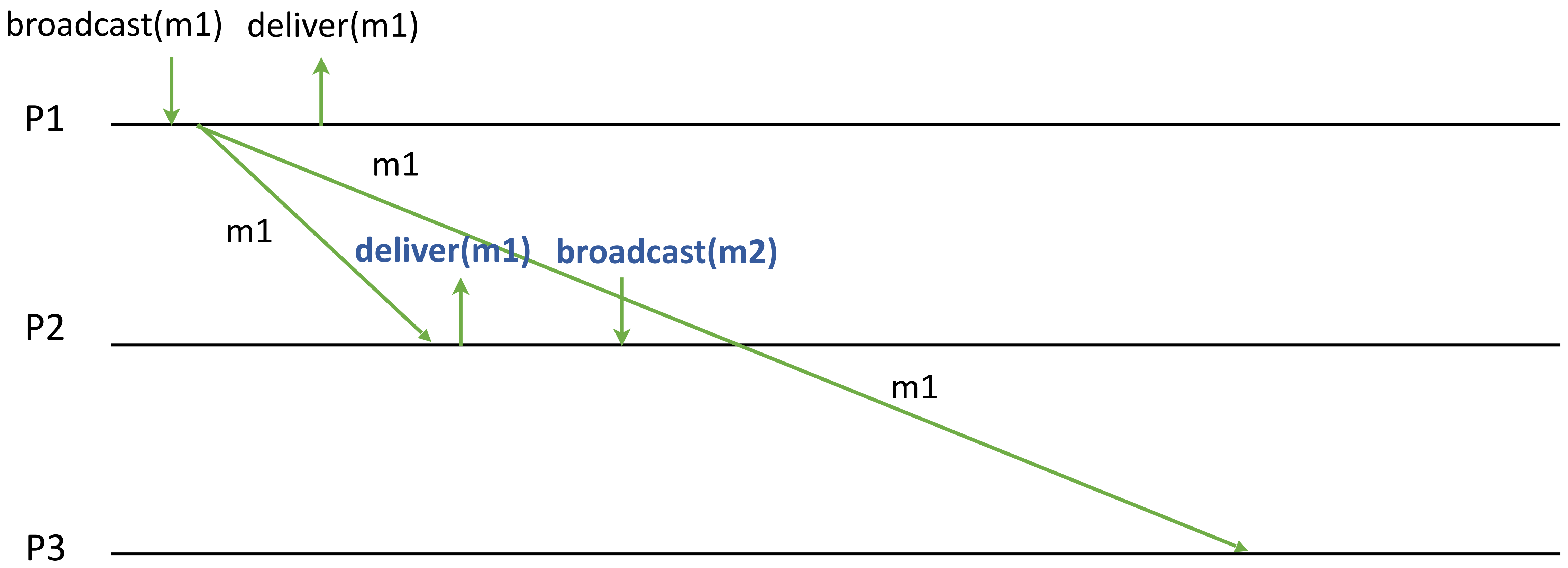

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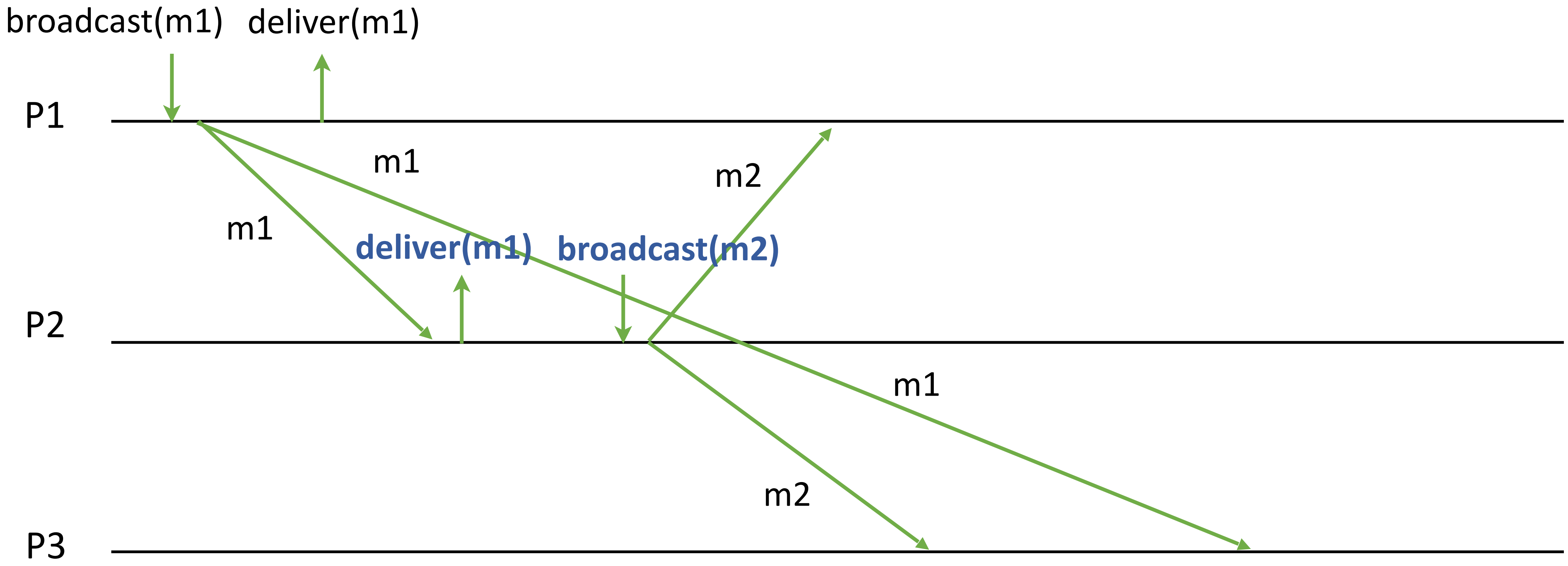

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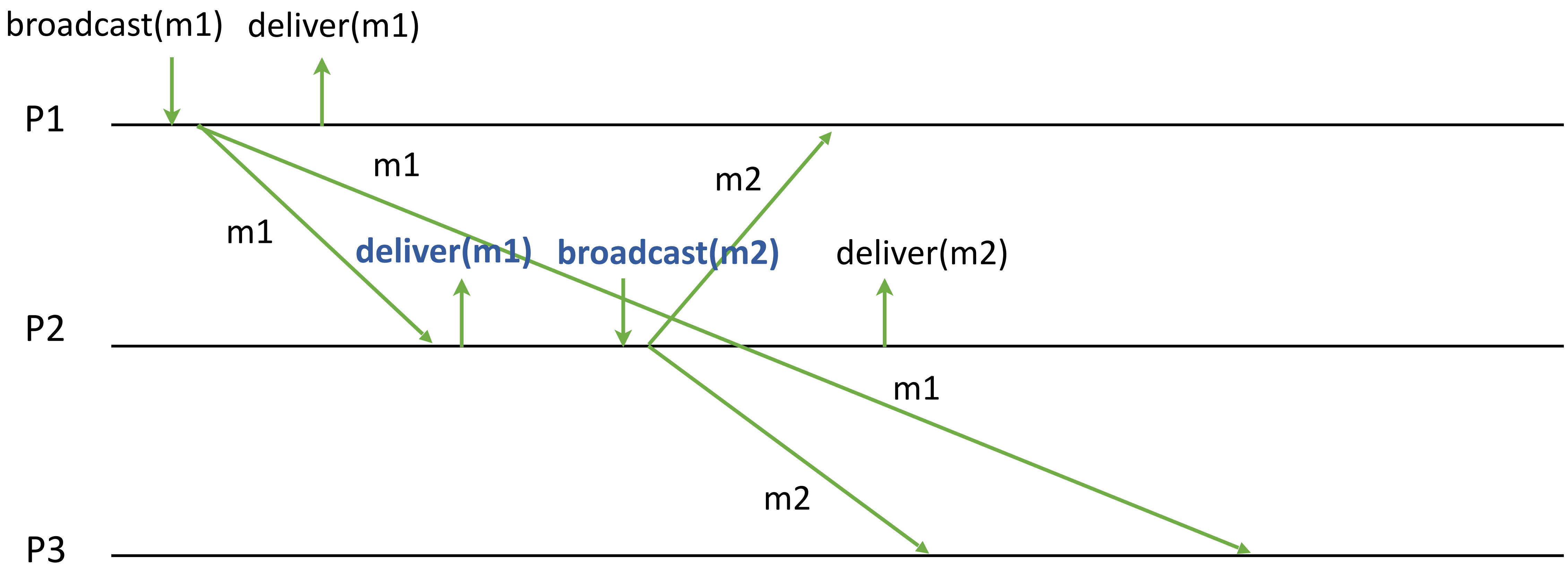

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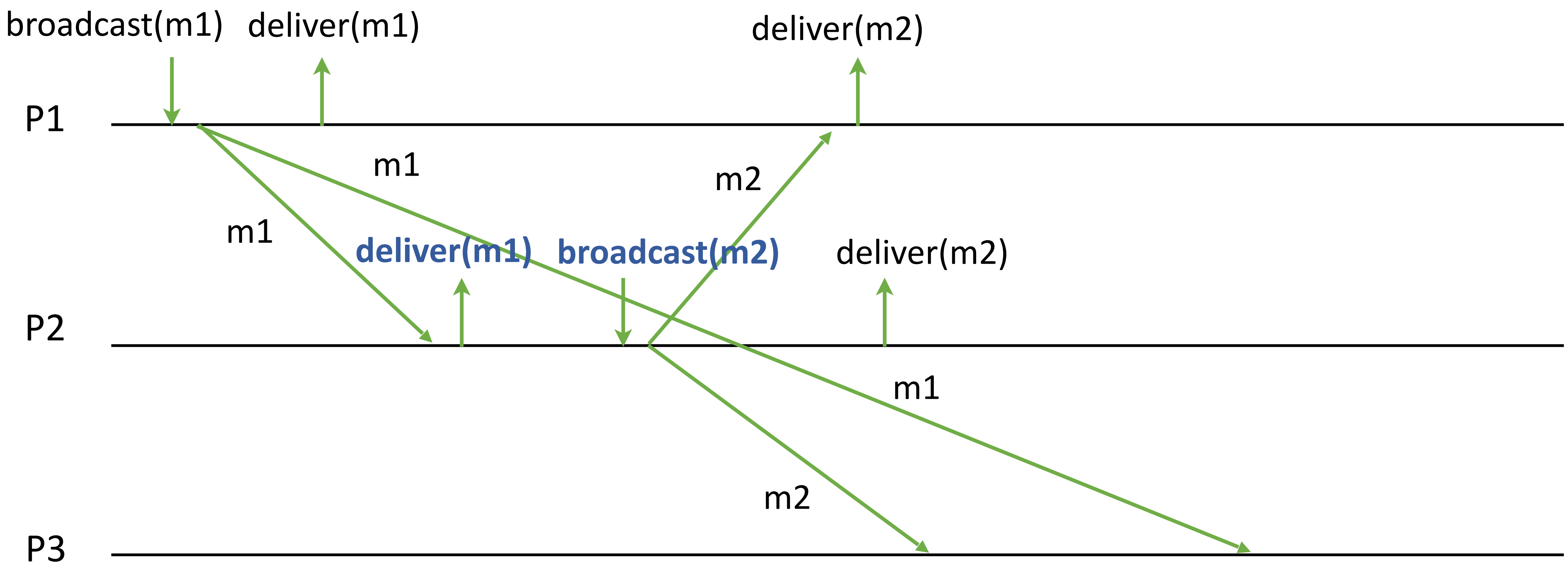

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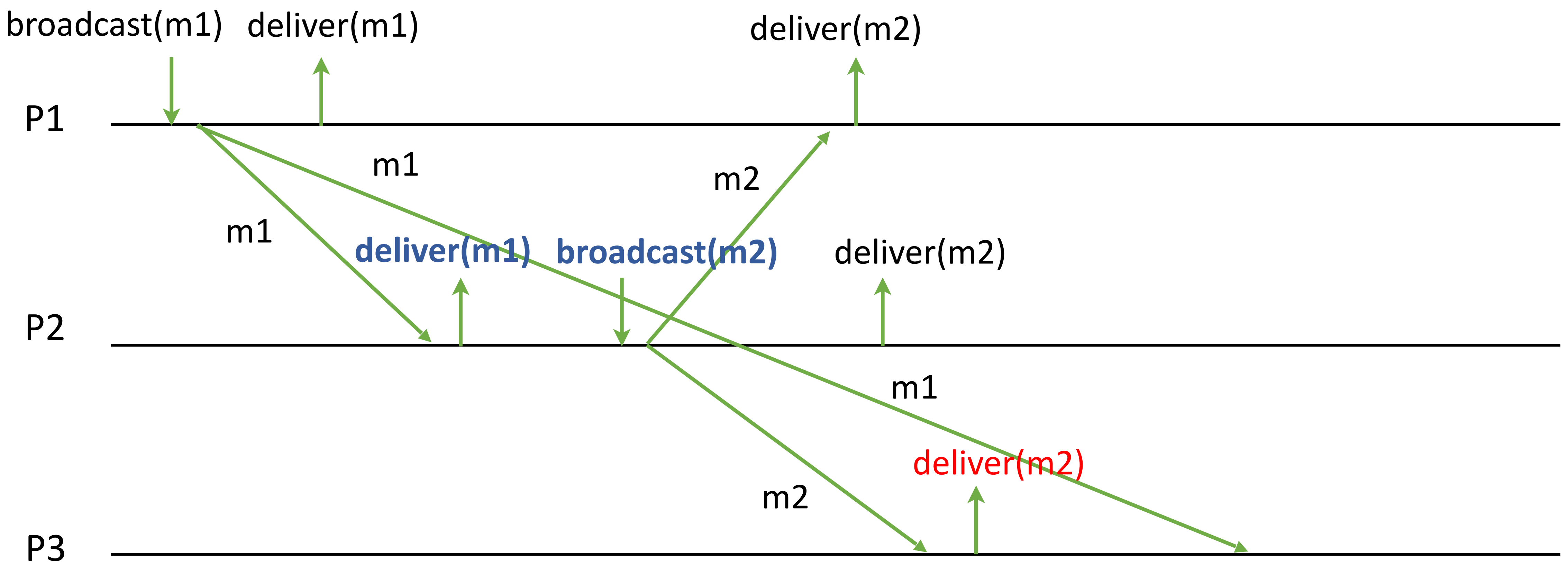

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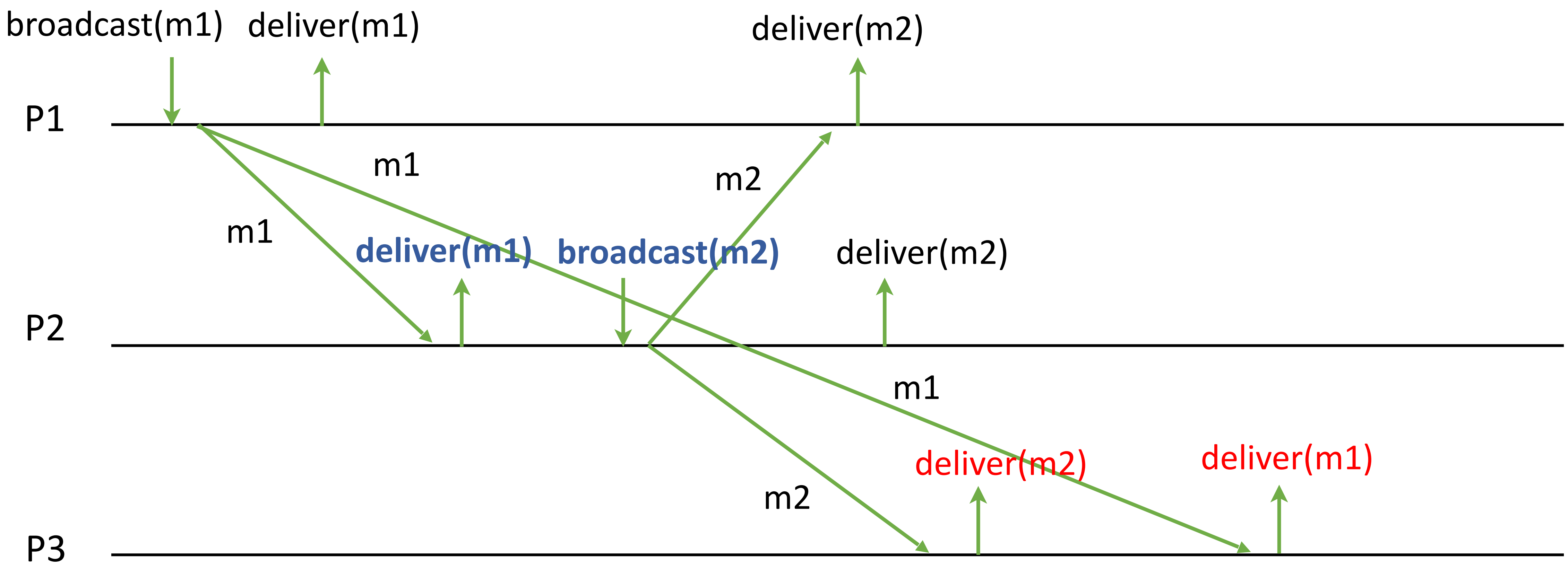

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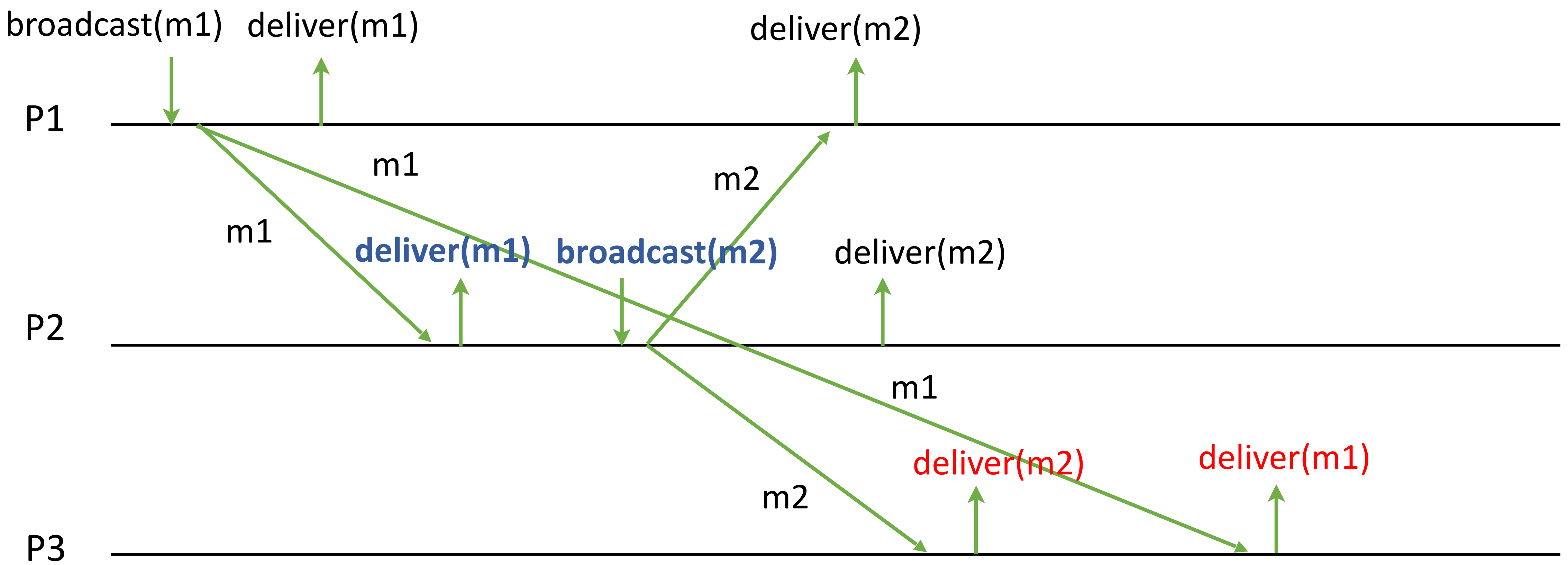


Local order of p2, m1 < m2, is not preserved.

Causal Relation (Dependency)

Let m1 and m2 be any two messages.
m1 < m2 (m1 is causally before m2, or m2 depends on m1) iff

- **FIFO order:**
  A process pi broadcasts m1 before broadcasting m2.

- **InOut order:**
  A process pi delivers m1 and then broadcasts m2.

- **Transitivity:**
  There is a message m3 such that m1 < m3 and m3 < m2.

Uniform Causal Broadcast (UCB)

- **Events**
  - Request: <broadcast (m)>
  - Indication: <deliver (src, m)>

  also called ucbBroadcast and ucbDeliver.
- **Properties**:
  - URB1, URB2, URB3, URB4 +
  - CO

Overview

- Motivation: why causal broadcast?
- Properties of causal broadcast
- **Protocols**

Protocols

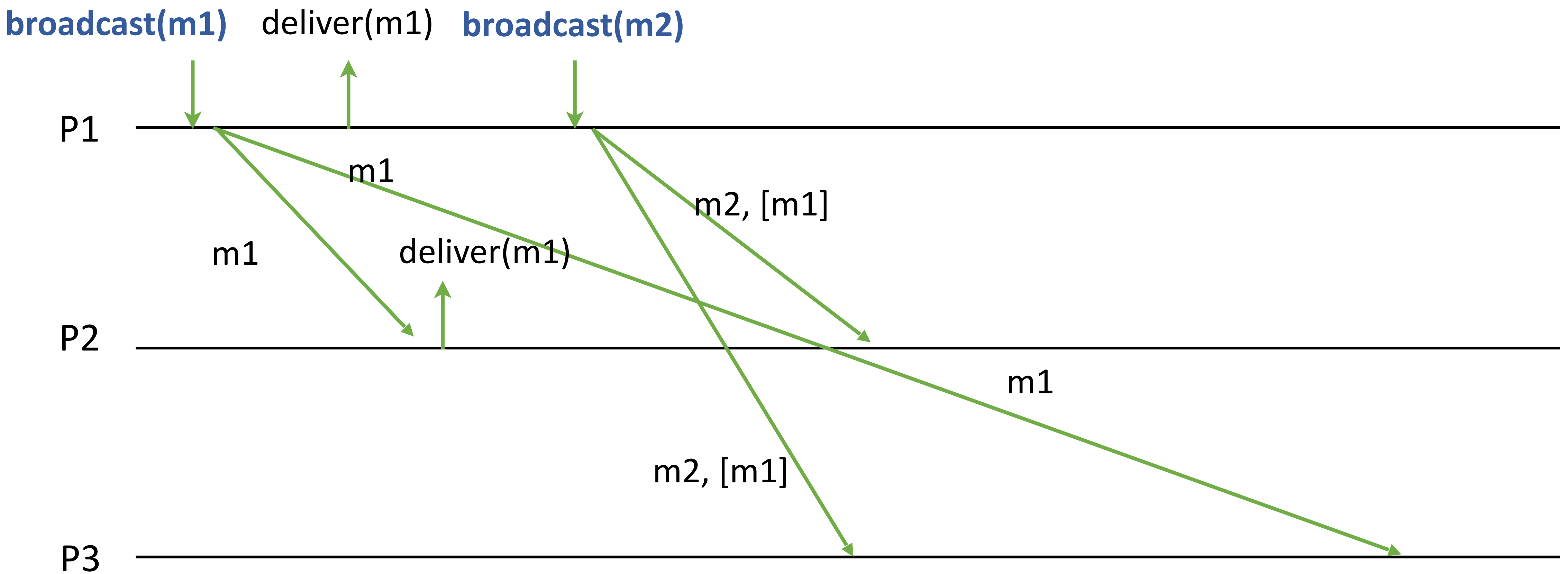
How do we preserve the causal order?

Protocol 1

Idea:

Remember the past messages and
sent them together with every new message.

Example 1: FIFO Order



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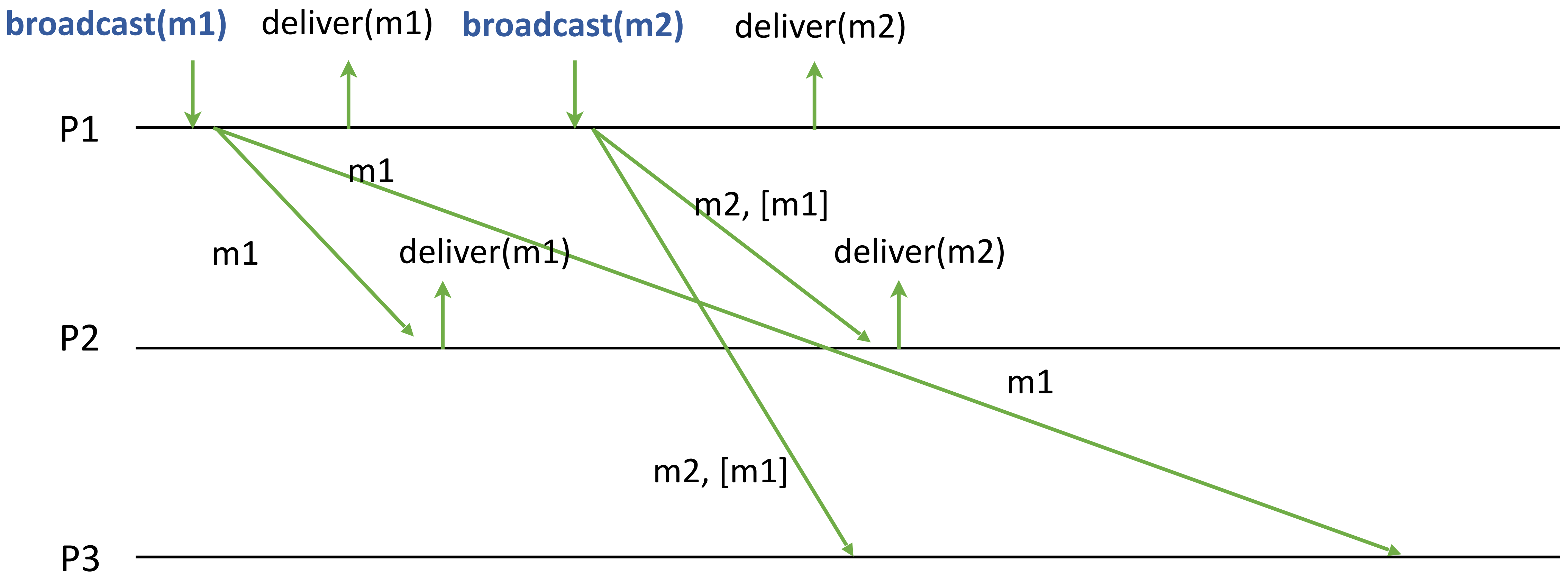

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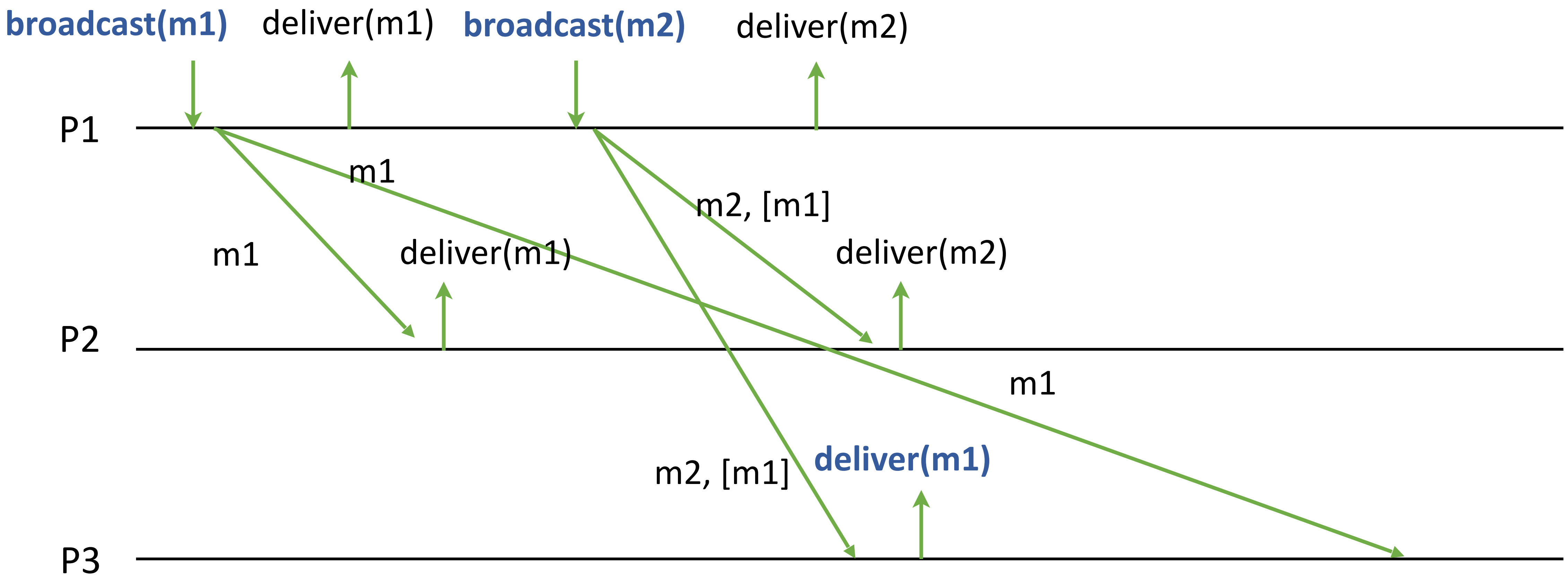

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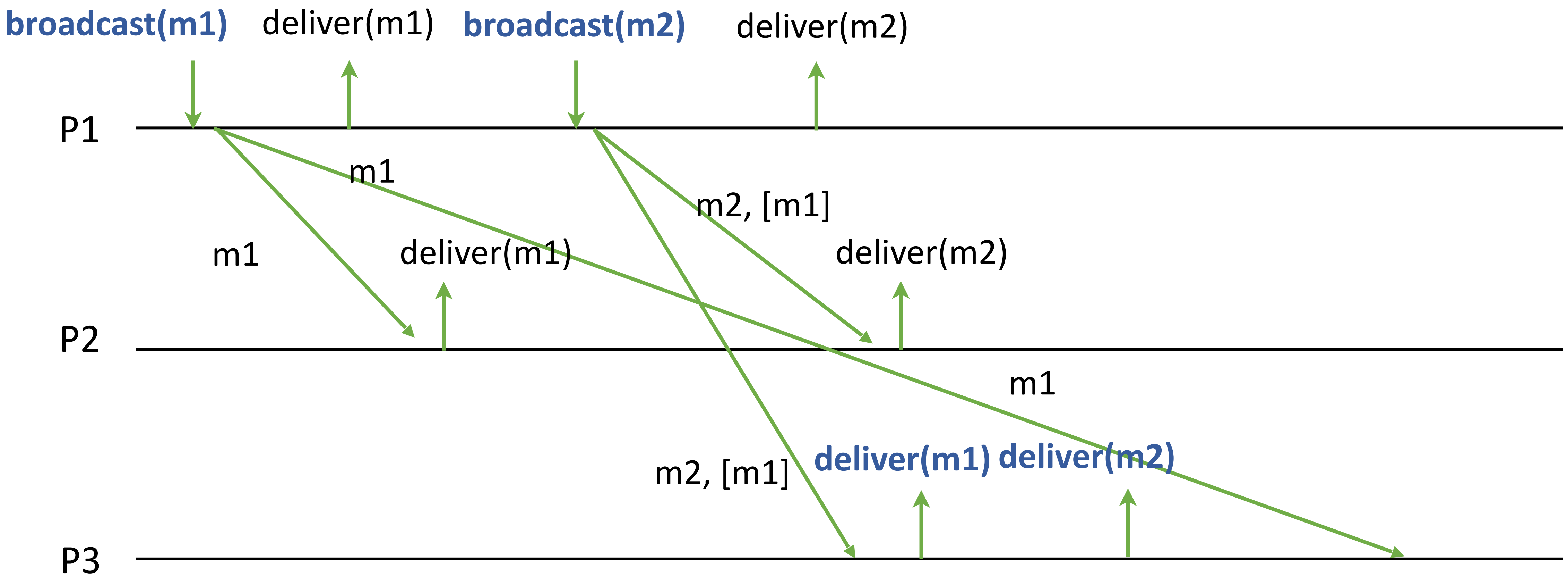

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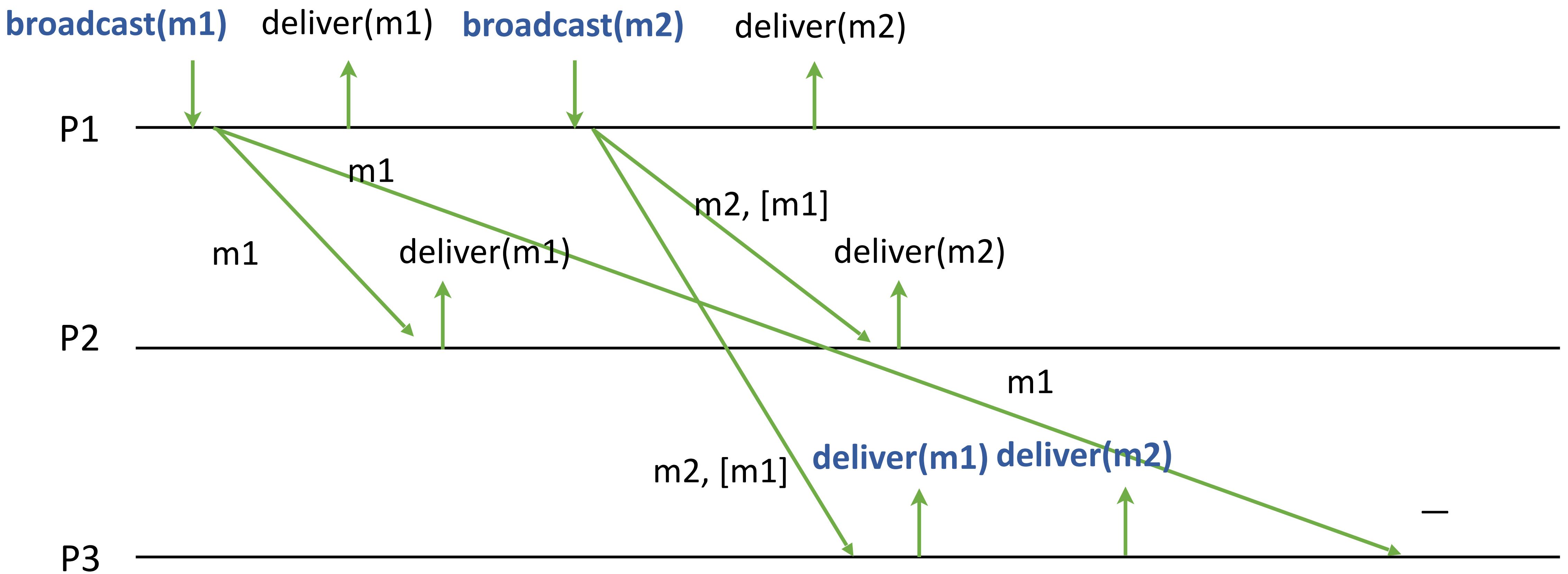
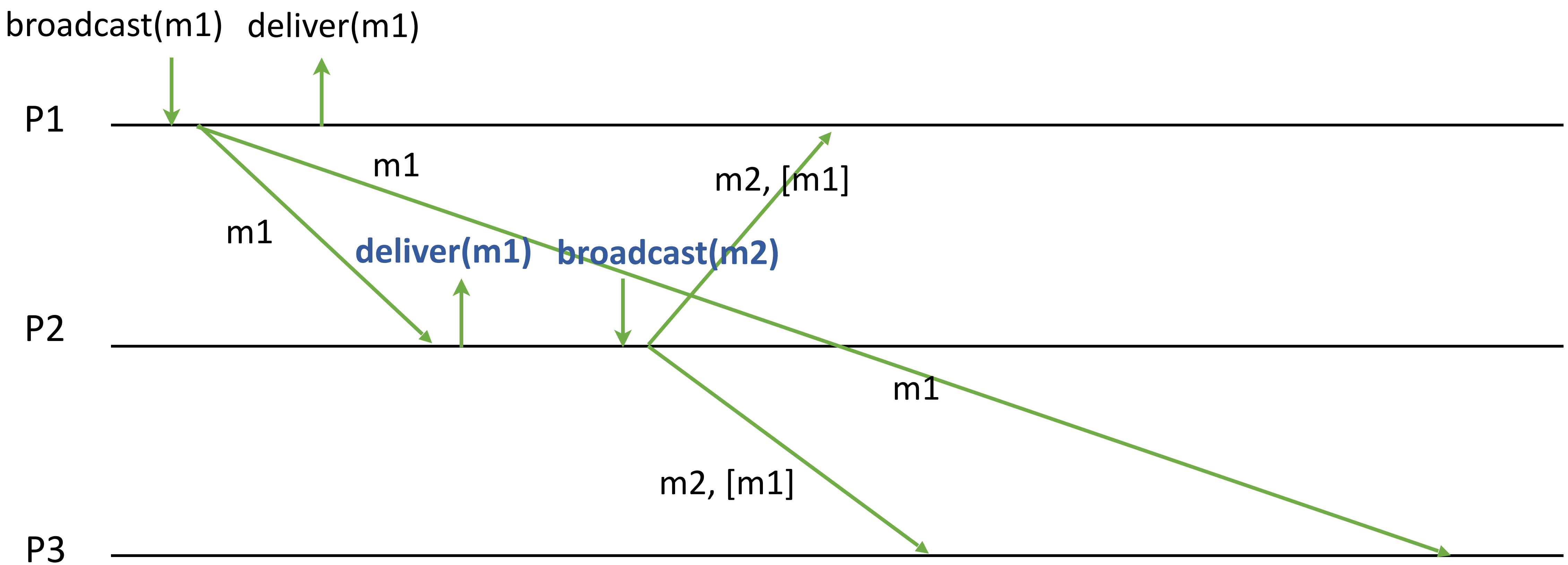


Example 2: InOut Order



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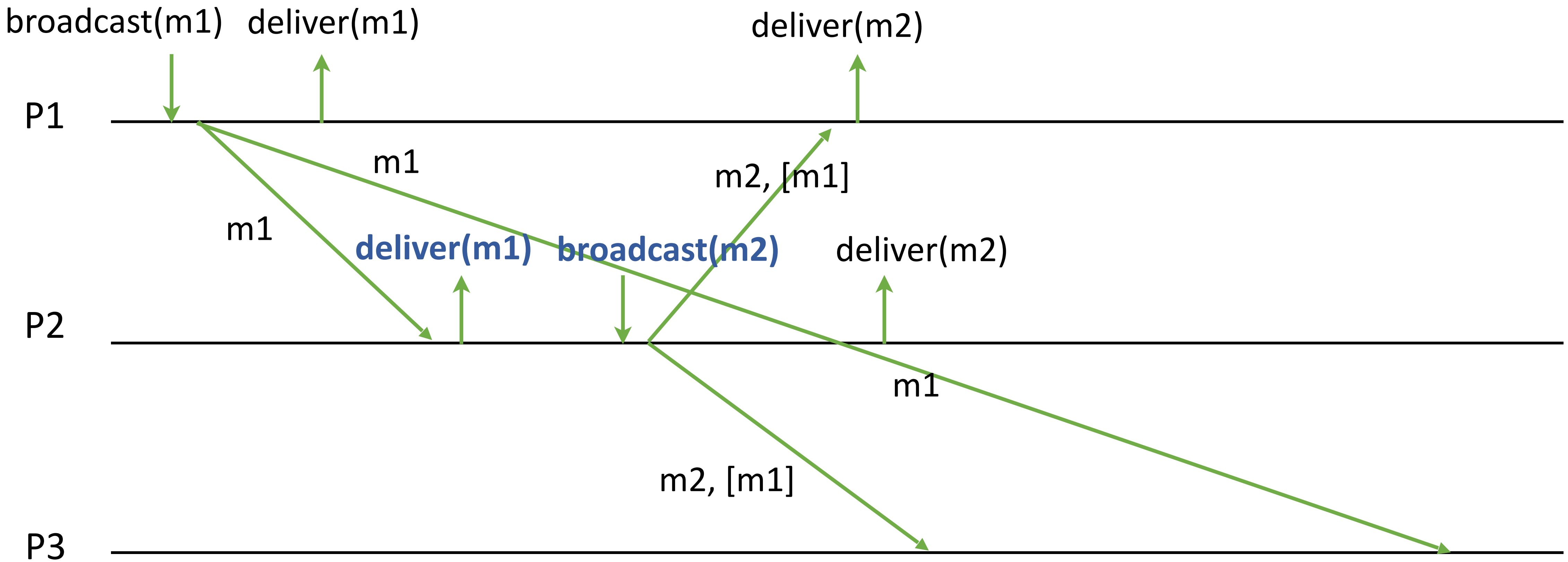

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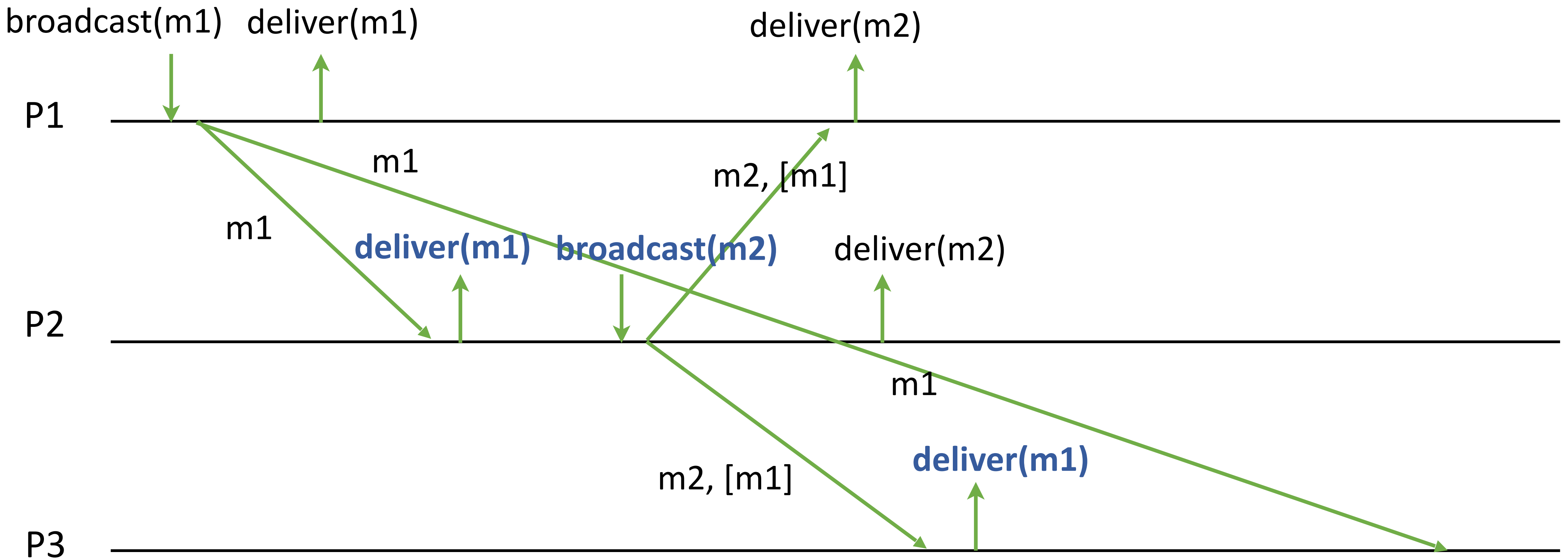

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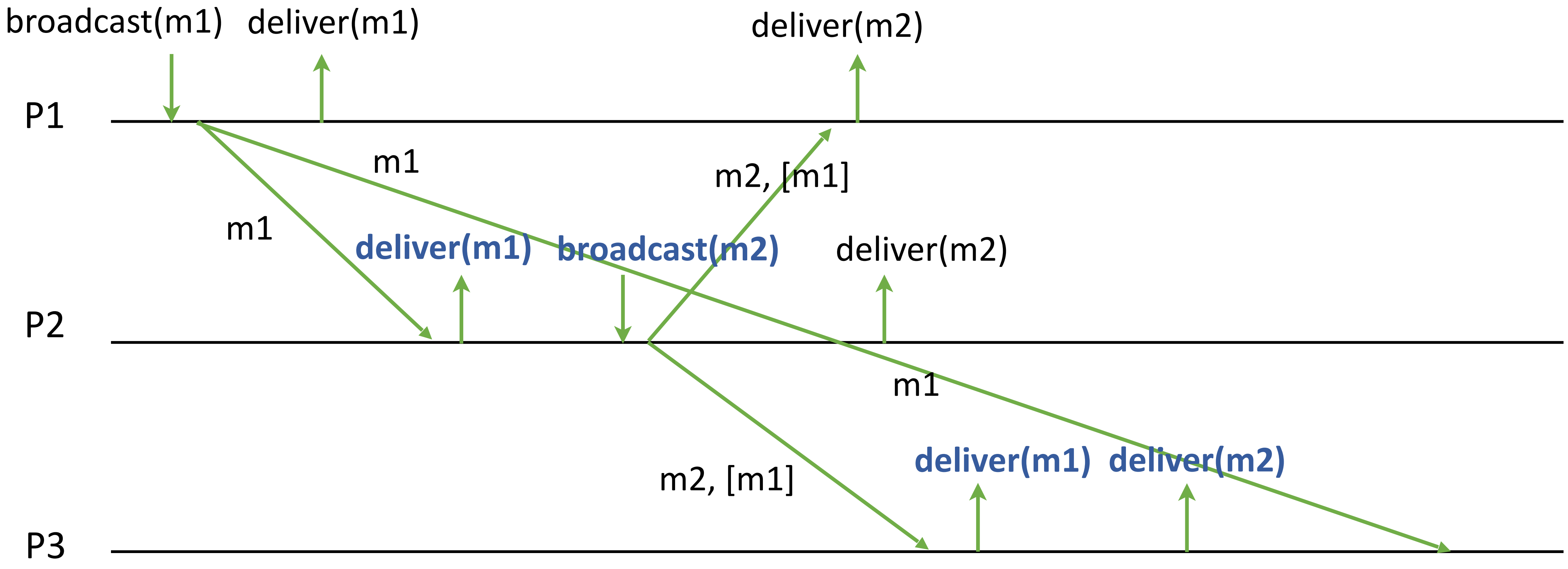

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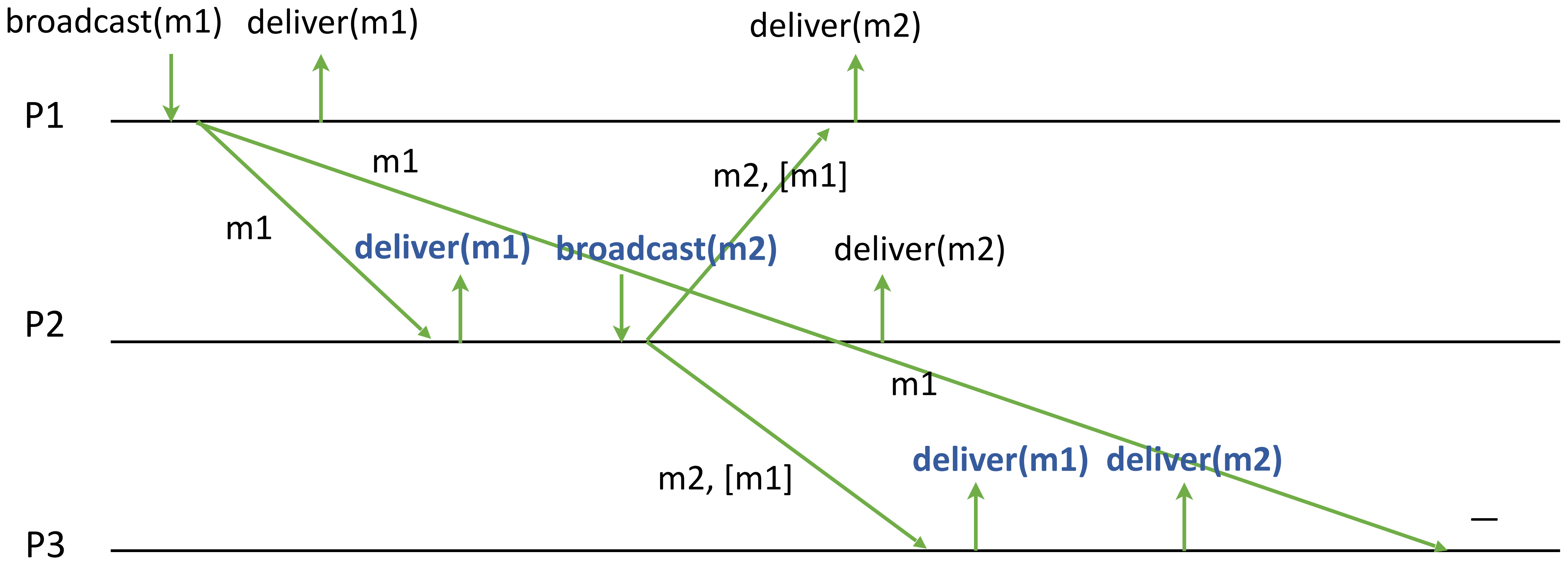

Observation

Messages that carry the past are large!

Protocol 2

Idea:

- Keep the number of messages delivered from each process as a vector (clock) of numbers.

p_1	p_2	p_3
2	1	0

- Send the vector clock (VC) together with new messages.

  (*except for the current process that is updated with the number of broadcast messages.)

Protocol 2

- Deliver a message only if the local vector clock is larger than the vector clock of the message.

p_1	p_2	p_3
2	1	0

Message’s VC

$\leq$

p_1	p_2	p_3
3	2	0

Receiver’s VC

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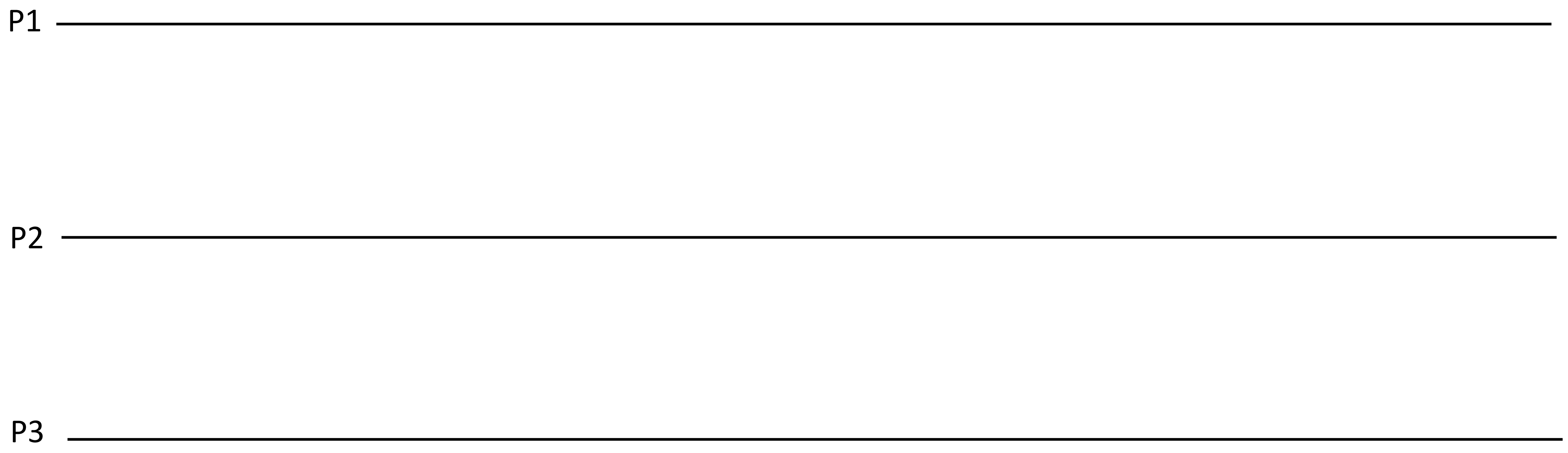

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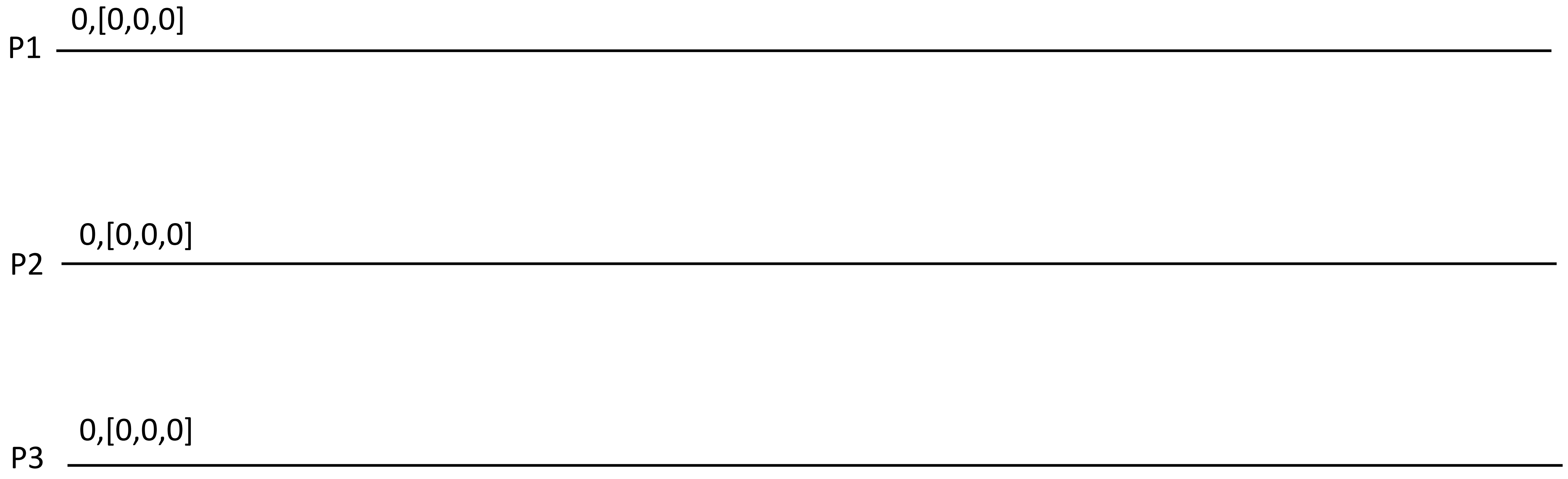

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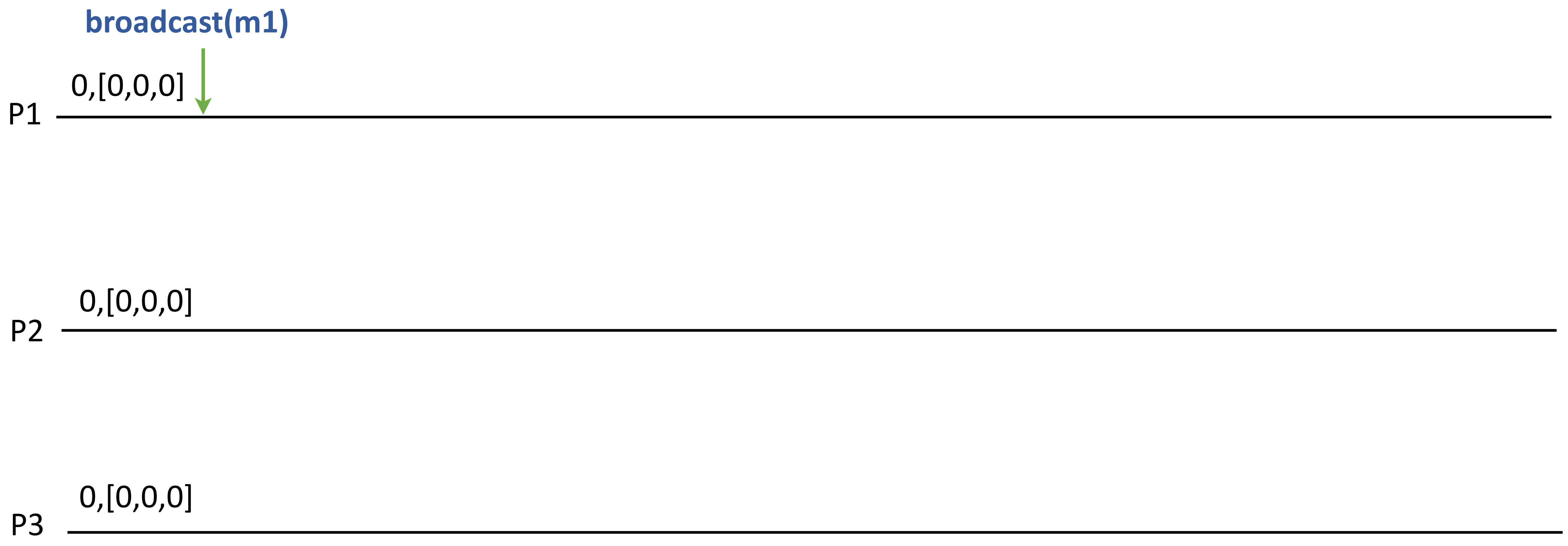

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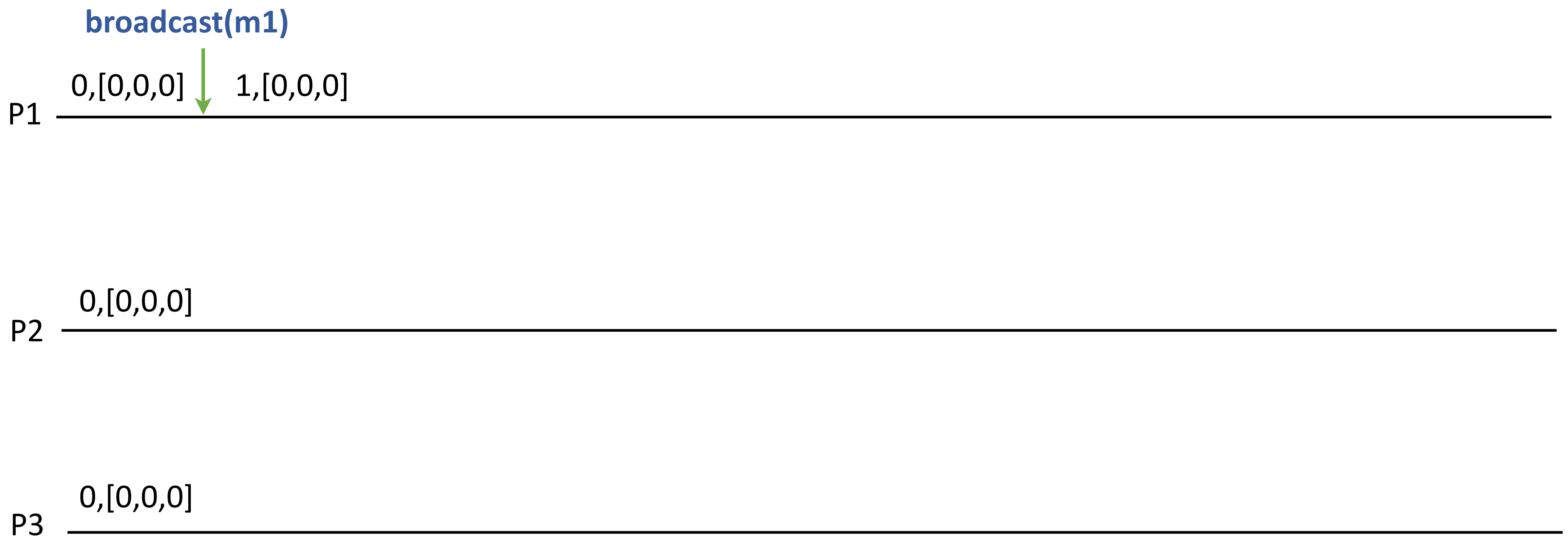

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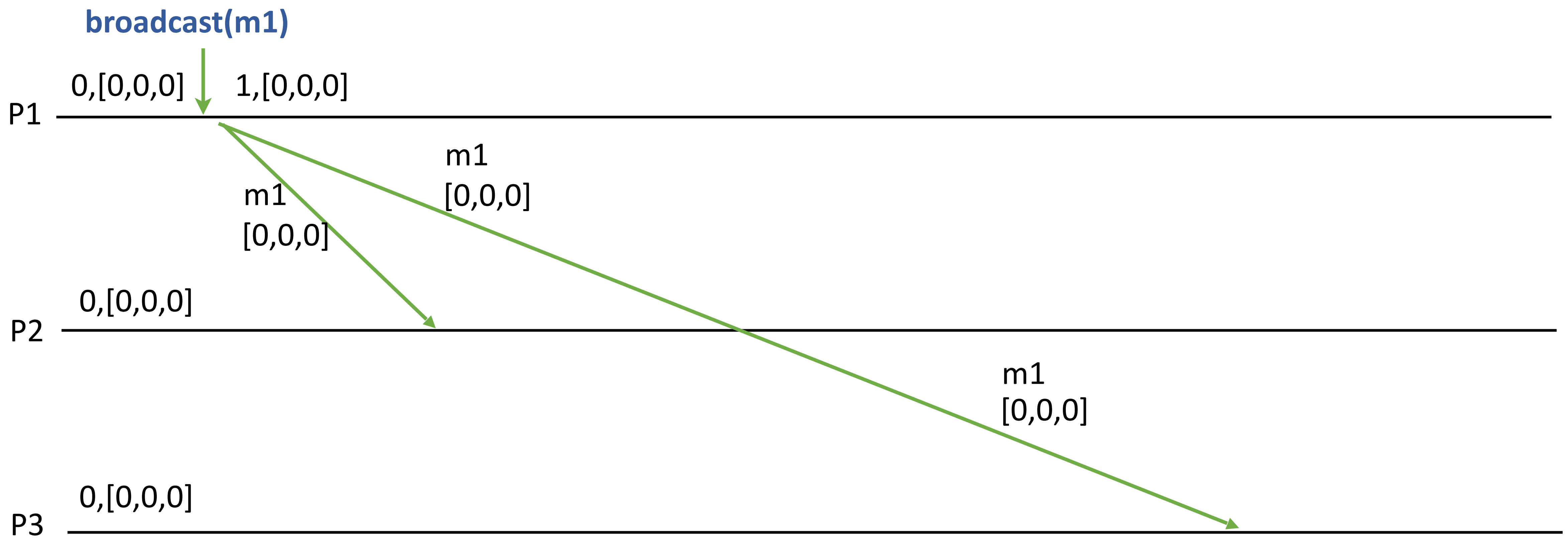

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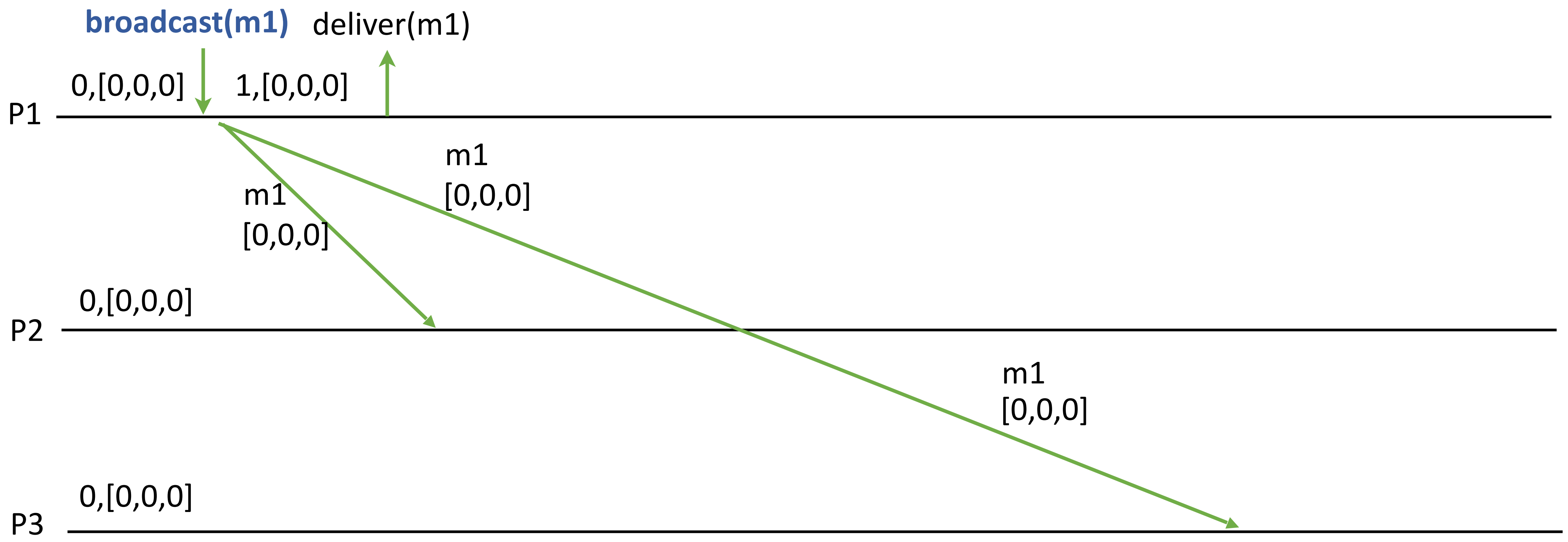

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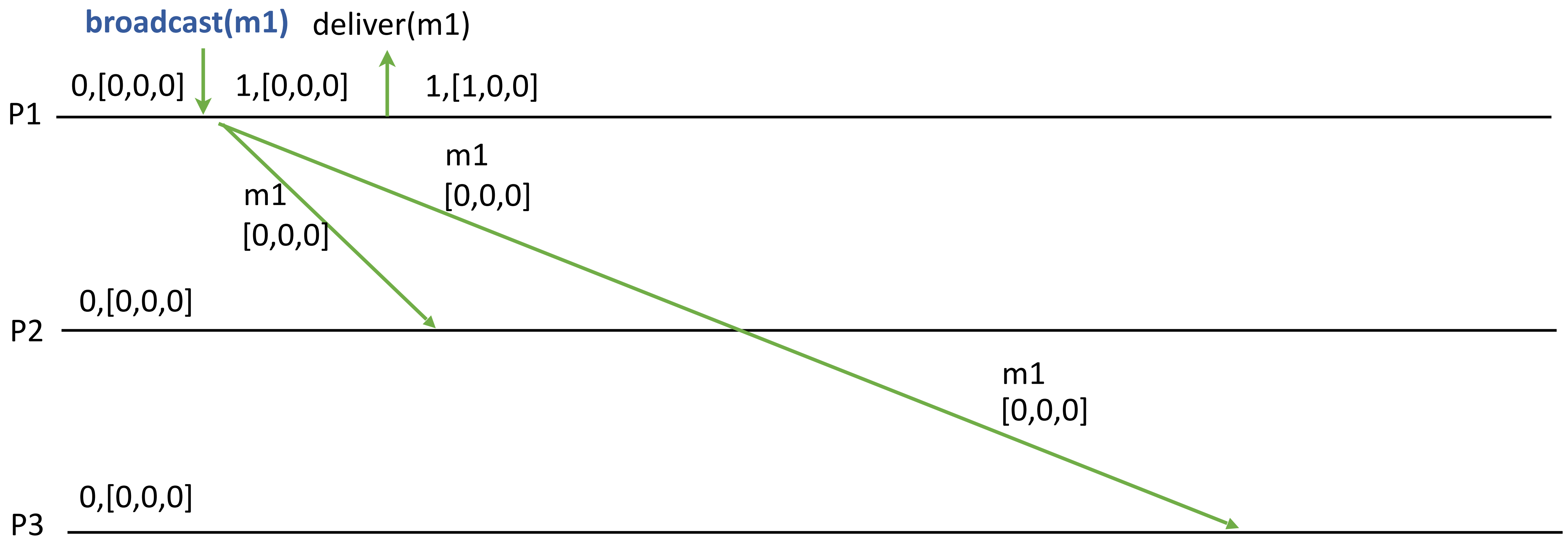

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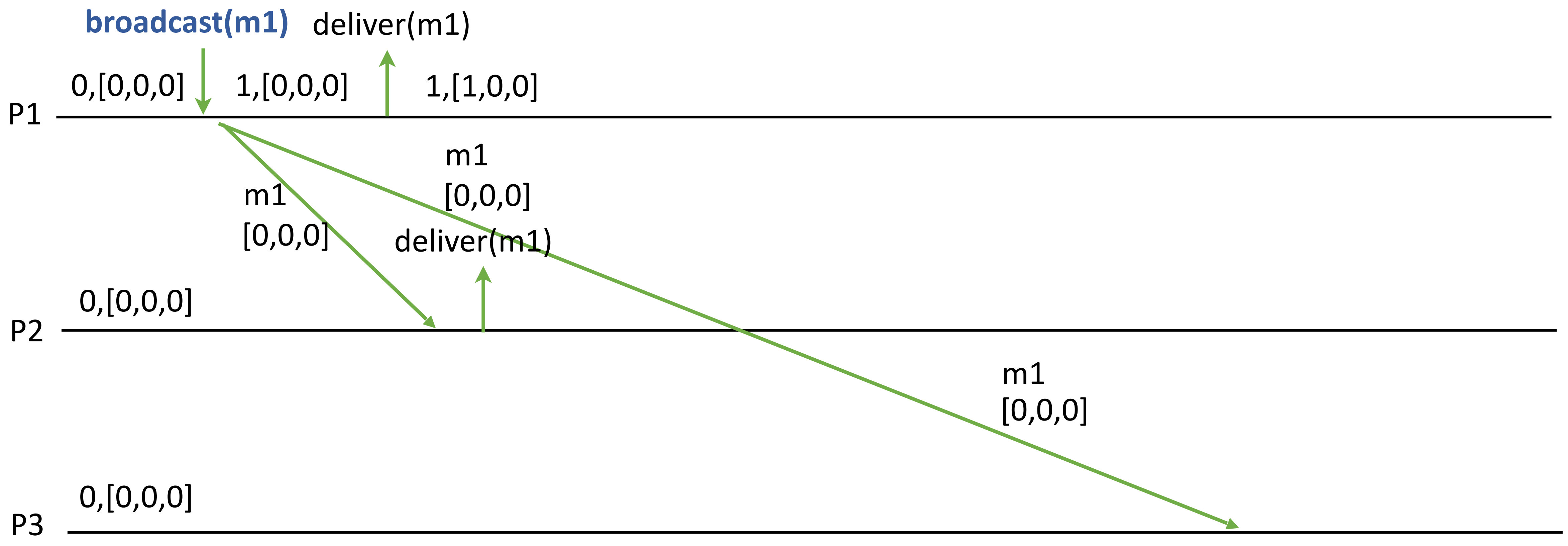

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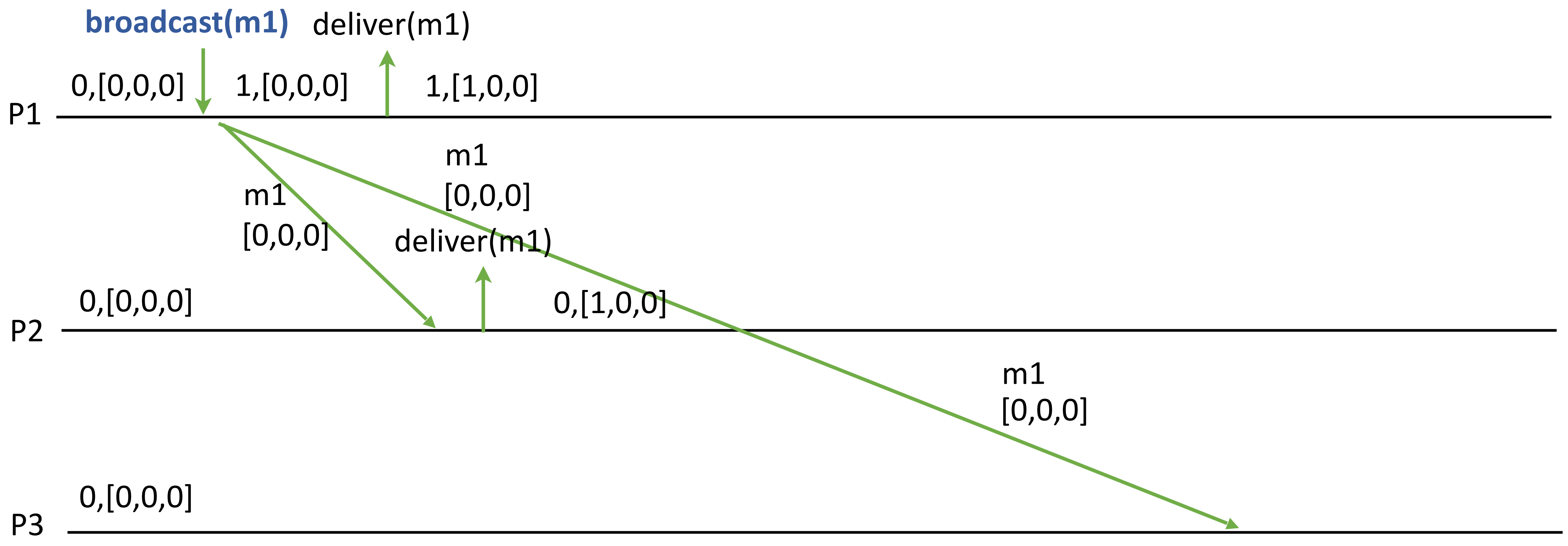

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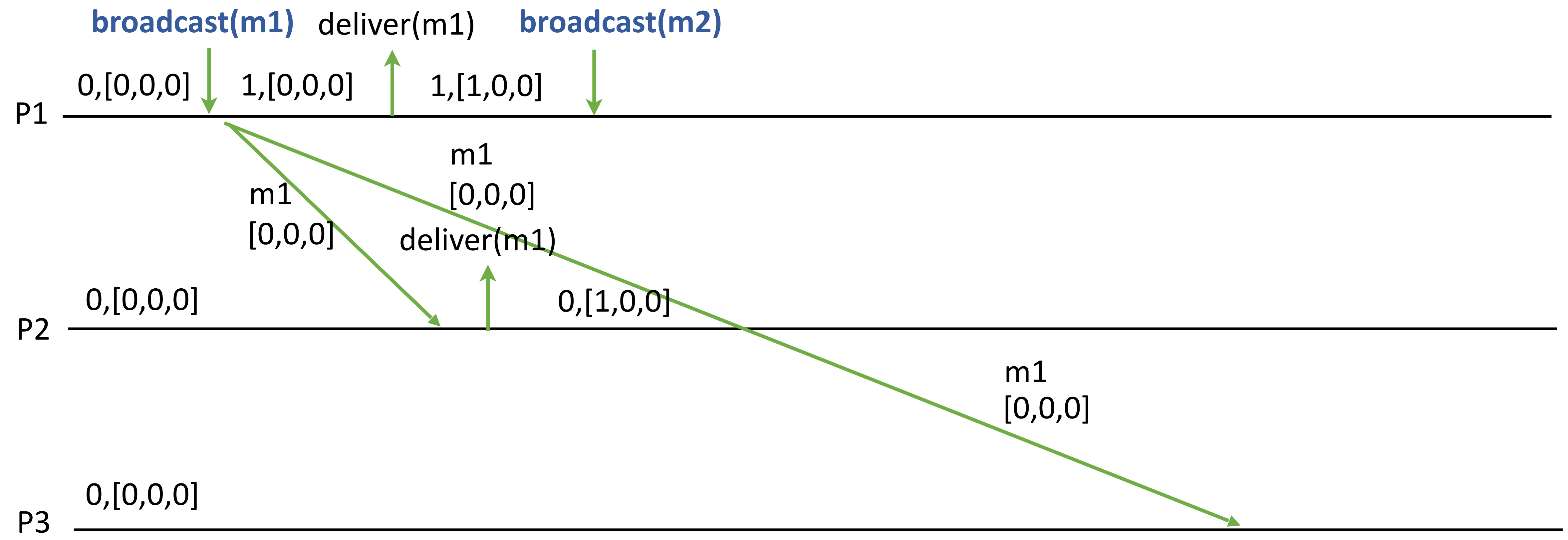

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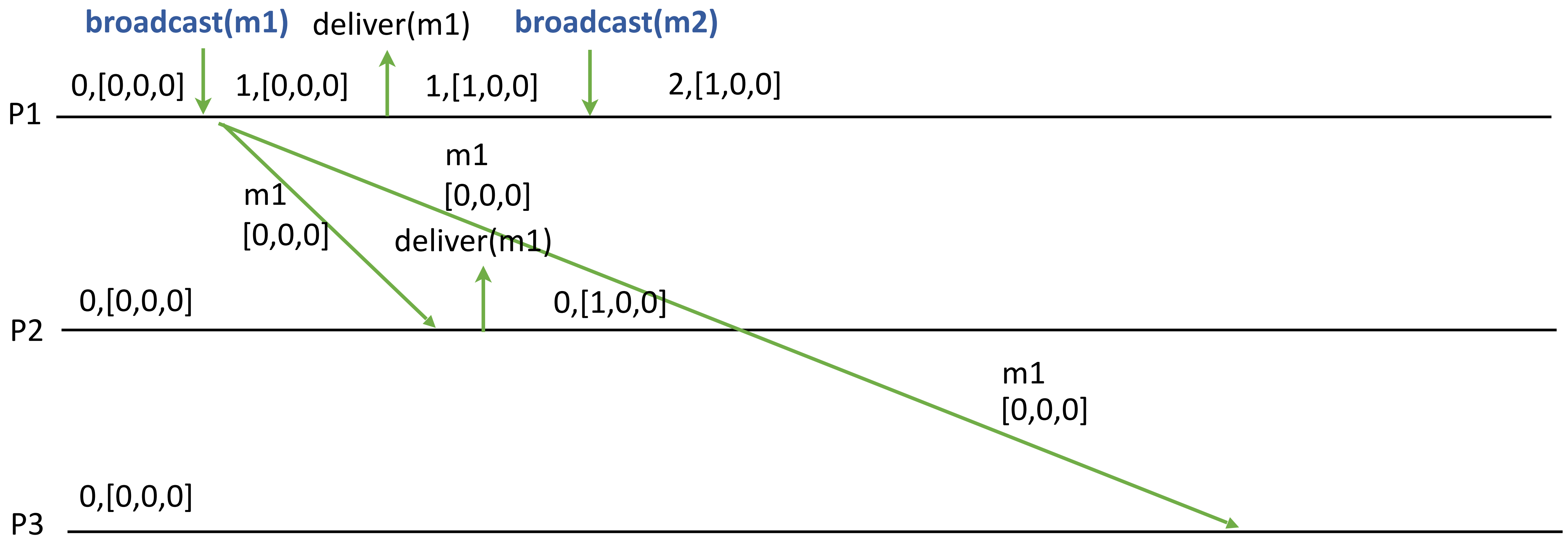

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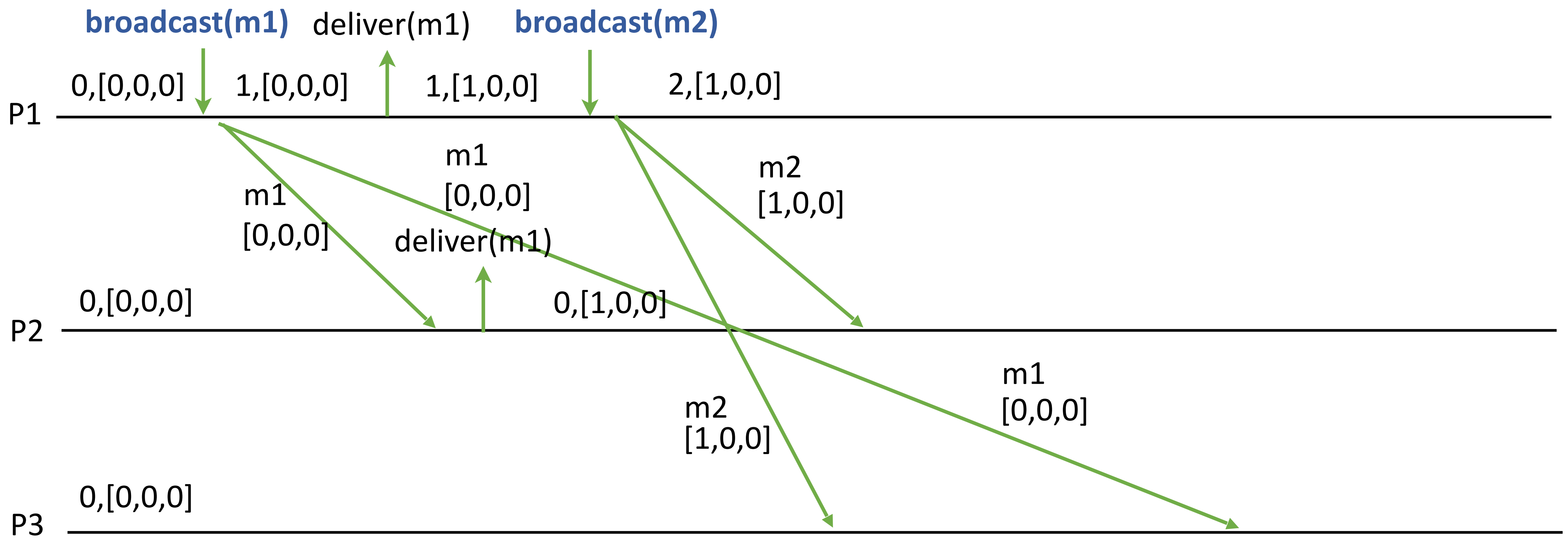

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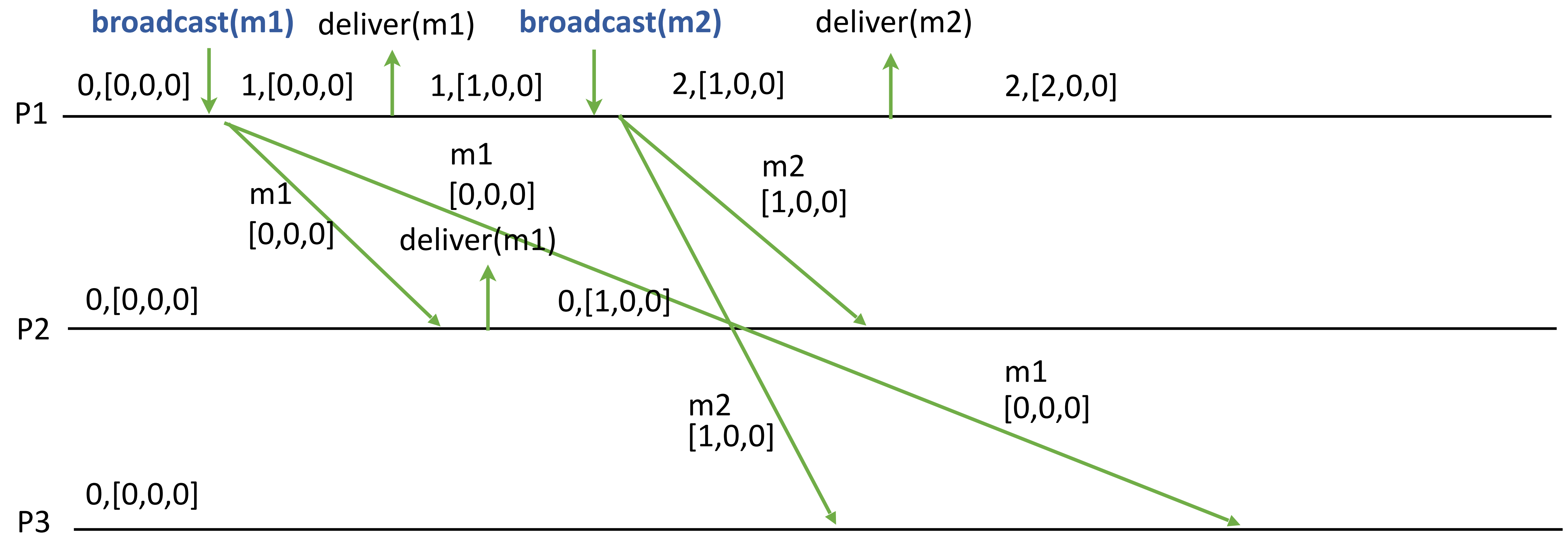

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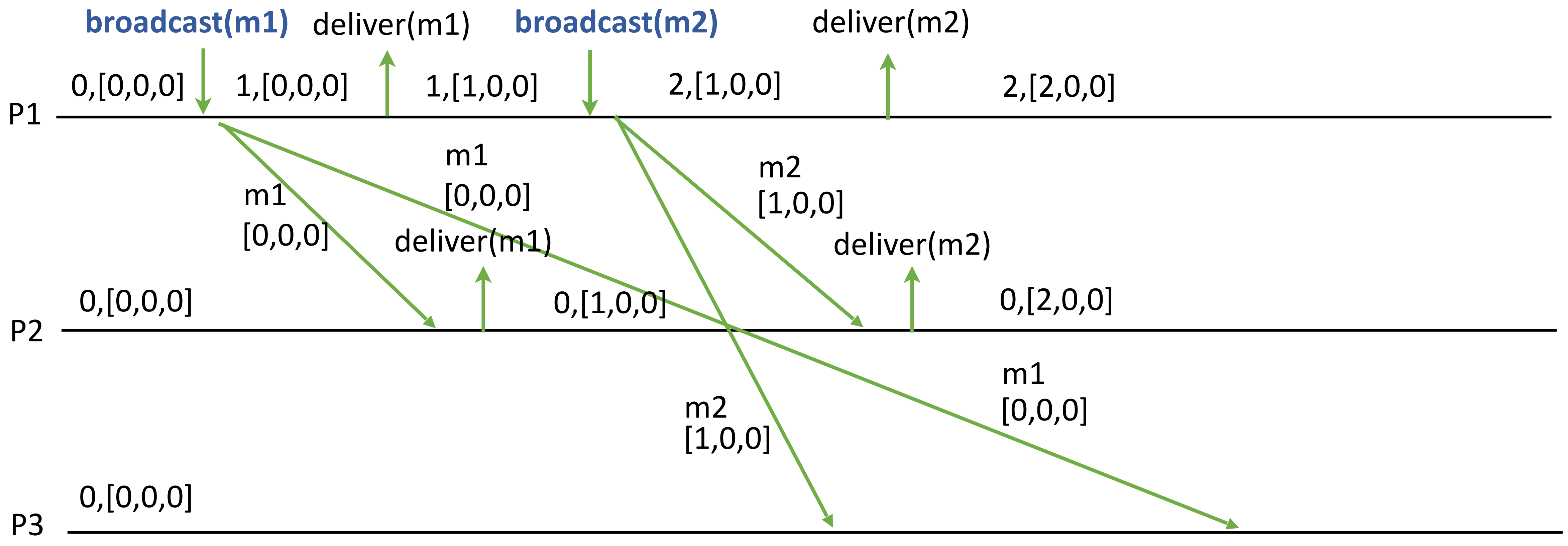

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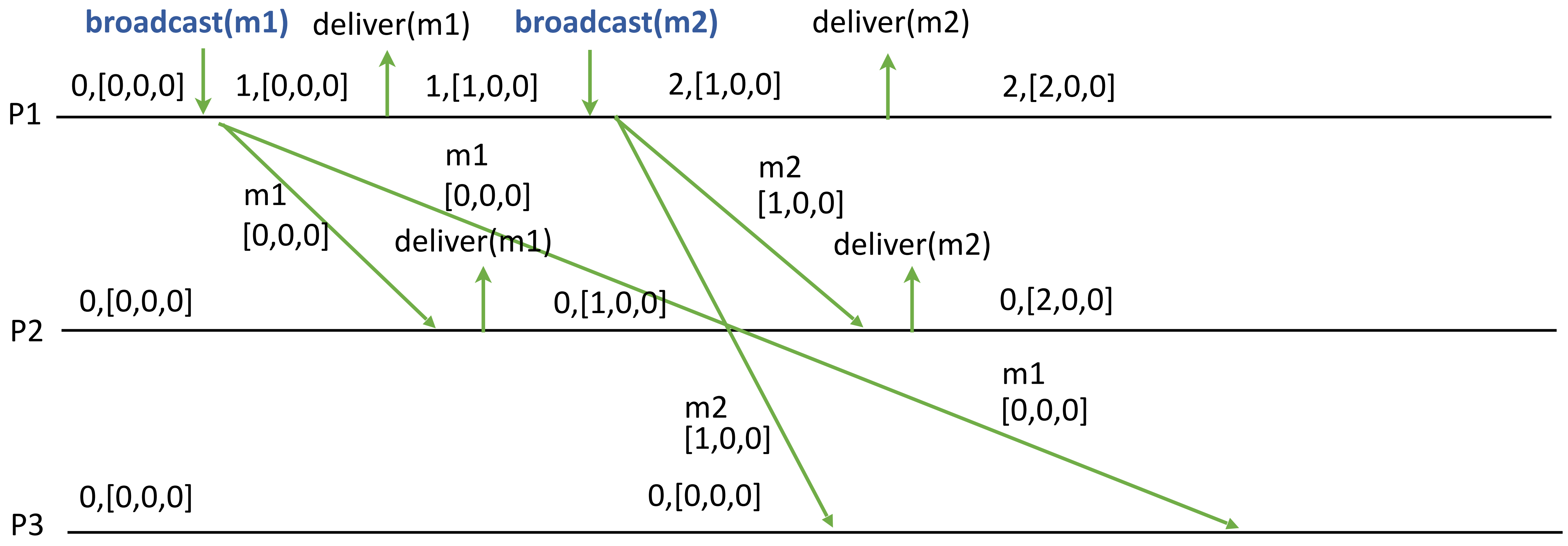

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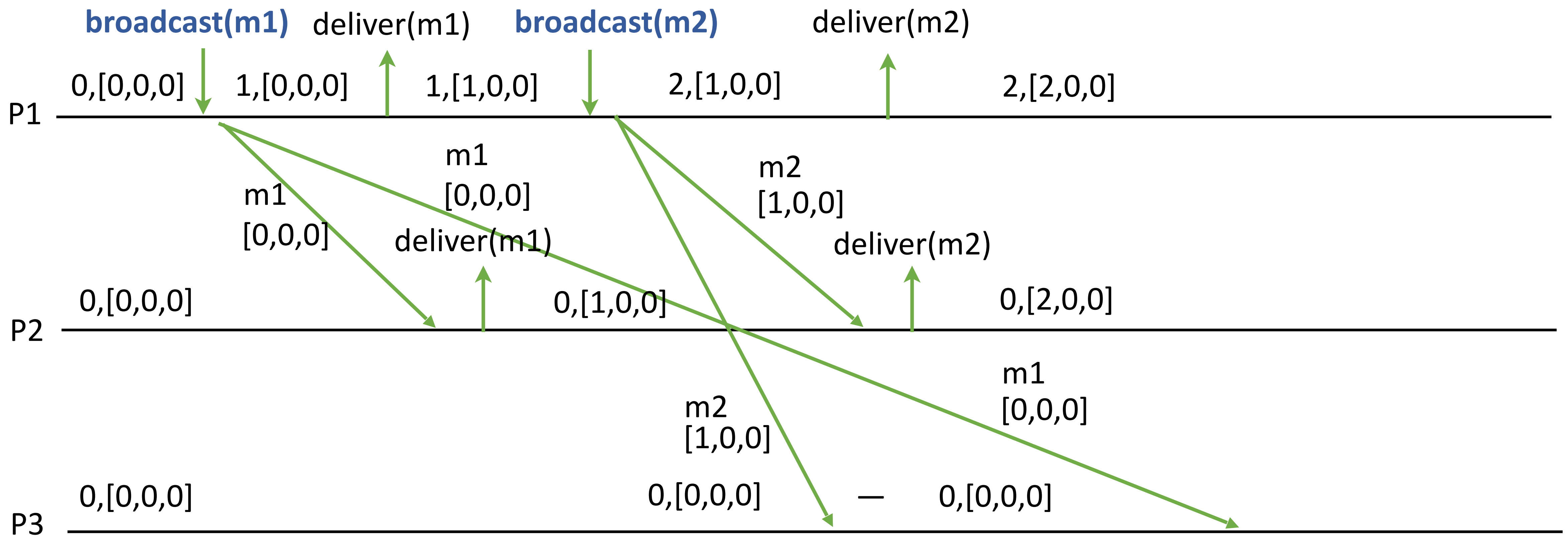

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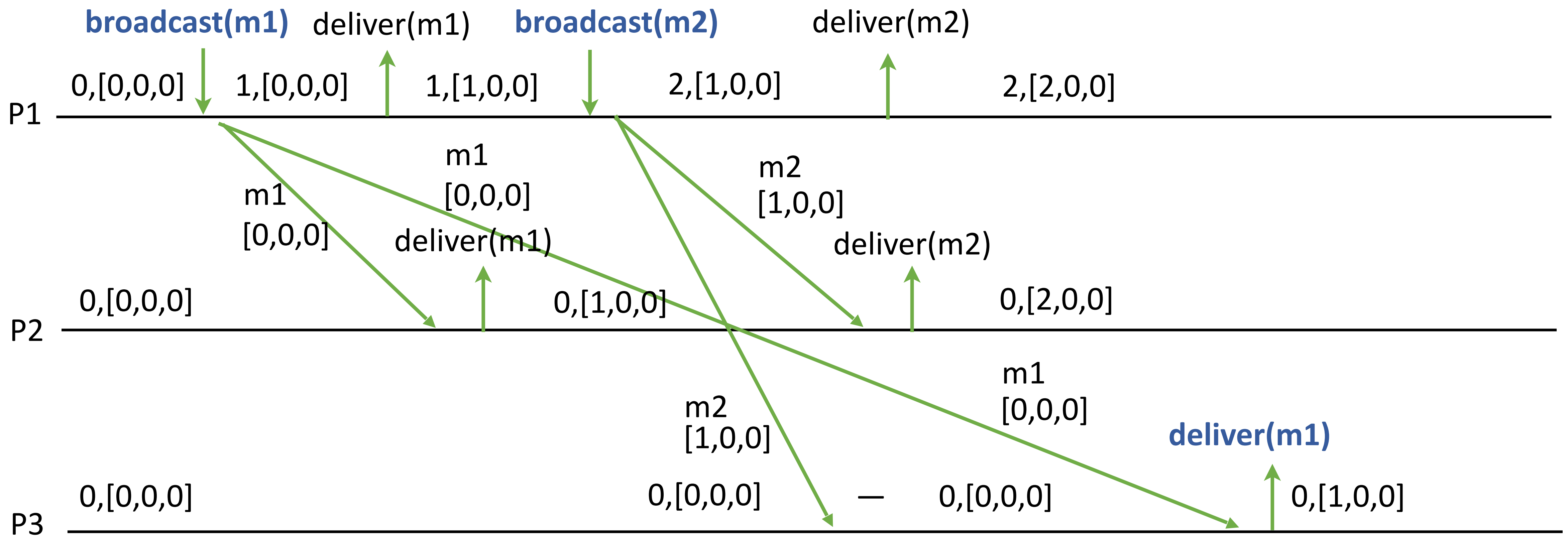

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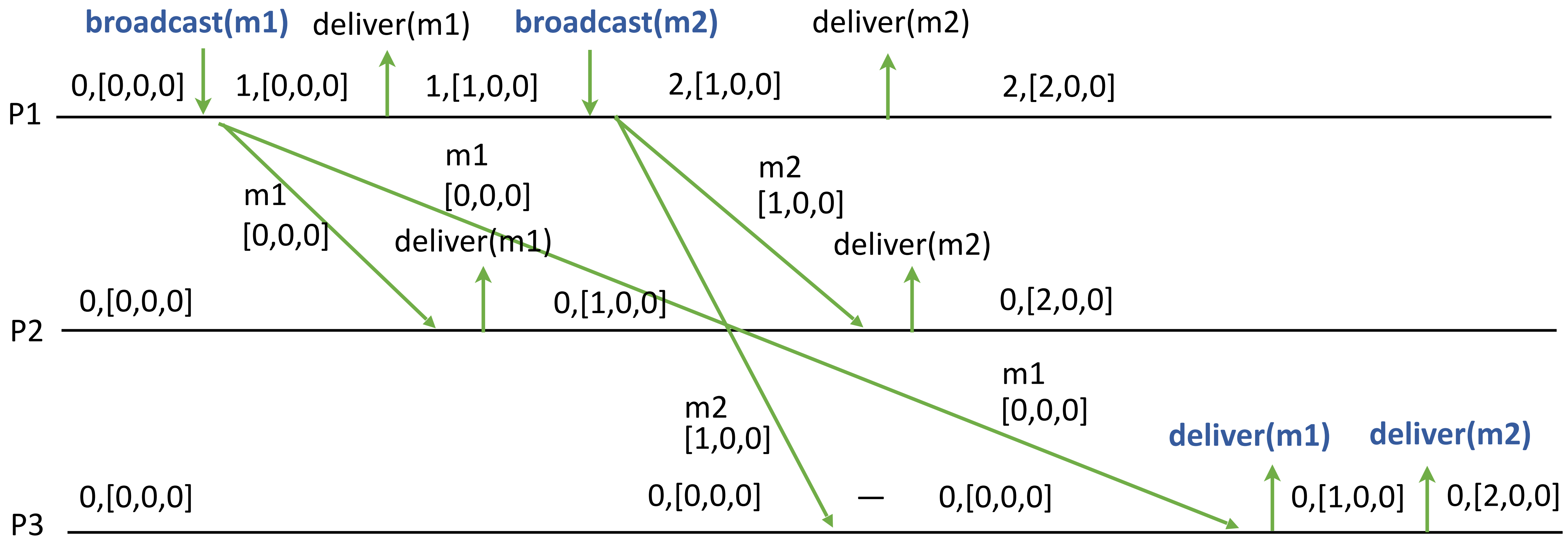
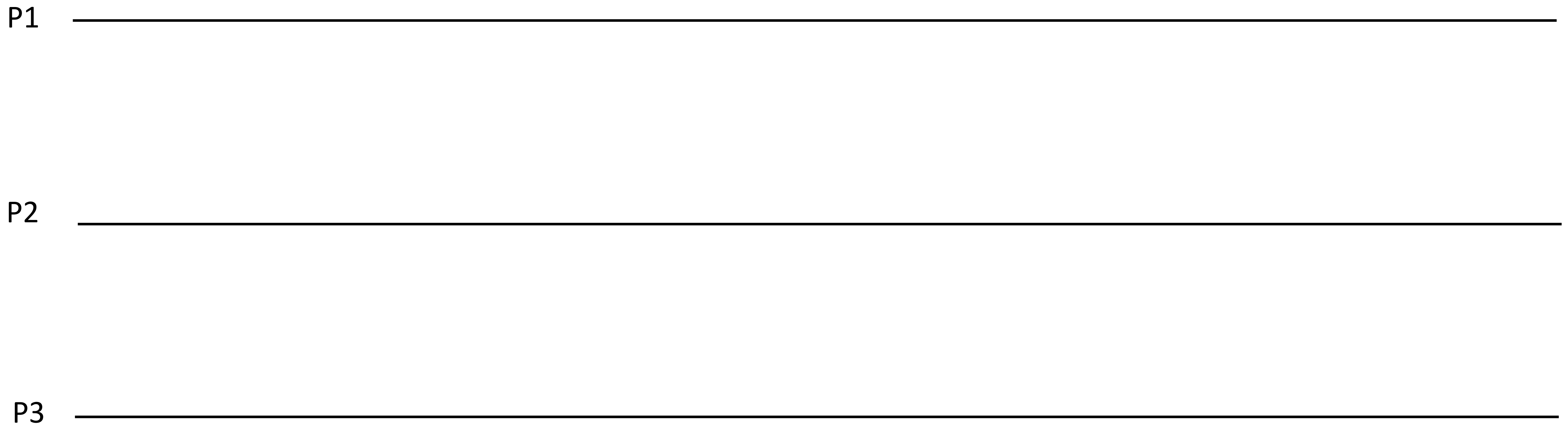


Example 2: InOut Order



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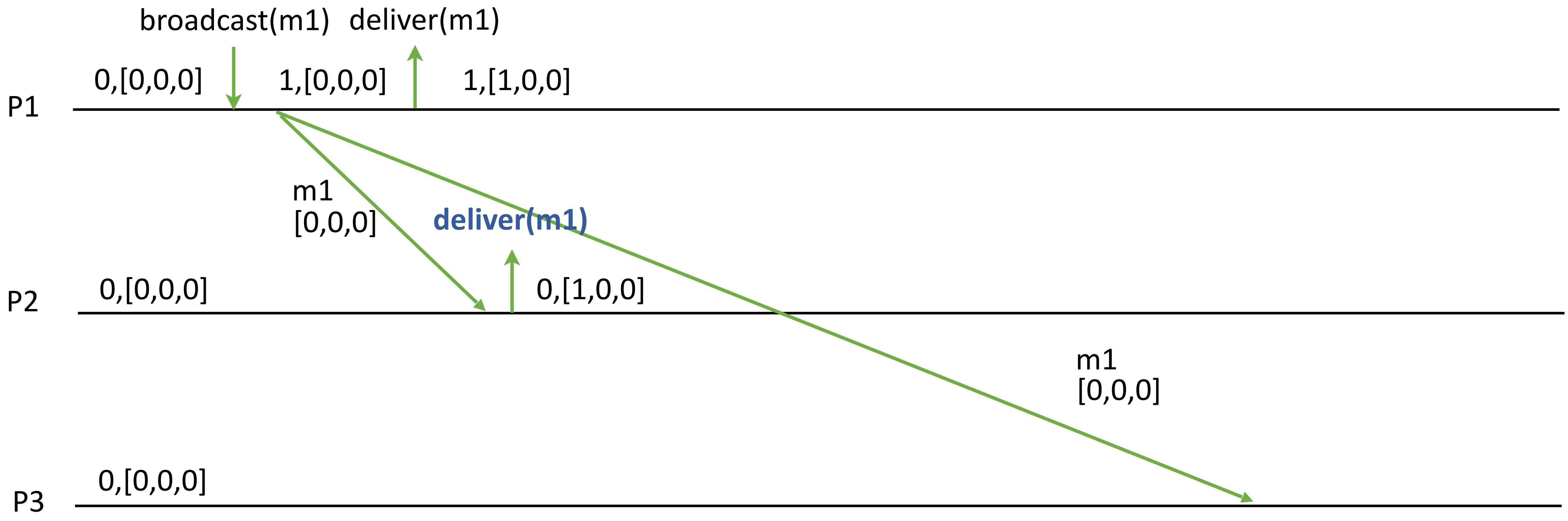

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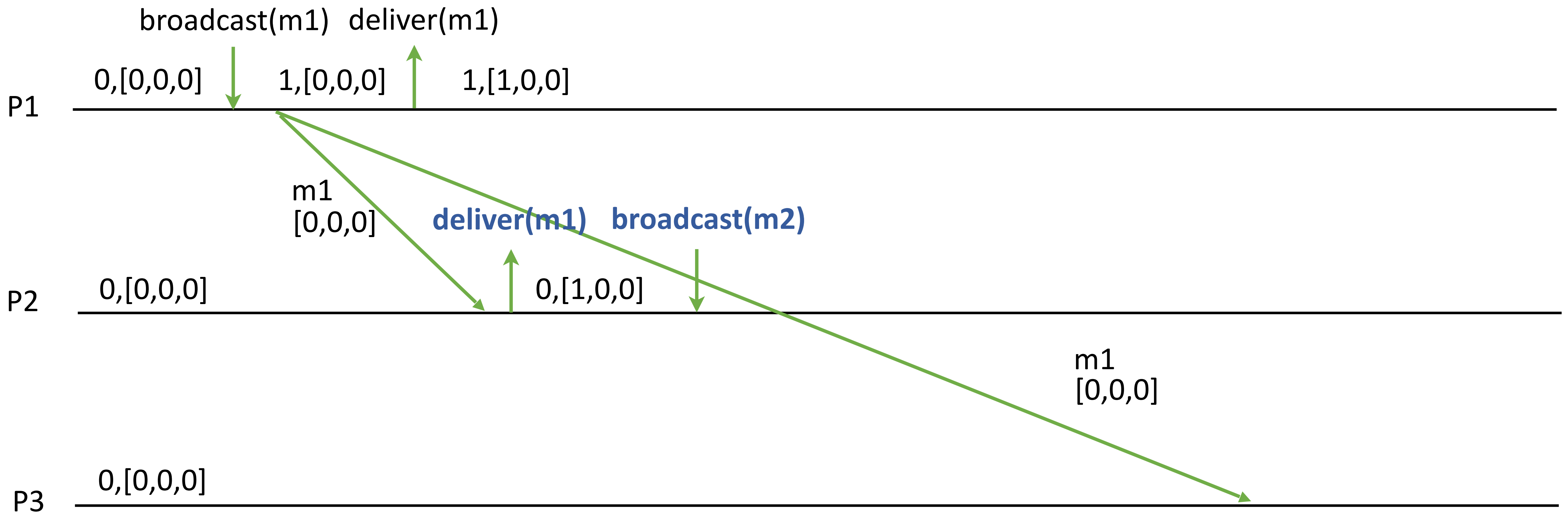

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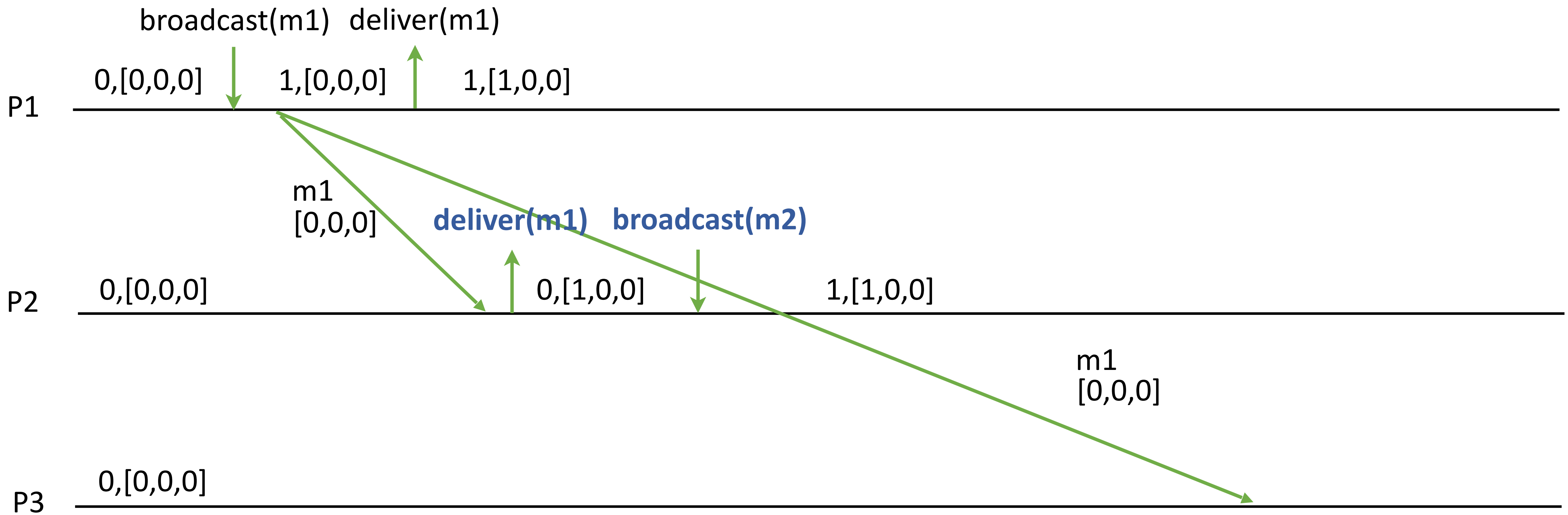

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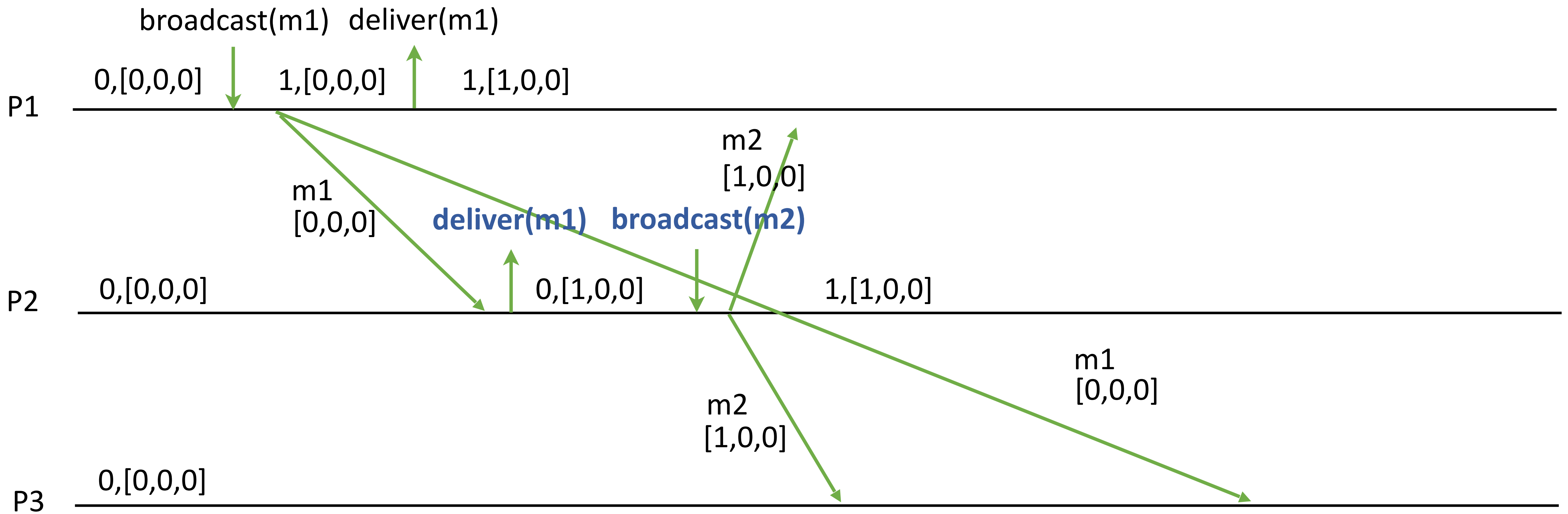

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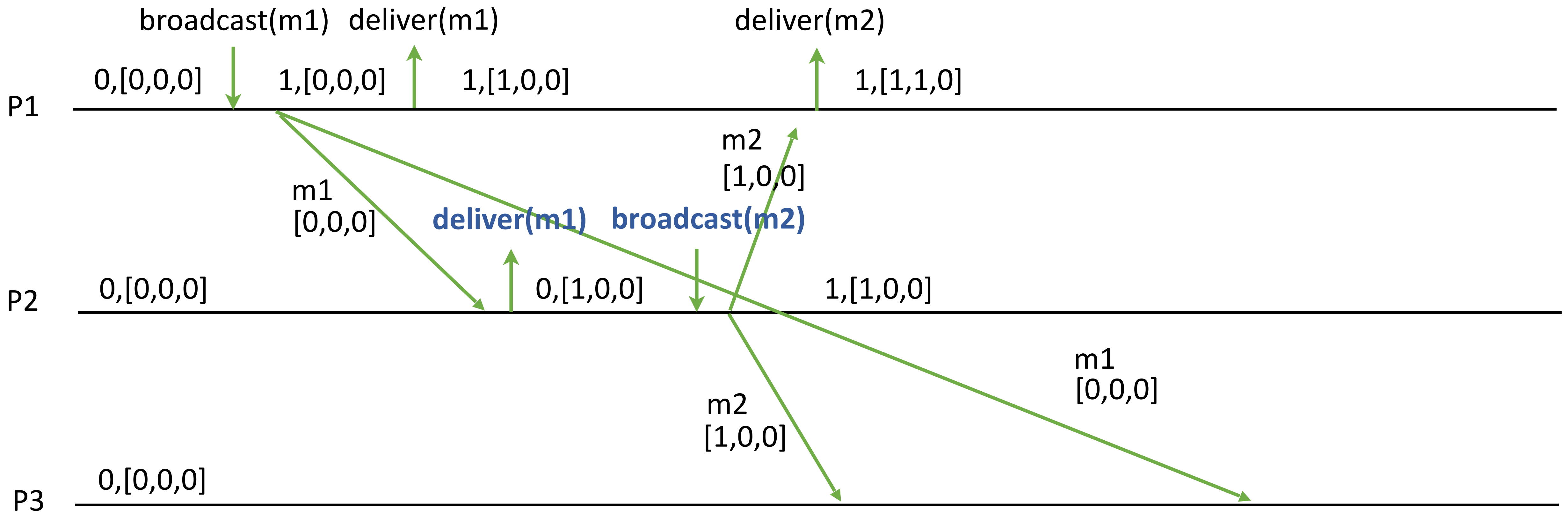

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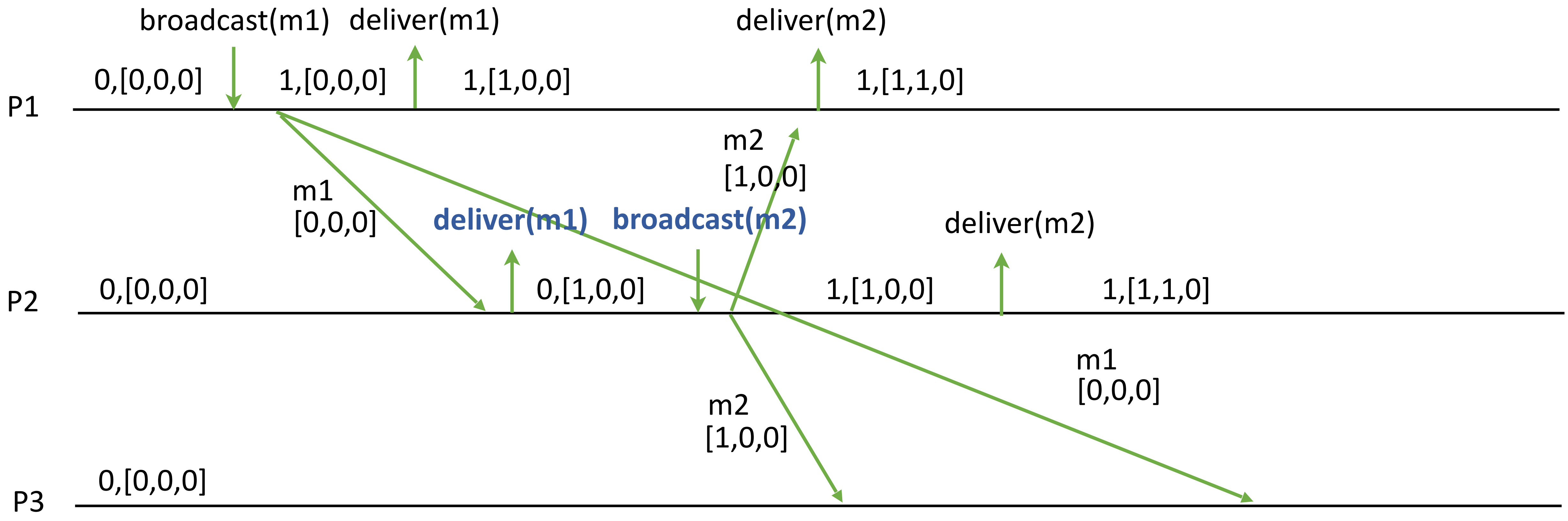

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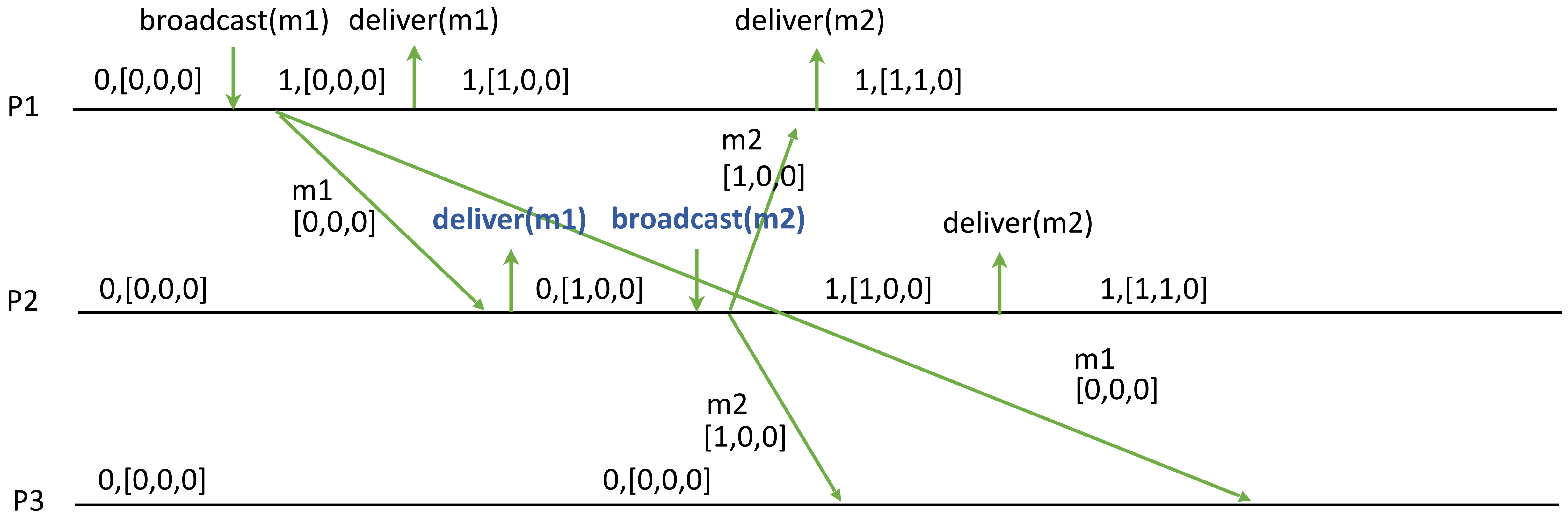

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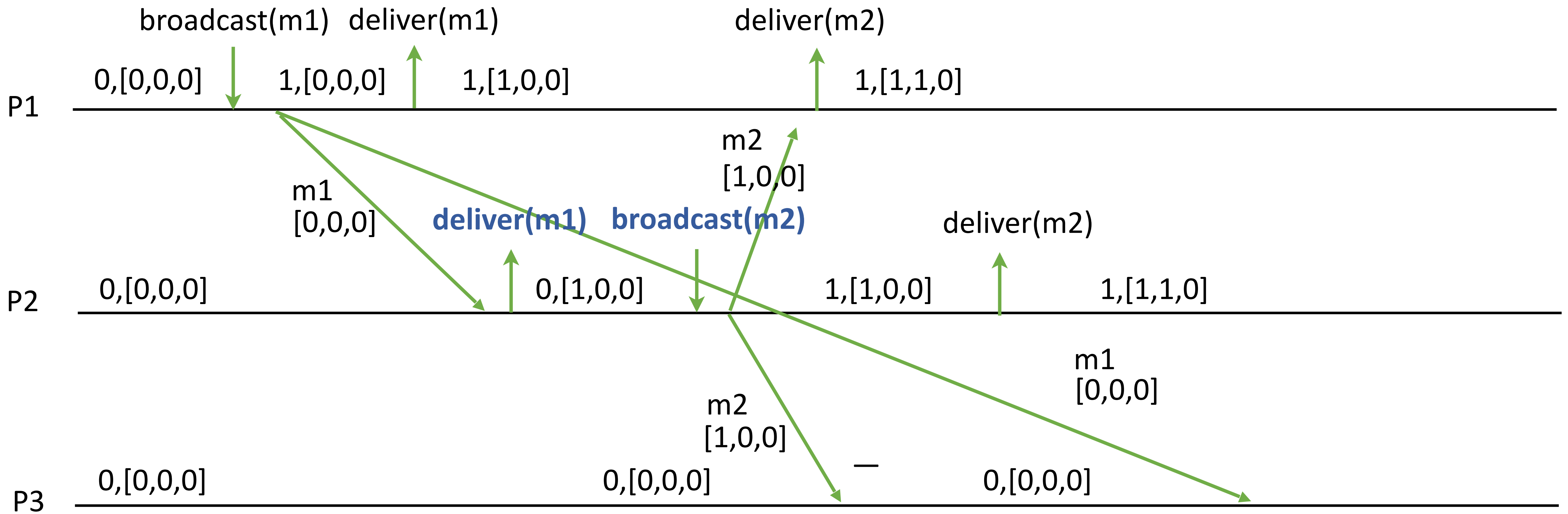

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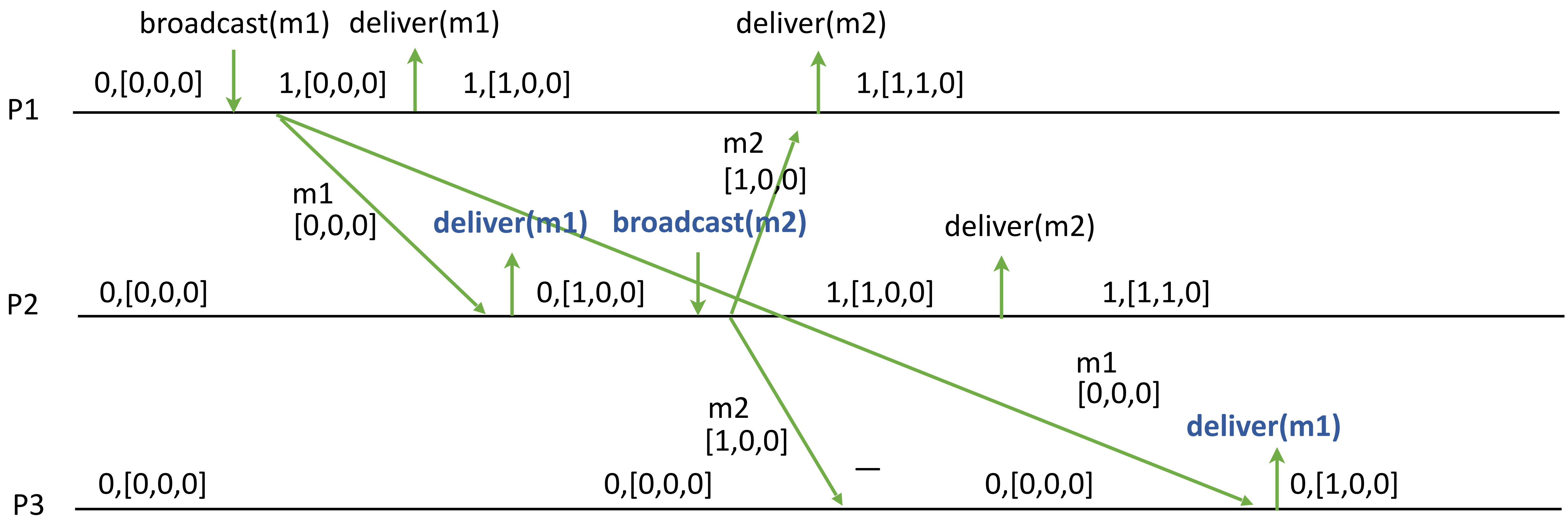

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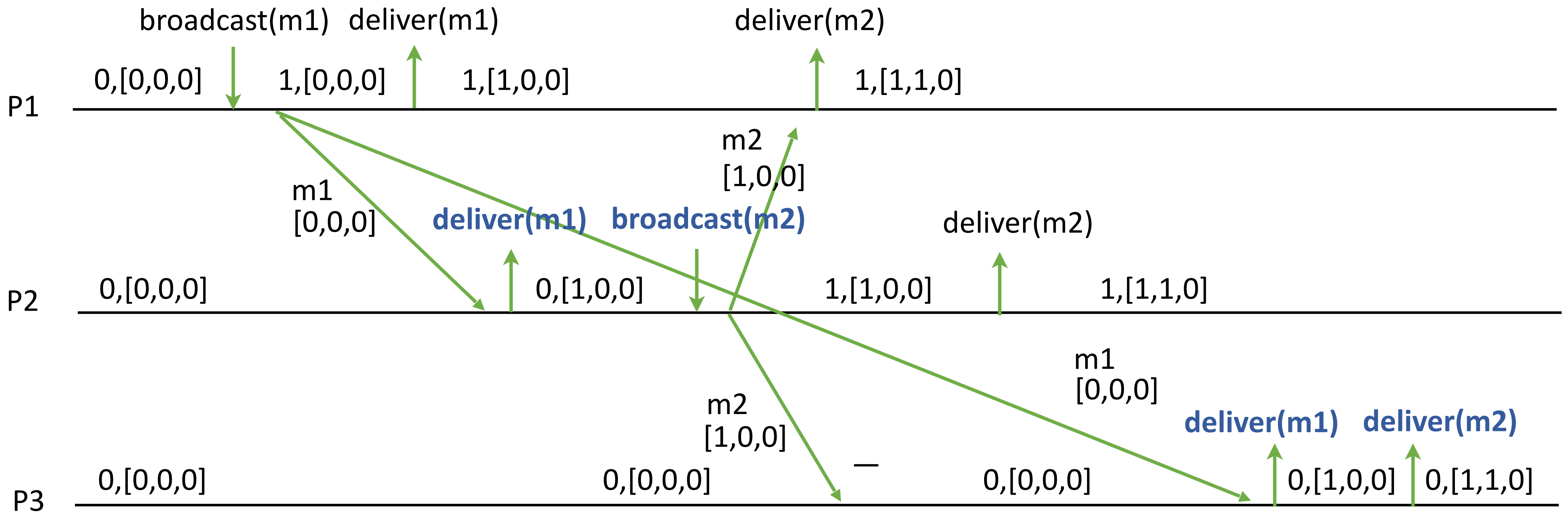
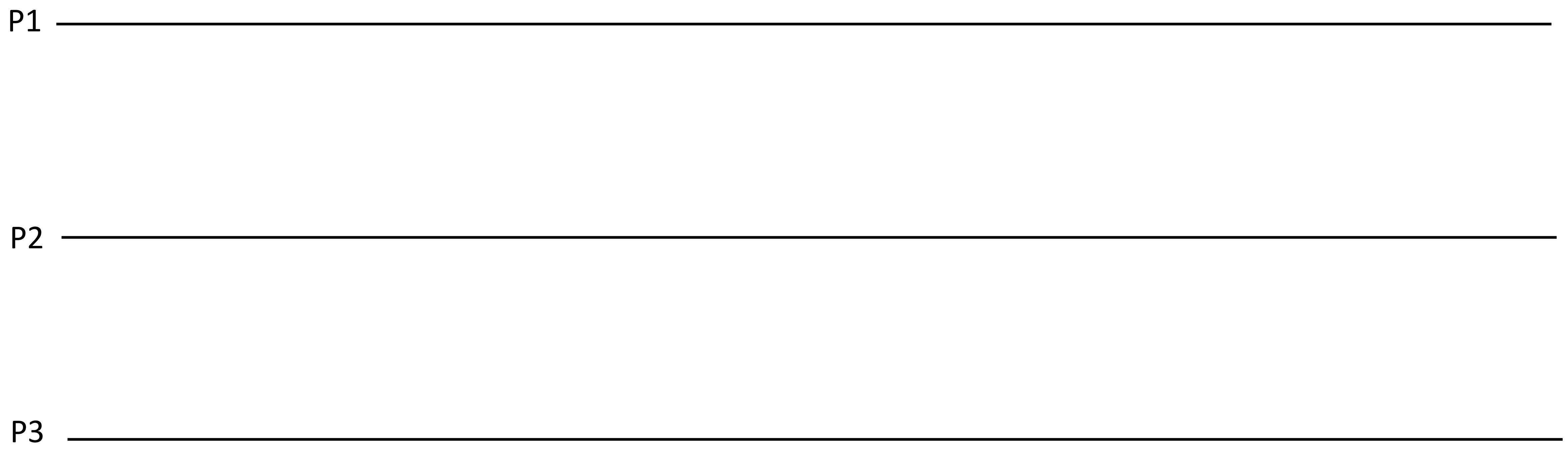


Example 1: FIFO Order (VC updated)



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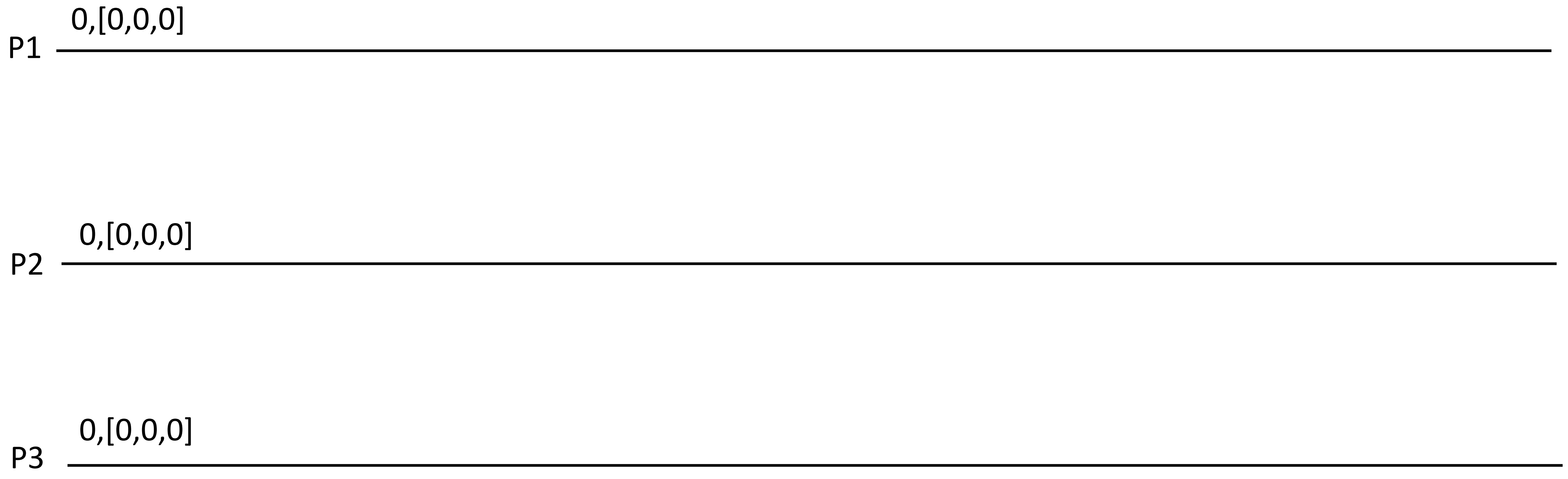

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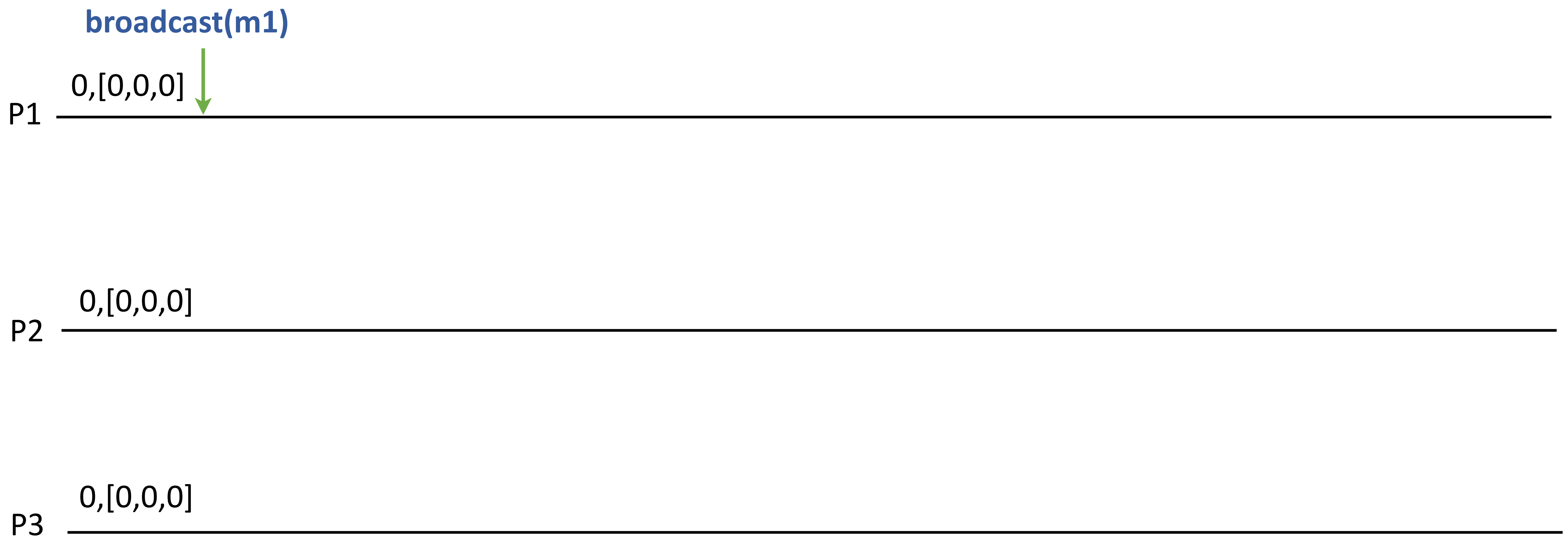

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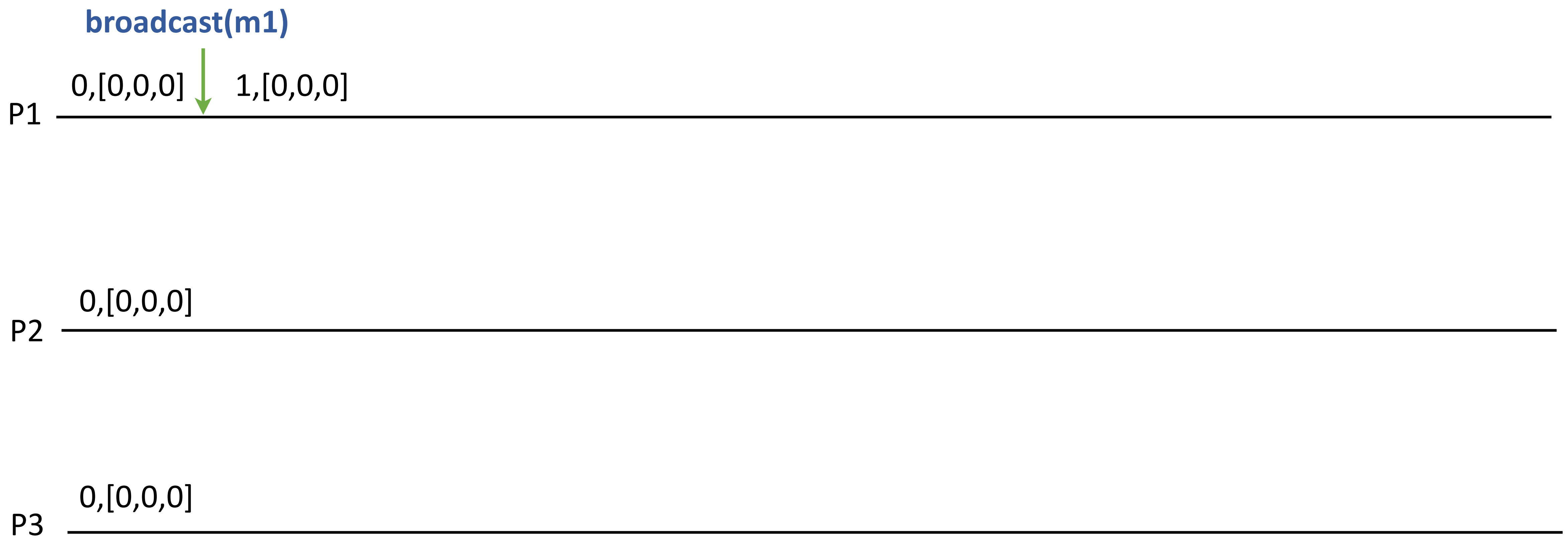

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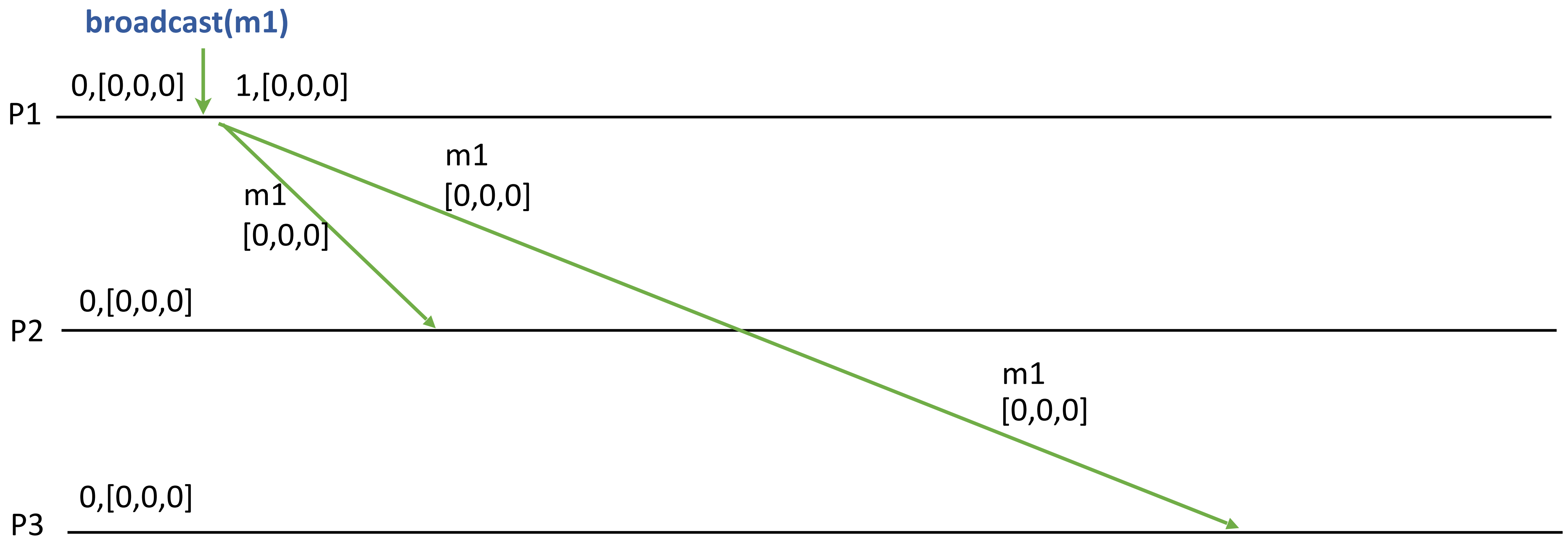

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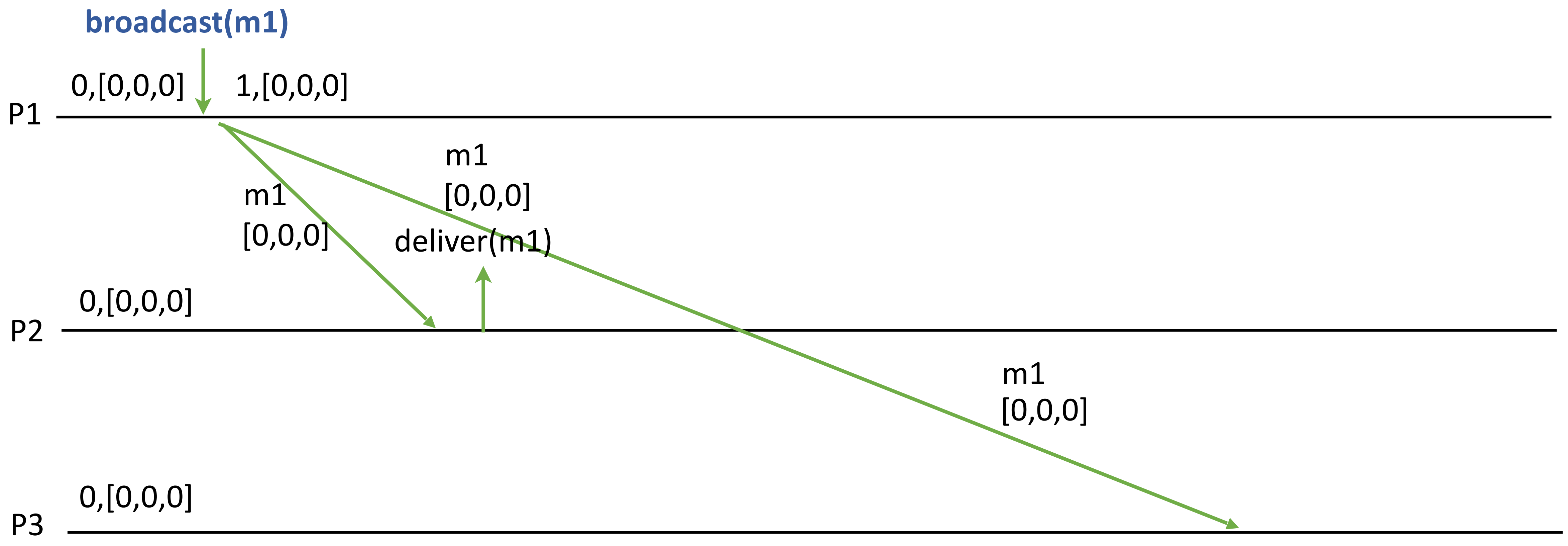

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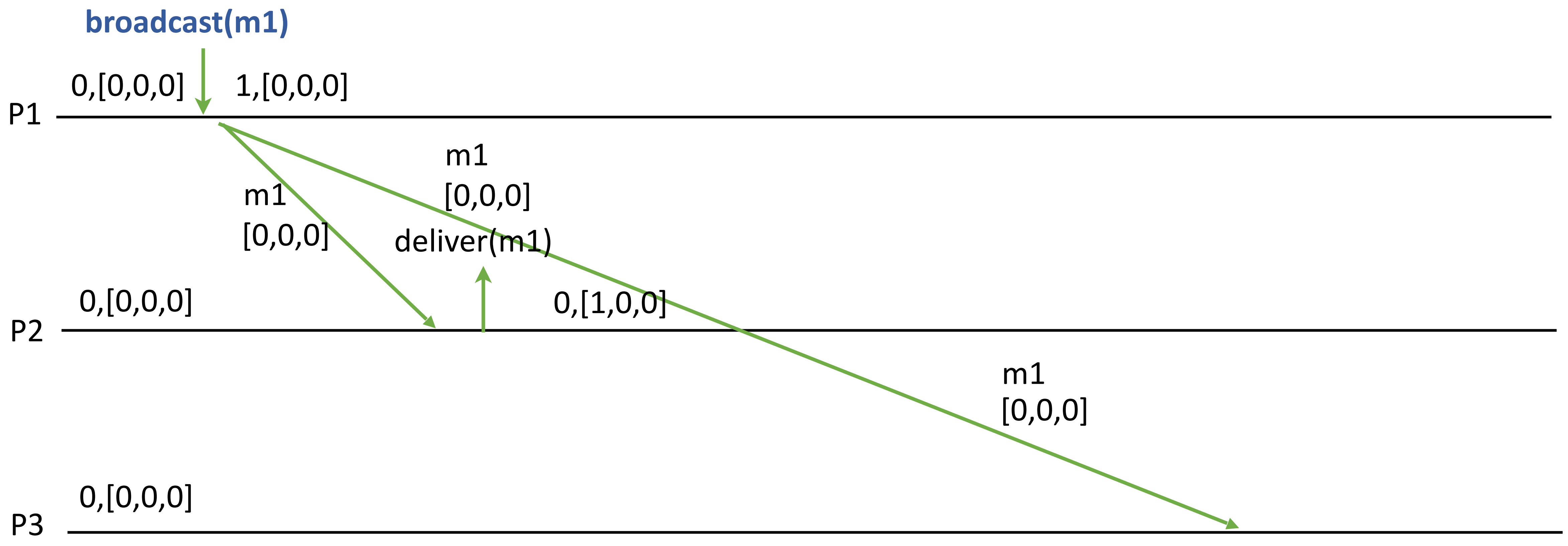

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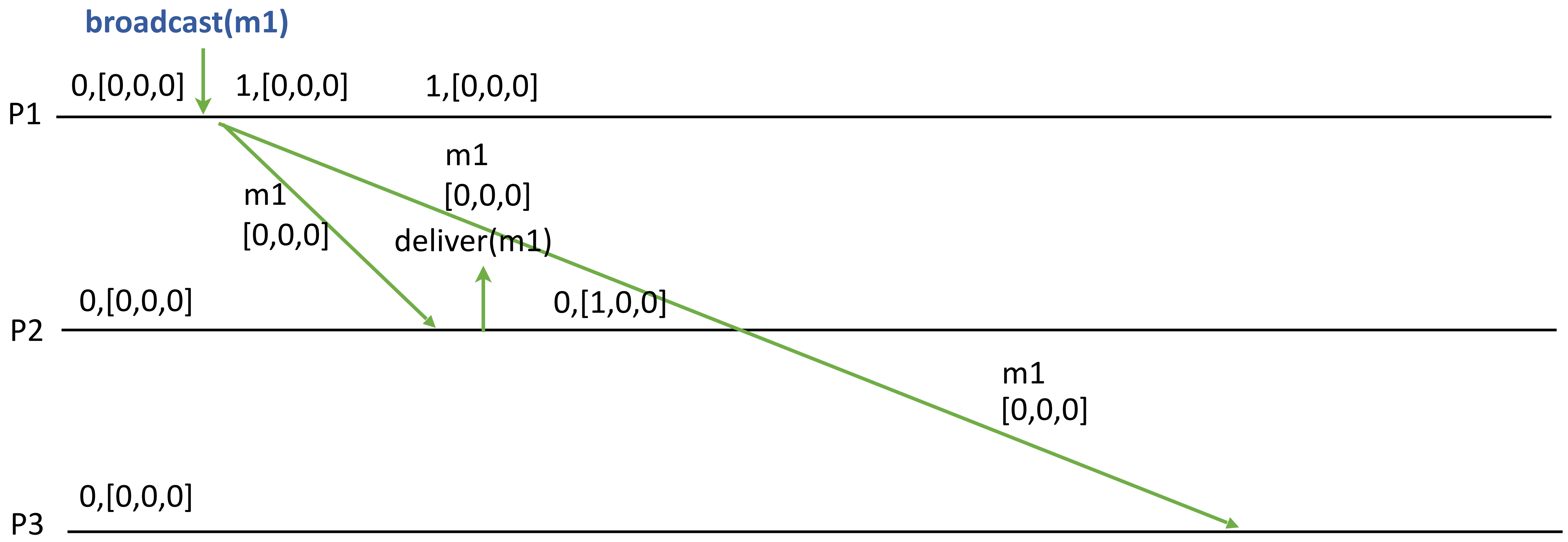

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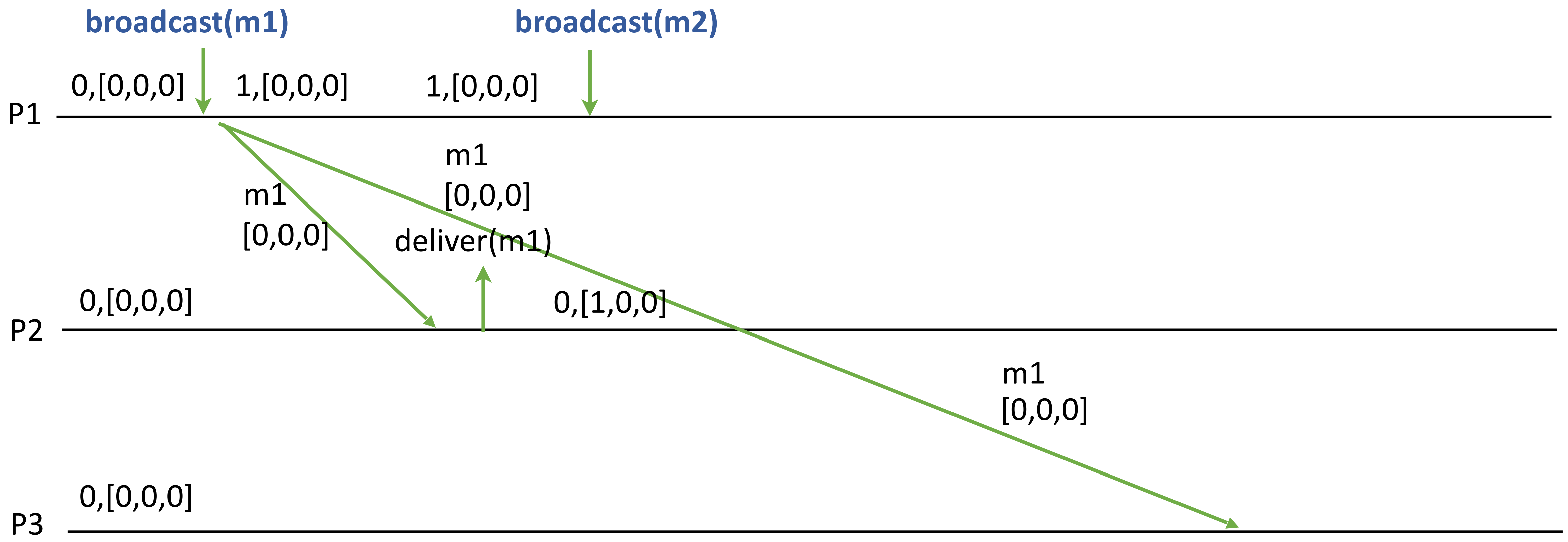

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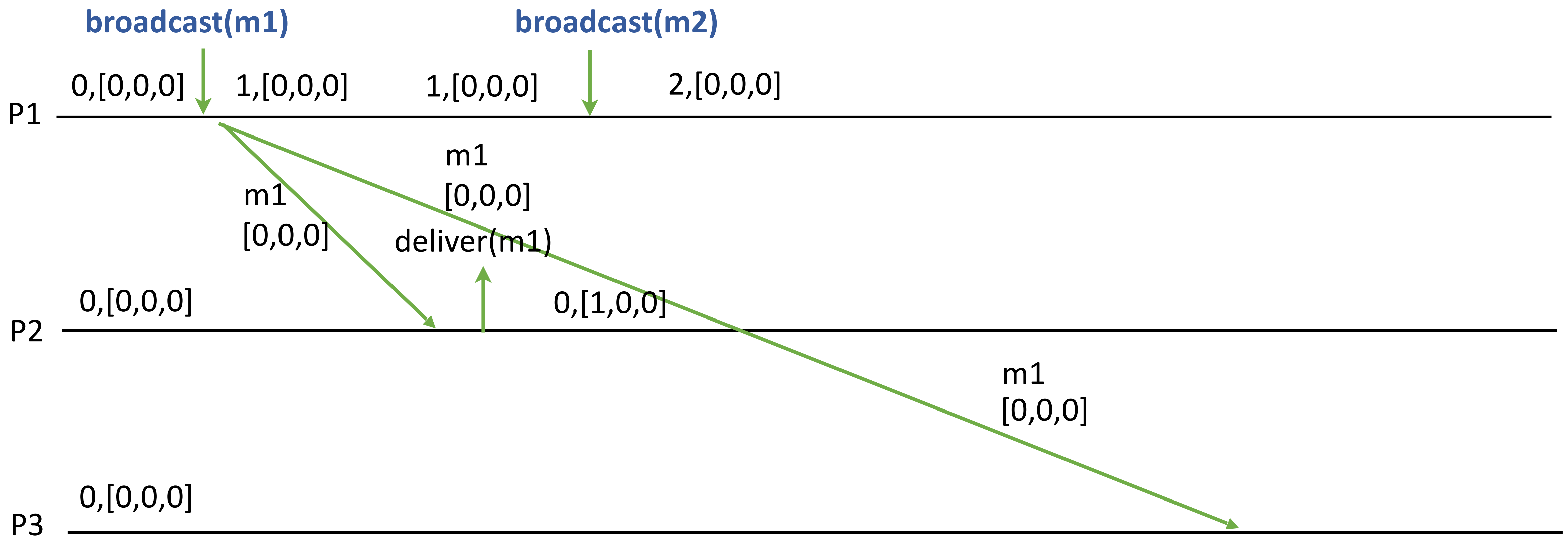

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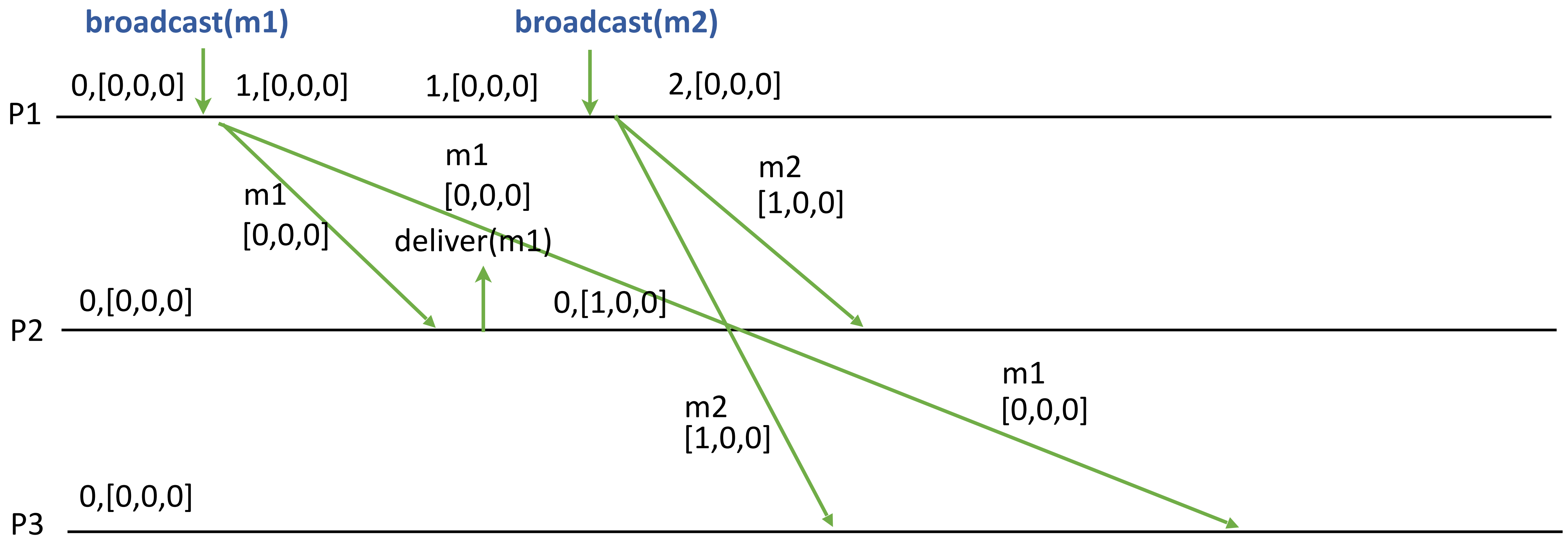

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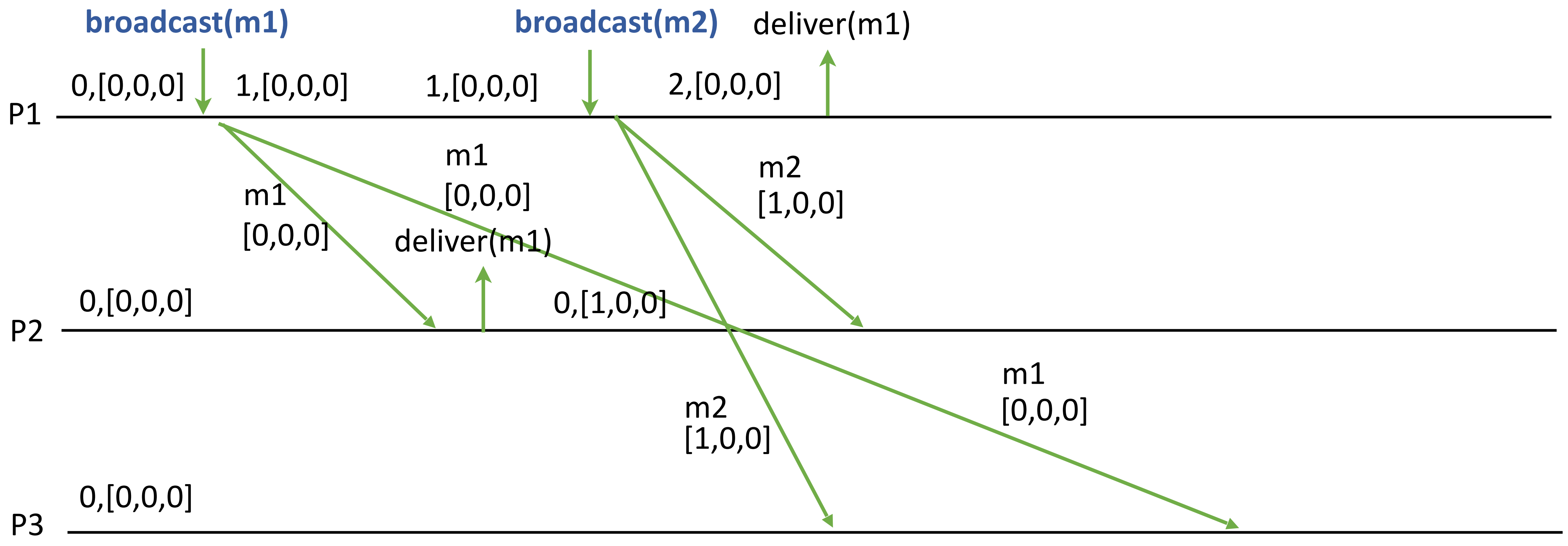

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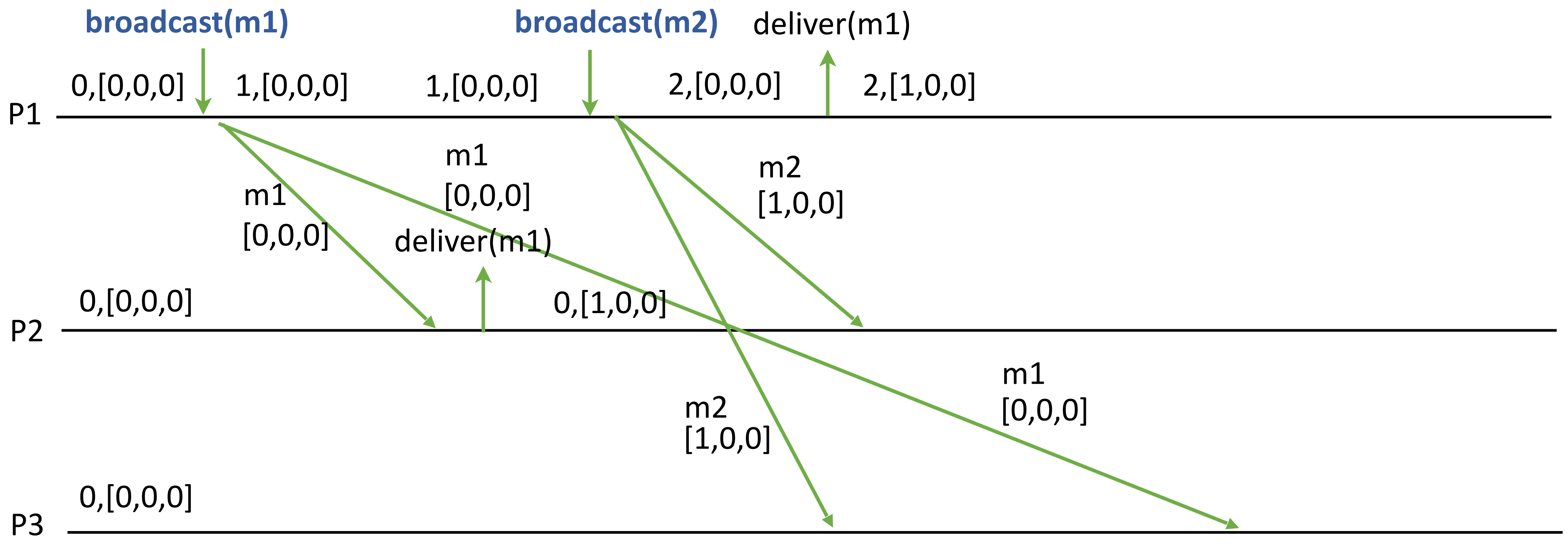

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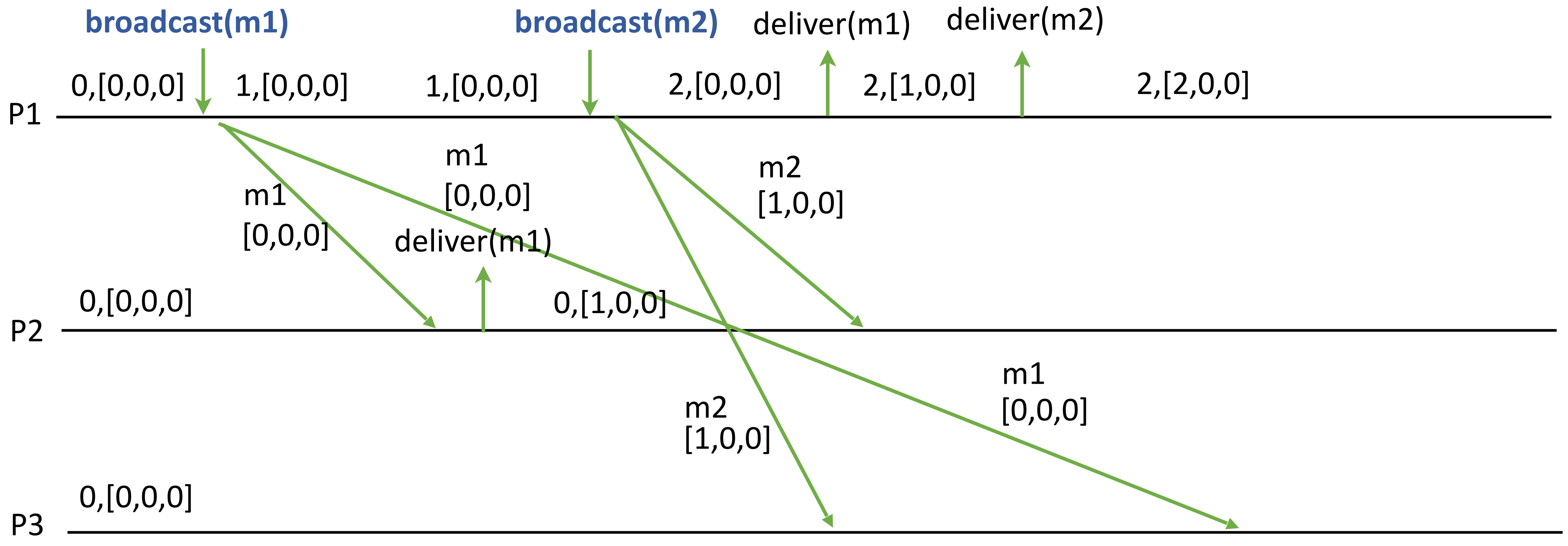

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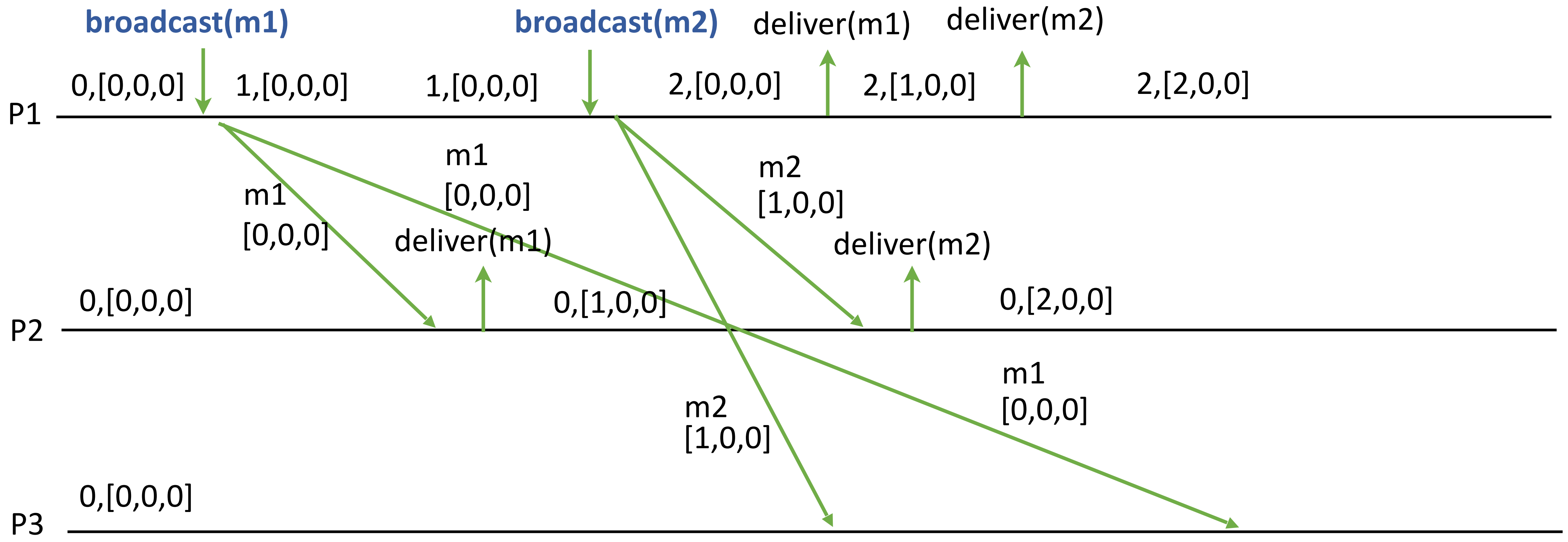

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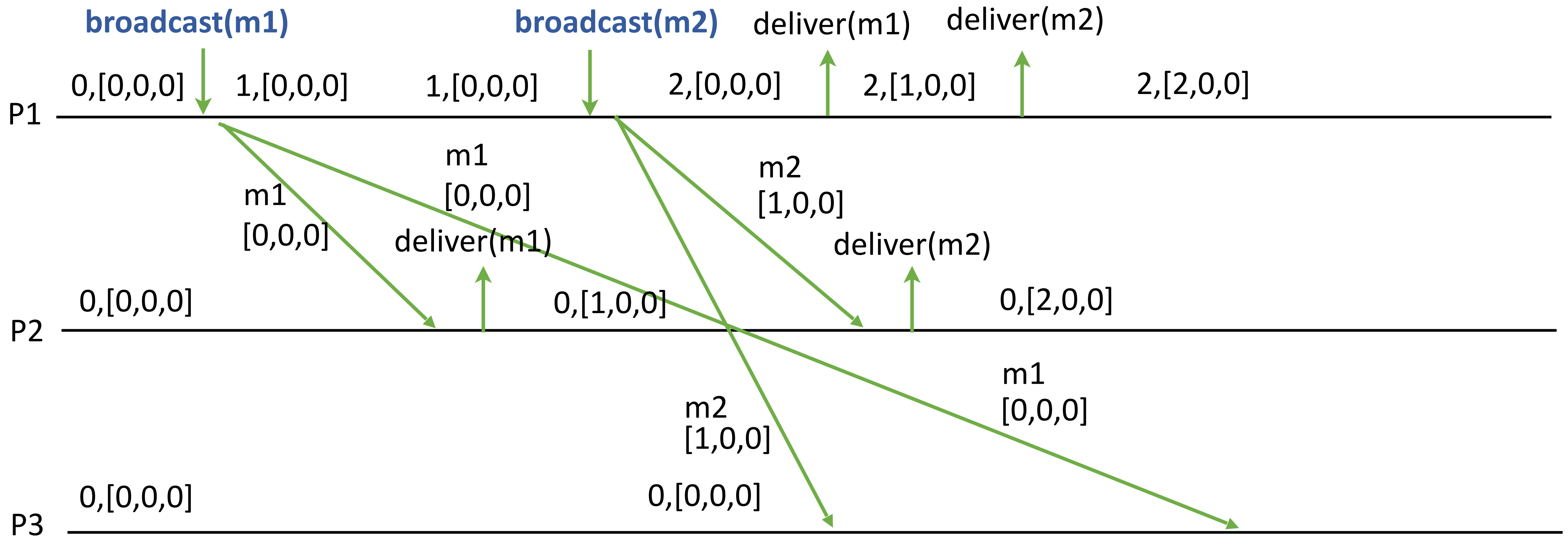

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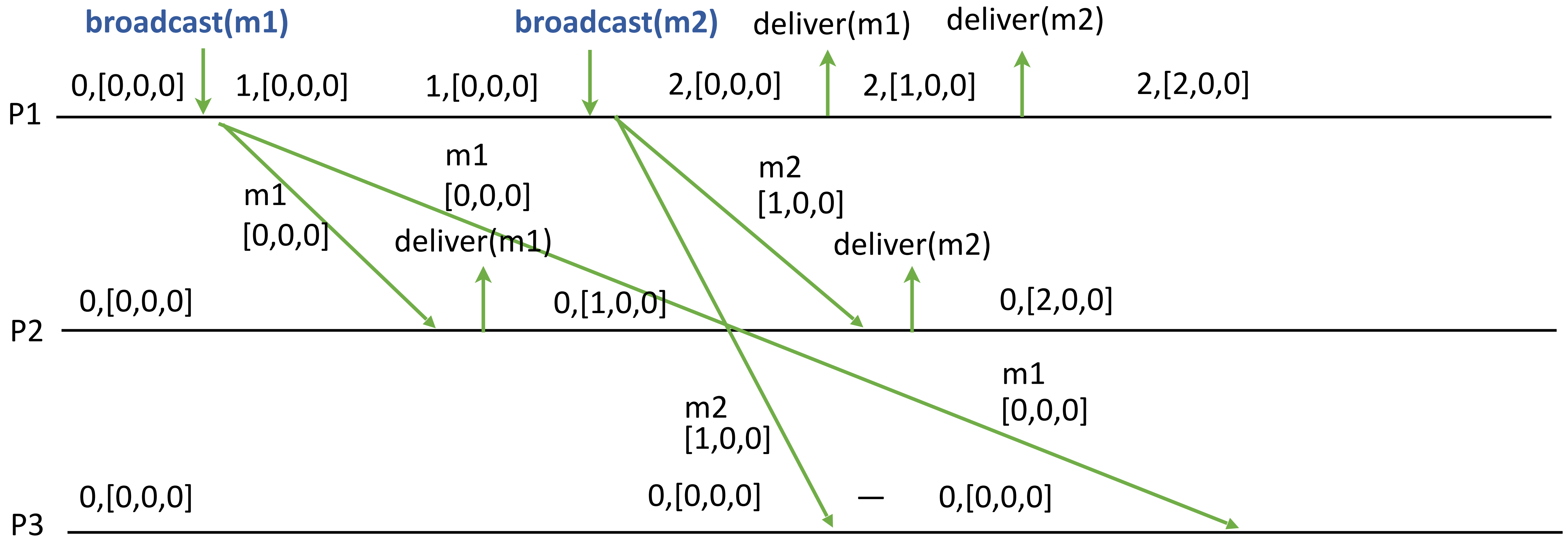

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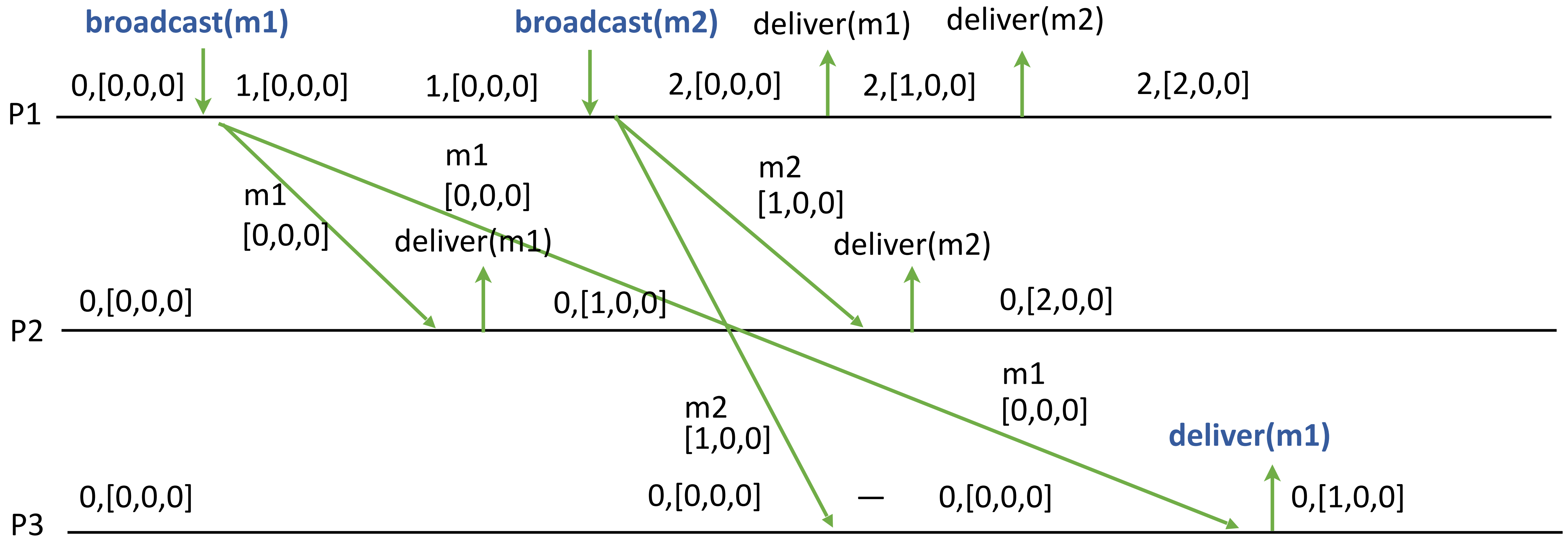

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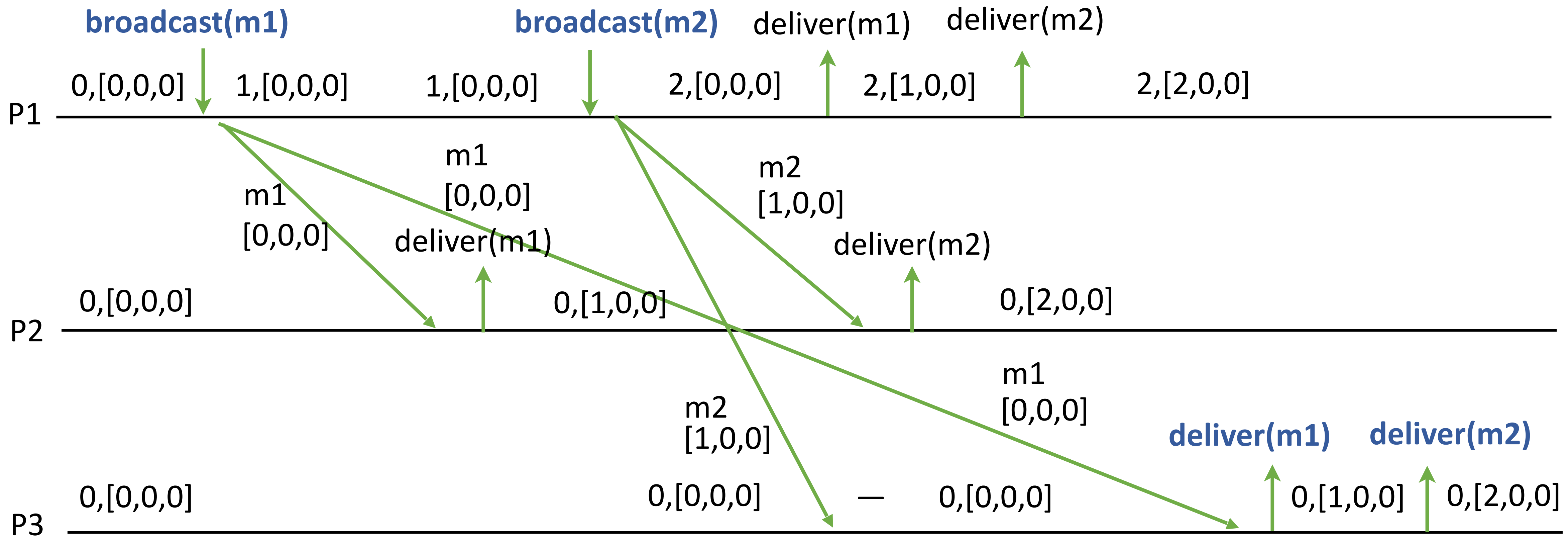
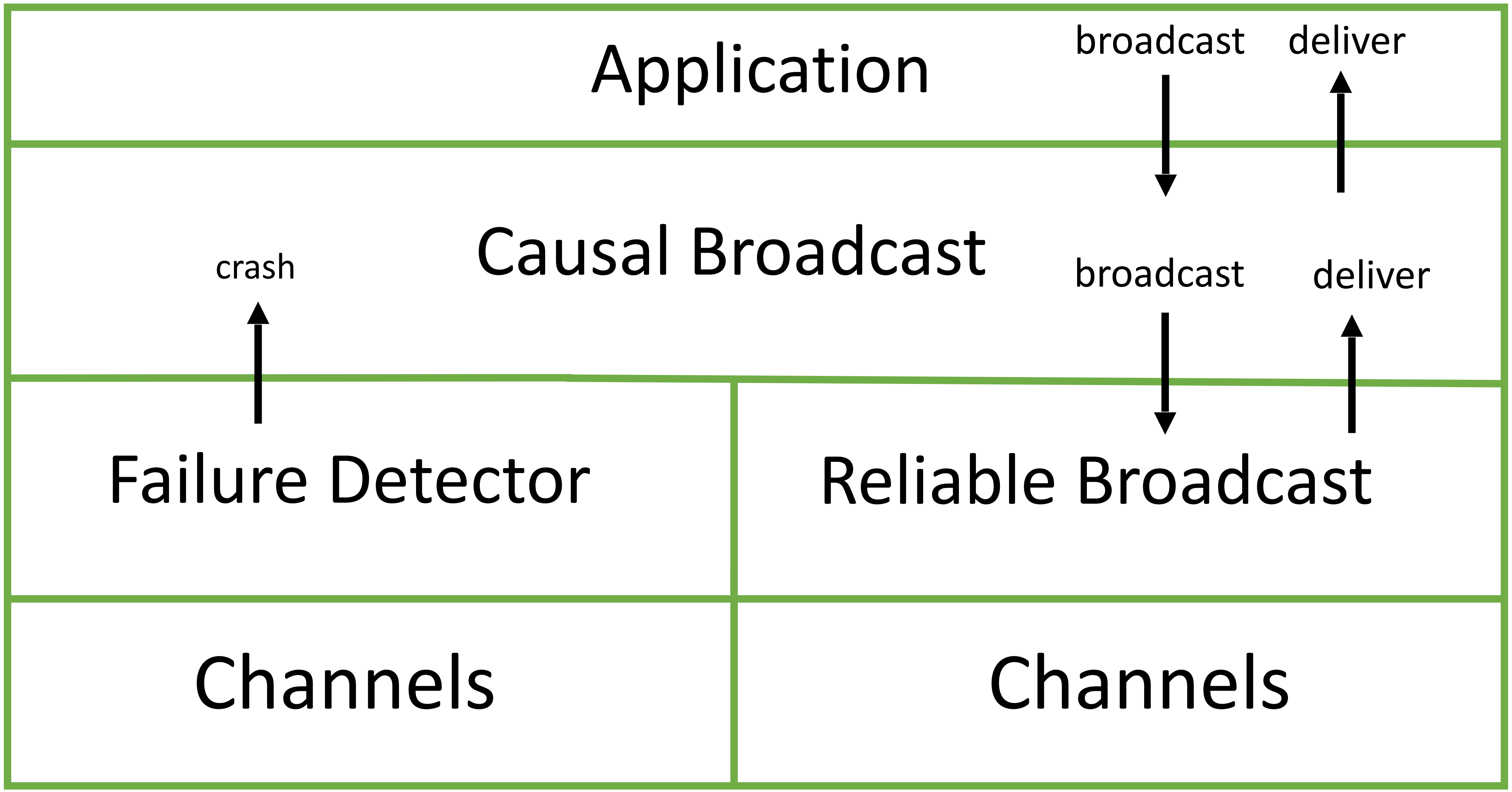


Modular Design



Protocol 1

Implements: UniformCausalBroadcast (ucb).

Uses: UniformReliableBroadcast (urb).

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upon event < broadcast (m) > do
    trigger < urb, broadcast ([past, m]) >
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    past := past U {[self, m]}
```

Similarly Reliable broadcast can be used to get Reliable causal broadcast.

Every new message is added to past. This preserves the FIFO order property.

Protocol 1

```
upon event <urb, deliver (pi, [pastm, m])> do
    if m $\notin$ delivered then
        forall [sn, n] $\in$ pastm do
            if n $\notin$ delivered then
                trigger < deliver (sn, n) >
                delivered := delivered U {n}
                past := past U {[sn, n]}
```

Protocol 1

```
upon event <urb, deliver (pi, [pastm, m])> do
    if m ∉ delivered then
        forall [sn, n] ∈ pastm do
            if n ∉ delivered then
                trigger < deliver (sn, n) >
                delivered := delivered U {n}
                past := past U {[sn, n]}
```

The set pastm is added to past.
This preserves the transitivity property.

Protocol 1

```
upon event <urb, deliver (pi, [pastm, m])> do
    if m ∉ delivered then
        forall [sn, n] ∈ pastm do
            if n ∉ delivered then
                trigger < deliver (sn, n) >
                delivered := delivered U {n}
                past := past U {[sn, n]}
        trigger < deliver (pi, m) >
        delivered := delivered U {m}
        past := past U {[pi, m]}
```

The set pastm is added to past.
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Protocol 1

```
upon event <urb, deliver (pi, [pastm, m])> do
    if m ∉ delivered then
        forall [sn, n] ∈ pastm do
            if n ∉ delivered then
                trigger < deliver (sn, n) >
                delivered := delivered U {n}
                past := past U {[sn, n]}
        trigger < deliver (pi, m) >
        delivered := delivered U {m}
        past := past U {[pi, m]}
```

The set pastm is added to past.
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Every delivered message is added to past.
This preserves the InOut property.

Observation

If we keep remembering the past,
we eventually run out of space!

Protocol 1 + Garbage Collection

Idea:

- Broadcast an ack when a message is delivered.
- Forget a message after receiving acks from all correct processes.

Protocol 1 + Garbage Collection

```
Implements: CausalOrderBroadcast (co).
Uses:
    ReliableBroadcast (rb).
    PerfectFailureDetector (P).
upon event < Init > do
    …
    correct := $\Pi$
    ack(m) := $\emptyset$ (for all m)
```

Protocol 1 + Garbage Collection

```
upon event < P, crash (pi) > do
    correct := correct \ {pi}
```

Protocol 1 + Garbage Collection

```
upon event < P, crash (pi) > do
    correct := correct \ {pi}

upon event <urb, deliver (p, Msg[pastm, m])> do
    …
    trigger <urb, broadcast (Ack[p, m])>
```

Protocol 1 + Garbage Collection

```
upon event < P, crash (pi) > do
    correct := correct \ {pi}

upon event <urb, deliver (p, Msg[pastm, m])> do
    …
    trigger <urb, broadcast (Ack[p, m])>

upon event <urb, deliver (p, Ack[s, m])> do
    ack(m) := ack(m) U {p}
    if correct ⊆ ack(m) then
        past := past \ {[s, m]}
```

Protocol 2

```
**Implements**:  UniformCausalBroadcast (ucb).
**Uses**:  UniformReliableBroadcast (urb).

upon event < Init > do
    sq := 0
    foreach pi in Π: VC[pi] := 0
```

Protocol 2

```
**upon event** < broadcast (m) > **do**
    VC' = VC[self ↦ sq]
    **trigger** < urb, broadcast ([VC’, m]) >
    sq = sq + 1
```

Protocol 2

```
upon event < broadcast (m) > do
    VC' = VC[self ↦ sq]
    trigger < urb, broadcast ([VC’, m]) >
    sq = sq + 1


upon event < urb, deliver (pj, [VCm, m]) > do
    wait until (VC ≥ VCm)
    trigger < deliver (pj, m) >
    VC[pj] := VC[pj] + 1
```