

A Link-Level Multiplexing Mechanism

Rodney Van Meter, Ryosuke Satoh, Makoto Nakai, **Shota Nagayama**

for the QITF/MoonShot Nagayama Project

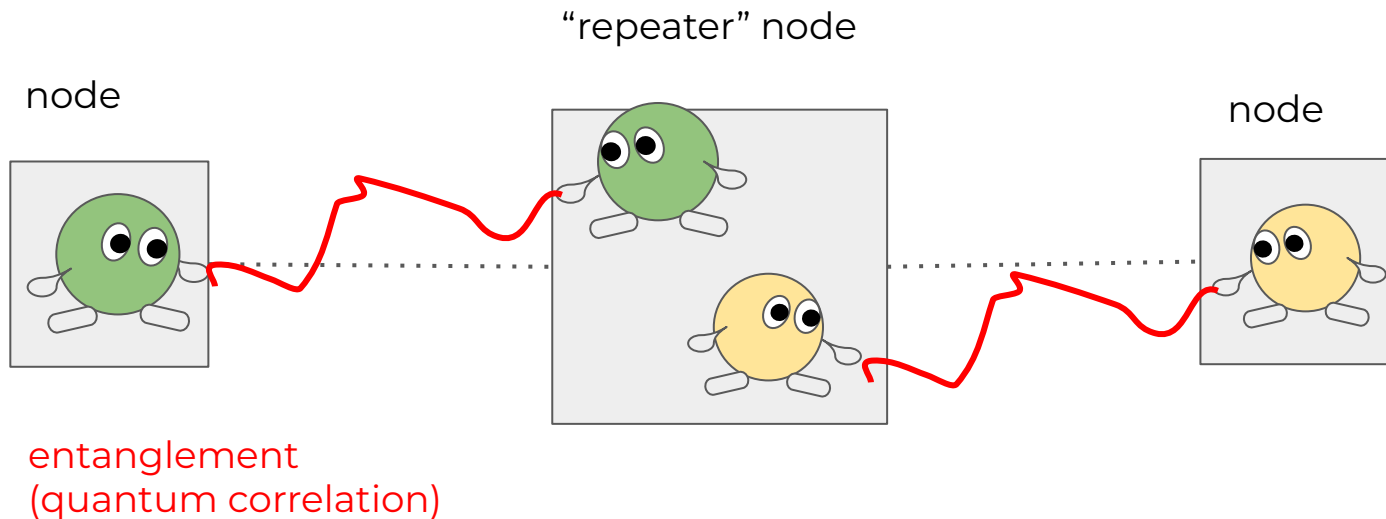
2024/03/20@IETF119

Summary

- Our proposal:
 - Multiplexing management by **Link Allocation Update** and **Barrier**
- Functionality:
 - Operation order (add/delete): **Link Allocation Update**
 - Timing to move next LA: **Barrier**
- Problem to solve:
 - mis-connection of entanglement caused by inconsistent allocation of entangled qubits to connections

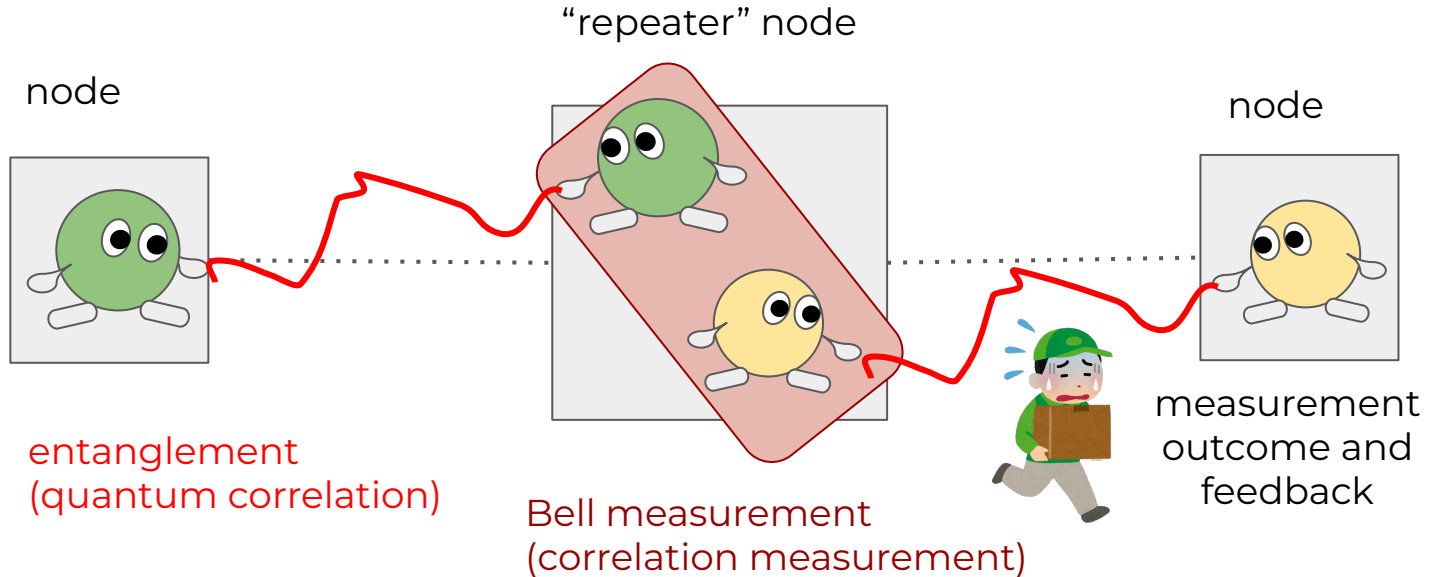
Quantum repeating (Entanglement Swapping)

- link-level entanglement generation



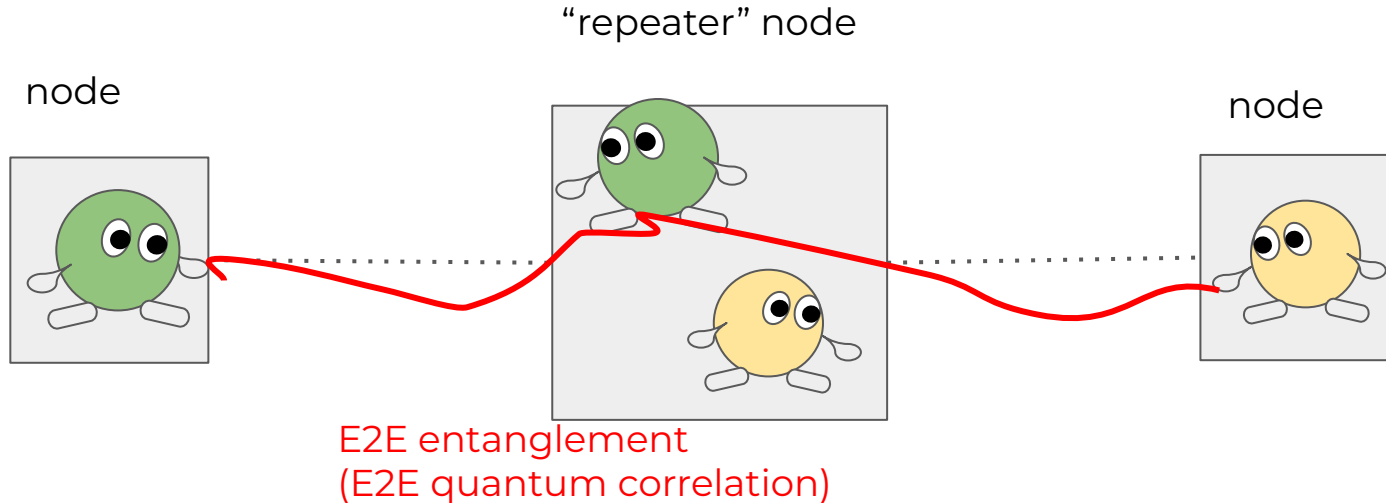
Quantum repeating (Entanglement Swapping)

- Correlation measurement at “repeater” node
- Classical transfer of measurement outcome

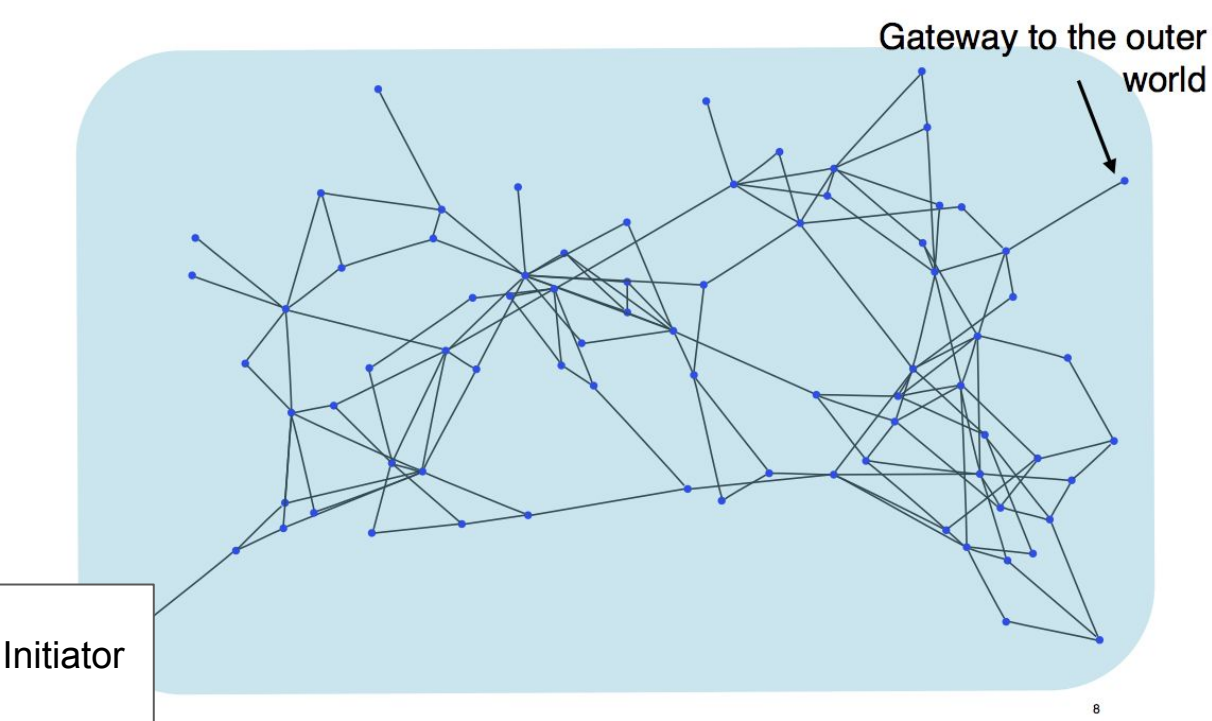


Quantum repeating (Entanglement Swapping)

- entanglement swapping completed

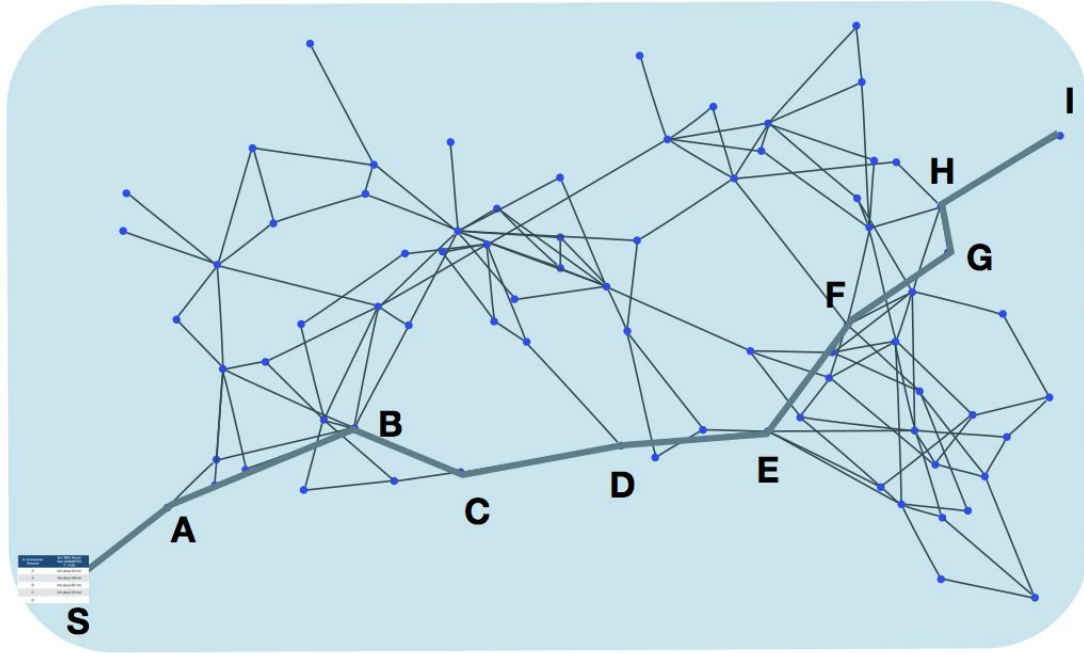


RuleSet-based networking



1. find a path from Initiator to Responder
2. collect parameters of each link, with finding a path
3. Responder creates RuleSet for each link
4. distribute RuleSet to each link
5. start Quantum Communication

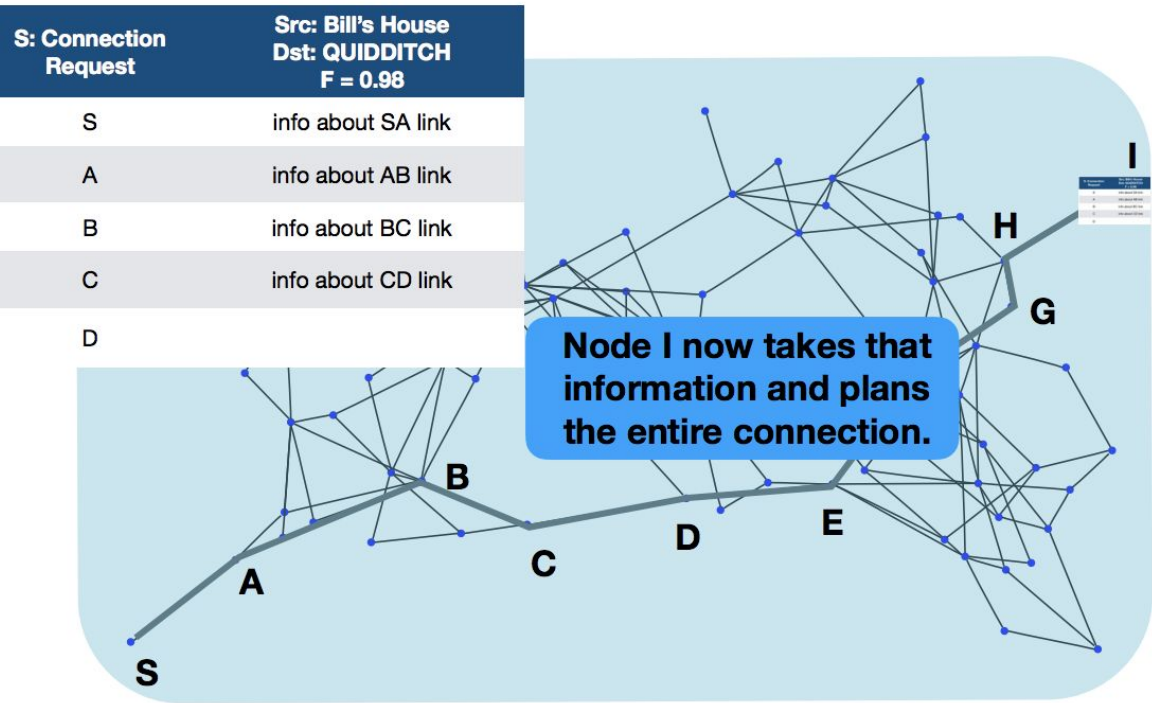
RuleSet-based networking



1. find a path from Initiator to Responder
2. collect parameters of each link, with finding a path
3. Responder creates RuleSet for each link
4. distribute RuleSet to each link
5. start Quantum Communication

9

RuleSet-based networking

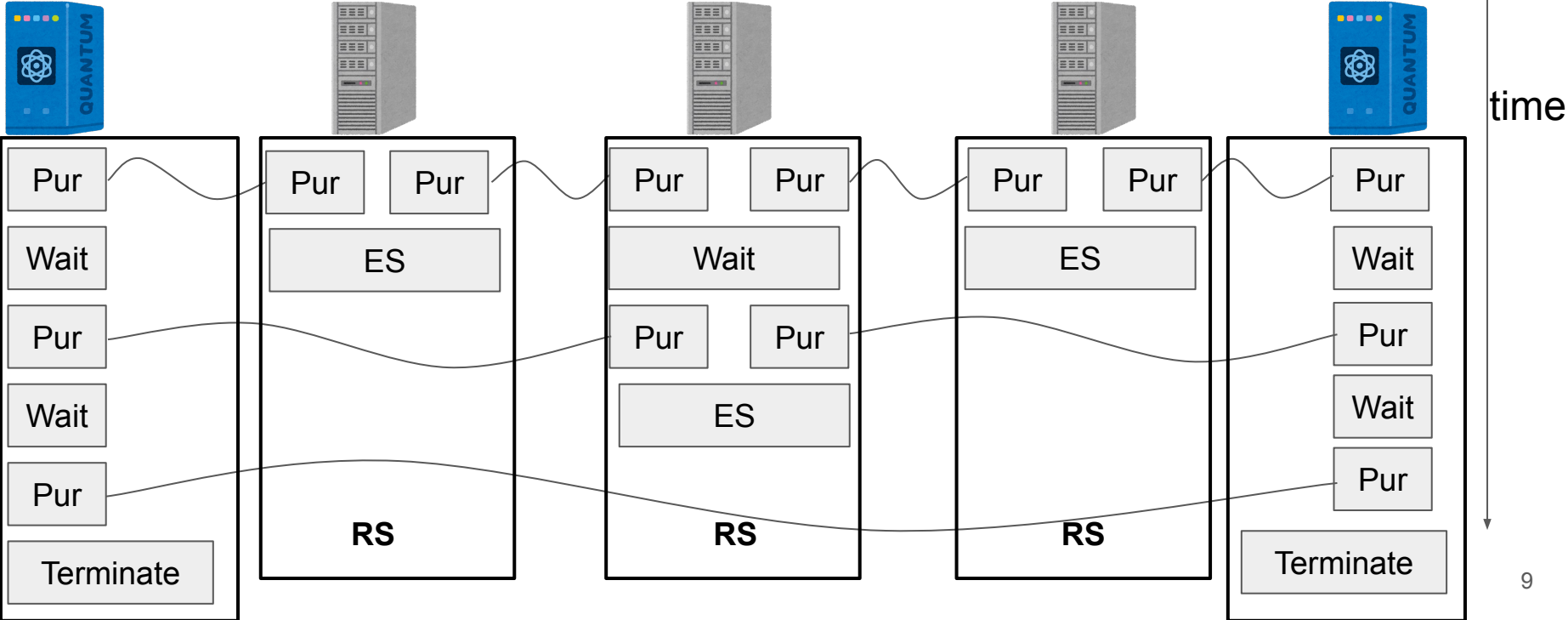


15

1. find a path from Initiator to Responder
2. collect parameters of each link, with finding a path
3. Responder creates RuleSet for each link
4. distribute RuleSet to each link
5. start Quantum Communication

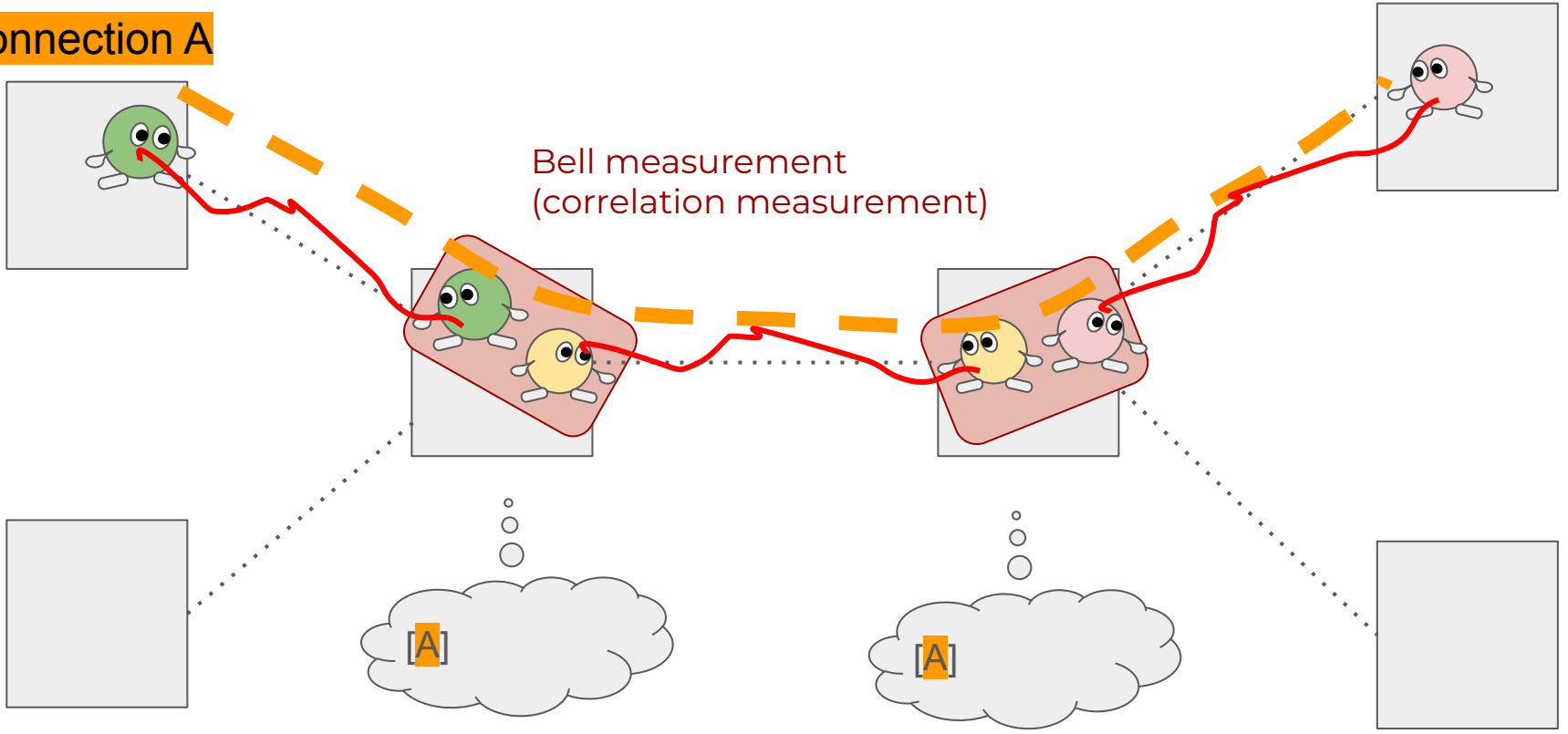
RuleSet to establish an E2E entanglement

Here is the set of operations for each node to establish an E2E entanglement



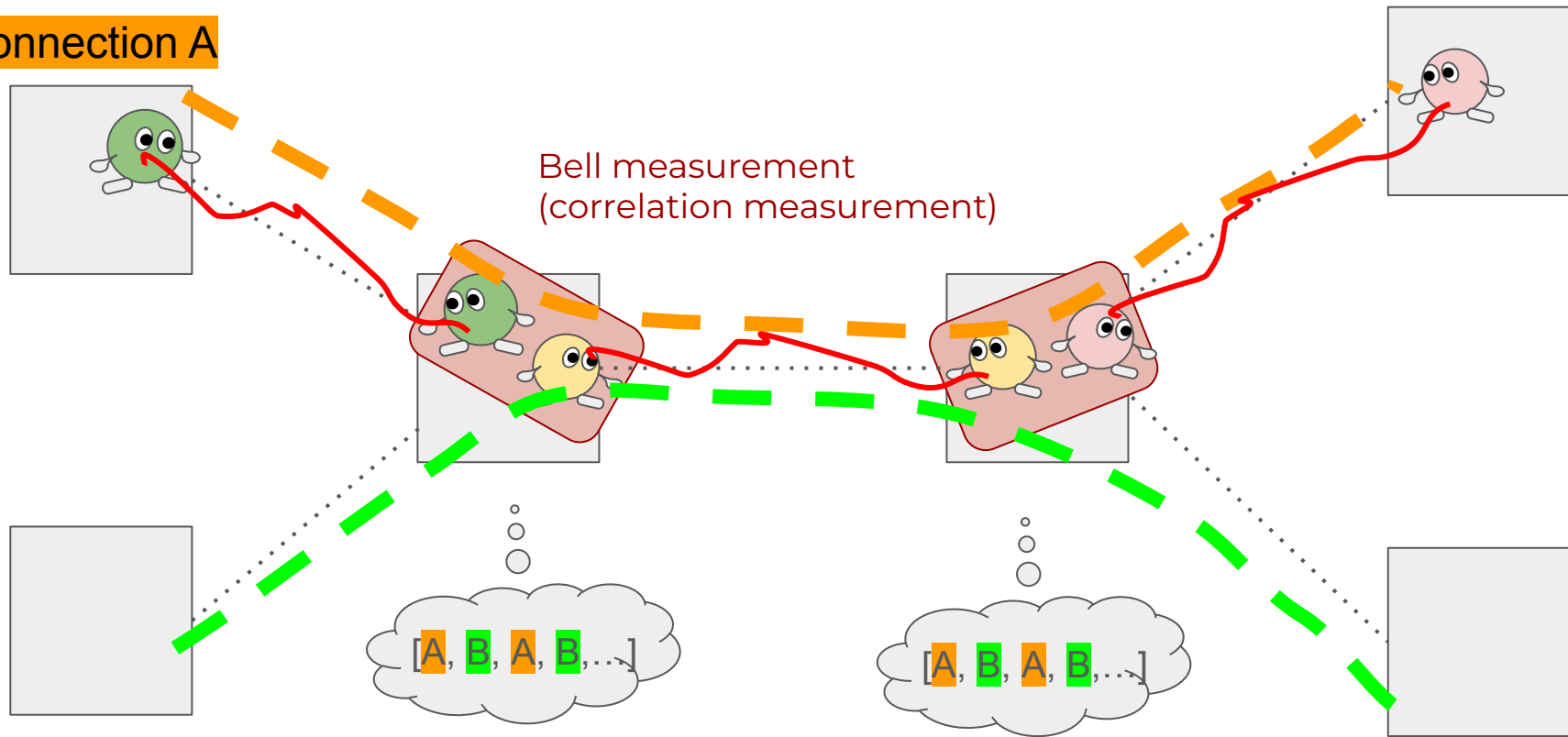


connection A



Multiplexing begins

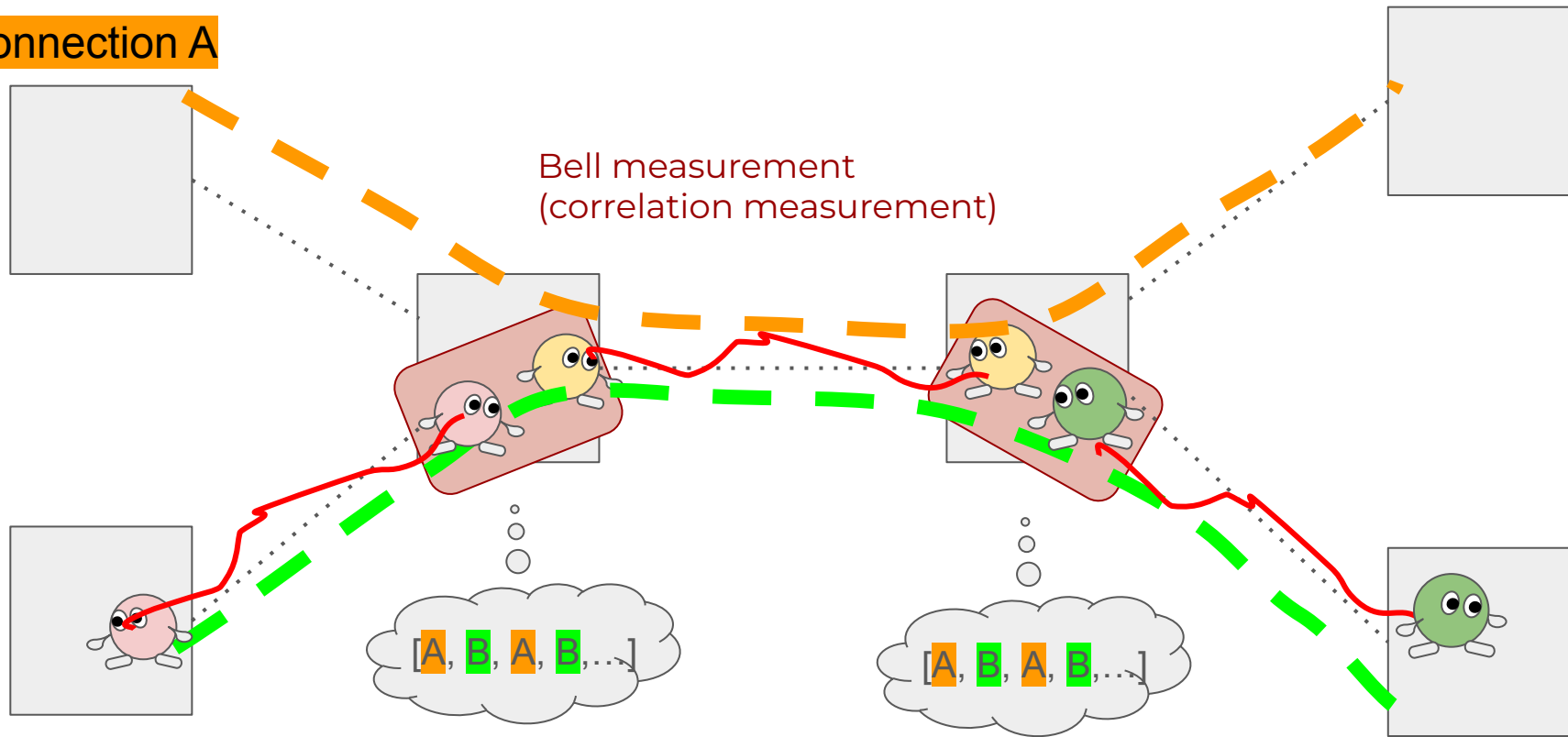
connection A



connection B

Time Division Multiplexing

connection A

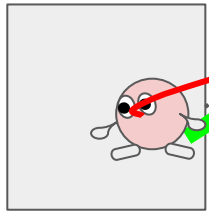


connection B

Quantum Networking = Distributed Computation

Frequent Problem in DC: **inconsistent resource allocation**

connection A



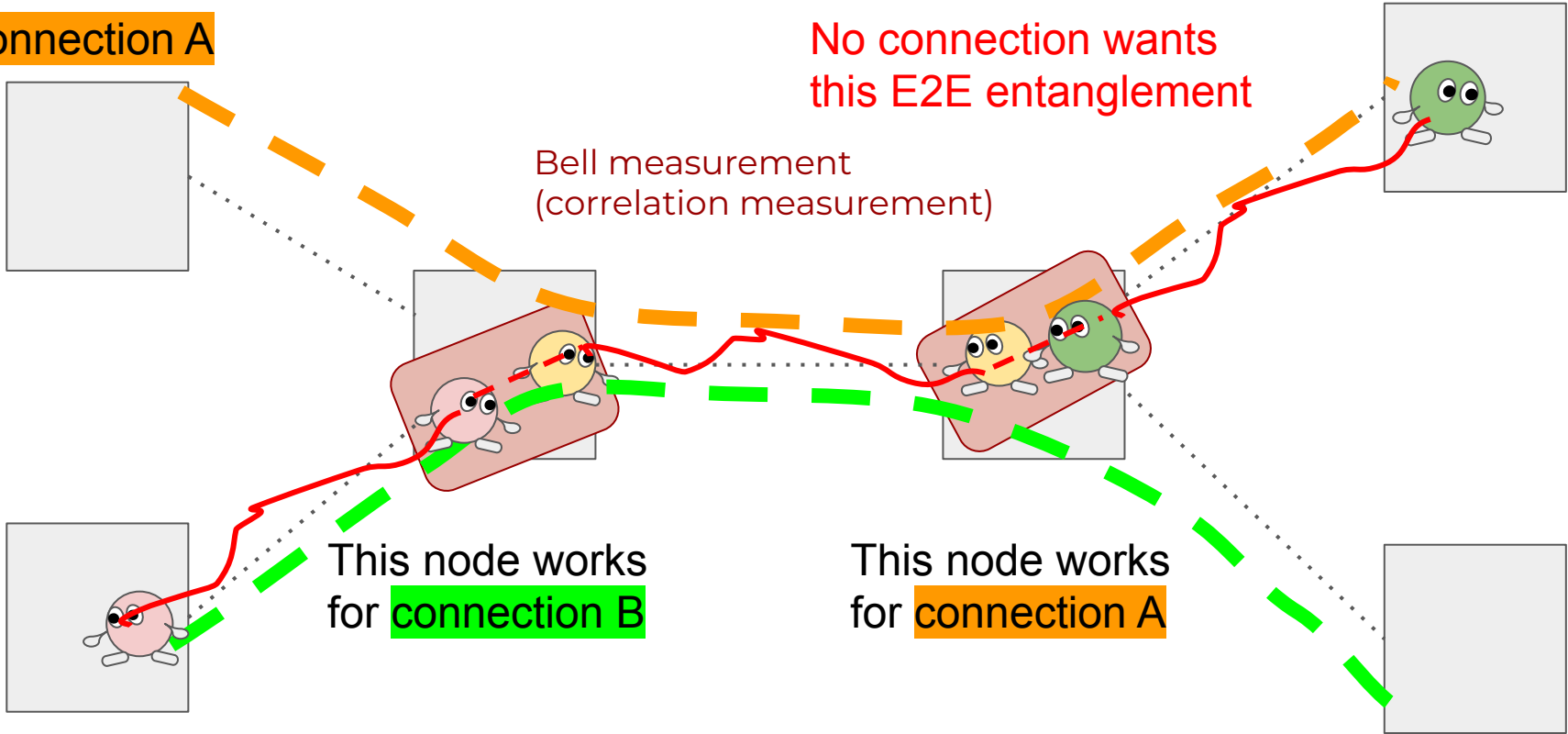
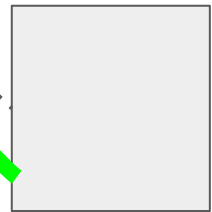
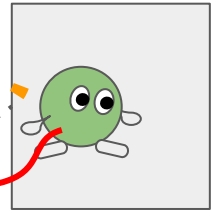
connection B

This node works for **connection B**

This node works for **connection A**

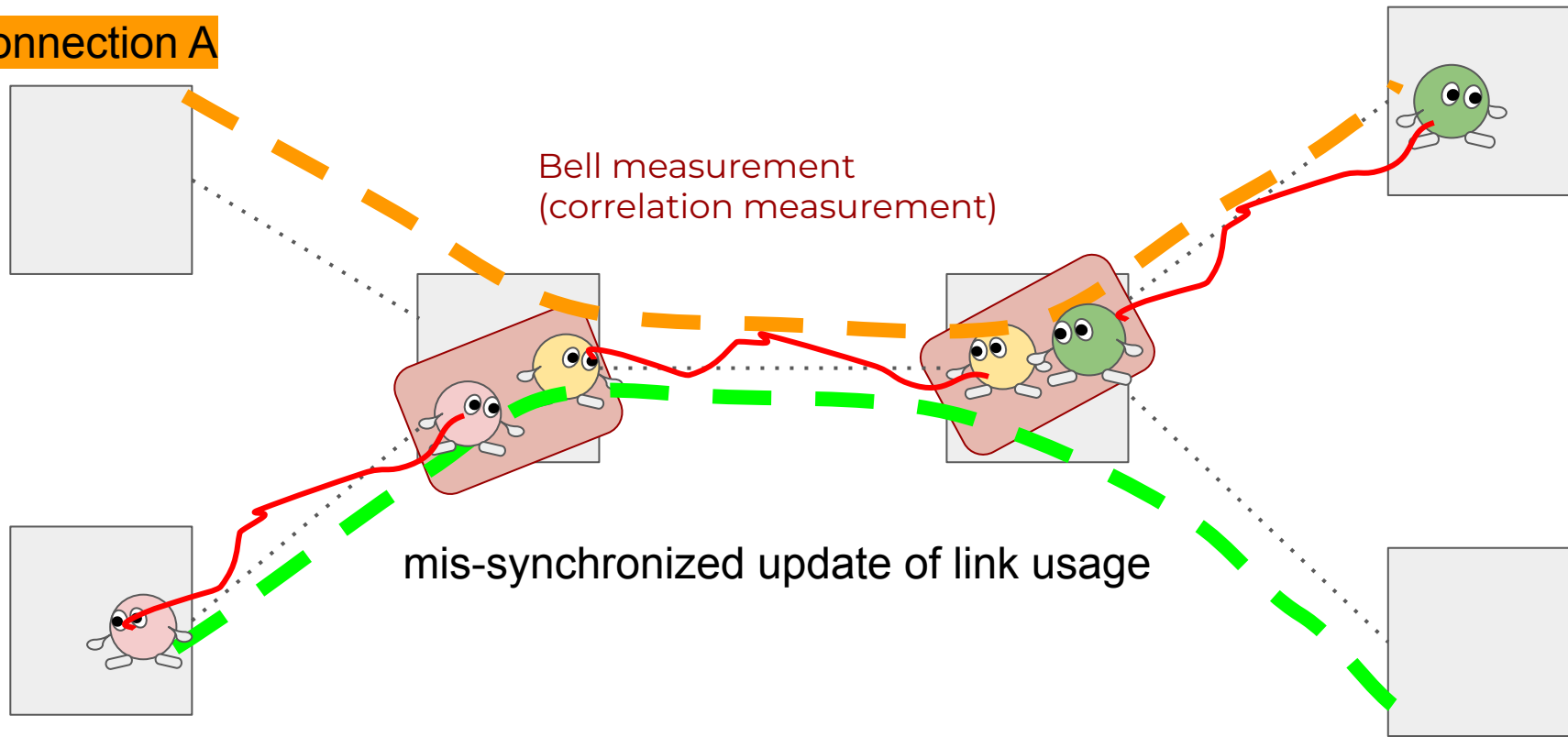
No connection wants this E2E entanglement

Bell measurement (correlation measurement)



What may cause **incoherent data** ?

connection A



connection B

Allocation to connection A

Allocation to connection B

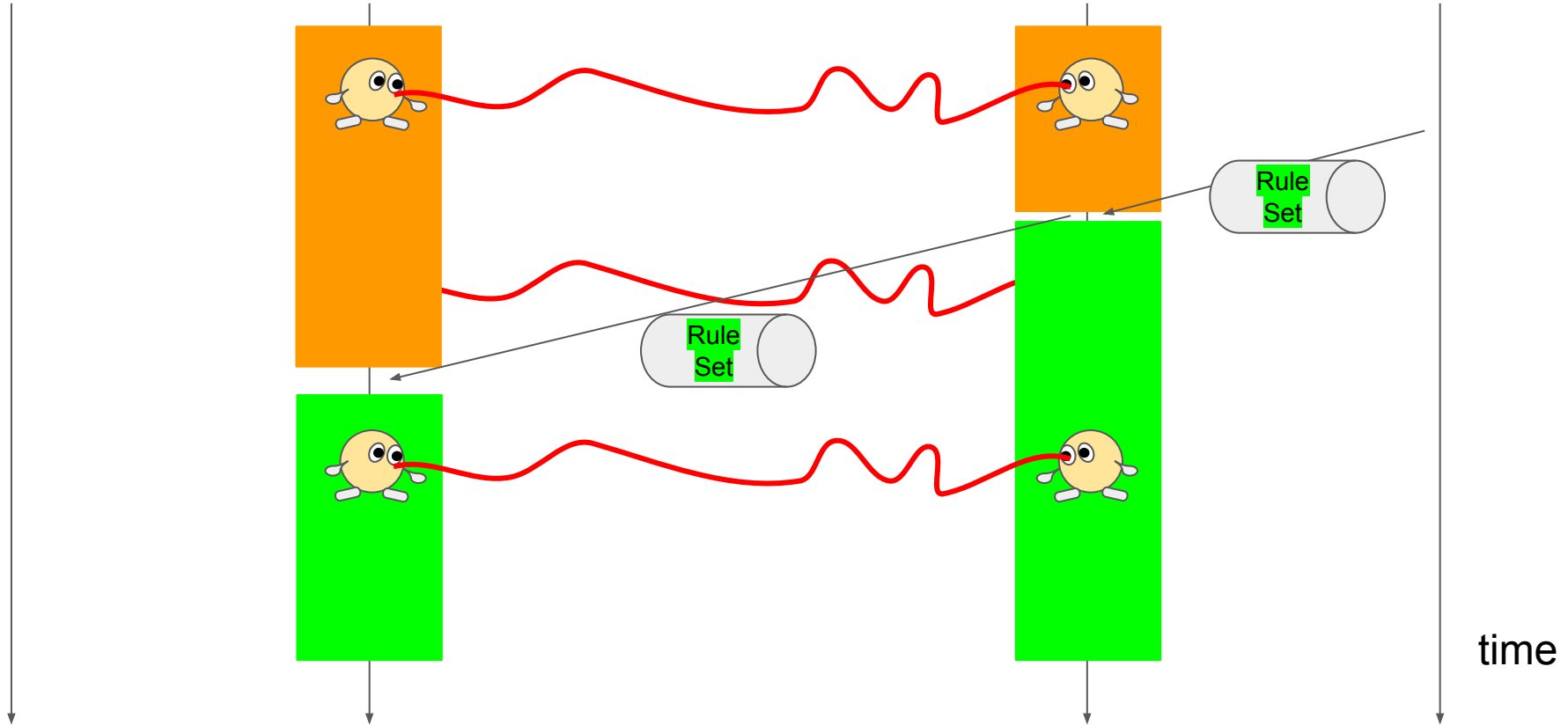
Revisit the problem

node I

node II

node III

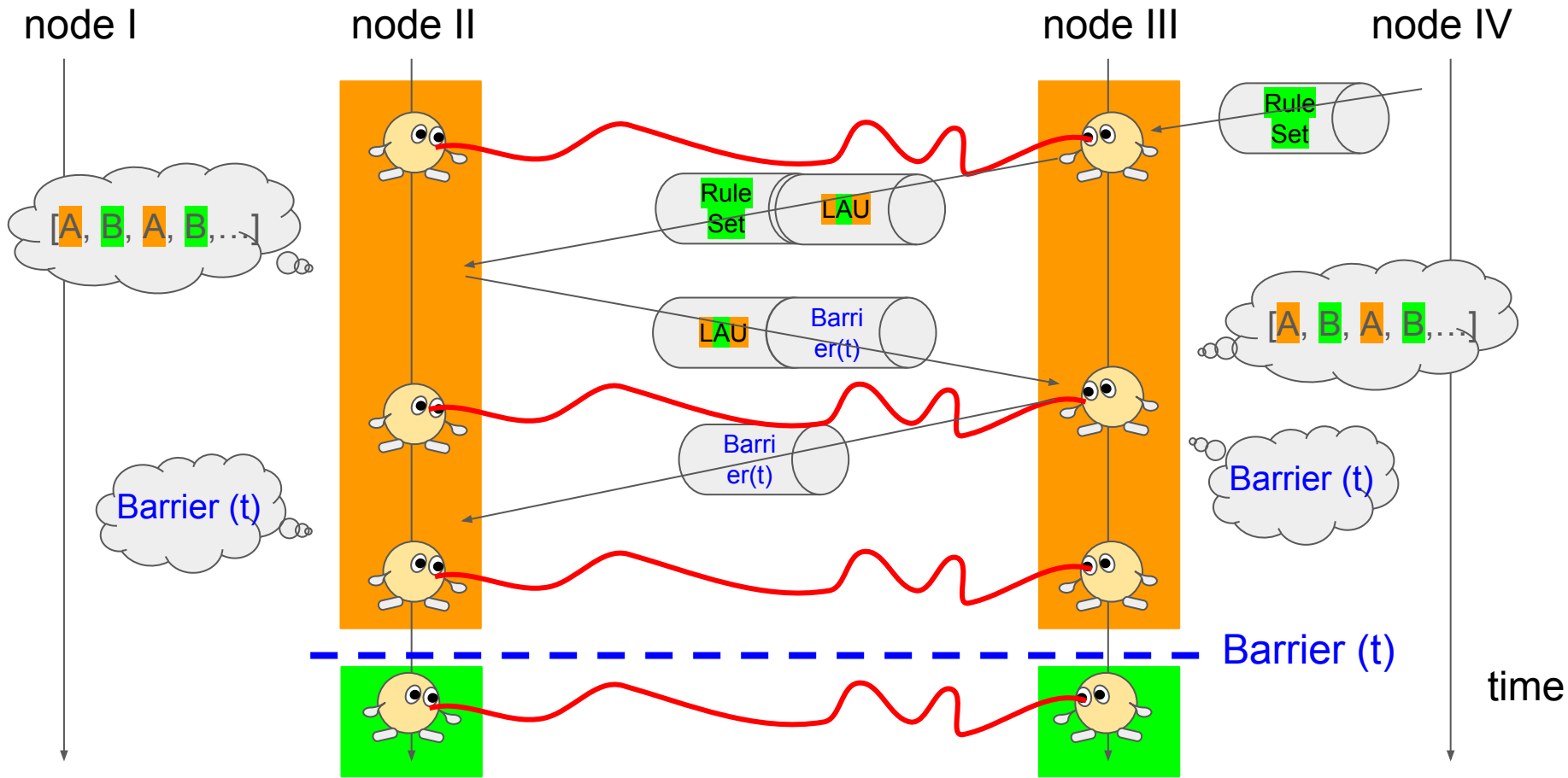
node IV



Allocation to connection A

Allocation to connection B

Solution: Link Allocation Update and Barrier



Details of Link Allocation Update

- Purpose:
 - Resource & Multiplexing Management in link layer
- Functionality:
 - **add** new RuleSets along with new connection setup
 - **delete** RuleSets along with a connection tear down
- Negotiation:
 - **Resource allocation order:** which RuleSets (& corresponding connection) will be executed in what order

```
{
  "title": "Link Allocation Update",
  "description": "Negotiation for link allocation policy",
  "type": "object",
  "required": [
    "activeLA",
    "nextLA",
    "randNumber"
  ],
  "properties": {
    "activeLA": {
      "type": "array",
      "description": "Current set of connection IDs",
      "items": {
        "type": "string",
        "description": "Connection ID"
      }
    },
    "nextLA": {
      "type": "array",
      "description": "Next set of connection IDs. The order is matter.",
      "items": {
        "type": "string",
        "description": "Connection ID"
      }
    },
    "randNumber": {
      "type": "number",
      "description": "Random Number to decide primary LA"
    }
  }
}
```

Details of Barrier

```
{
  "title": "Barrier",
  "description": "Sync Link Allocation switching timing",
  "type": "object",
  "required": [
    "photonPairTrialSequenceNumber"
  ],
  "properties": {
    "photonPairTrialSequenceNumber": {
      "type": "number",
      "description": "Incremental trial id for link Bell pair for switch timing alignment."
    }
  }
}
```

- Purpose:
 - make both nodes move to next Link Allocation at the same time
- Functionality:
 - align timing to next Link Allocation
- Negotiation:
 - **Barrier**: when move to the next RuleSets
- Metric for alignment
 - time ?
 - depends on synchronization protocol accuracy, clock accuracy, distance, ...
 - ID of generated entanglement ?
 - anyway entanglement are managed with ID
 - should be more reliable

our specs



Summary

- Our proposal:
 - Multiplexing management by **Link Allocation Update** and **Barrier**
- Functionality:
 - Operation order (add/delete): **Link Allocation Update**
 - Timing to move next LA: **Barrier**
- Problem to solve:
 - mis-connection of entanglement caused by inconsistent allocation of entangled qubits to connections