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EXPLOITING WIRELESS NETWORK BROADCASTING FOR A MORE EFFICIENT 2-WAYS RANGING

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IMT ATLANTIQUE, IRISA
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- **An almost indispensable function**
  - When an object is mobile (IoT, Drone, etc.)
  - To check that a property is retained
- **"Typical" solution: GPS**
  - Power consumption / integration cost
  - Accuracy ~ decametric (submetric with RTK)
- **An alternative: geolocation via the network**
  - Interface already present: no or low additional cost if added
  - UWB: possibility of being sub-centimetric
  - Relative positioning

General principle of coordinate calculation

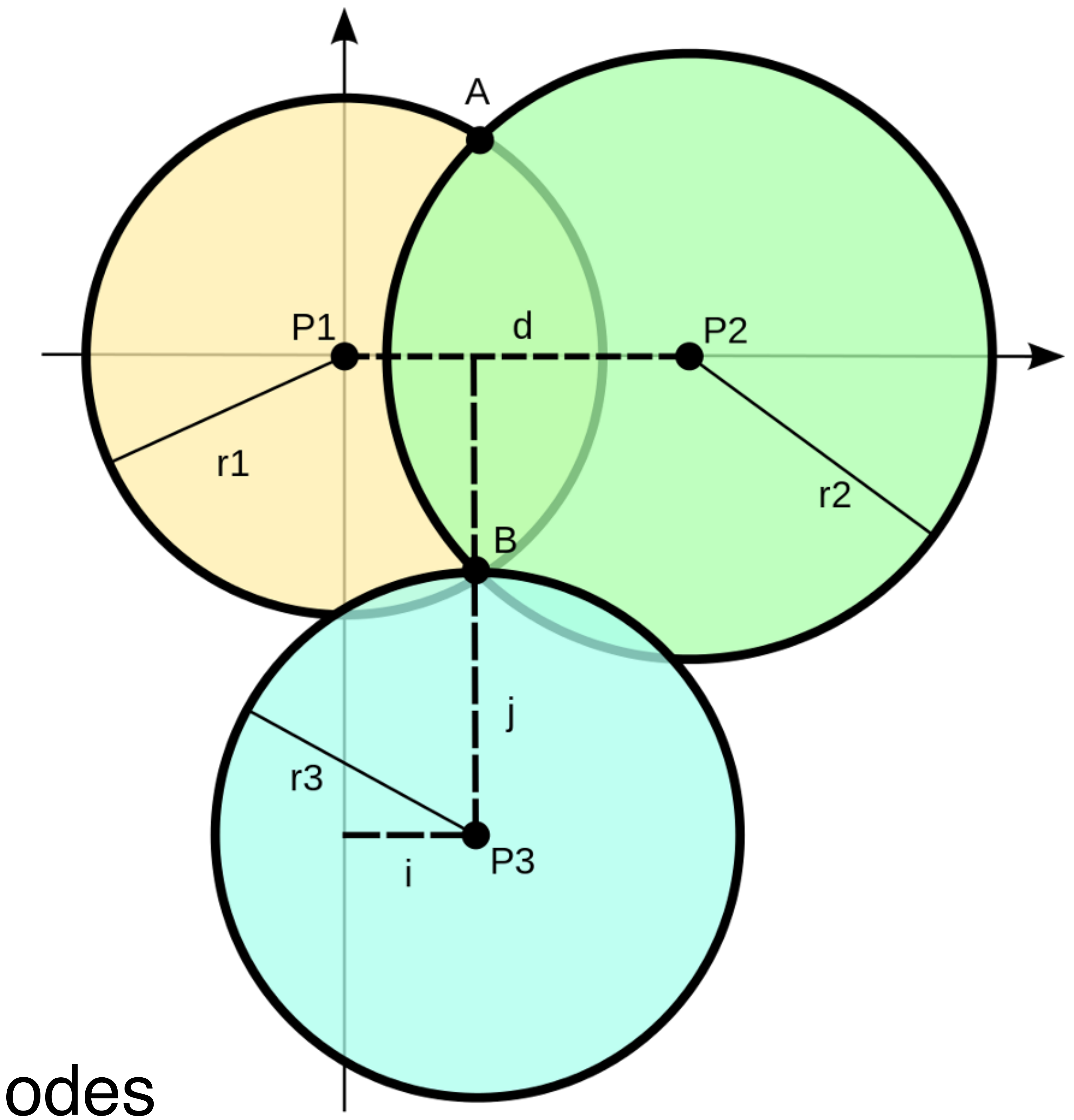
- 3 references (in 2D, 4 otherwise) minimum
- 3 relative distances
- A quadratic system: $d_i^2 = (x_i - x)^2 + (y_i - y)^2$

Intersection of > 3 circles

- Imprecision => minimisation and approximation
- GPS: ten or so satellites

How to estimate distances?

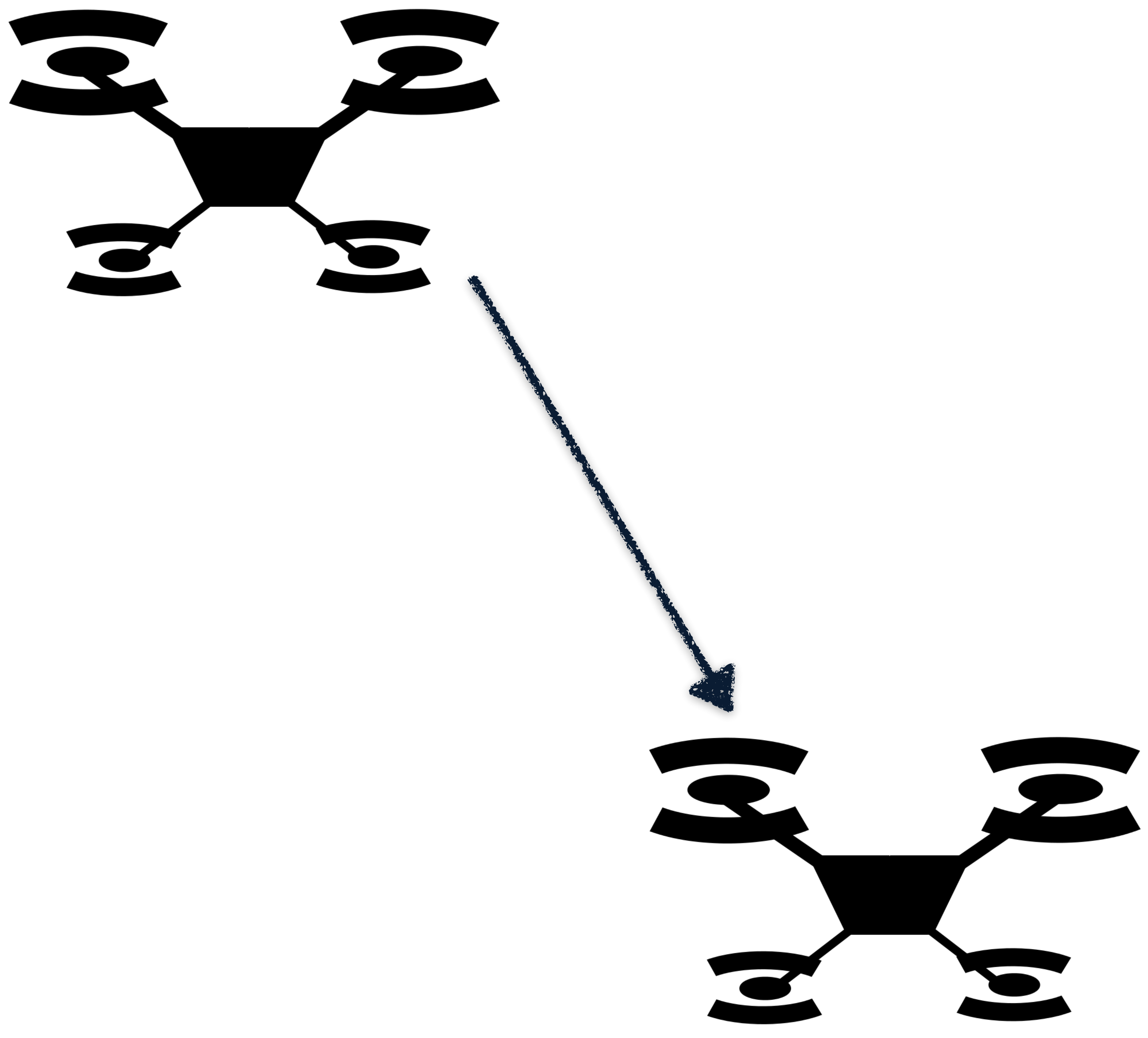
- This is where radio can be used: $d = c * t_{vol}$
- It is "enough" to estimate the time of flight between 2 nodes



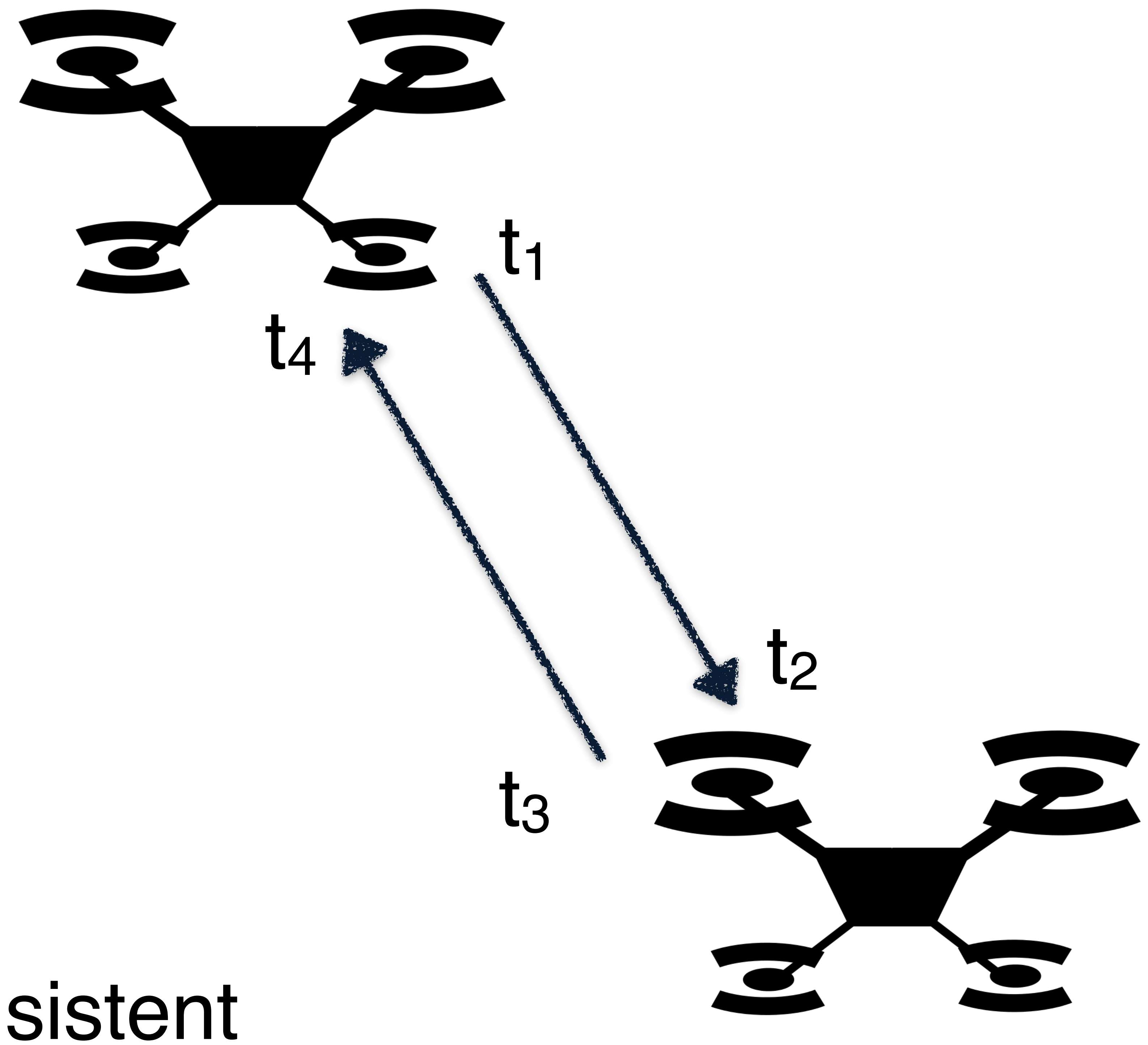
- **Time of Arrival**
  - $t_{arrival} - t_{departure}$: easy!

- **Need for synchronous clocks**
  - NTP : precise ~ $10^{-5}s$
  - But $c \simeq 3.10^9 m.s^{-1}$ => error of $10^4 m$!!

- **We want to avoid relying on synchronisation**



- **Estimation of a round trip time**
  - $\frac{t_2 - t_1 + t_4 - t_3}{2}$
  - We always compare non-synchronised clocks
  - $\frac{t_2 - t_1 + t_4 - t_3}{2} = \frac{(t_4 - t_1) - (t_3 - t_2)}{2}$
- **2 time calculations, each on a different clock**
  - The times do not need to be synchronised to be consistent
  - Accuracy = resolution of the clocks = ten pico-seconds
  - Theoretically millimetre precision (the size of Theoryland)



BASELINE FOR FTM

FINE TIMING MEASUREMENT

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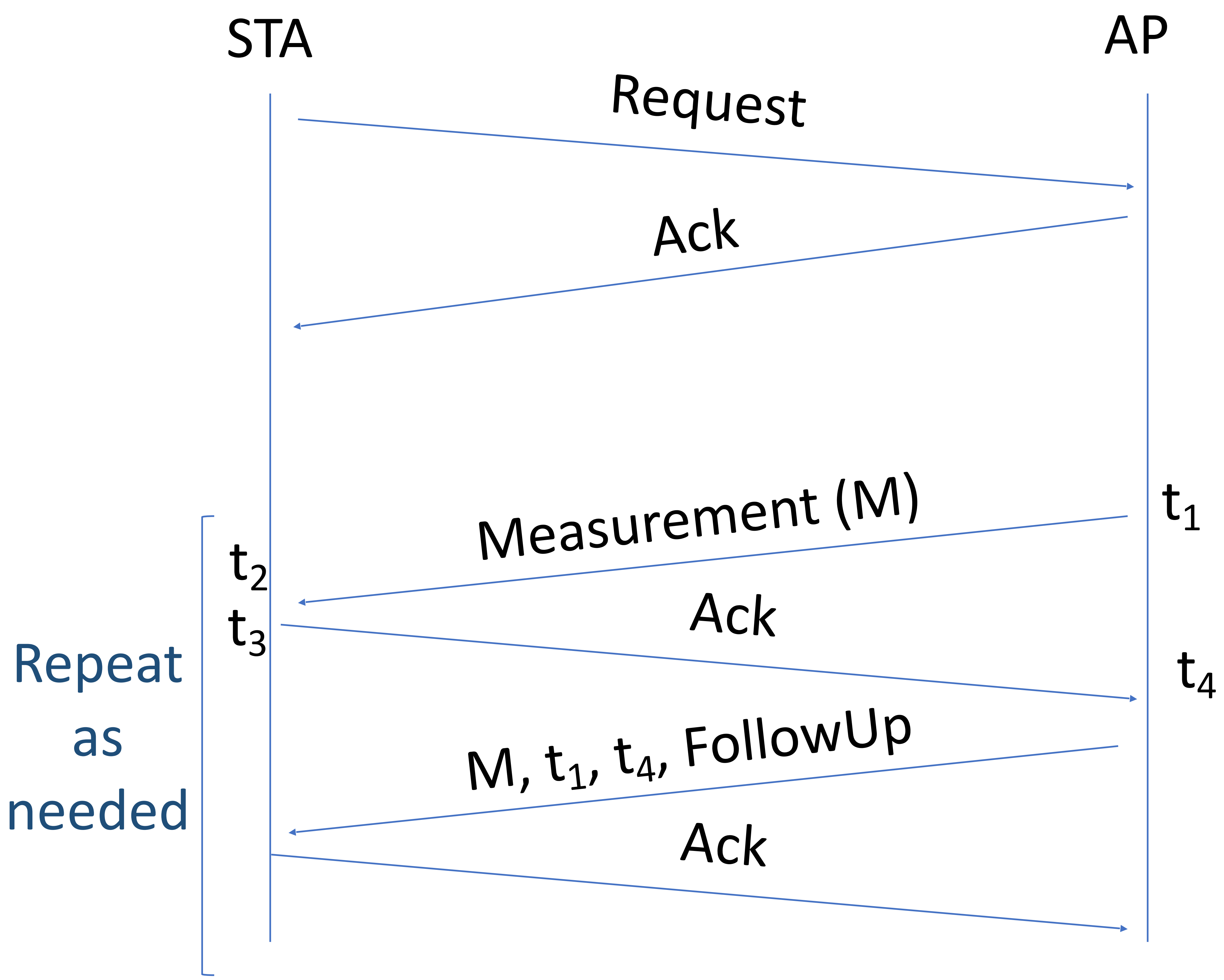
802.11-2012 – Timing Measurement

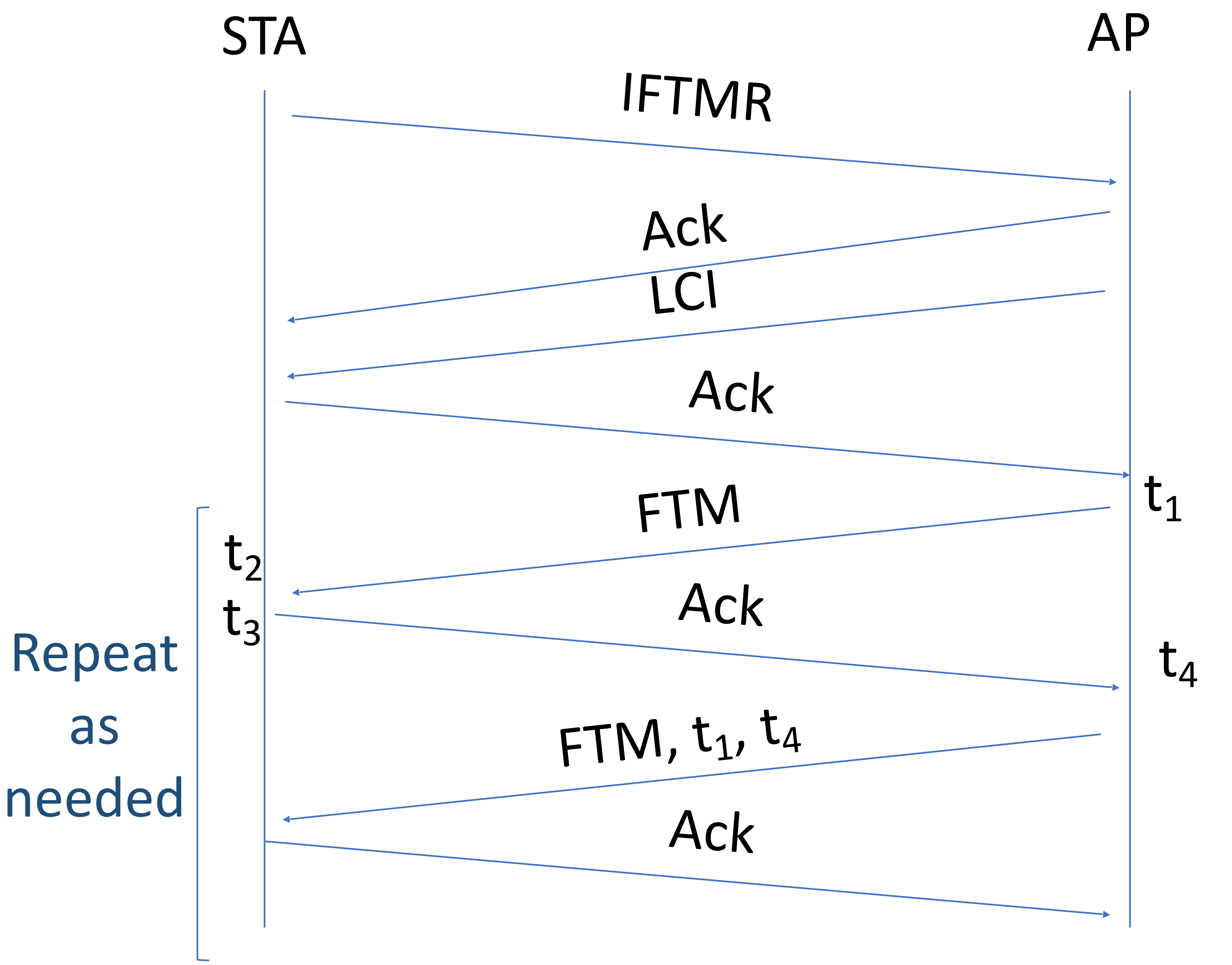


- **STA clock offset is**

$$\tau = \frac{(t_2 - t_1) - (t_4 - t_3)}{2}$$

- **Characteristics of TM:**
  - Only to associated AP
  - Focus is time difference (no location angle)

802.11-2016 – Fine Timing Measurement



IFTMR: Initial FTM Request

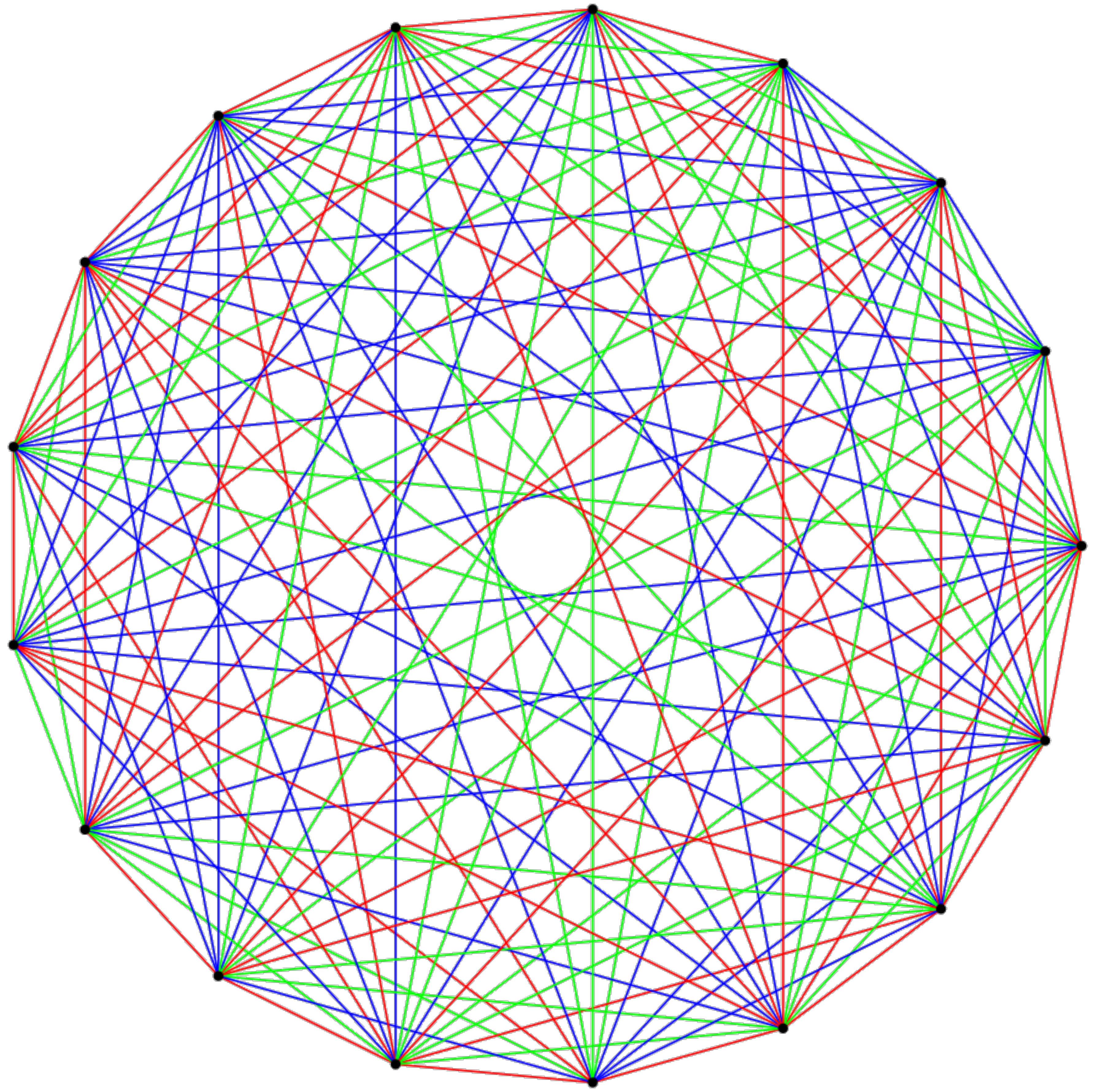
LCI: Location Configuration Information

- **STA distance is**

$$\delta = \frac{(t_4 - t_1) - (t_3 - t_3)}{2} c$$

- **Characteristics of FTM:**
  - To any AP (associated or not)
  - Time Drifts are theoretically cancelled
    - Only to associated AP
- **This mechanism fulfill the needs of modern indoor location**

- **FTM is based on Unicast**
  - Complexity explodes in dense networks
  - Not to mention collisions
- **Complexity: 4 messages on each radio link**
  - In a clique of n nodes : $O(n^2)$!
- **Can we benefit from wireless broadcast communications?**



WHY NOT TAKE ADVANTAGE OF BROADCAST COMMUNICATION?

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CORE IDEA OF FTM-BC (FINE TIMING MEASUREMENT BROADCAST)

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  - 4 steps pairwise

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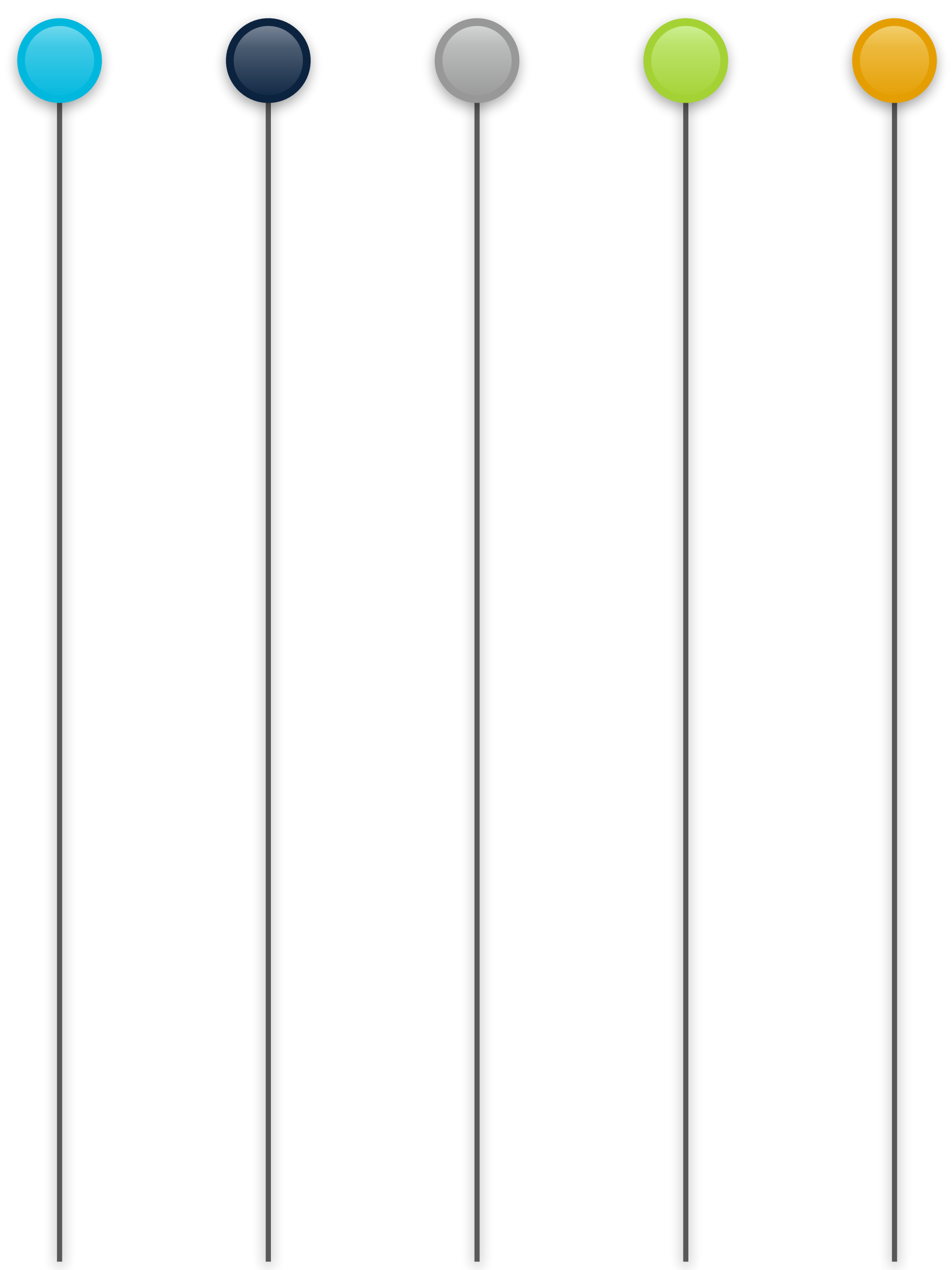

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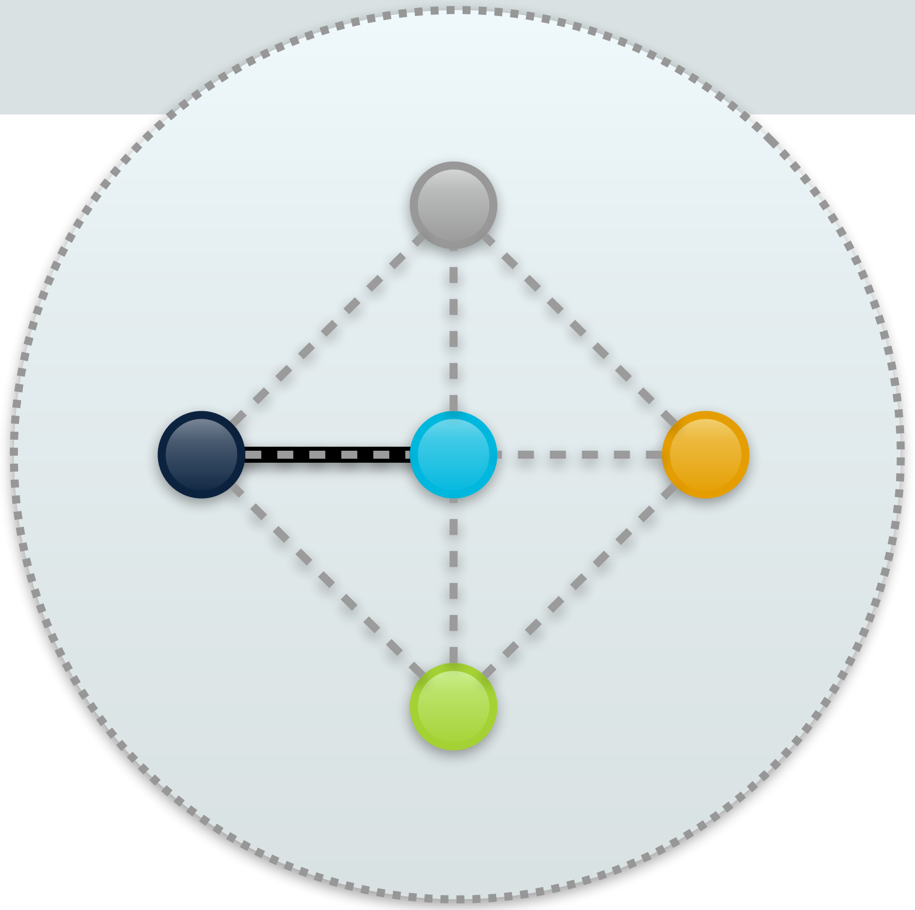

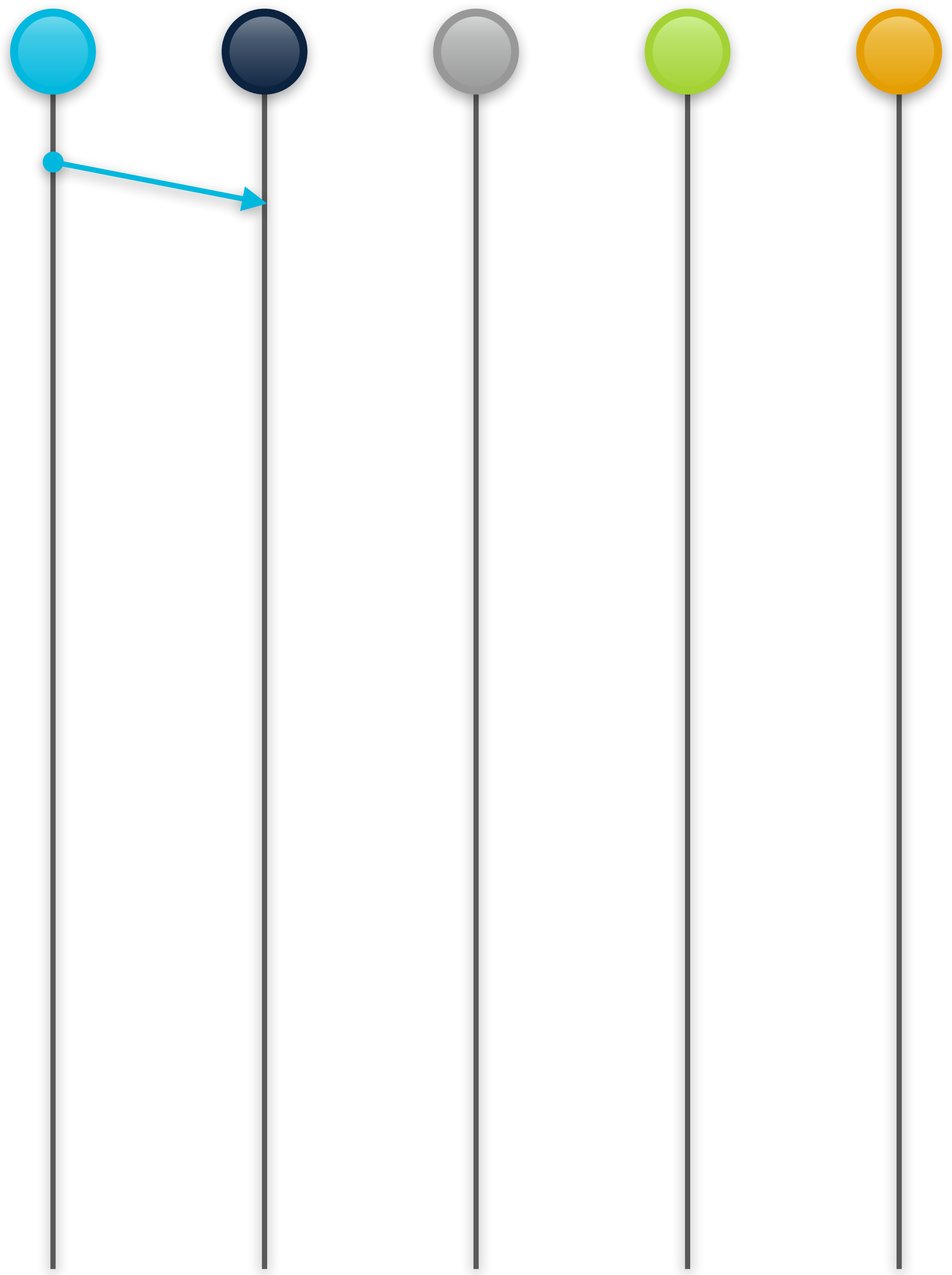

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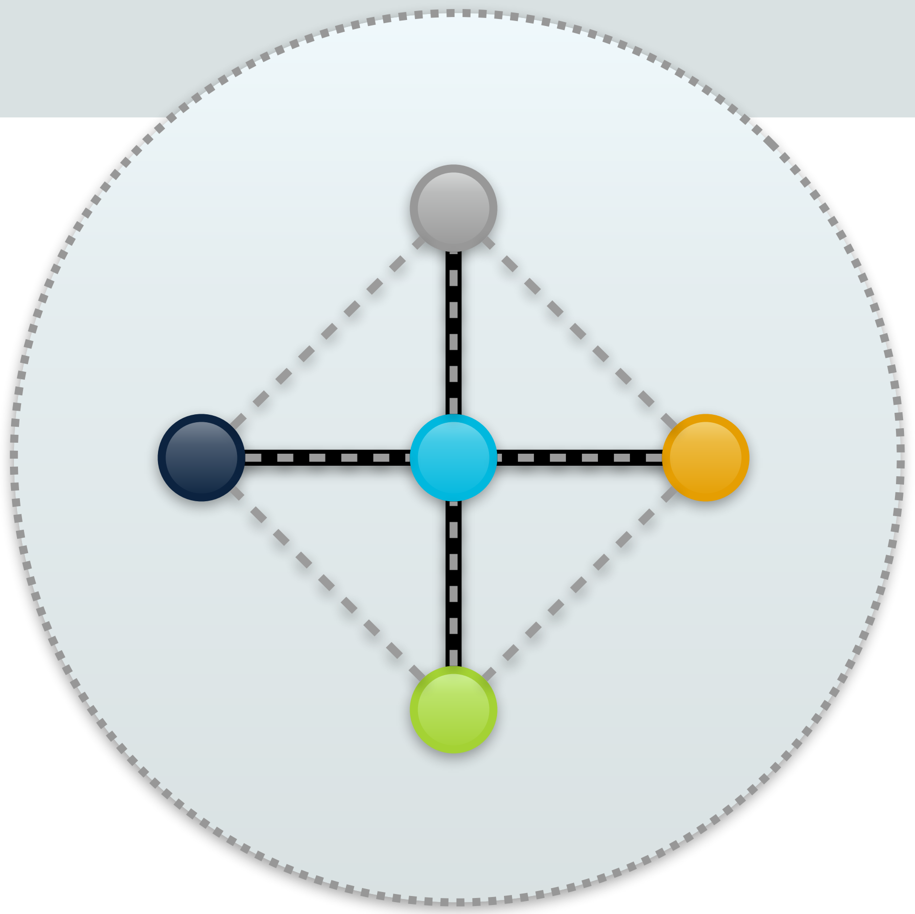

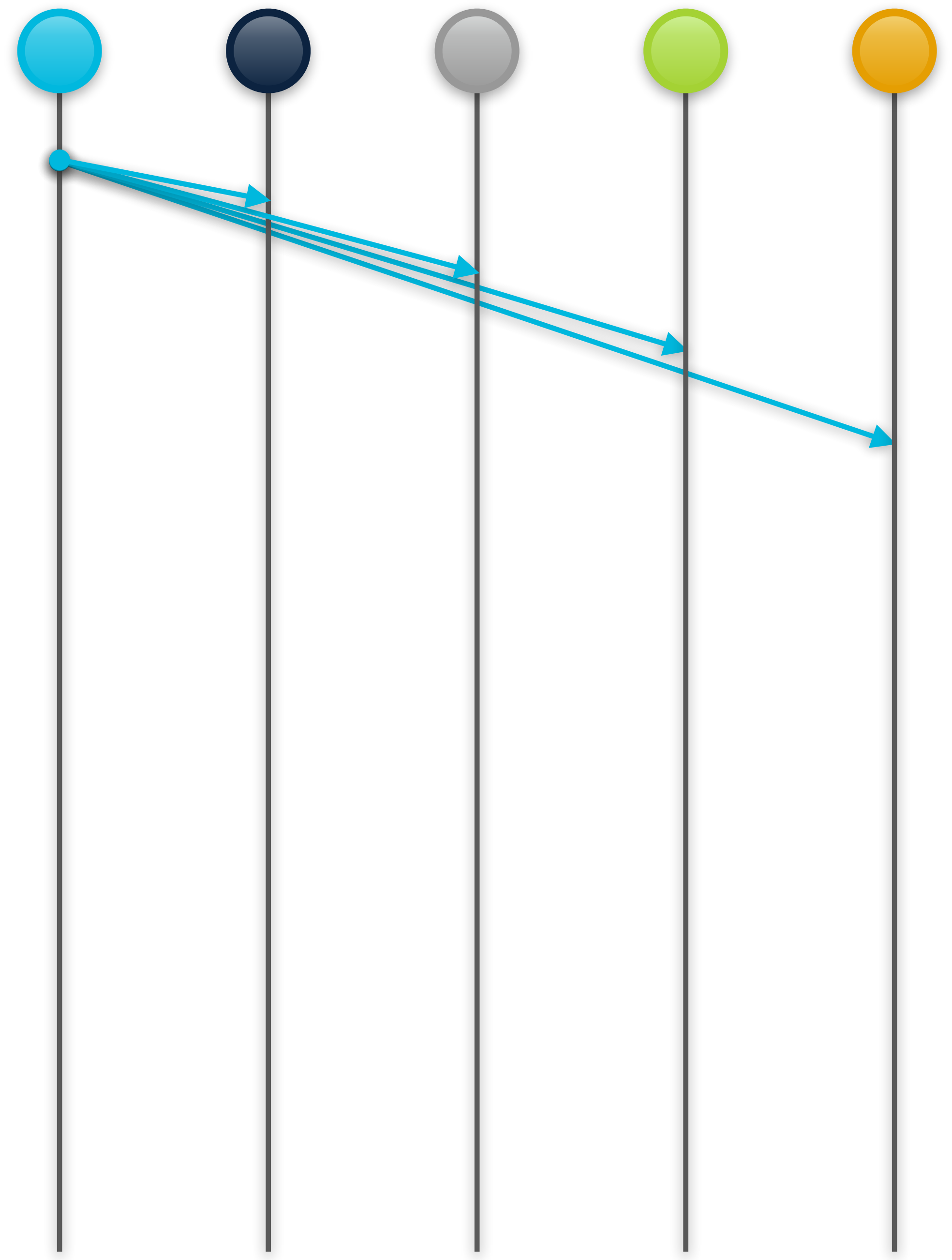

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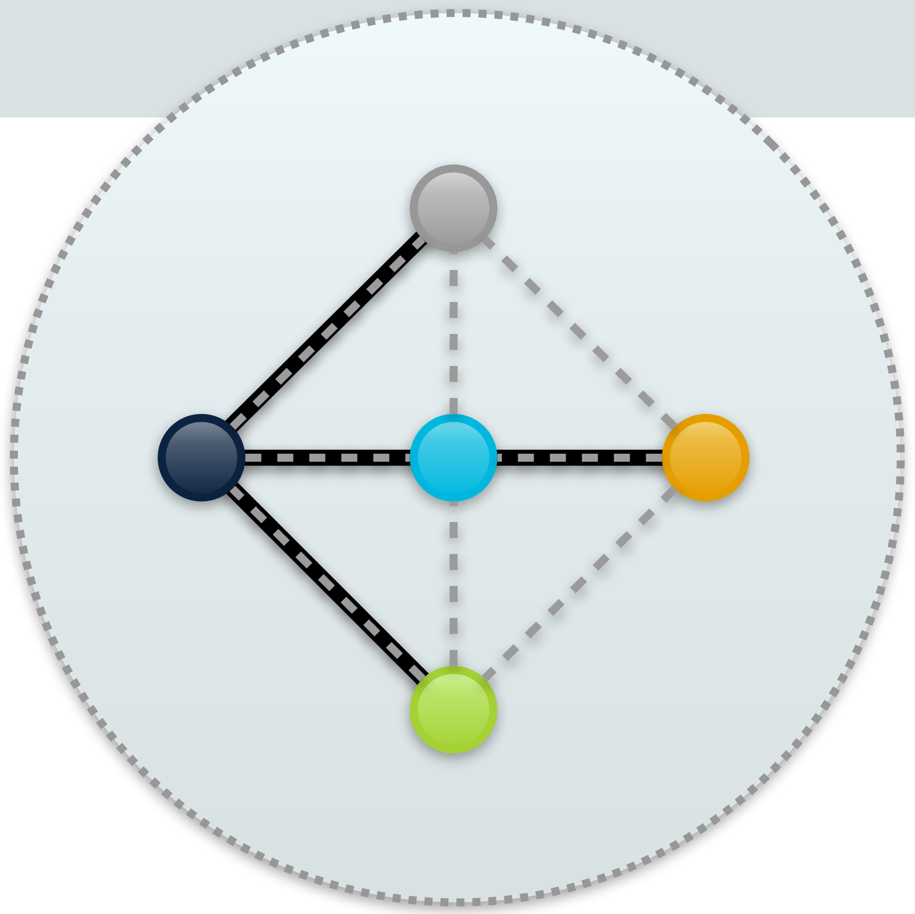

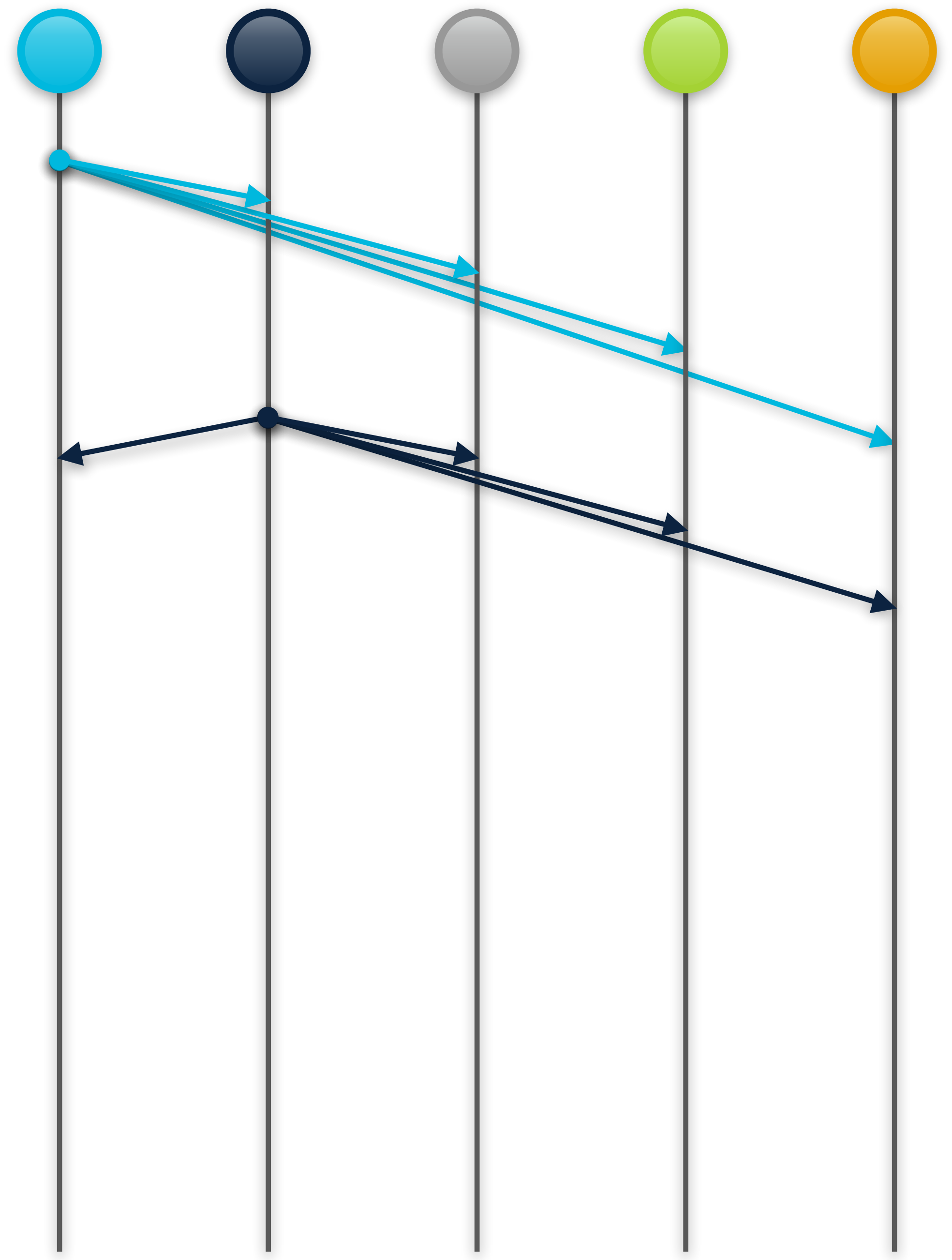

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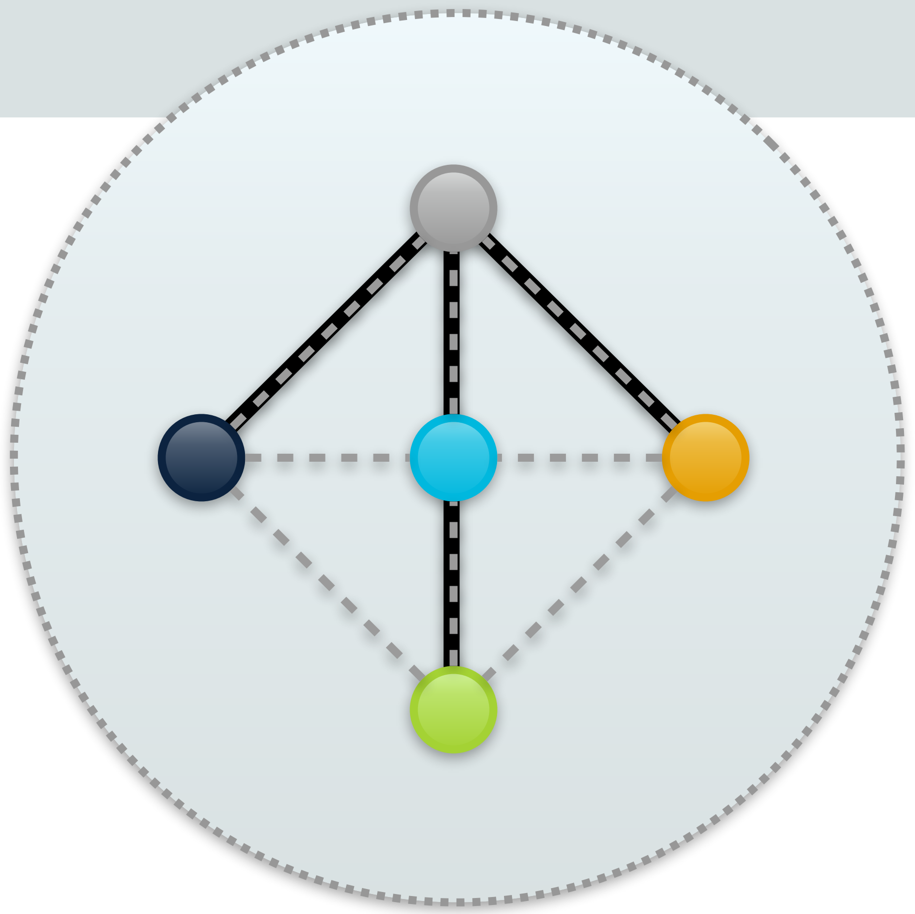

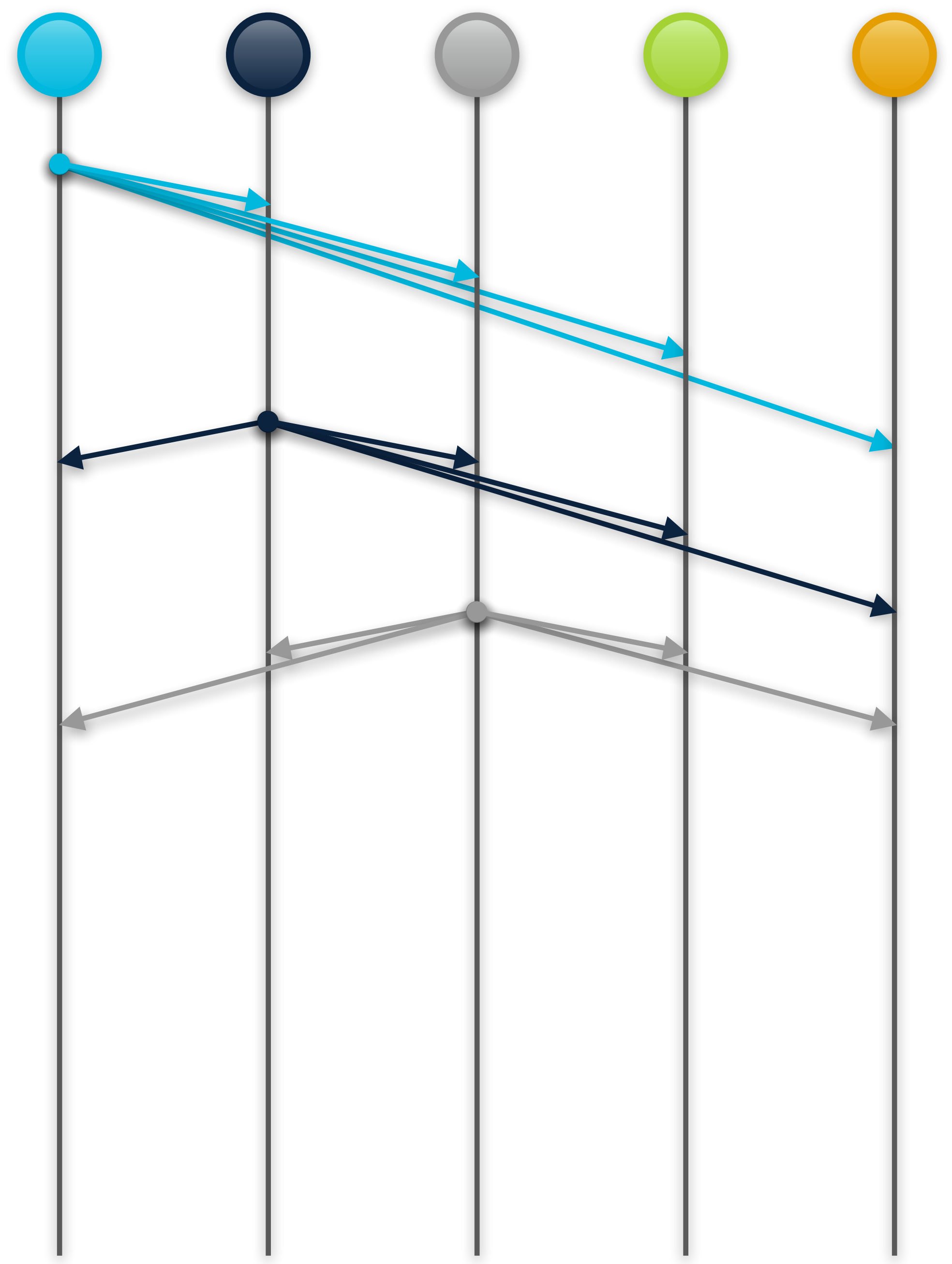

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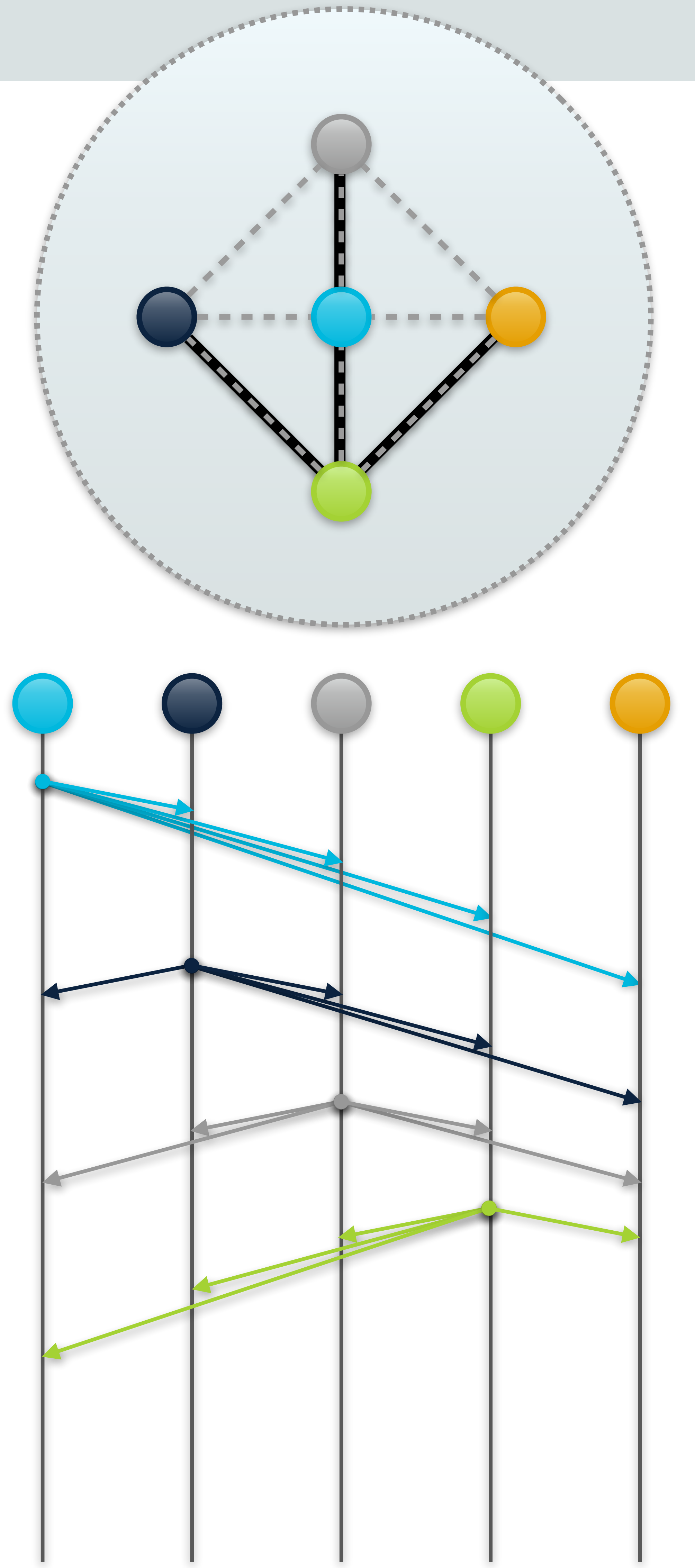

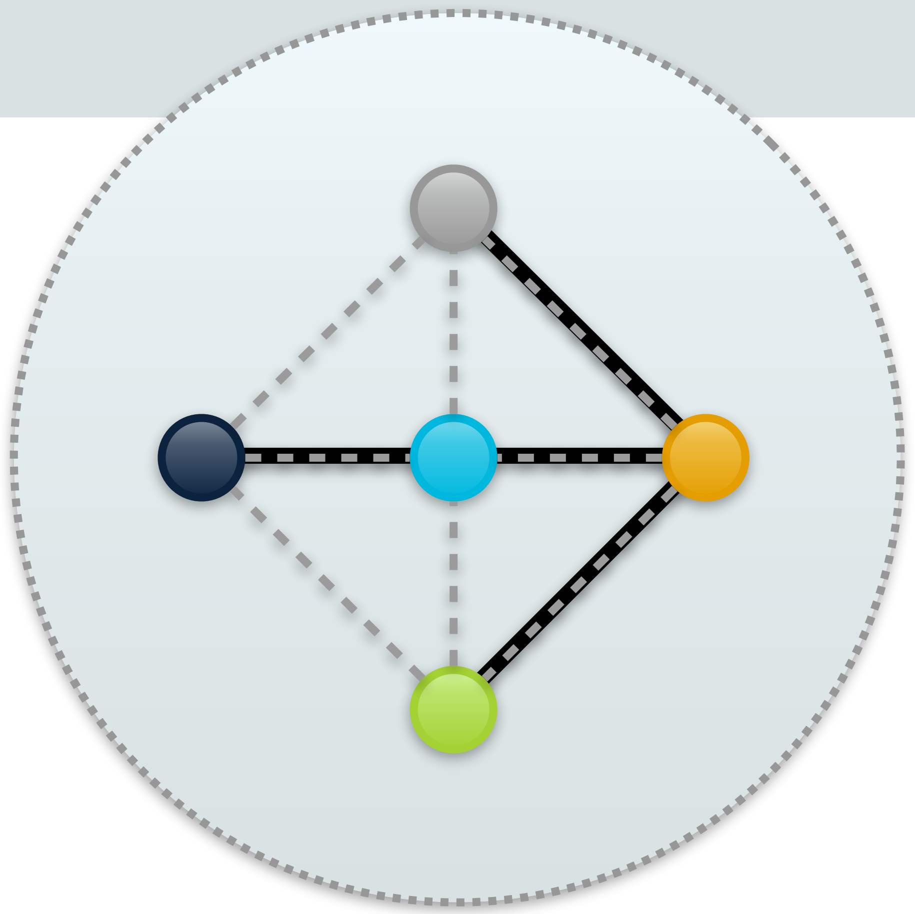

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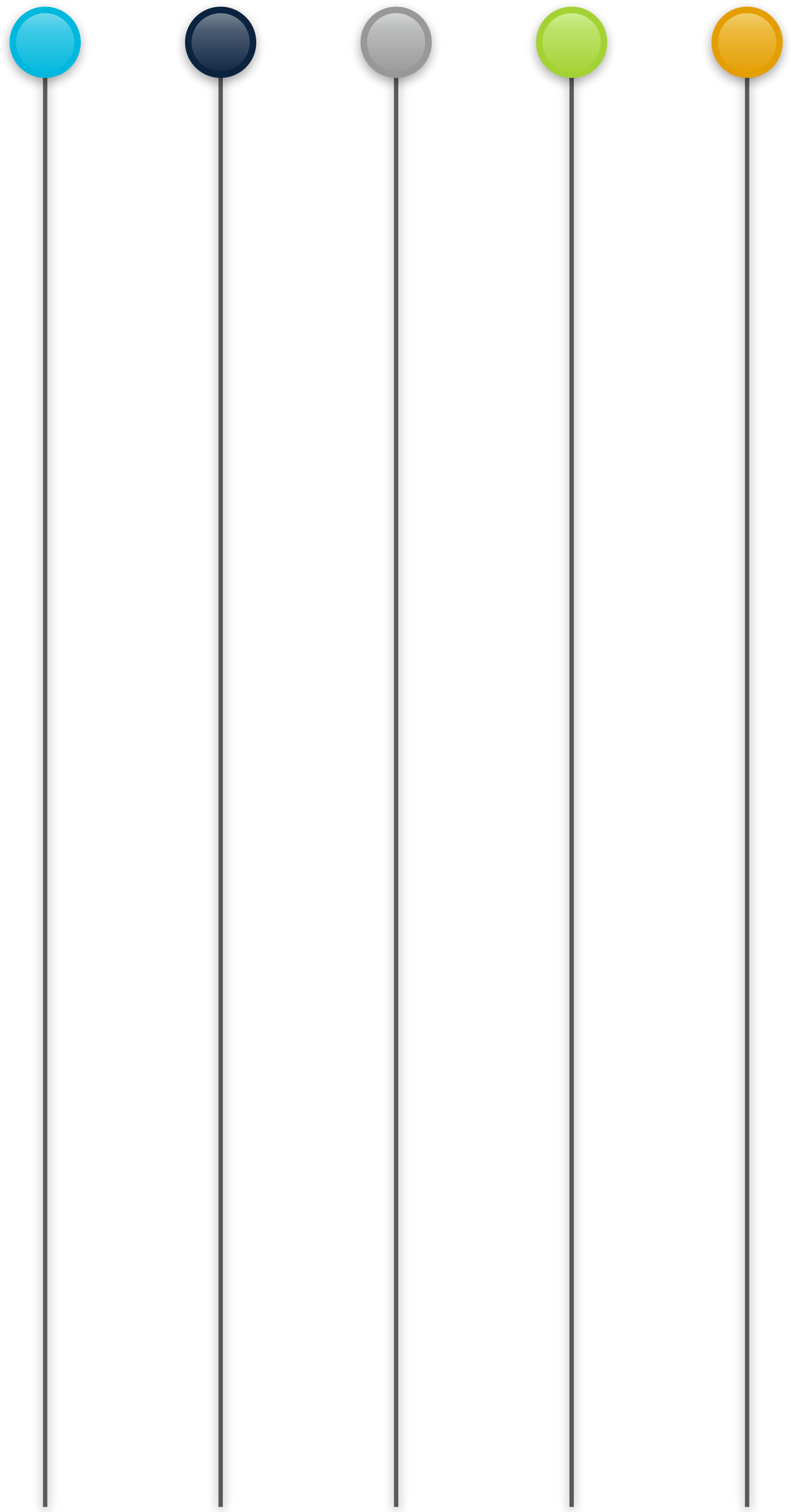
- **Example with a 5-node clique**
  - With FTM-UC (Unicast) : $4\frac{n(n-1)}{2} = 40$ messages
  - With FTP-BC (Broadcast) : $2n = 10$ messages

FTM-BC IN A NUTSHELL - 2-PHASE ALGORITHM — CASE 1 : CLIQUE

Phase 1



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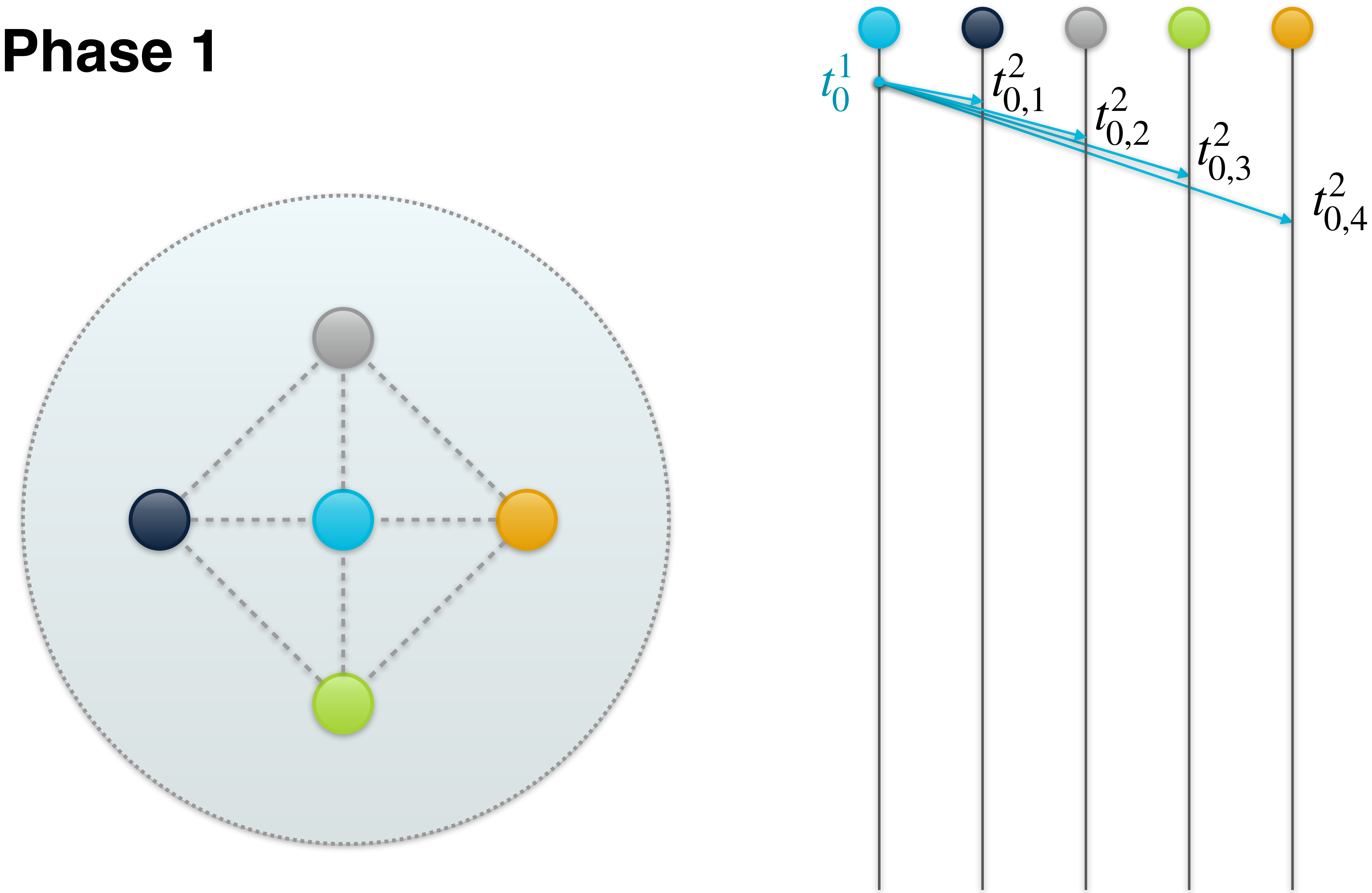

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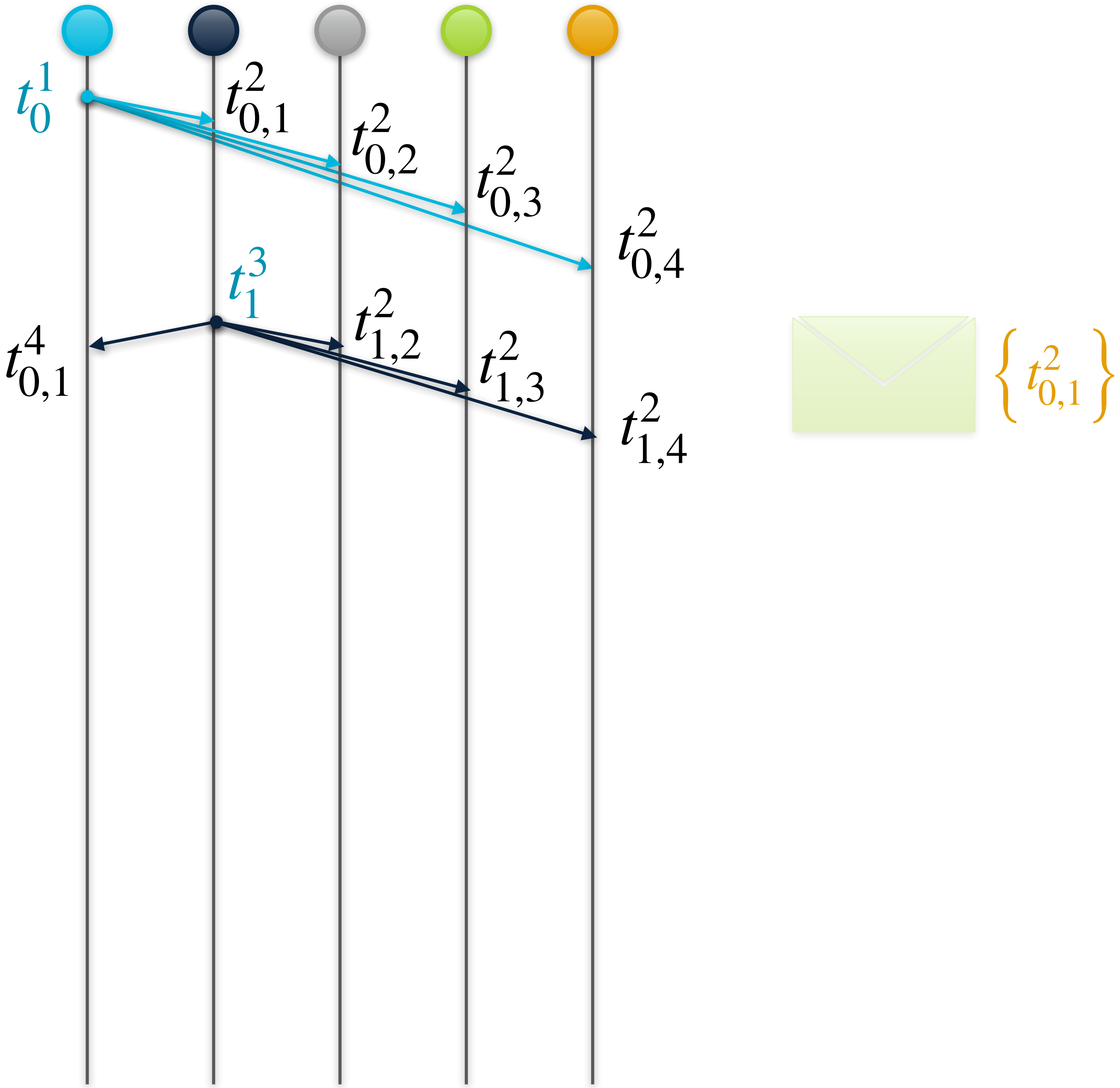

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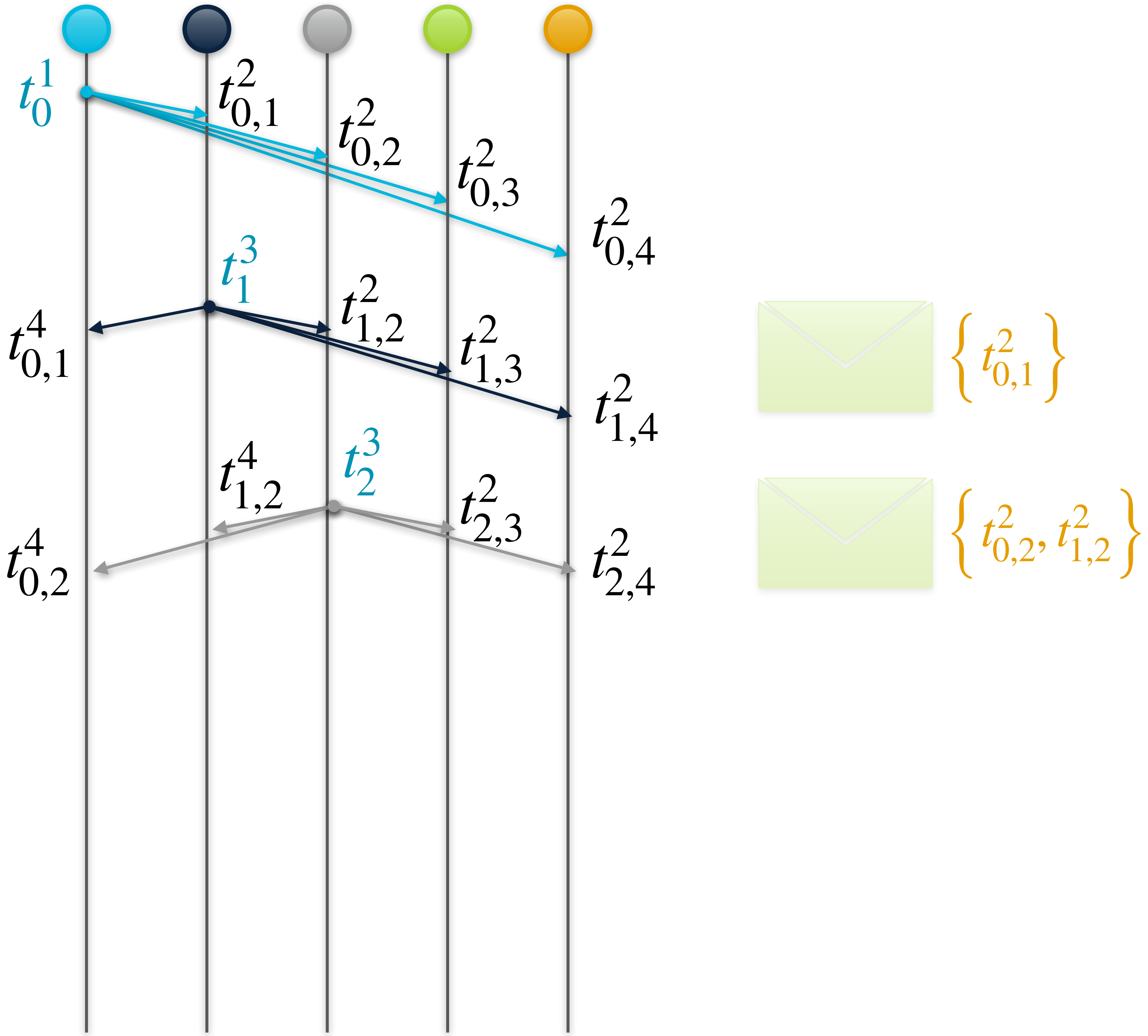

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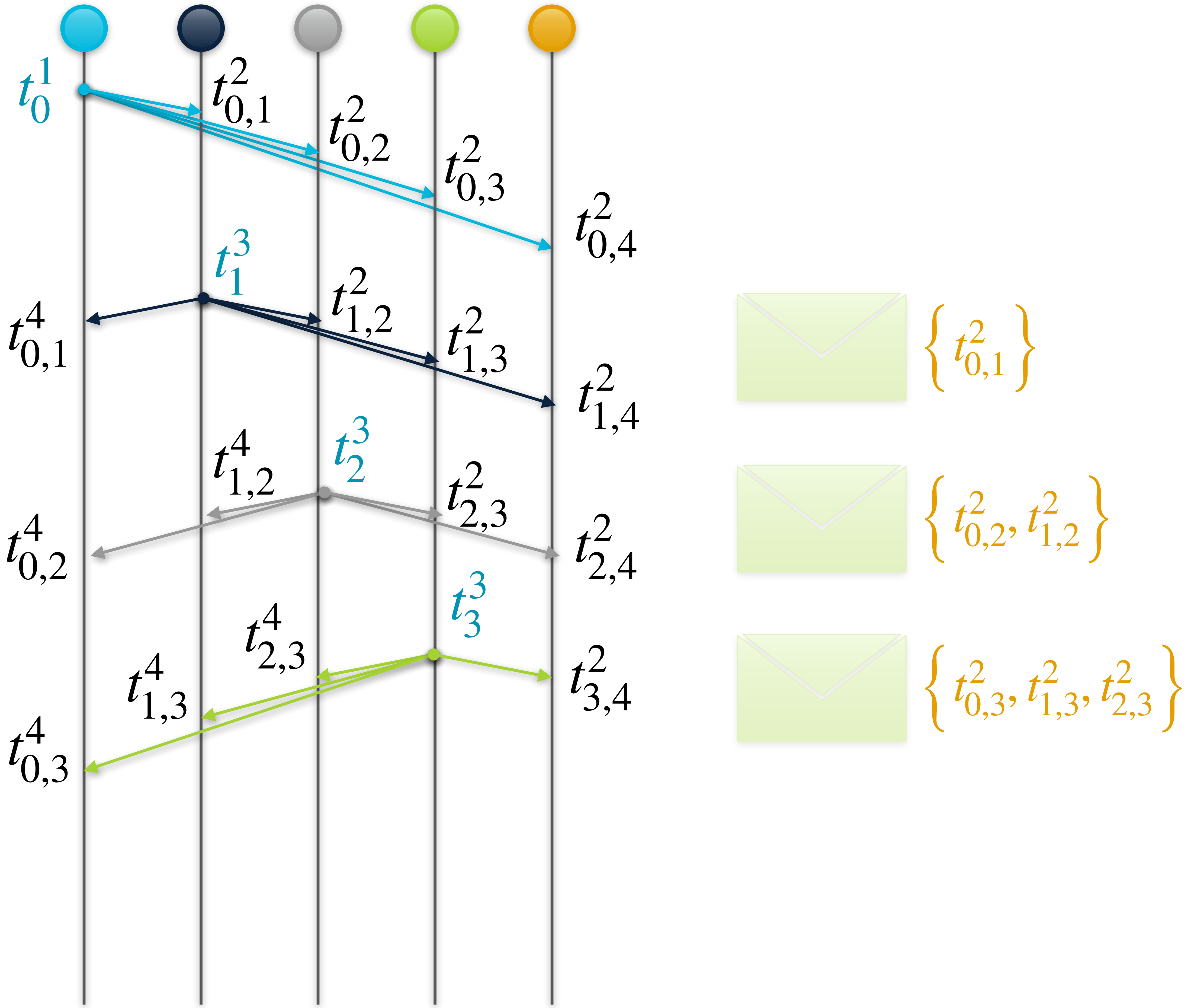

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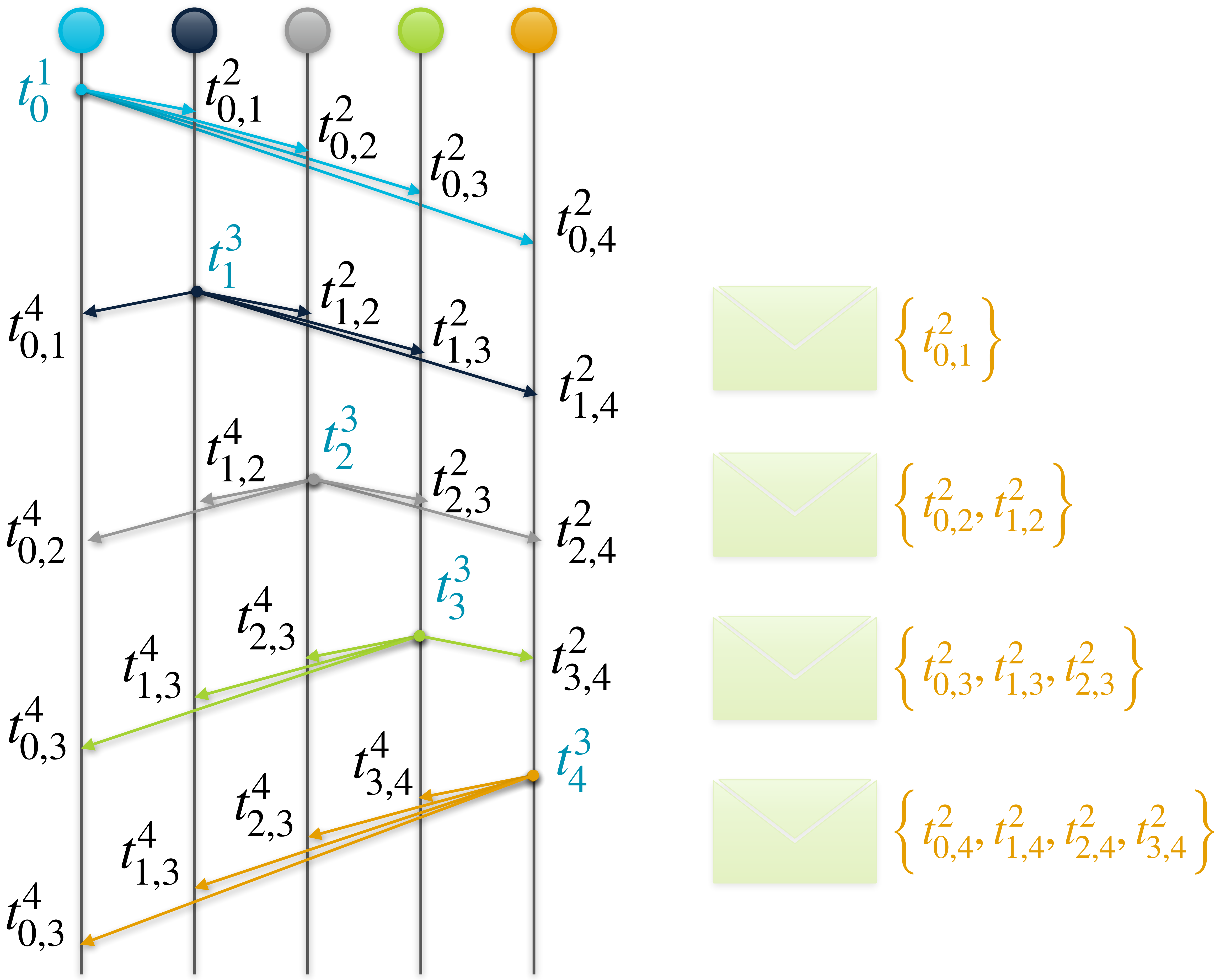
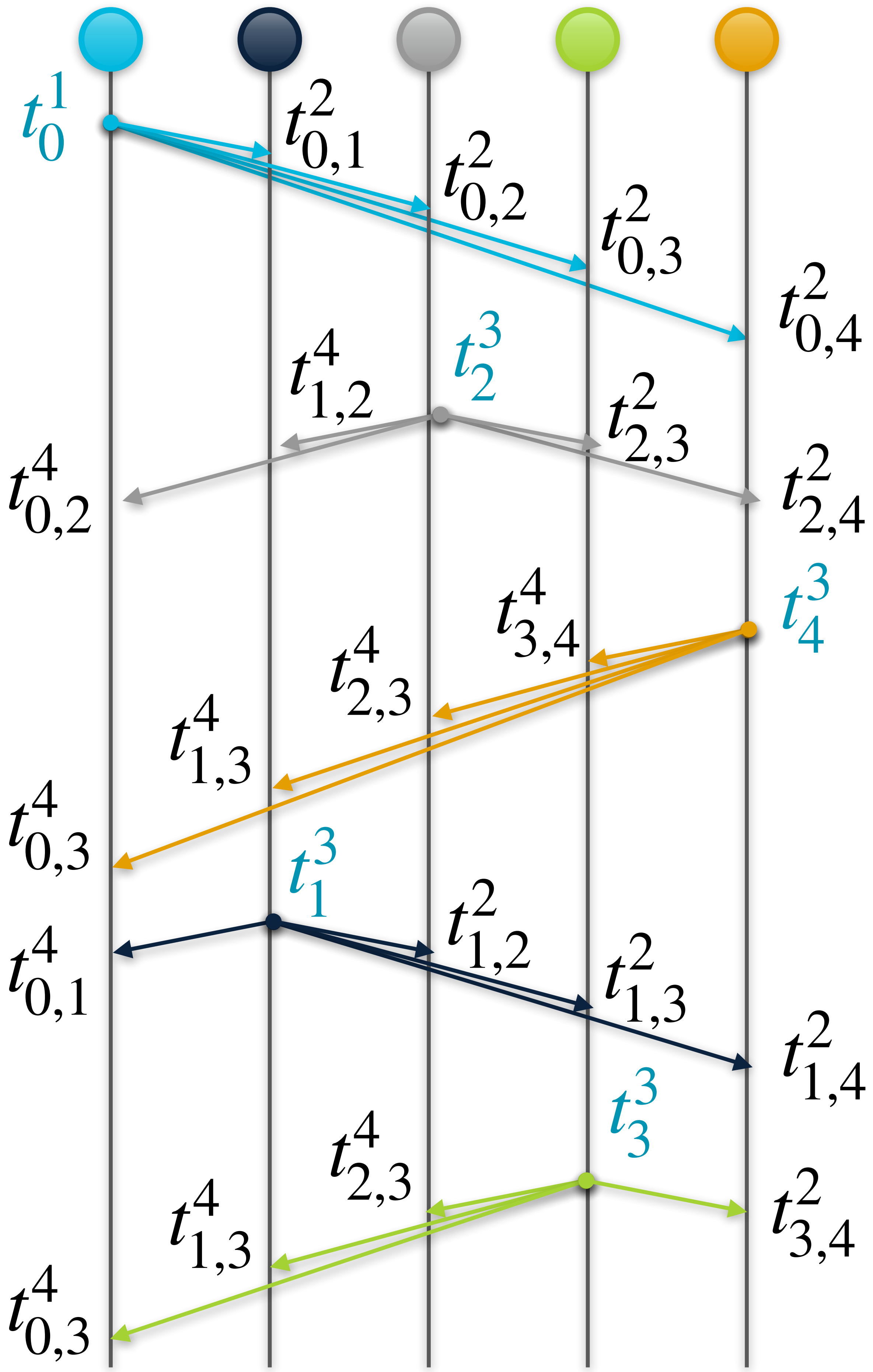


t_0^1
$t_{0,1}^2$
$t_{0,2}^2$
$t_{0,3}^2$
$t_{0,4}^2$
t_1^3
$t_{0,1}^4$
$t_{1,2}^2$
$t_{1,3}^2$
$t_{1,4}^2$
$t_{1,2}^4$
t_2^3
$t_{0,2}^4$
$t_{2,3}^2$
$t_{2,4}^2$
t_3^3
$t_{2,3}^4$
$t_{1,3}^4$
$t_{3,4}^2$
$t_{0,3}^4$
$t_{3,4}^4$
t_4^3
$t_{2,3}^4$
$t_{1,3}^4$
$t_{0,3}^4$
$\{t_{0,1}^2\}$
$\{t_{0,2}^2, t_{1,2}^2\}$
$\{t_{0,3}^2, t_{1,3}^2, t_{2,3}^2\}$
$\{t_{0,4}^2, t_{1,4}^2, t_{2,4}^2, t_{3,4}^2\}$

Phase 2

- Order does not matter



Same behavior

- Piggyback all previous timestamps

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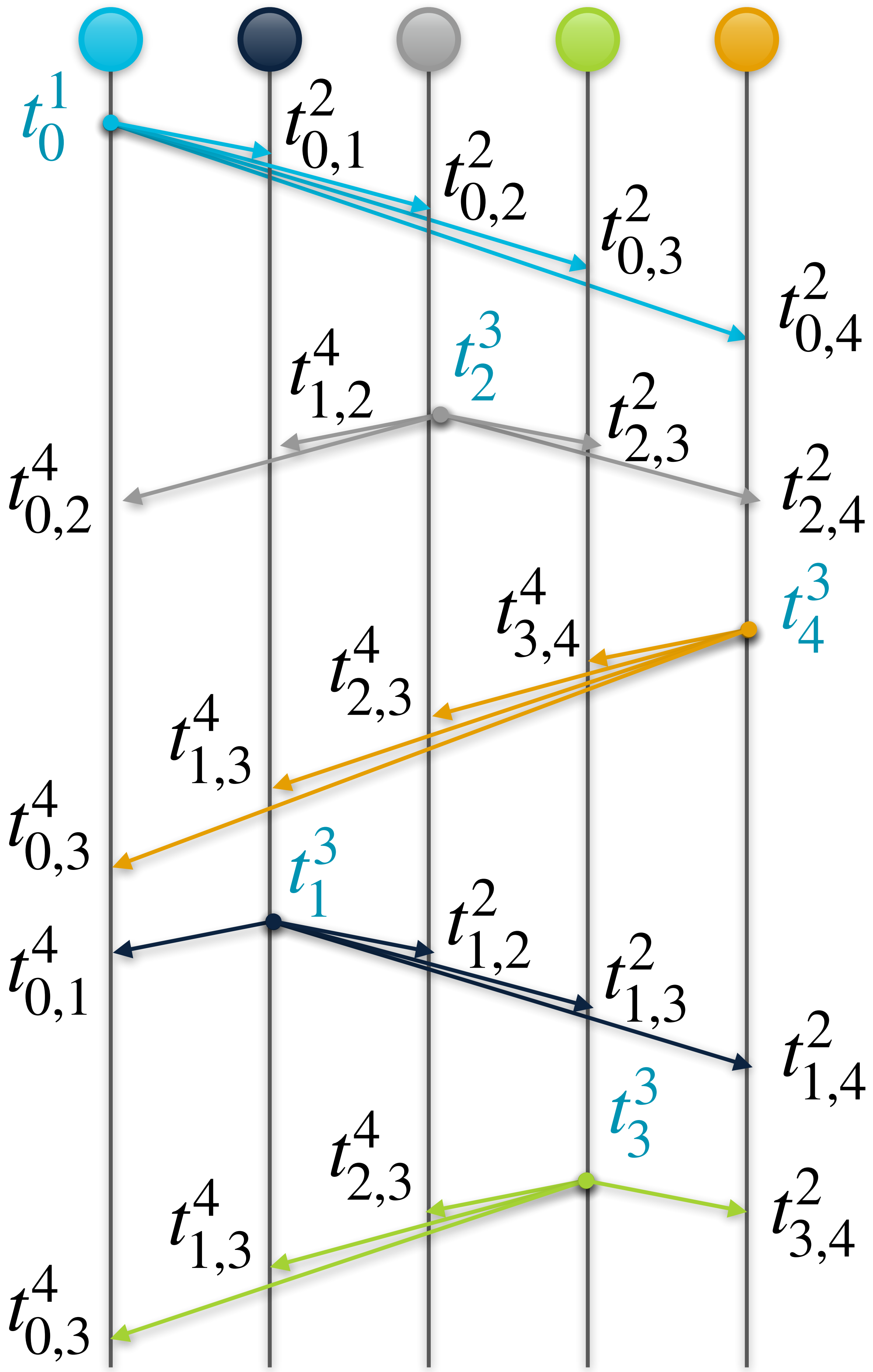

Same behavior

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$\left\{ t_0^1, t_{0,1}^4, t_{0,2}^4, t_{0,3}^4, t_{0,4}^4 \right\}$ of phase 1

$\left\{ t_2^3, t_{0,2}^2, t_{1,2}^2, t_{2,3}^4, t_{2,4}^4 \right\}$ of phase 1

$\left\{ t_4^3, t_{0,4}^2, t_{1,4}^2, t_{2,4}^2, t_{3,4}^2 \right\}$ of phase 1

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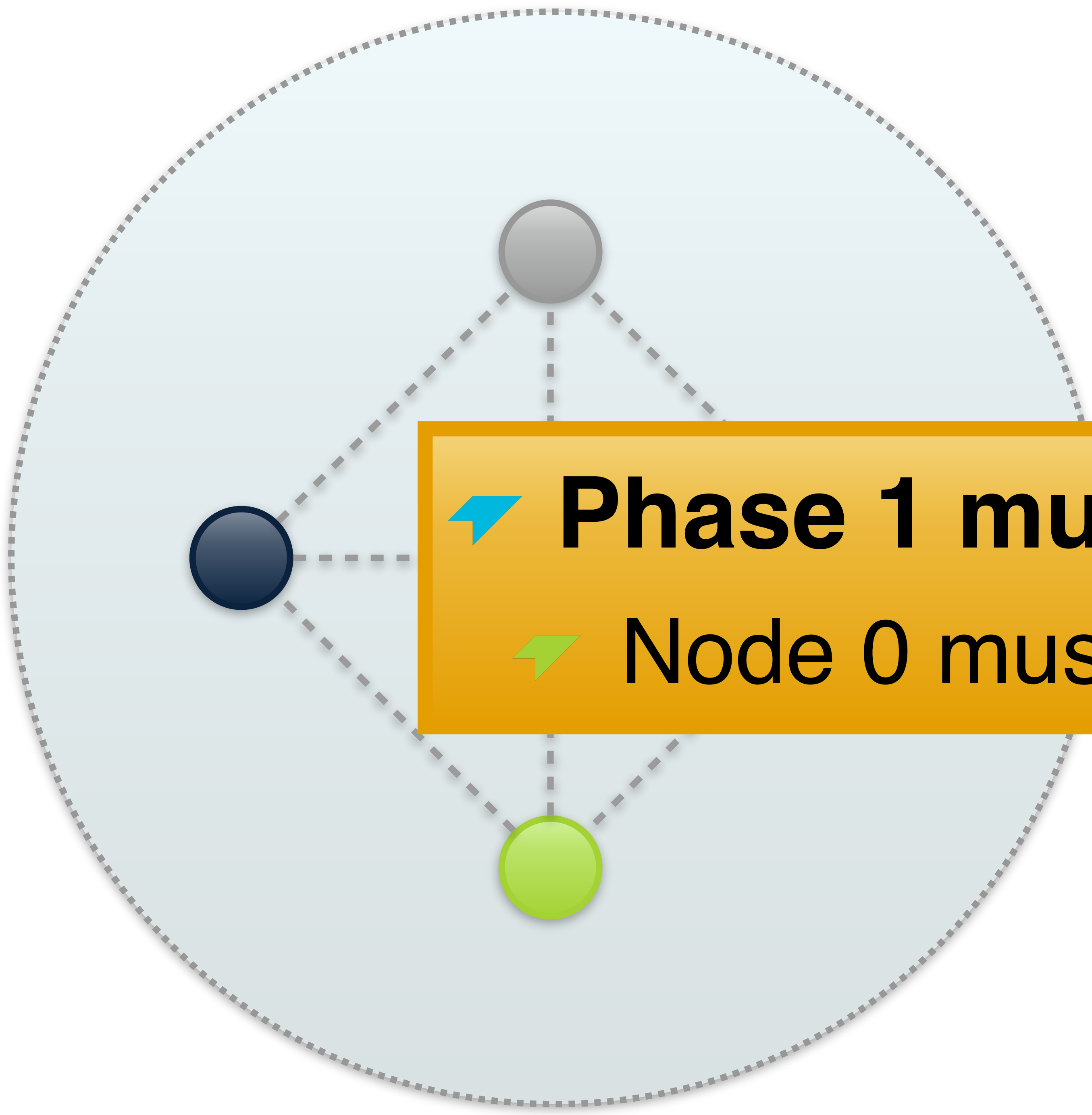

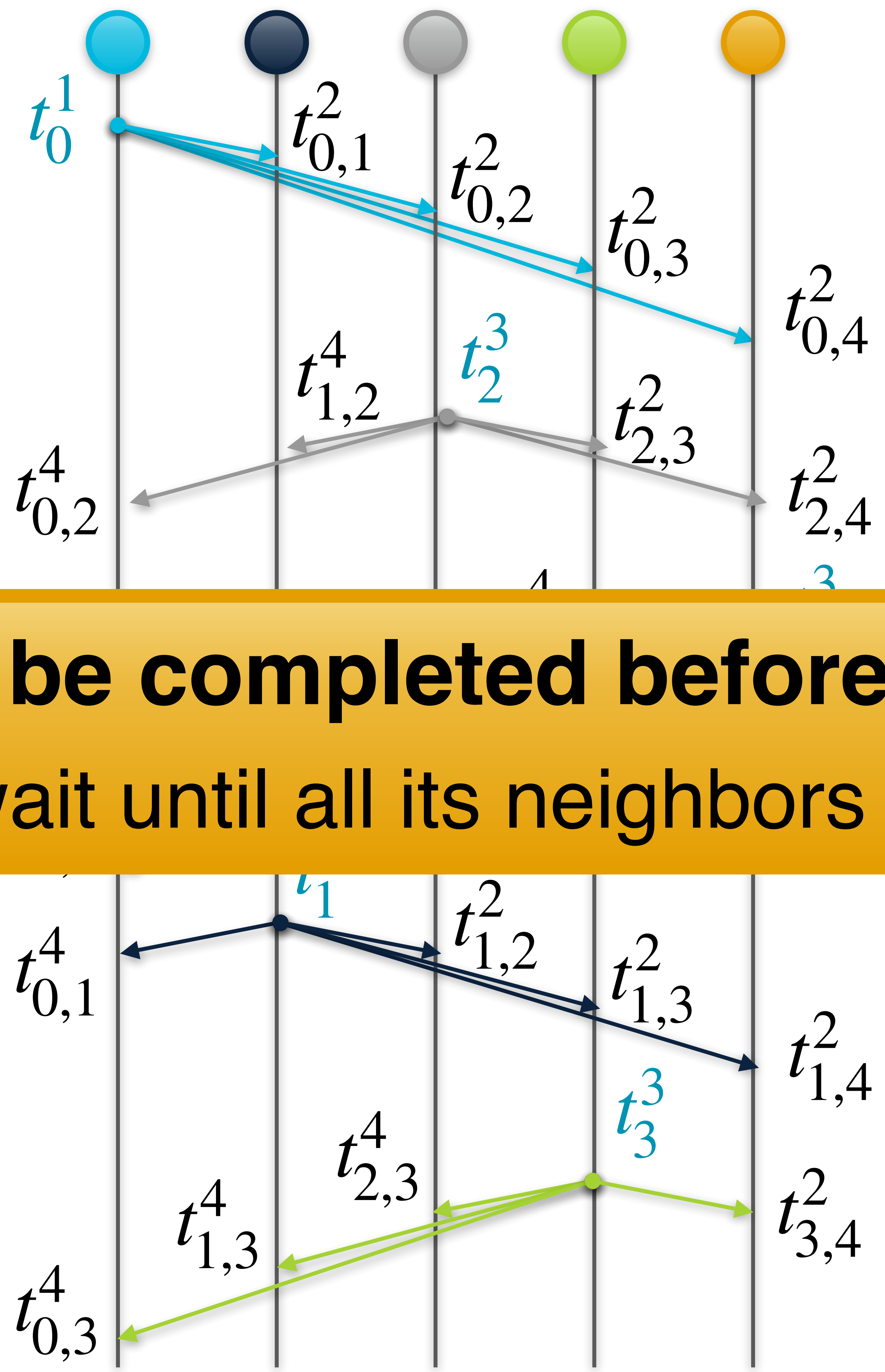

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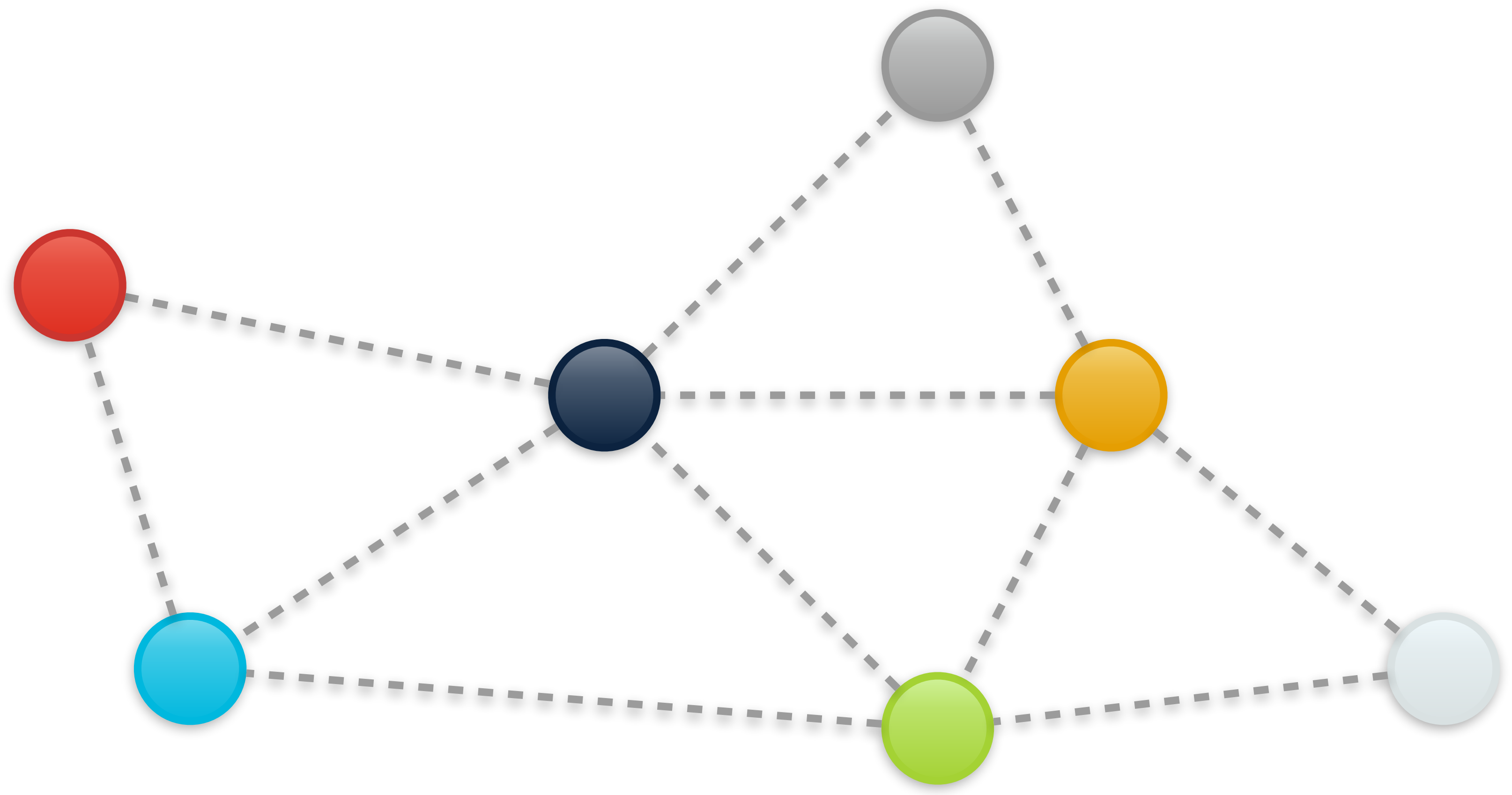
$\{t_3^3, t_{0,3}^2, t_{1,3}^2, t_{2,3}^2, t_{3,4}^4\}$ of phase 1

Phase 1 must be completed before phase 2 can be started

- Node 0 must wait until all its neighbors have responded

FTM-BC IN A NUTSHELL - 2-PHASE ALGORITHM — CASE 2 : GRAPH WITH DIAMETER > 1



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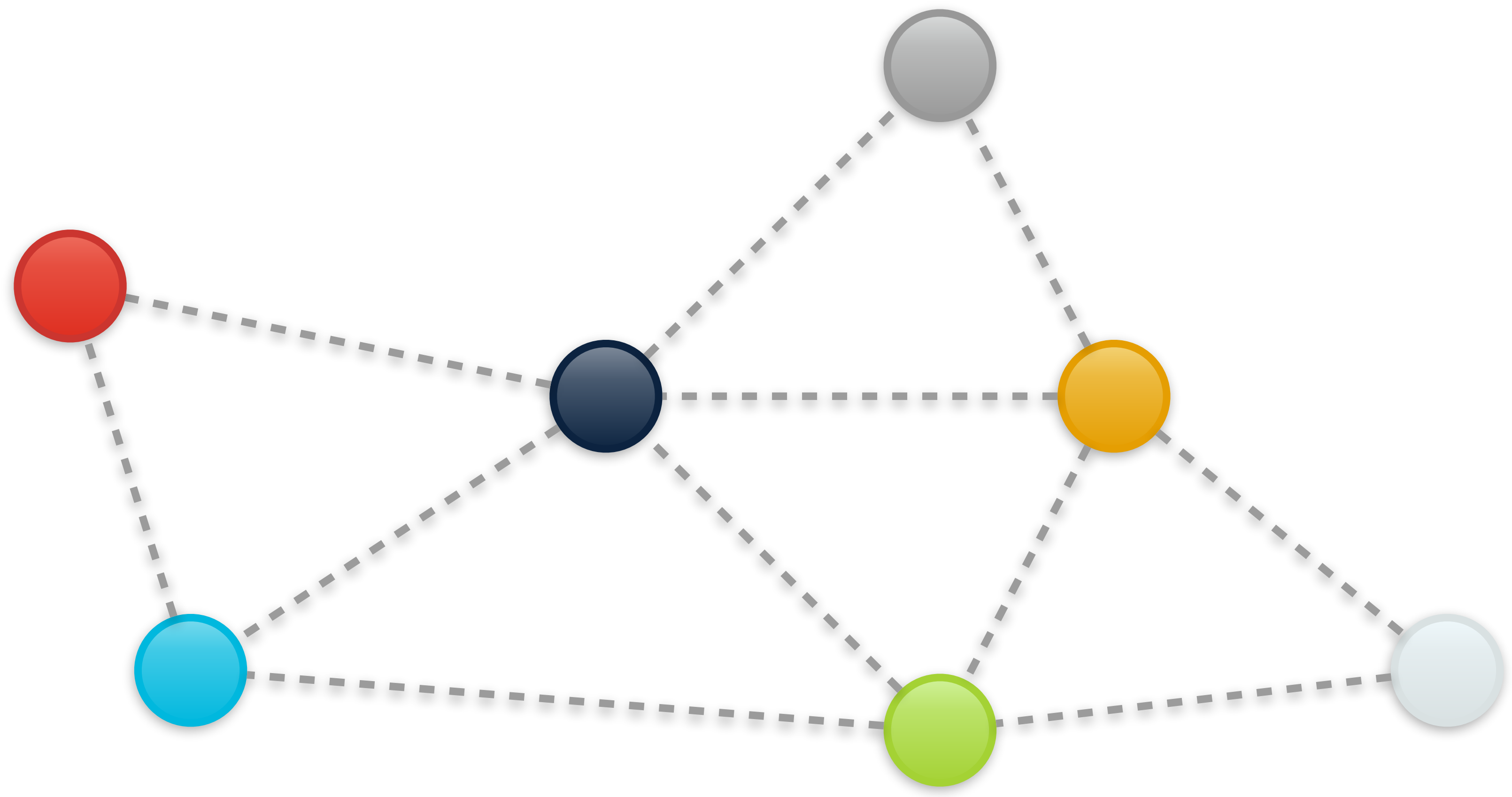
  - When a neighbor of initiator replies, 2-hop neighbors consider it as init



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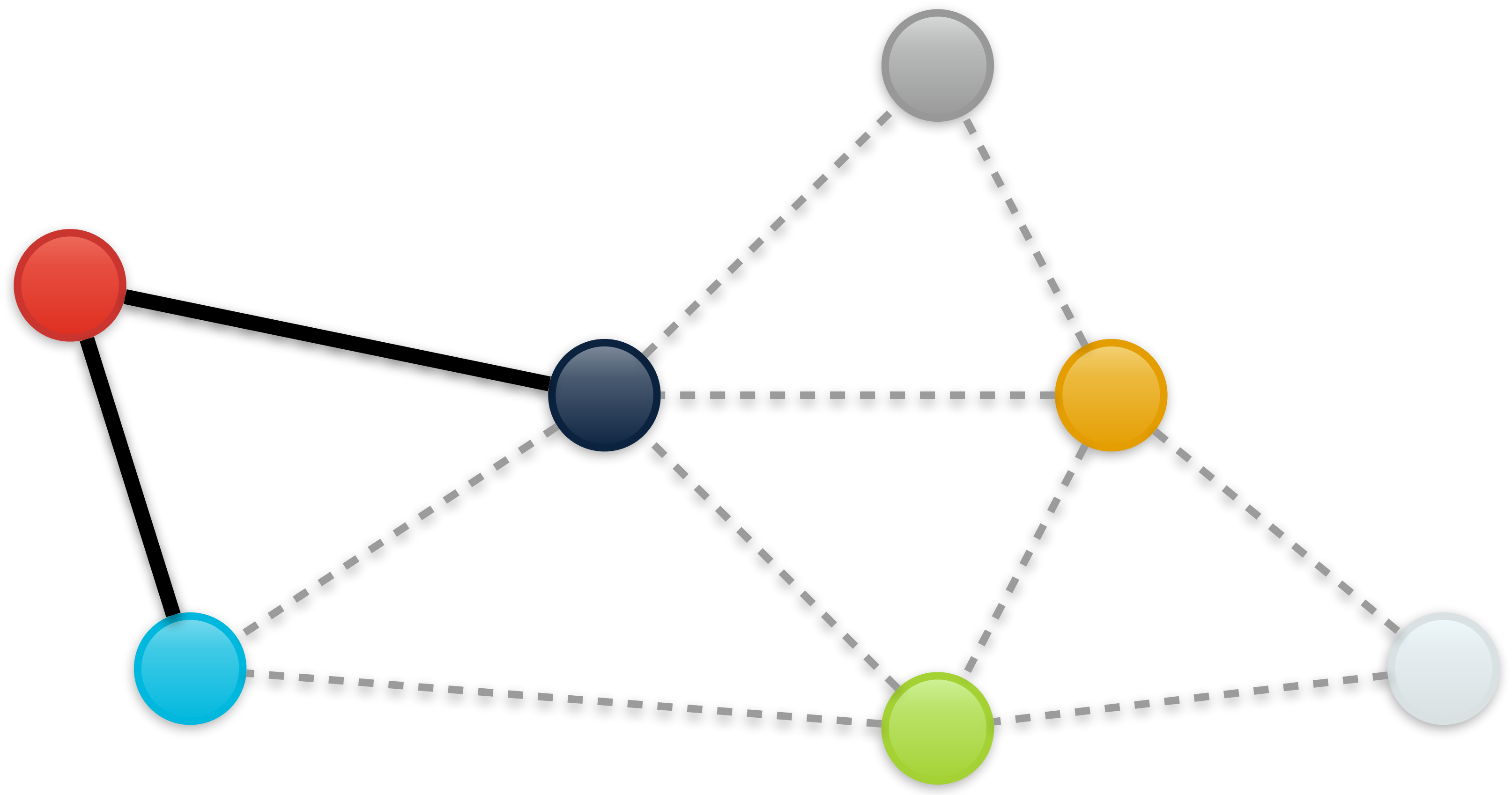

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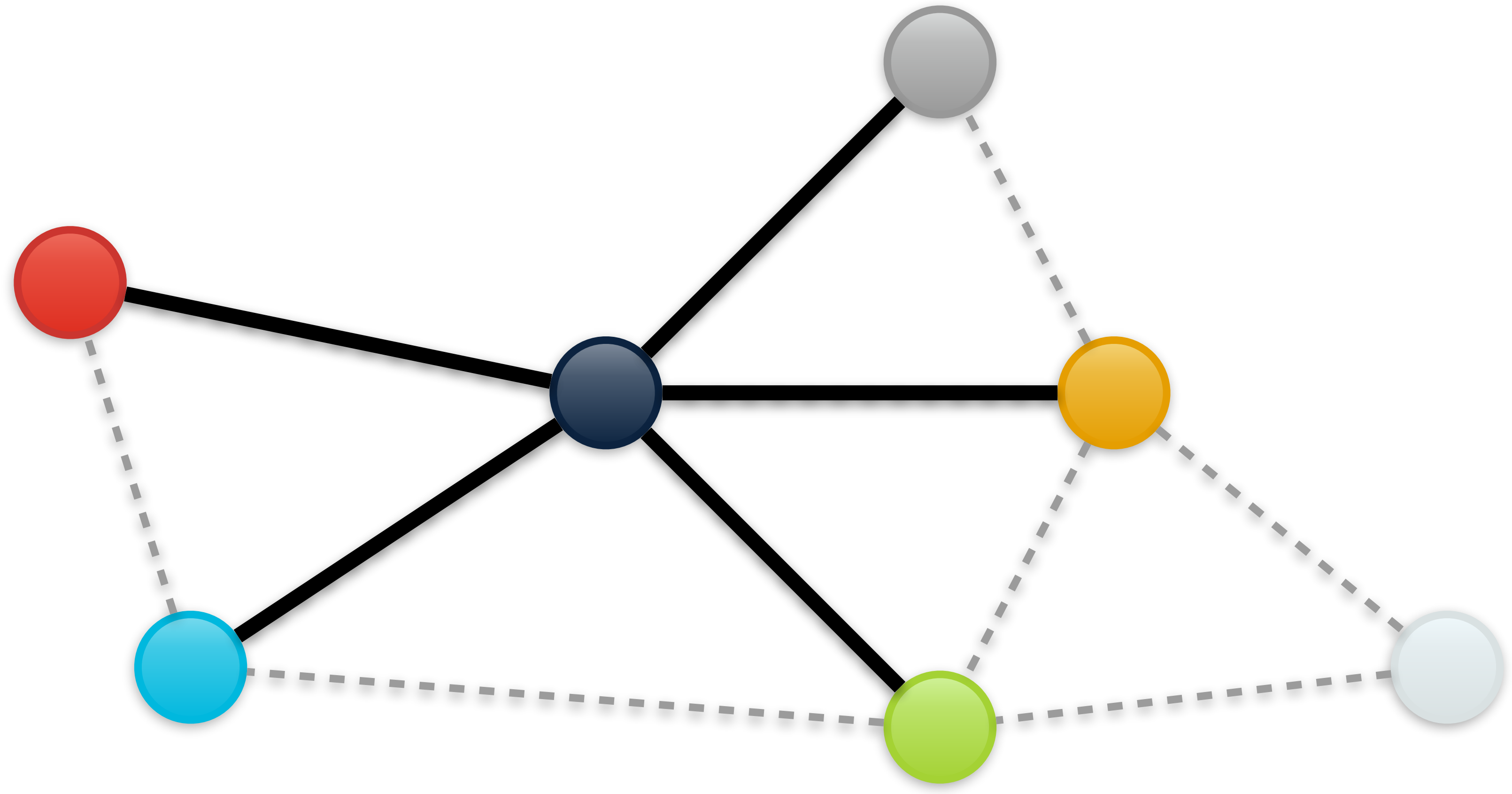

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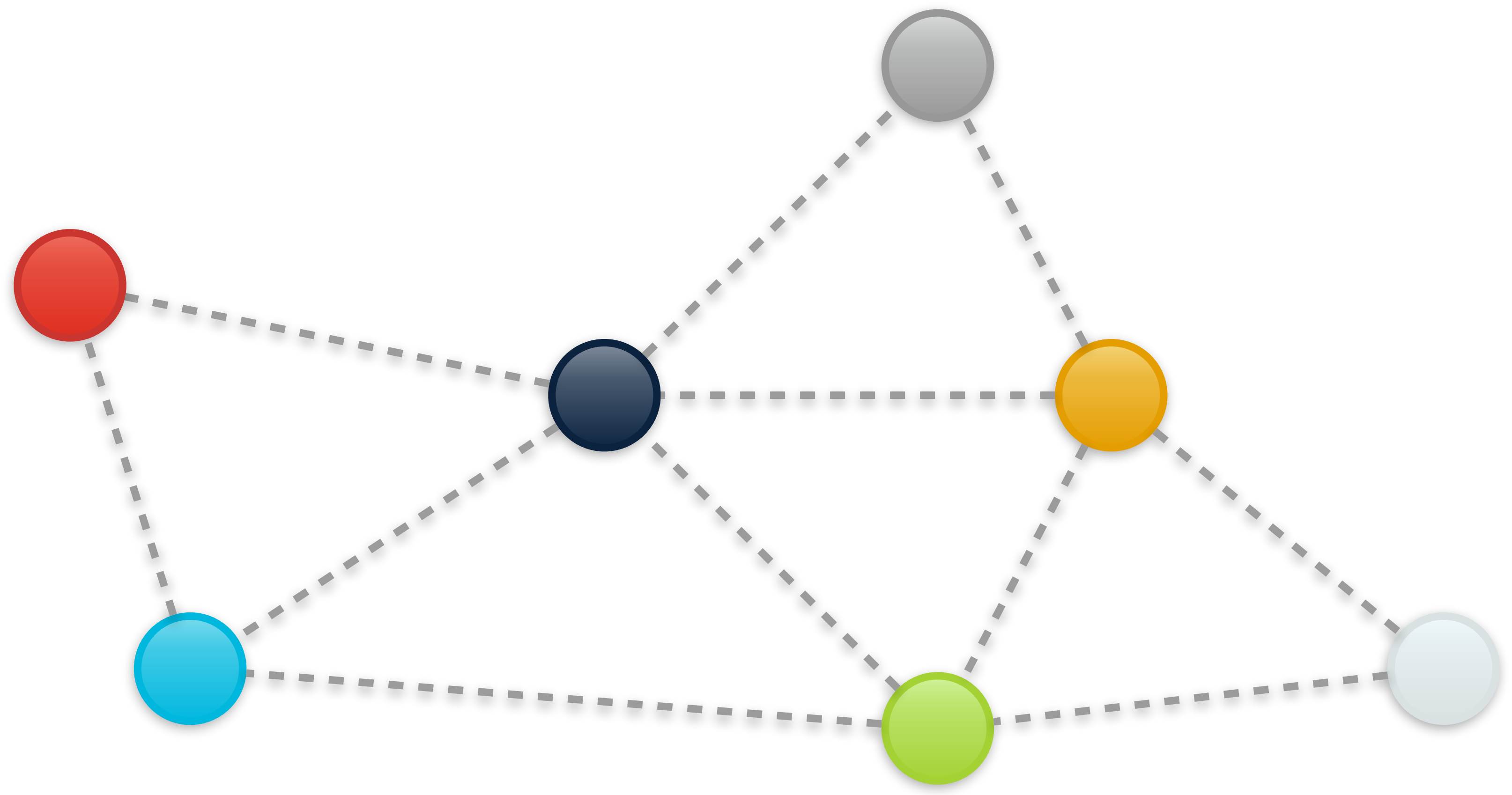

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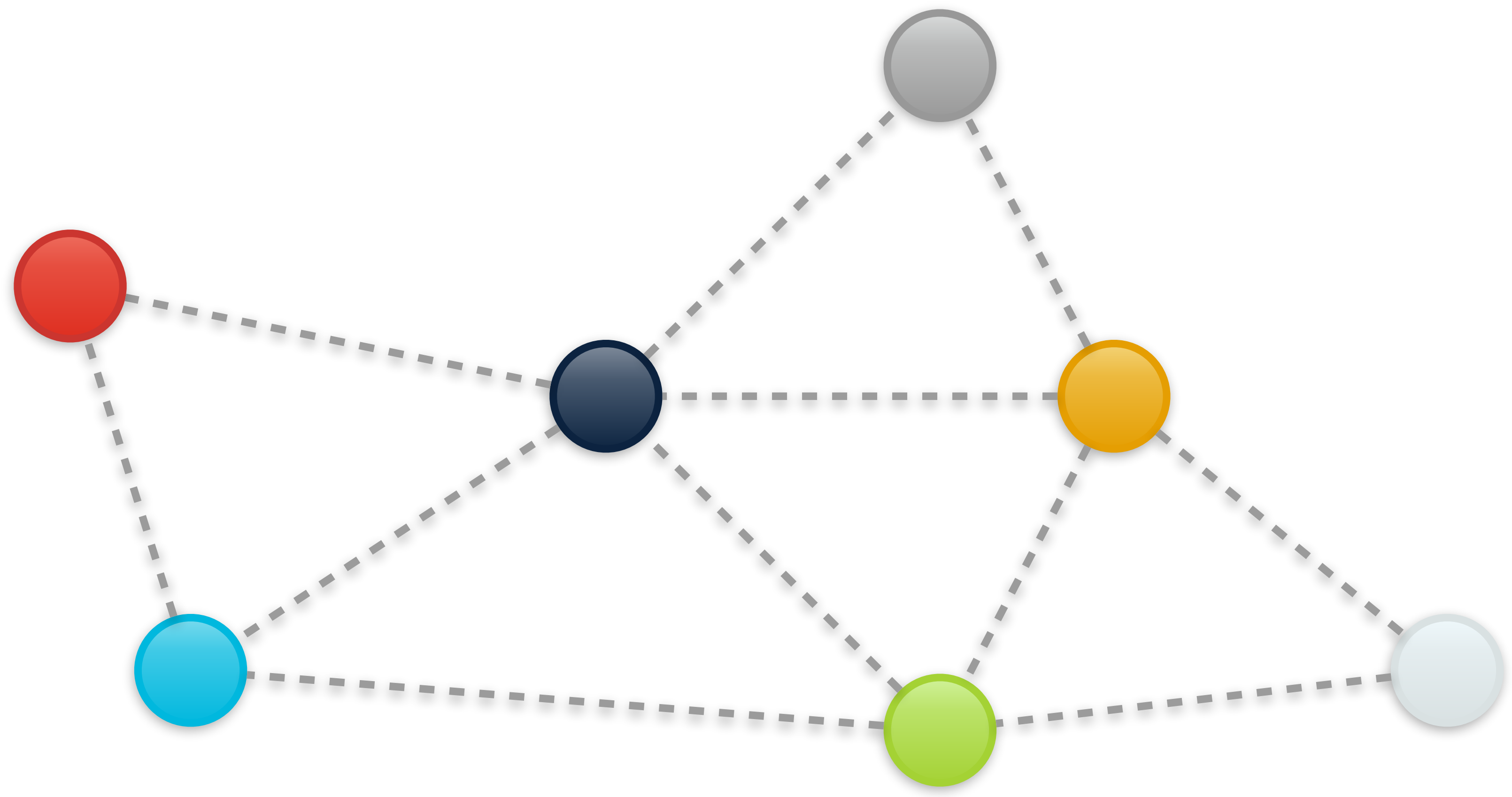

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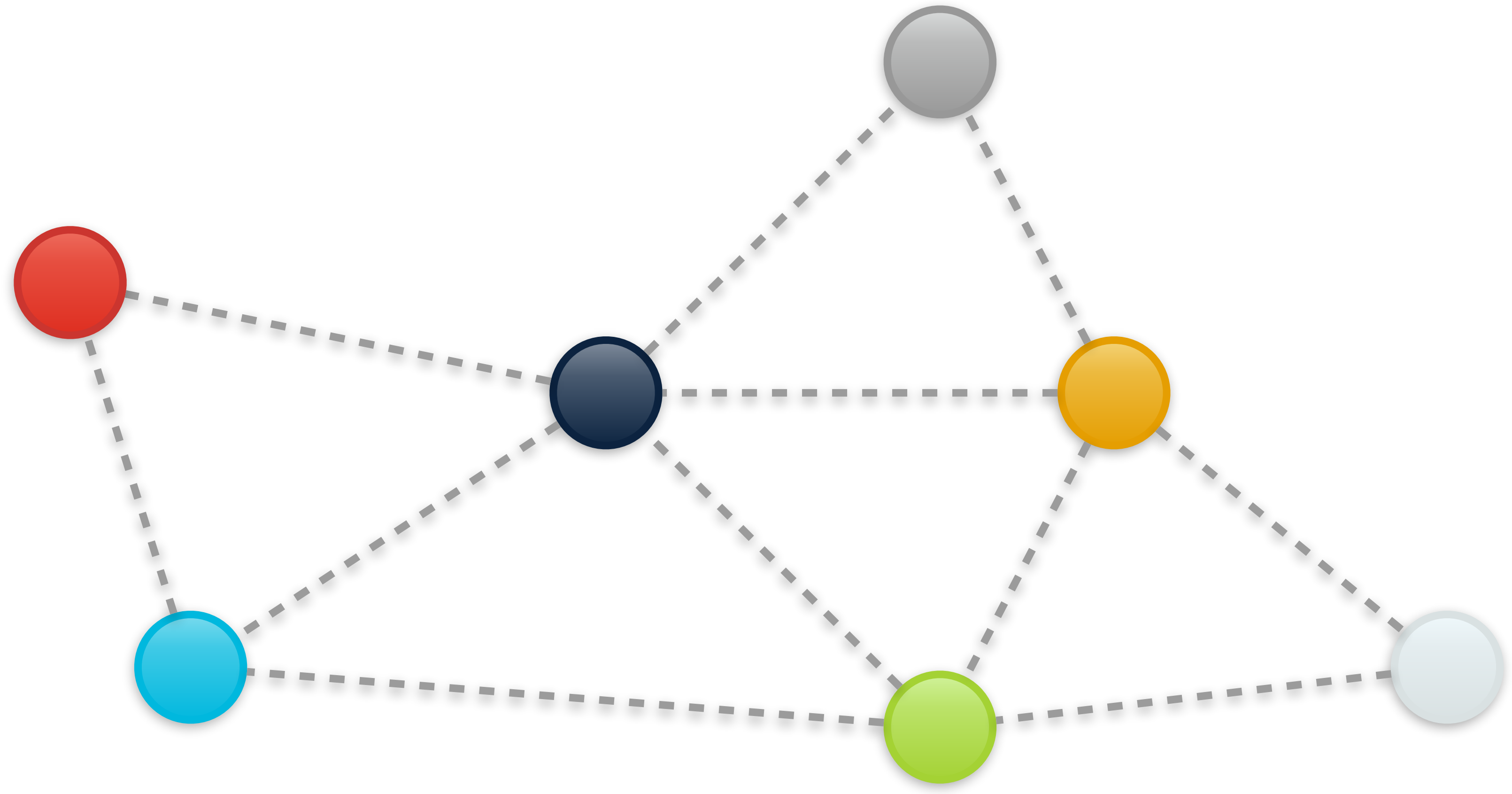

- **Problem: how to separate the two phases (in each neighborhood)?**
  - Introduction of a backoff-based delay mechanism
  - => build a wave crossing the network. Issue with large diameters

PERFORMANCE EVALUATION

AD-HOC SIMULATIONS

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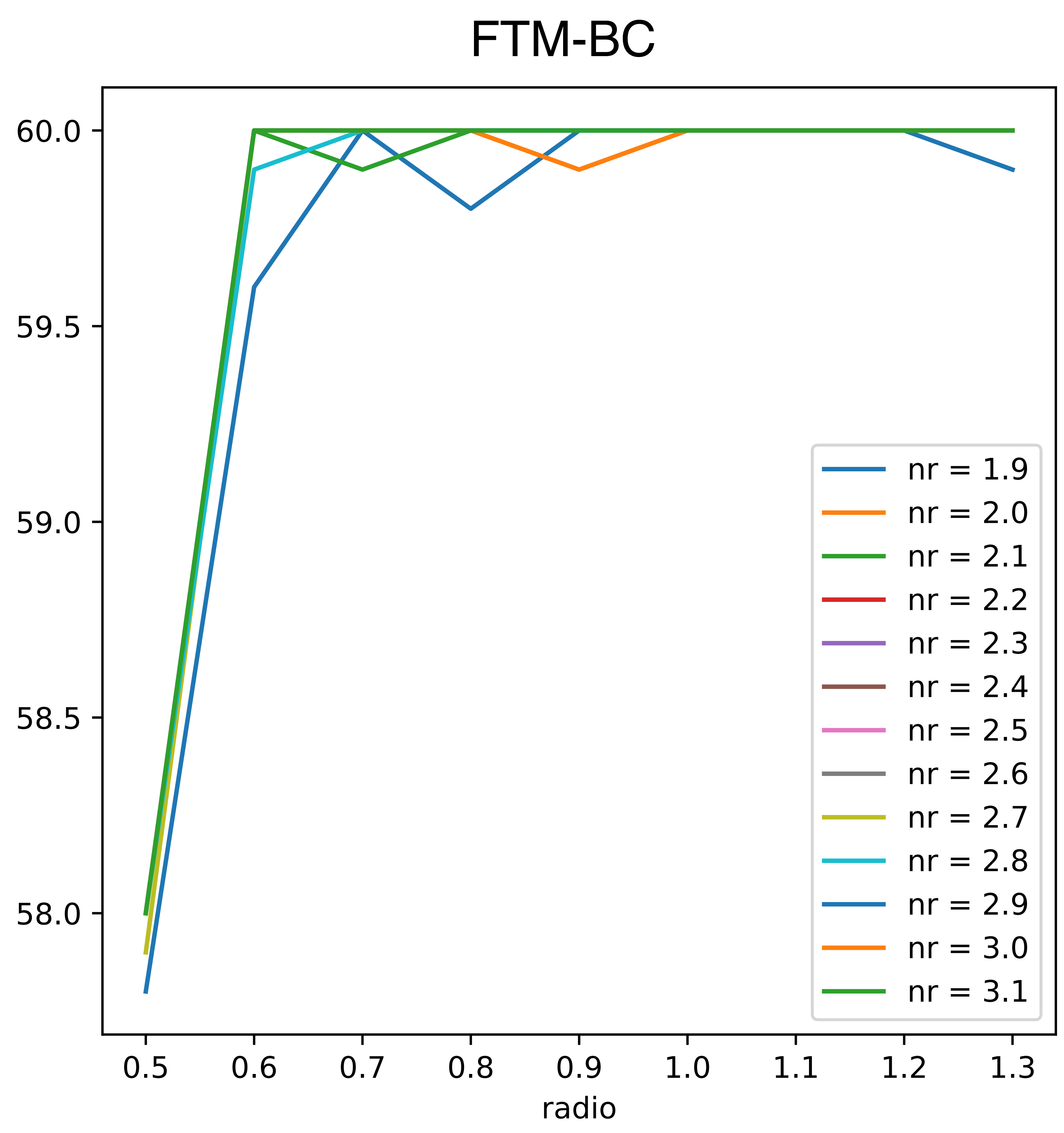
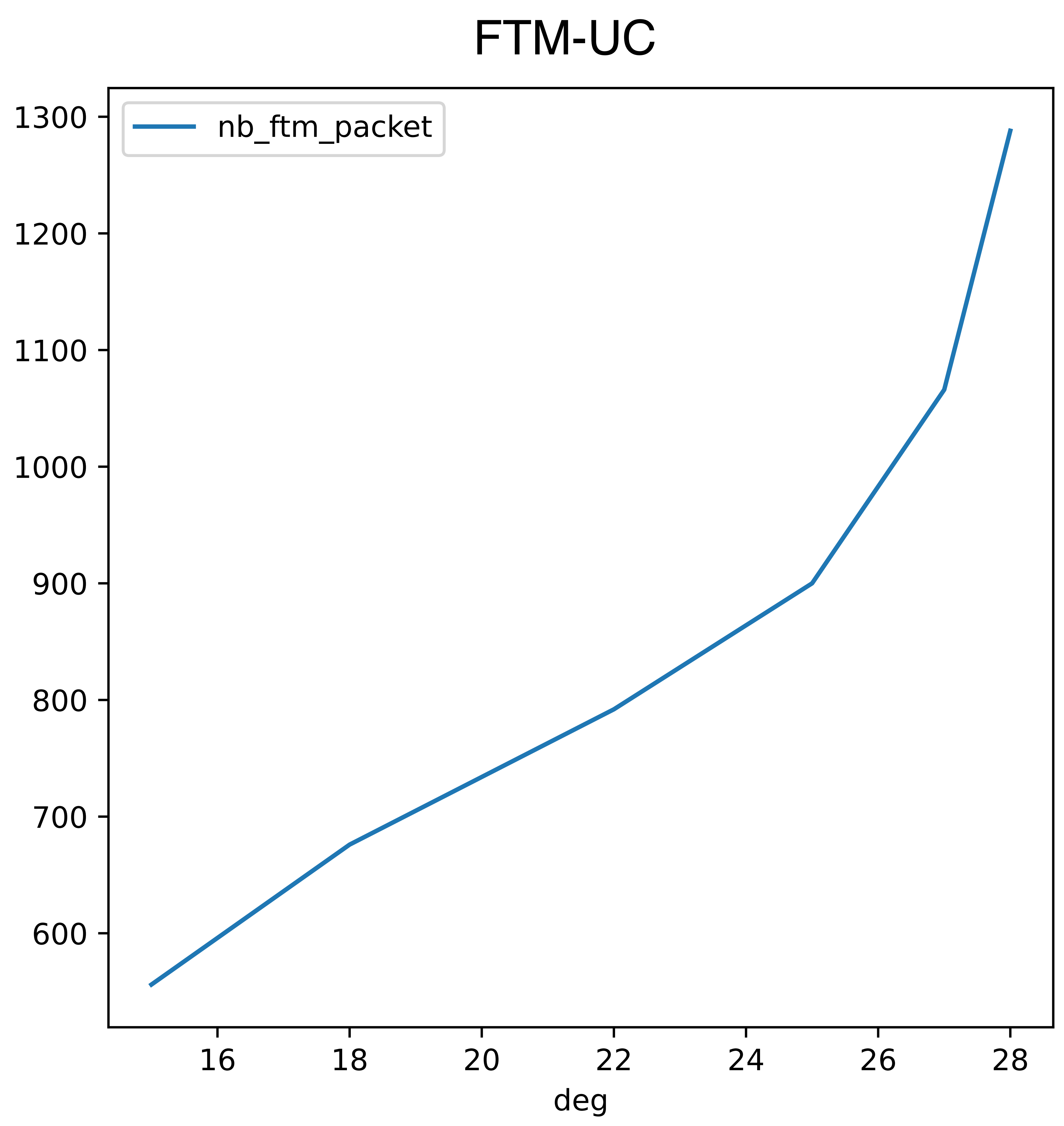
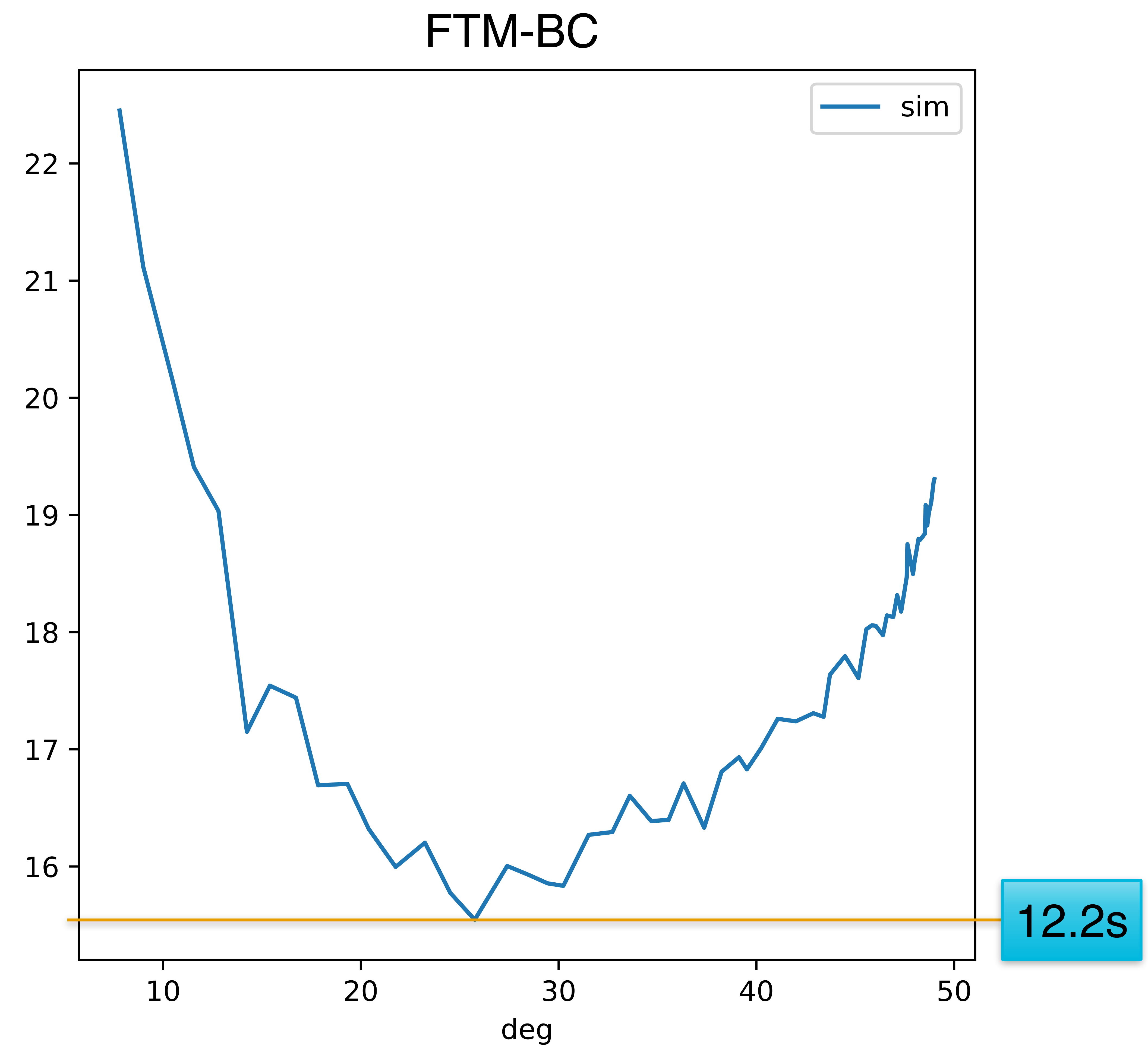
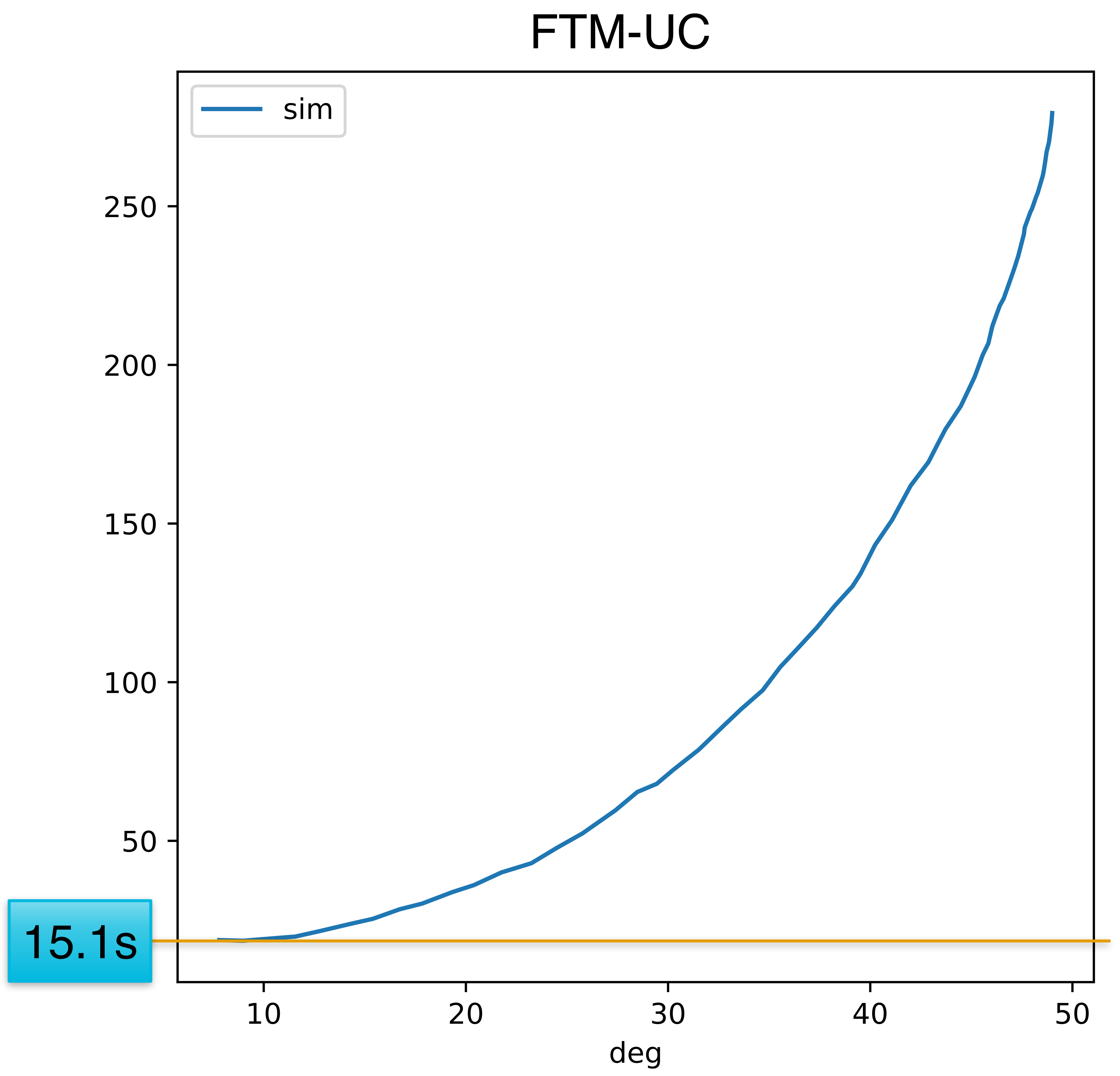
NB OF PACKETS SENT — FTM-BC VS FTM-UC (30 NODES)





EVALUATION TIME OF ALL PAIRWISE DISTANCES (RANDOM GRAPH, 50 NODES, TIME VS AVERAGE DEG=NB EDGES/50)





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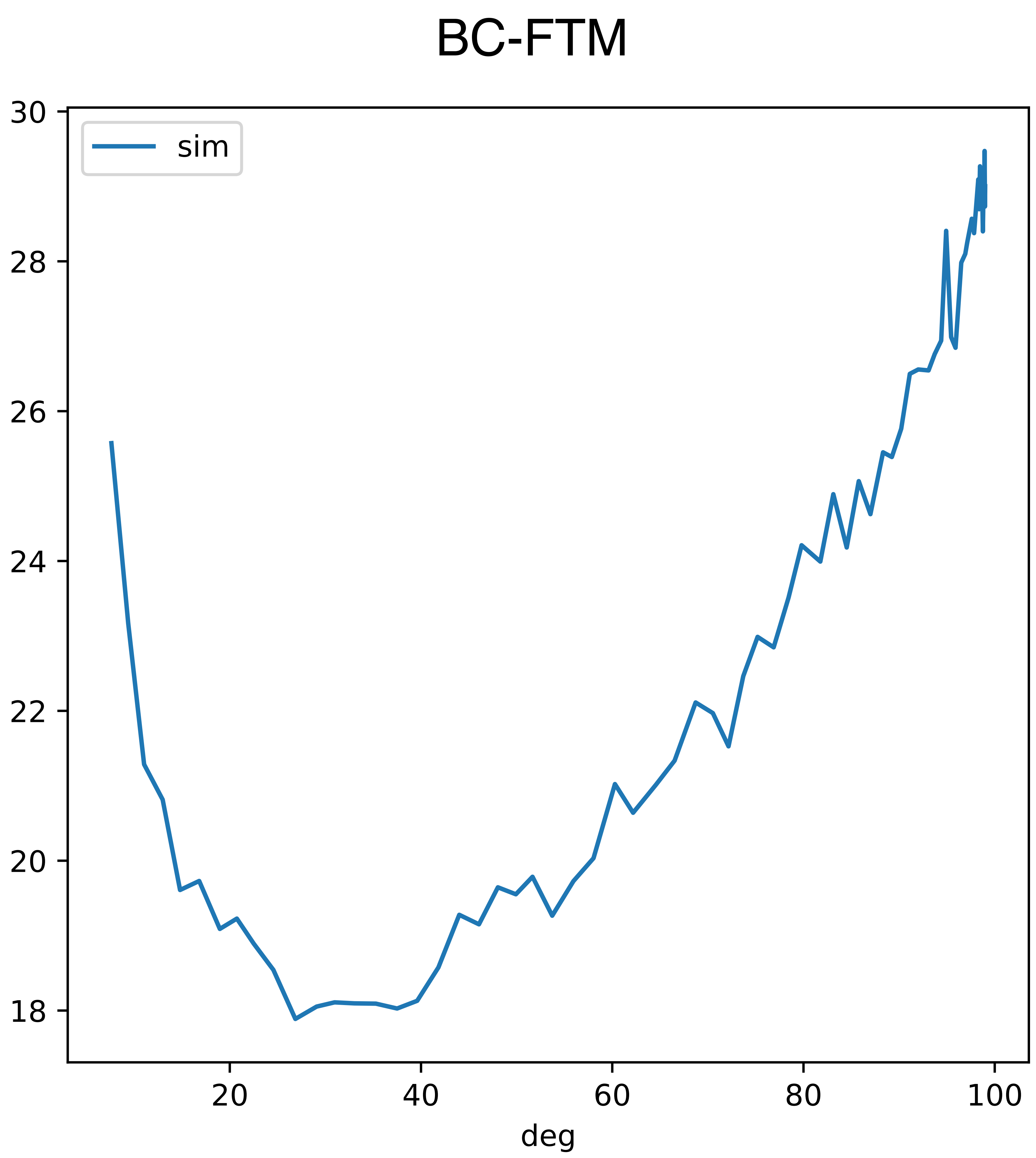
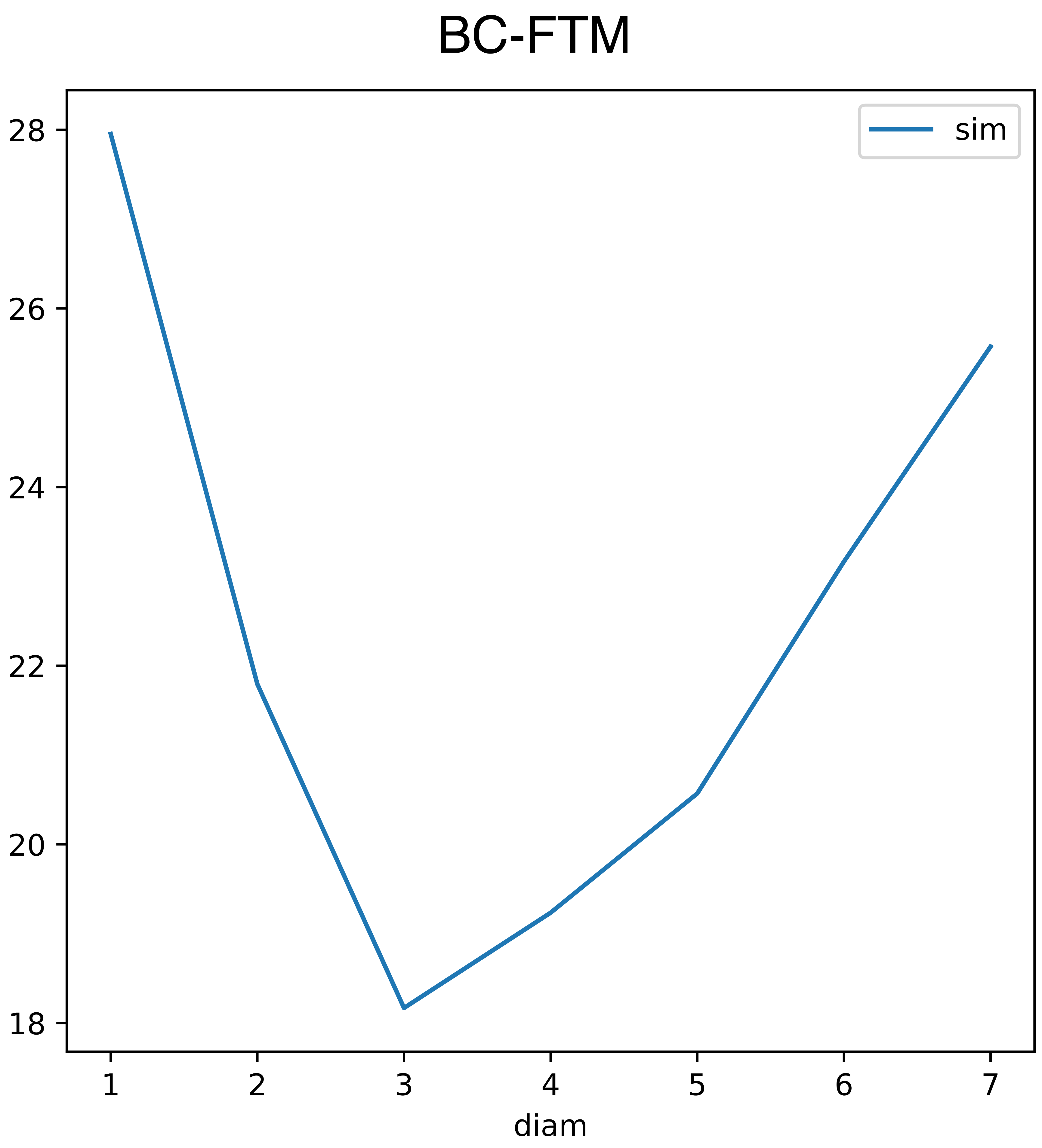
FTM-BC: IMPACT DEGREE AND DIAMETER ON EXECUTION TIME (RANDOM GRAPH, 100 NODES)





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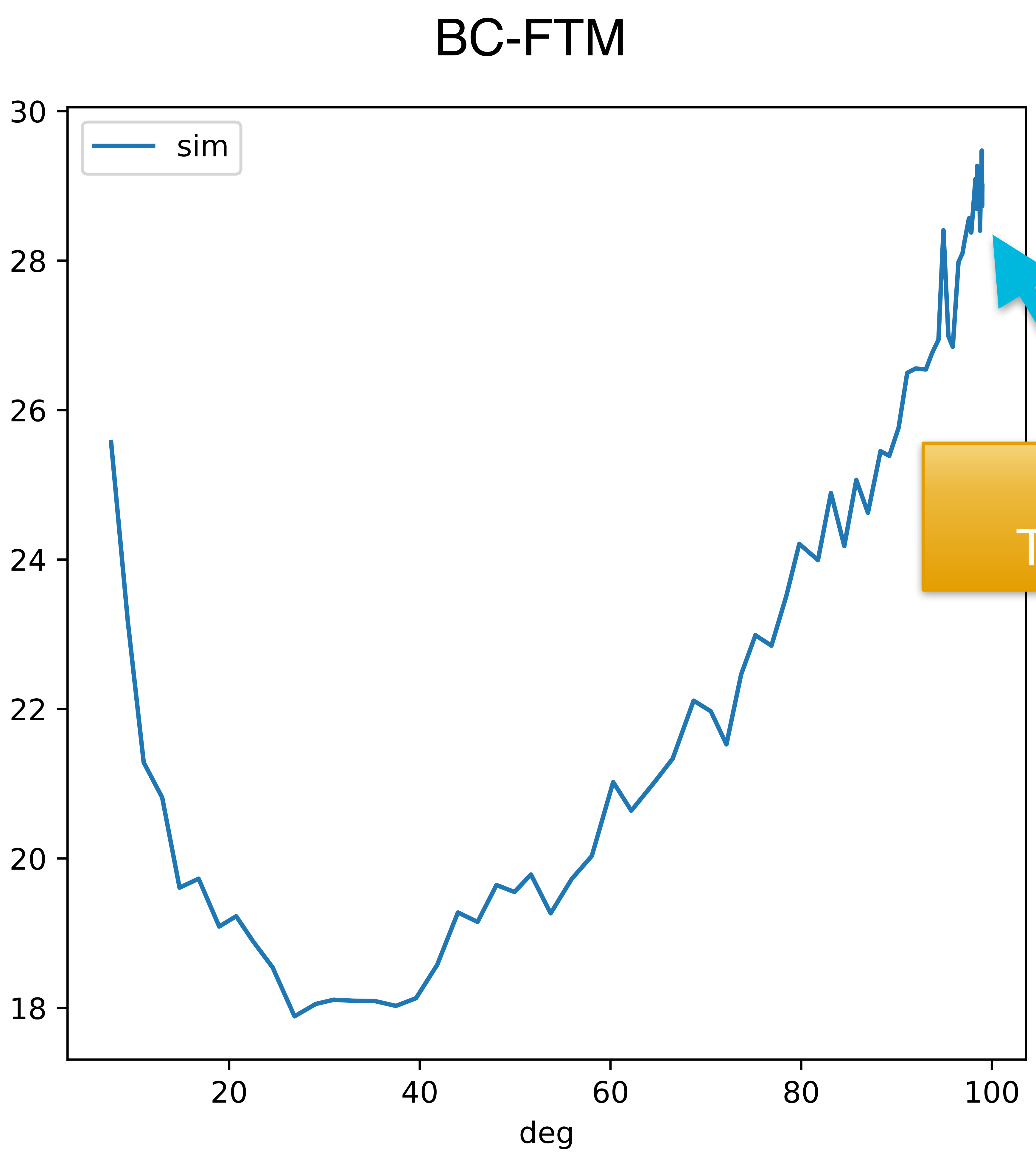
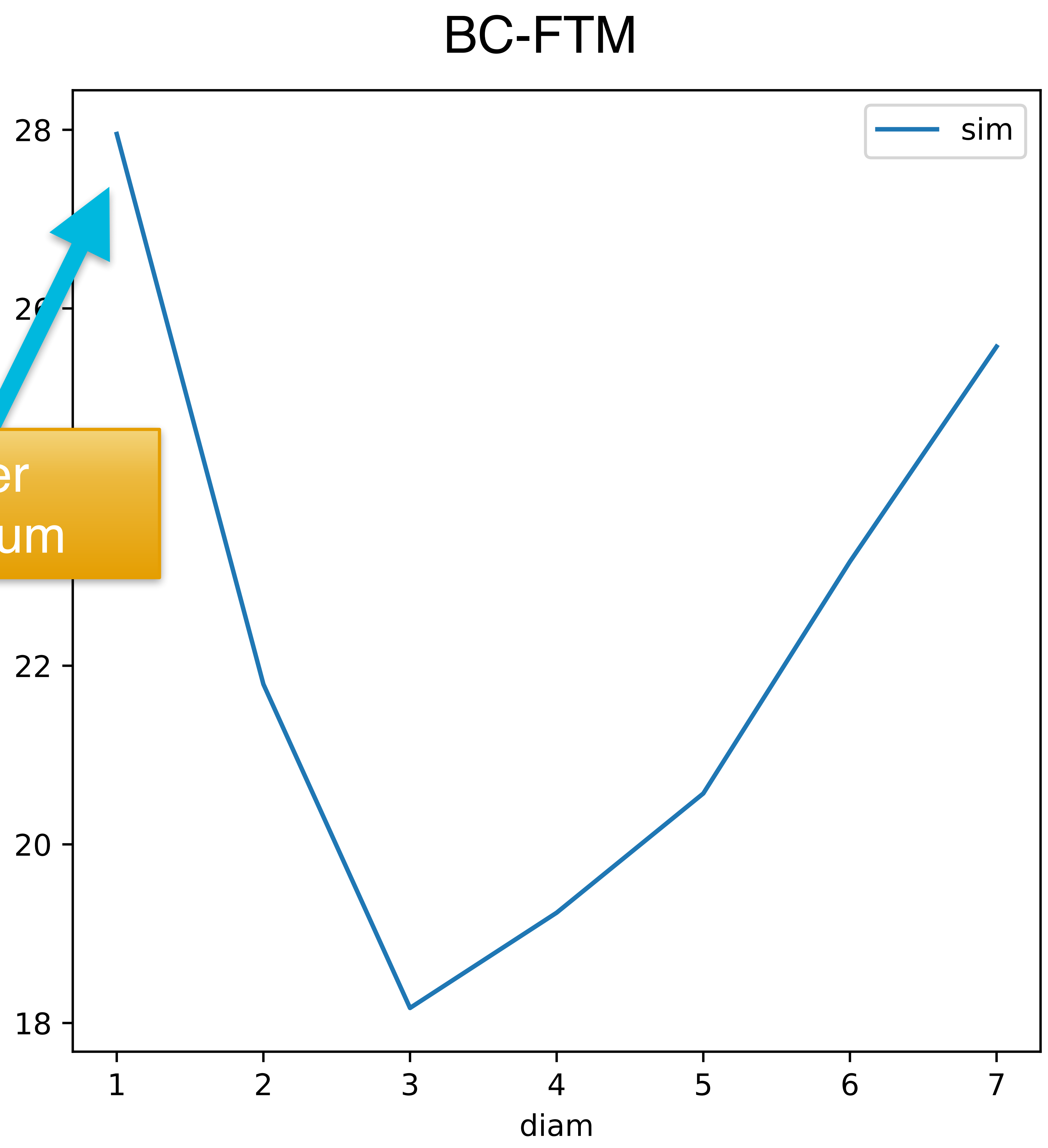


Large degree <=> Small diameter
Time: restraint access to the medium



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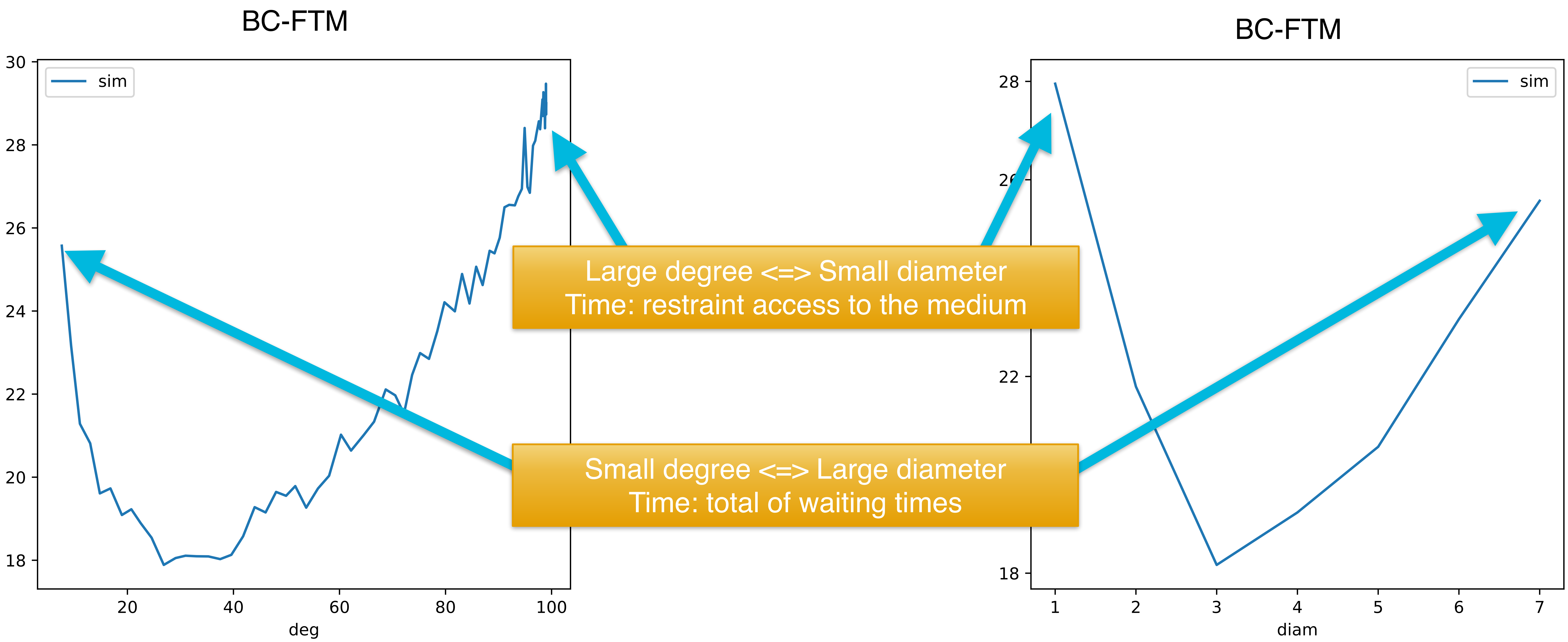
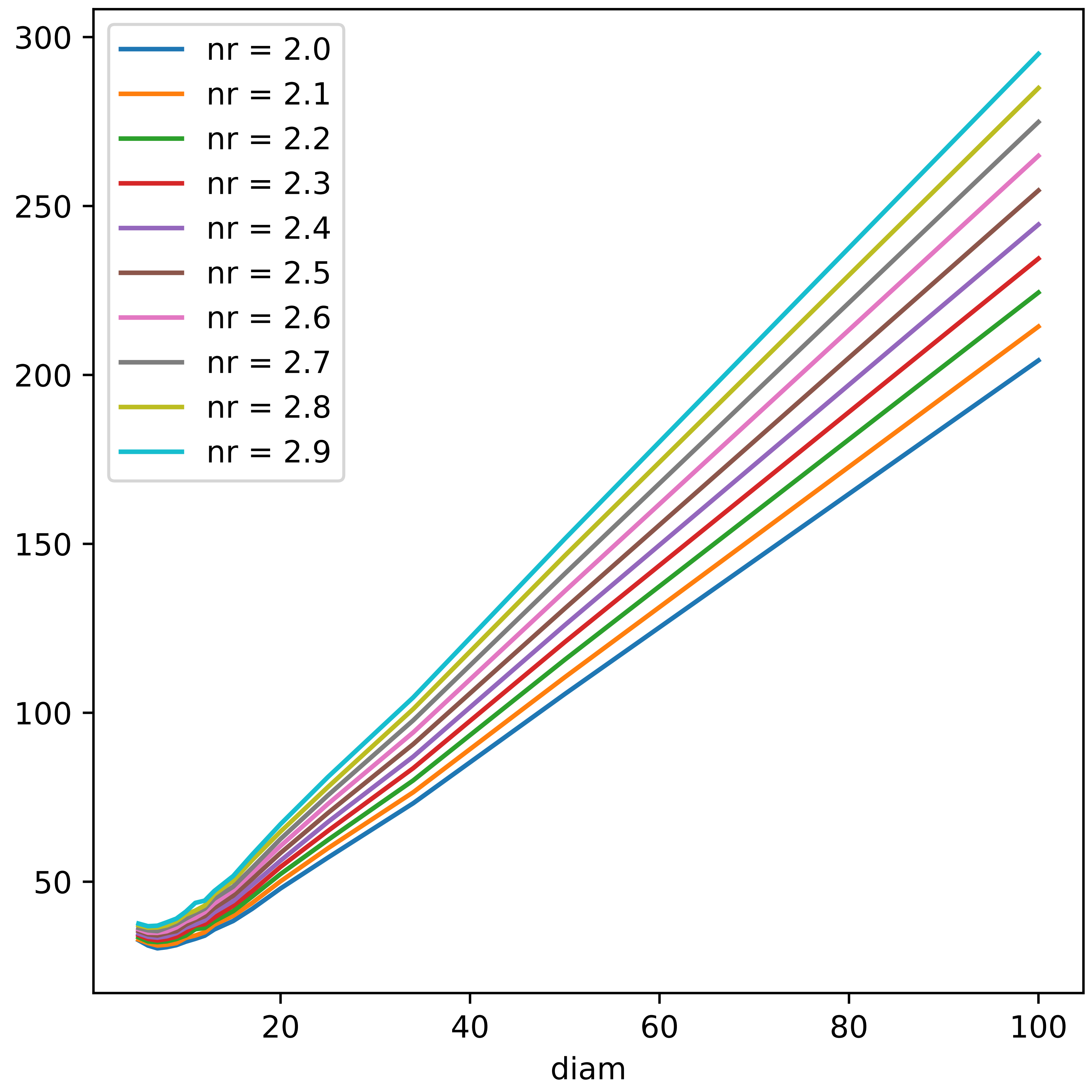
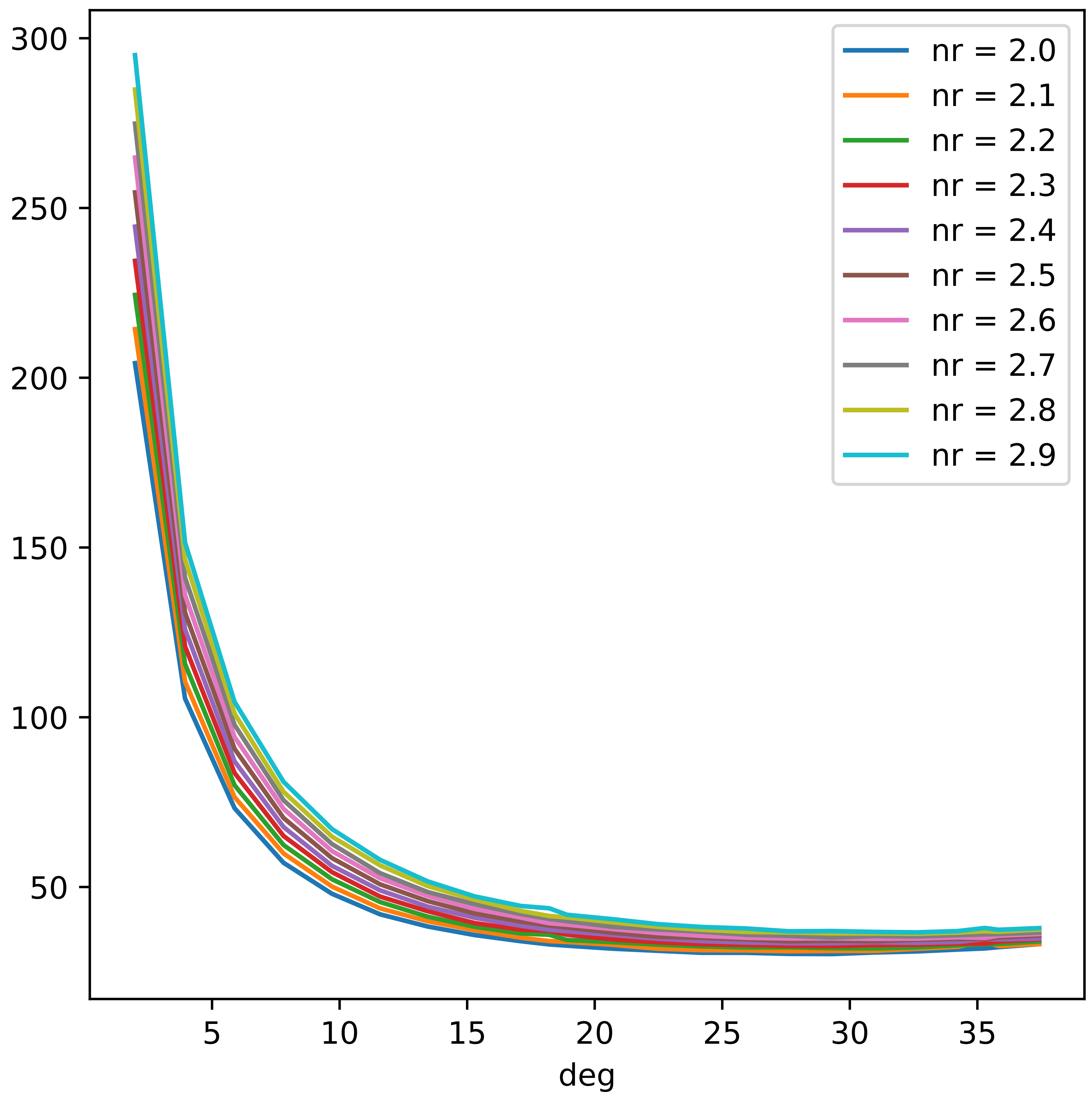


FTM-BC: IMPACT DEGREE AND DIAMETER ON EXECUTION TIME (LINEAR GRAPH, 101 NODES)





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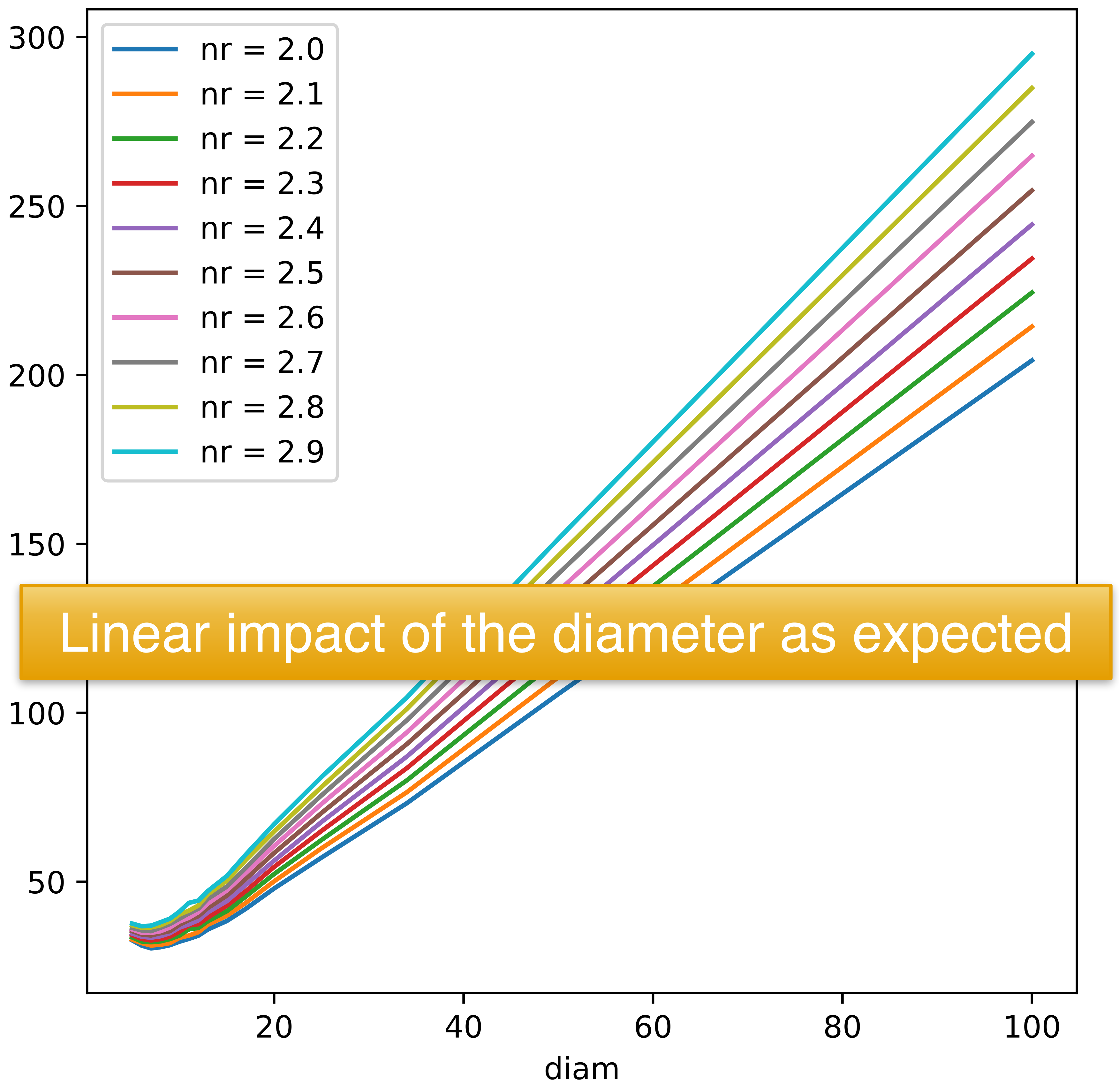

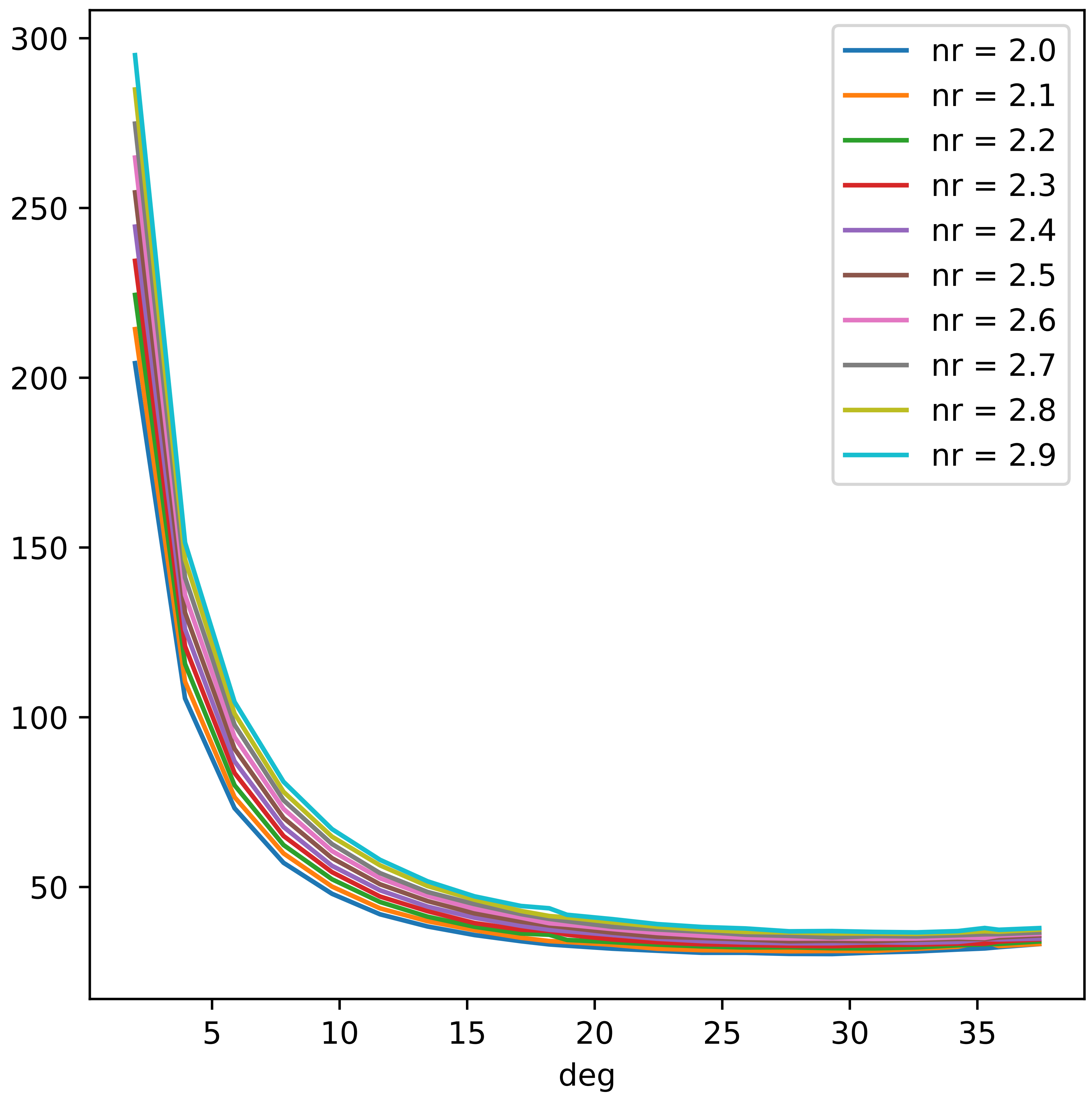

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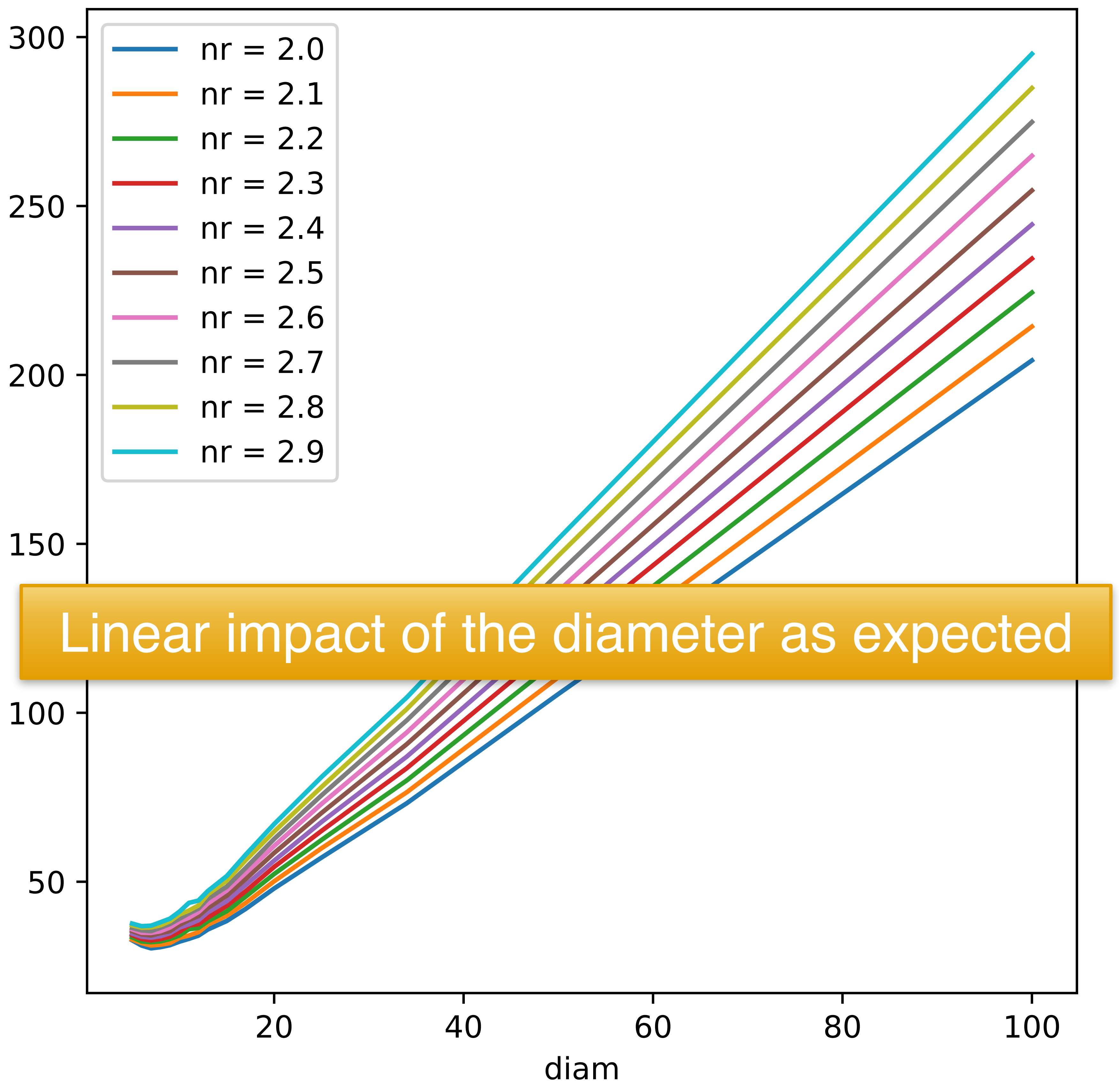
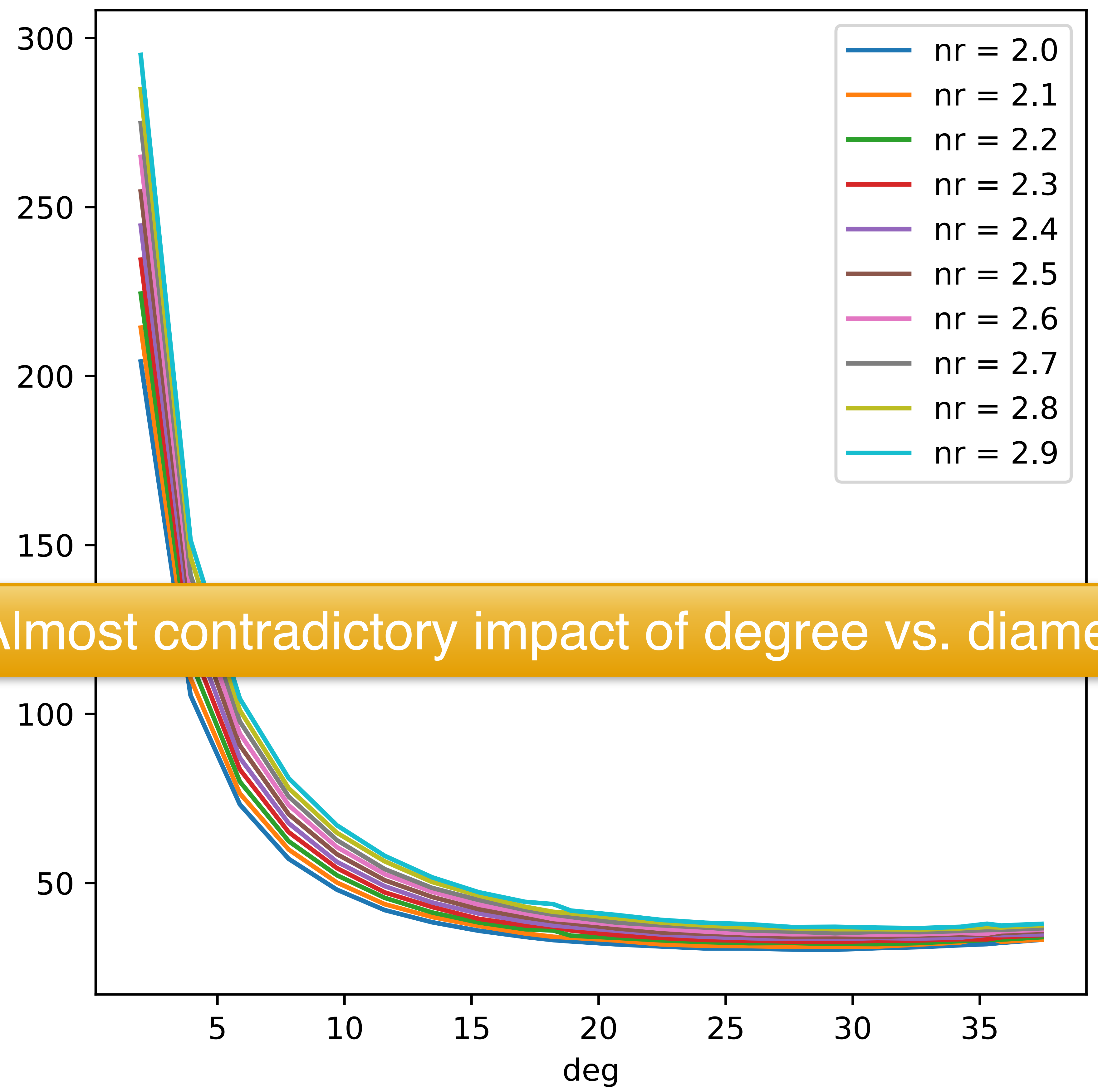


Linear impact of the diameter as expected



Almost contradictory impact of degree vs. diameter

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