A Scheduling Algorithm Compatible with a Distributed Management of Arrivals in the National Airspace System

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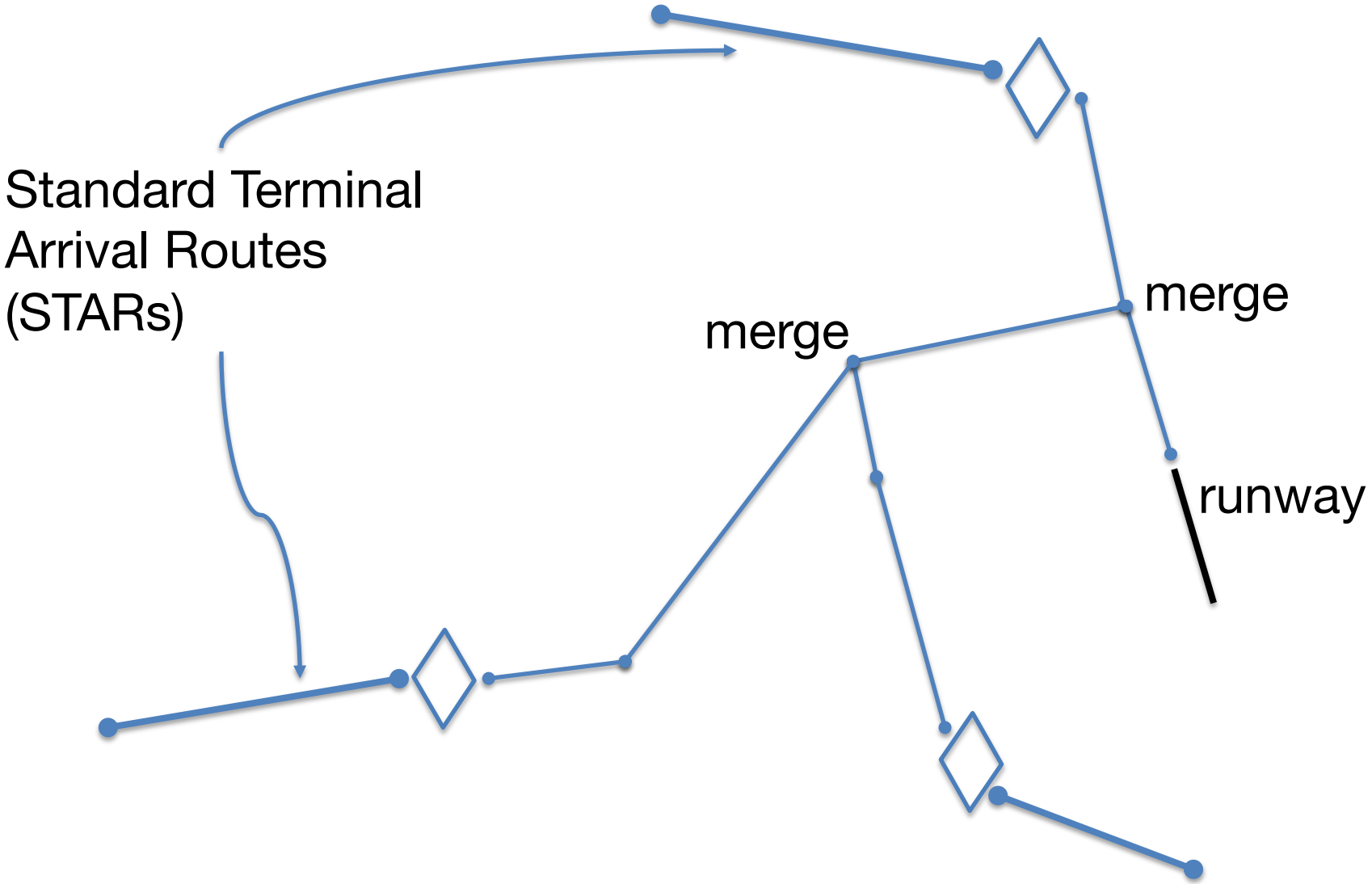
Context: Arrival Scheduling



Goals

- Explore the potential benefits of a distributed system (service-oriented architecture)
- Enable an airline operator to:
  - influence its schedule…
  - …toward its business objectives
  - keep objectives undisclosed
  - re-negotiate a schedule

Outline

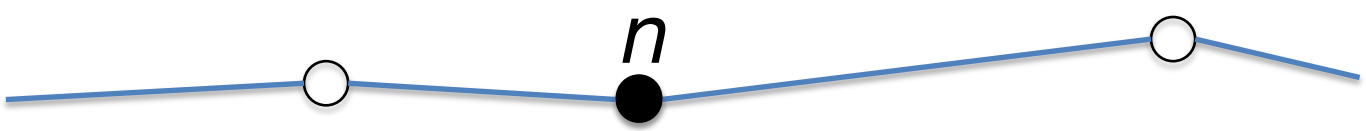
- Background: Arrival Scheduling
- Goals
- Context
- Definition of a “schedule”
- Computation of a schedule

Context

- Research of options for a 2045+ Air Traffic Control system
- NOT an advocacy for a distributed system
- Currently: scheduling algorithms used as part of Traffic-Based Flow Management (TBFM)
- Collaborative Decision Making (CDM)

What is a *schedule*?

- Along a flight's route, pick nodes.



- At each node, compute a Scheduled Time for flight to Arrive (STA).

A schedule:

Node	…	*n*	…
Scheduled Time of Arrival (STA)	…	STA^n	…

What is a *schedule*?

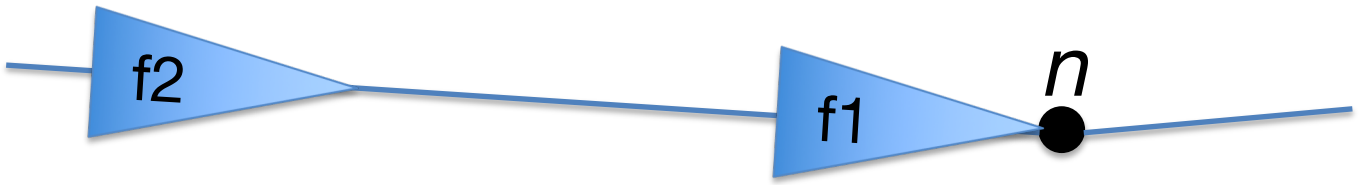
- The STAs are the decision variables
- What constrains the decisions?
  - *traffic*
  - *flight performance*
  - *weather*

Type 1: Node constraints

- STA no earlier than the *Estimated Time of Arrival*:

$$STA \geq ETA$$

- Time separation:



$$STA_{f2}^{n} - STA_{f1}^{n} \geq \text{(minimal required sep'n)}$$

Type 2: Link constraints

- Bounds on travel time:

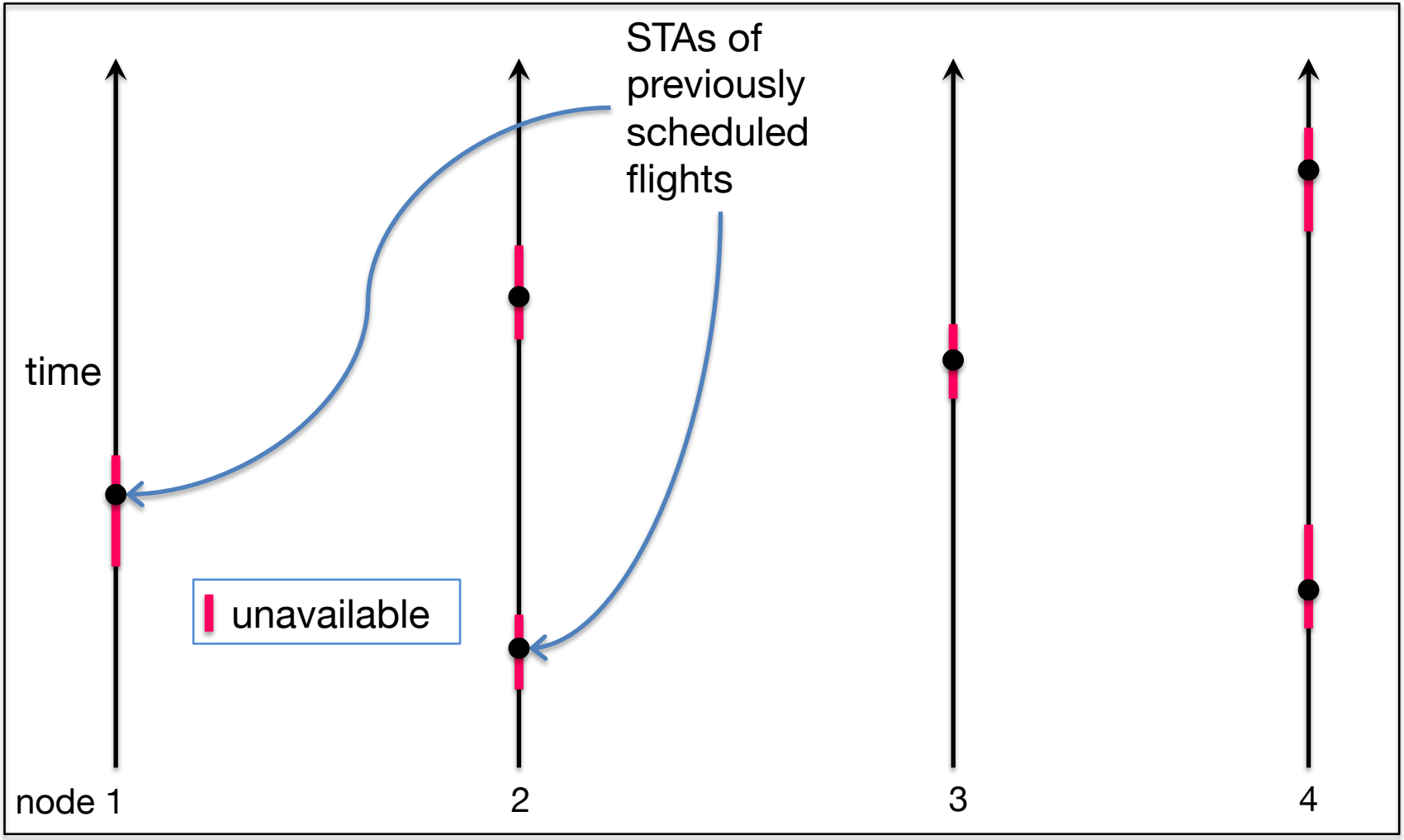
  (shortest t.t.) $\leq$ $STA_f^{n1} - STA_f^{n2}$ $\leq$ (longest t.t.)

- Some links: no passing

  $STA_{f1}^{n1} \leq STA_{f2}^{n1}$ implies $STA_{f1}^{n2} \leq STA_{f2}^{n2}$

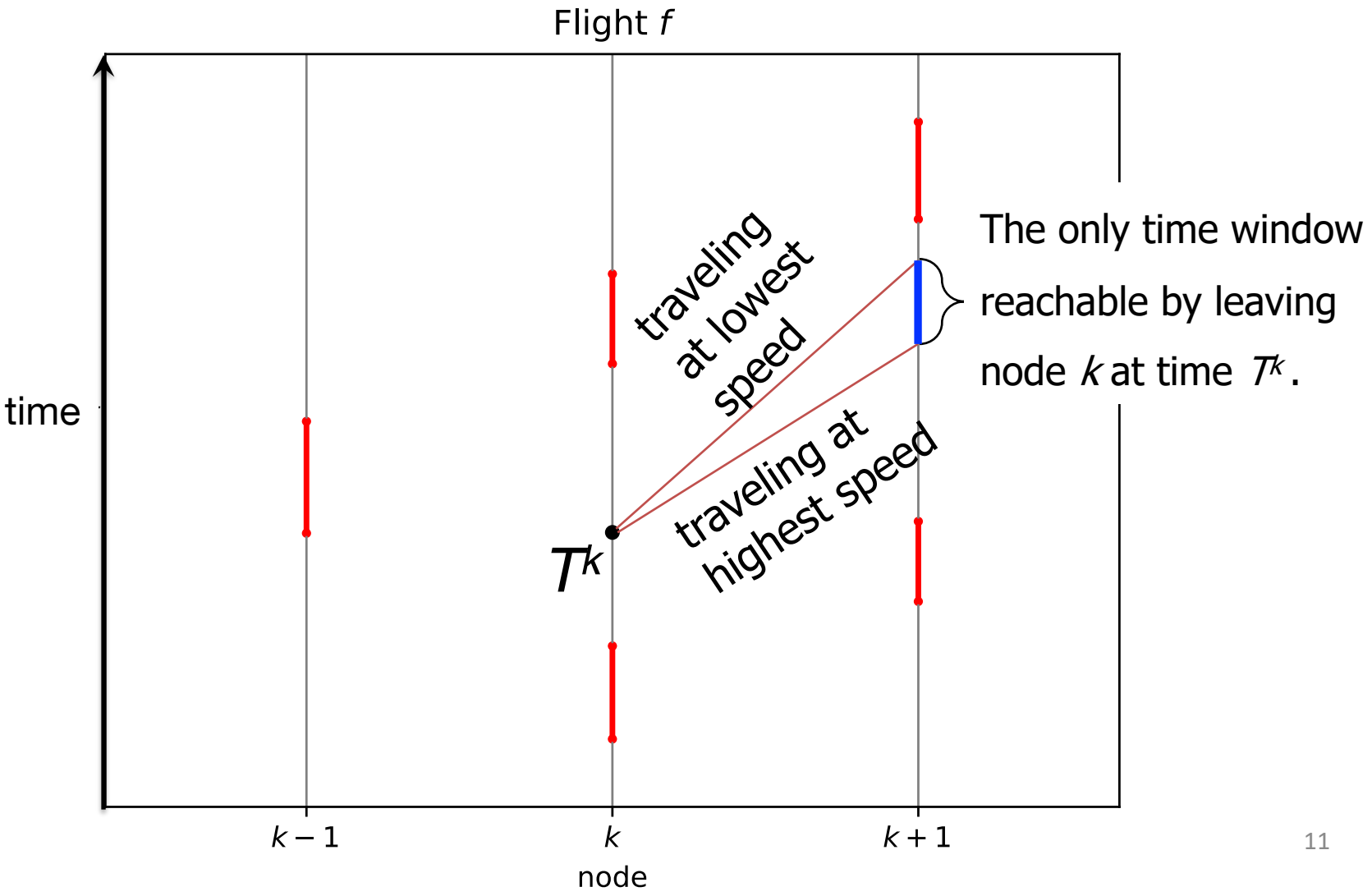
Effects of node constraints

scheduling flight *f*



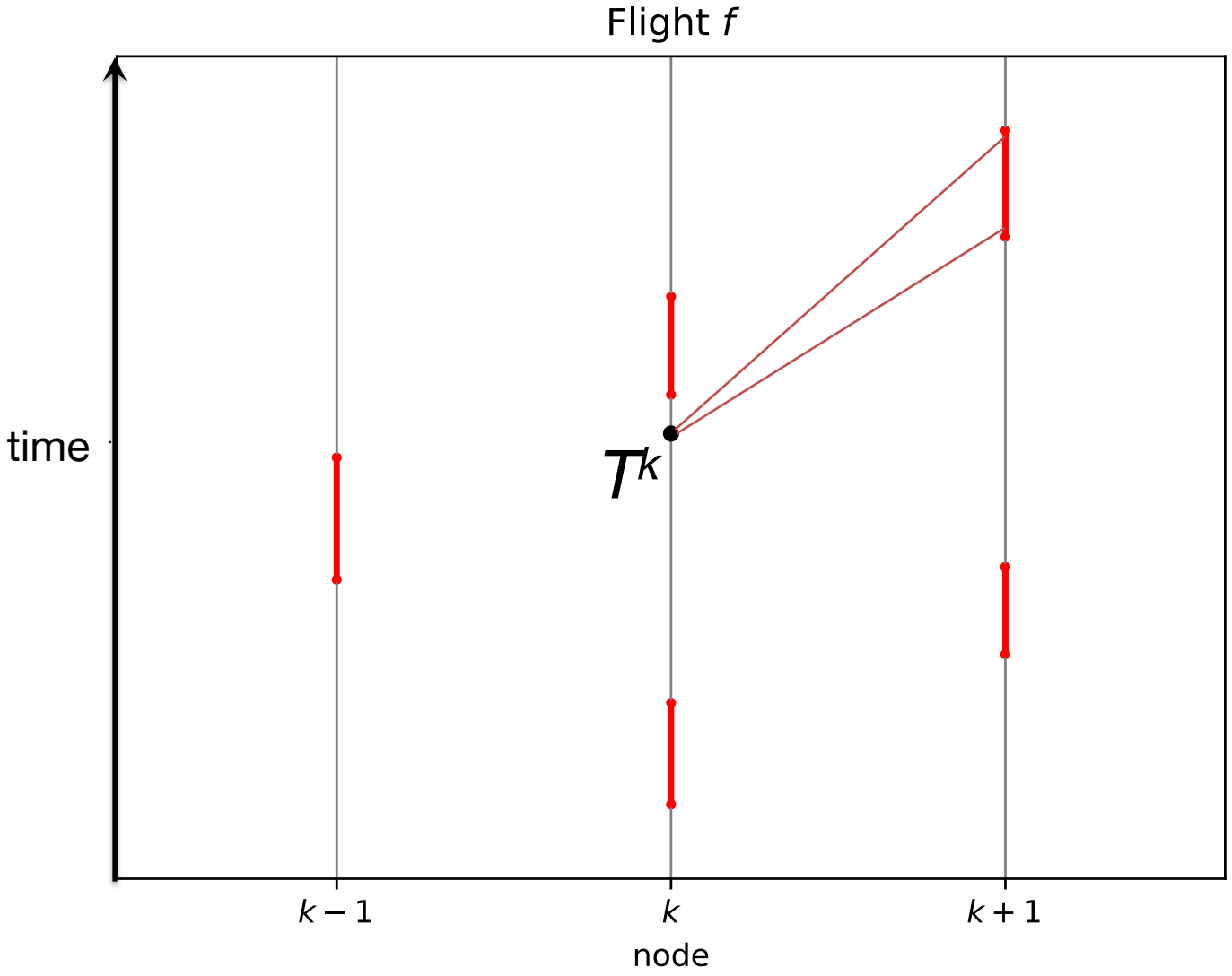
Effects of Constraints: Travel time limitations can…

…make a time window unreachable downstream:



Effects of Constraints: Travel time limitations can…

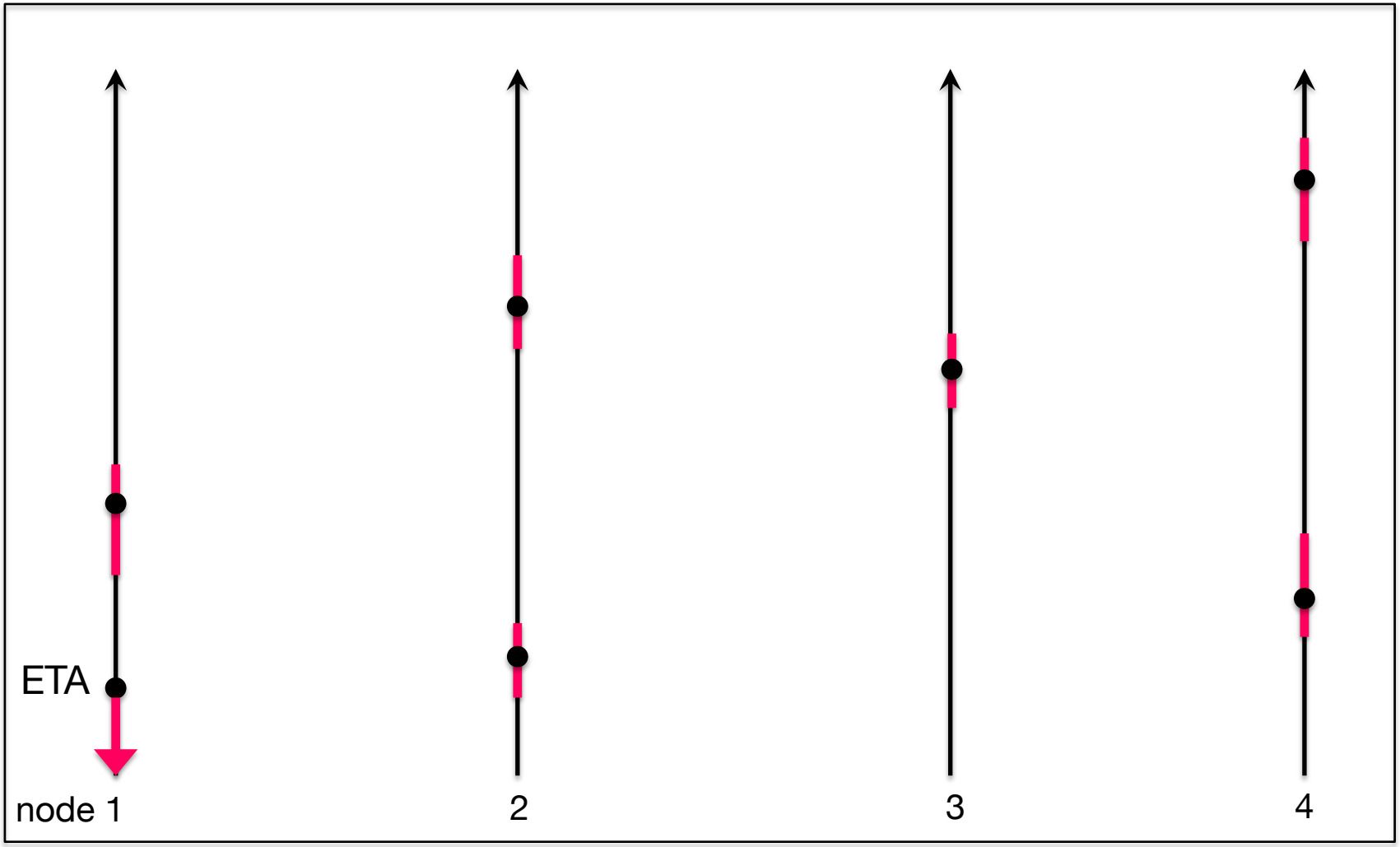
…make an upstream time window uncontrollable:



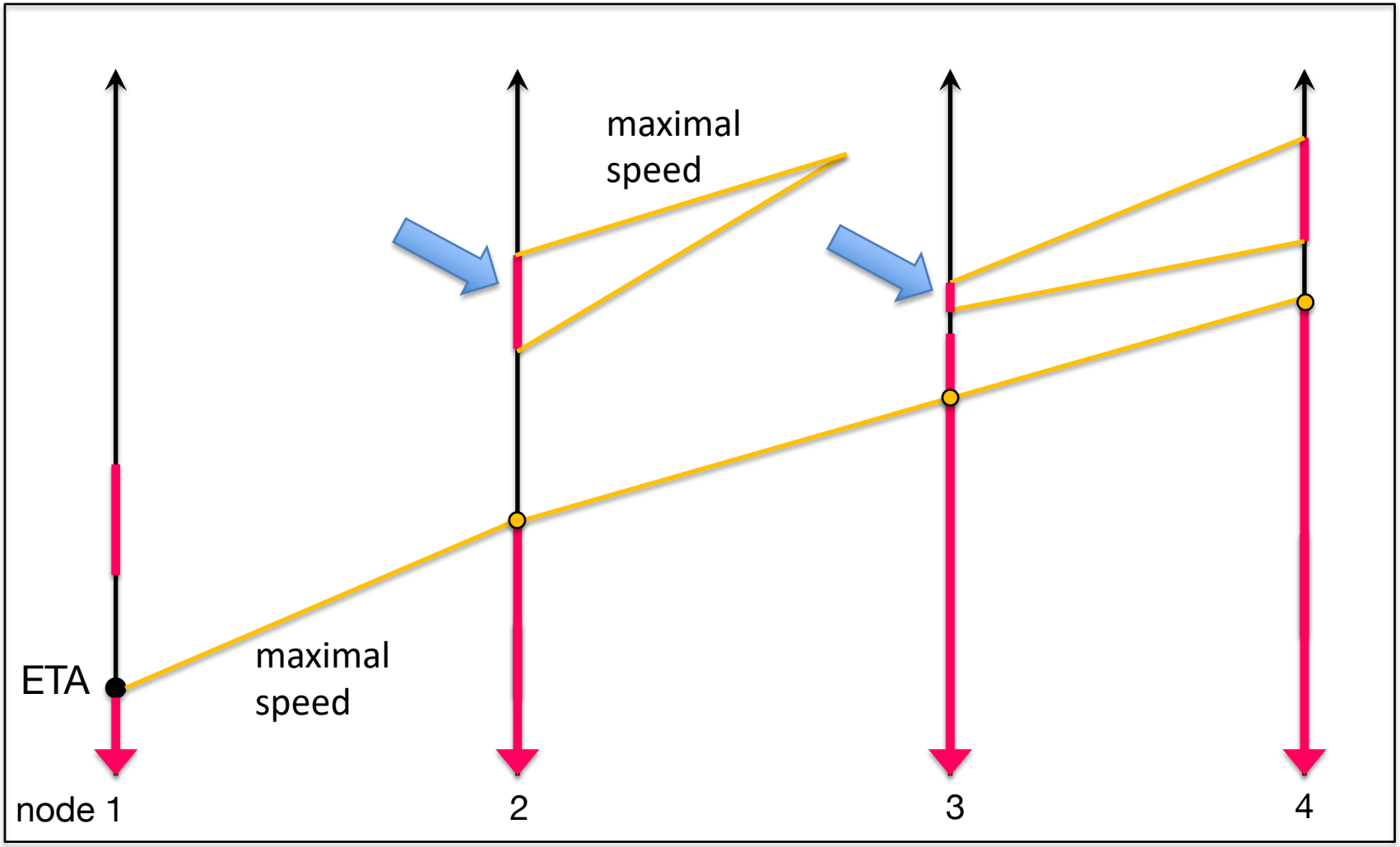
Scheduling Algorithm: Input

- A list of flights, ordered by priority
- Each flight has:
  - A sequence of nodes
  - A given ETA at first node
  - Aircraft type (separation)
  - Bounds on travel speed (t. t. bounds)

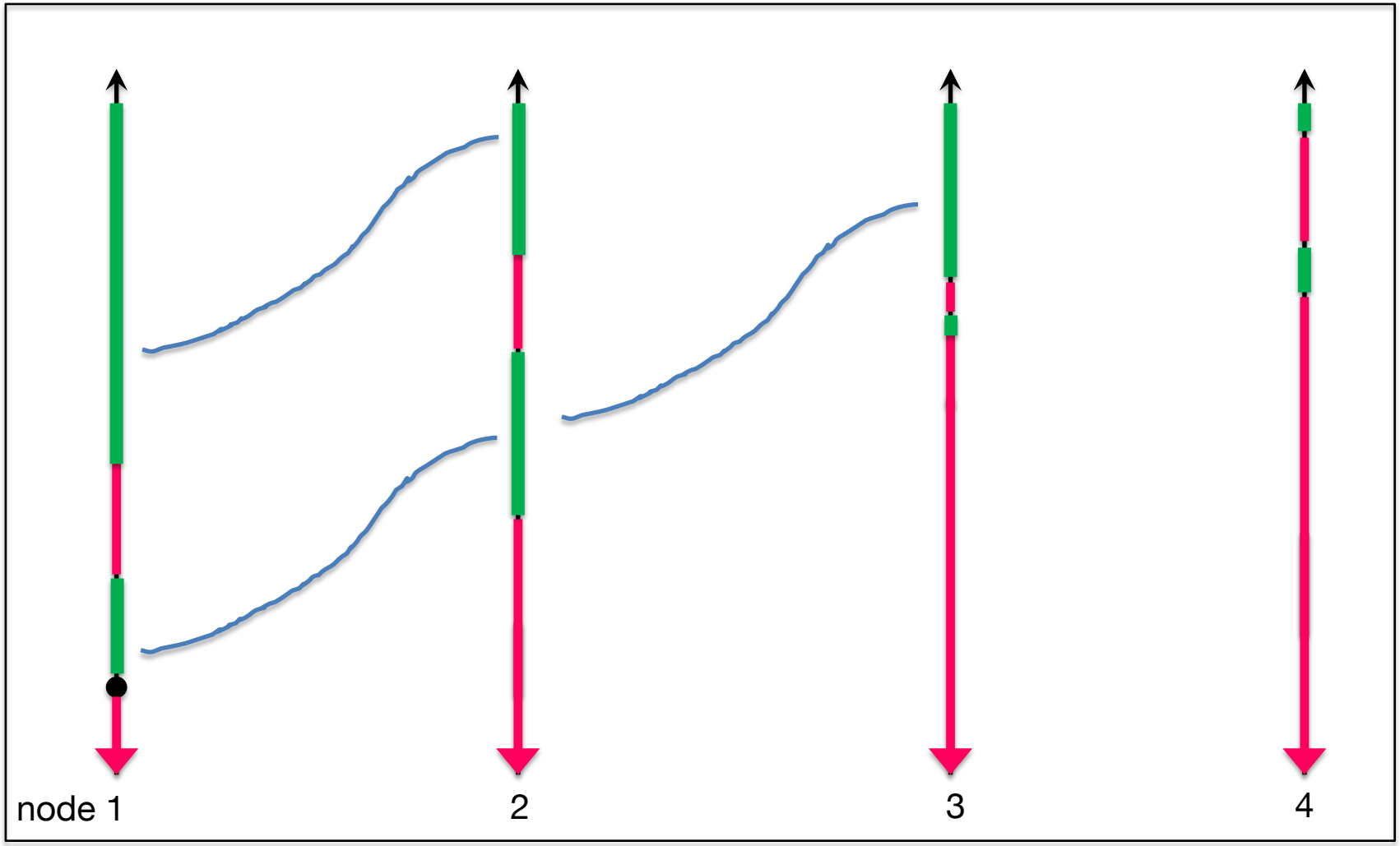
Scheduling Algorithm, Phase 1: Times Blocked by Prior Flights' STAs



Scheduling Algorithm, Phase 2: Effects of Travel Speed Bounds



Scheduling Algorithm, Phase 3: Pairing Available Time Intervals



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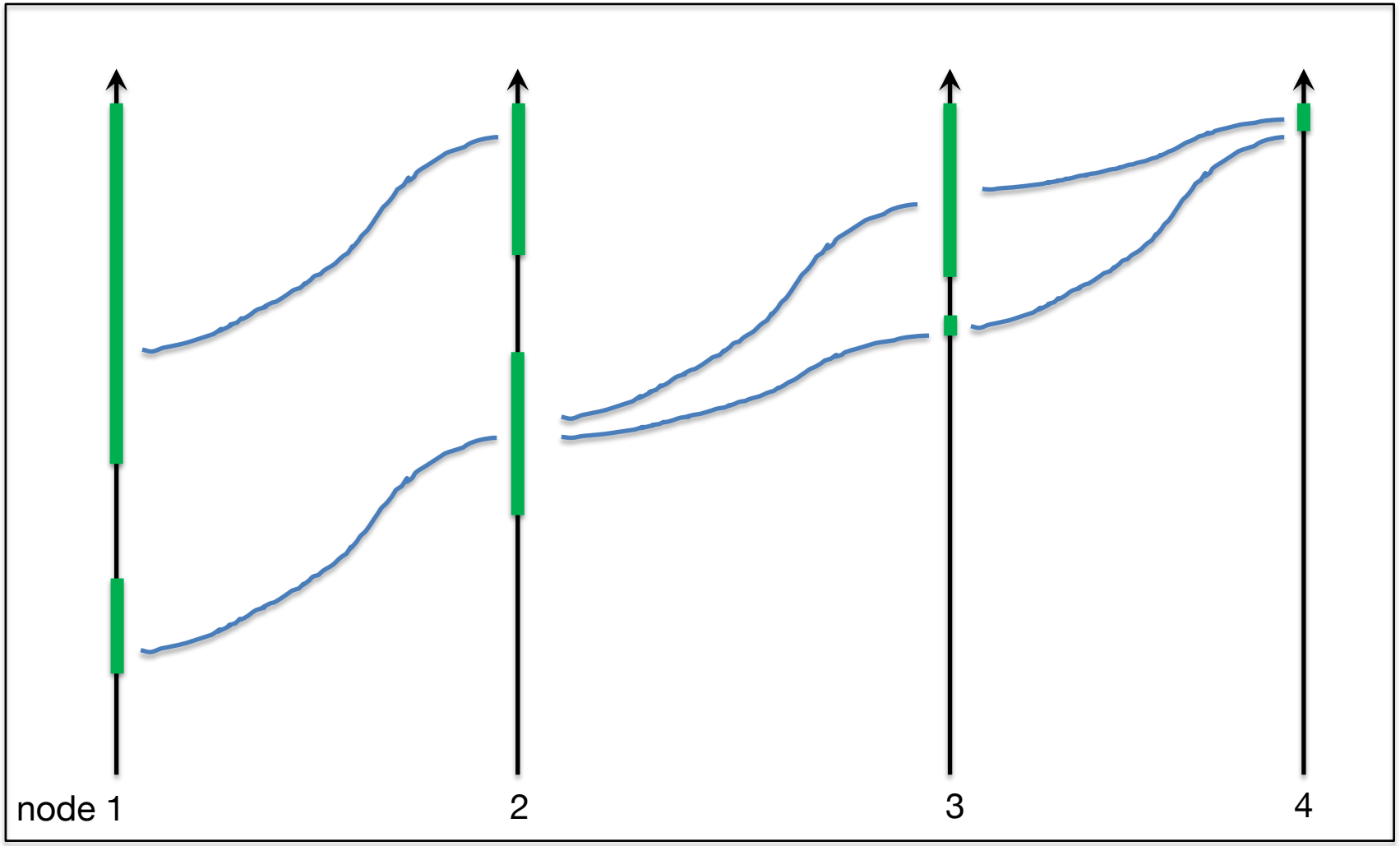
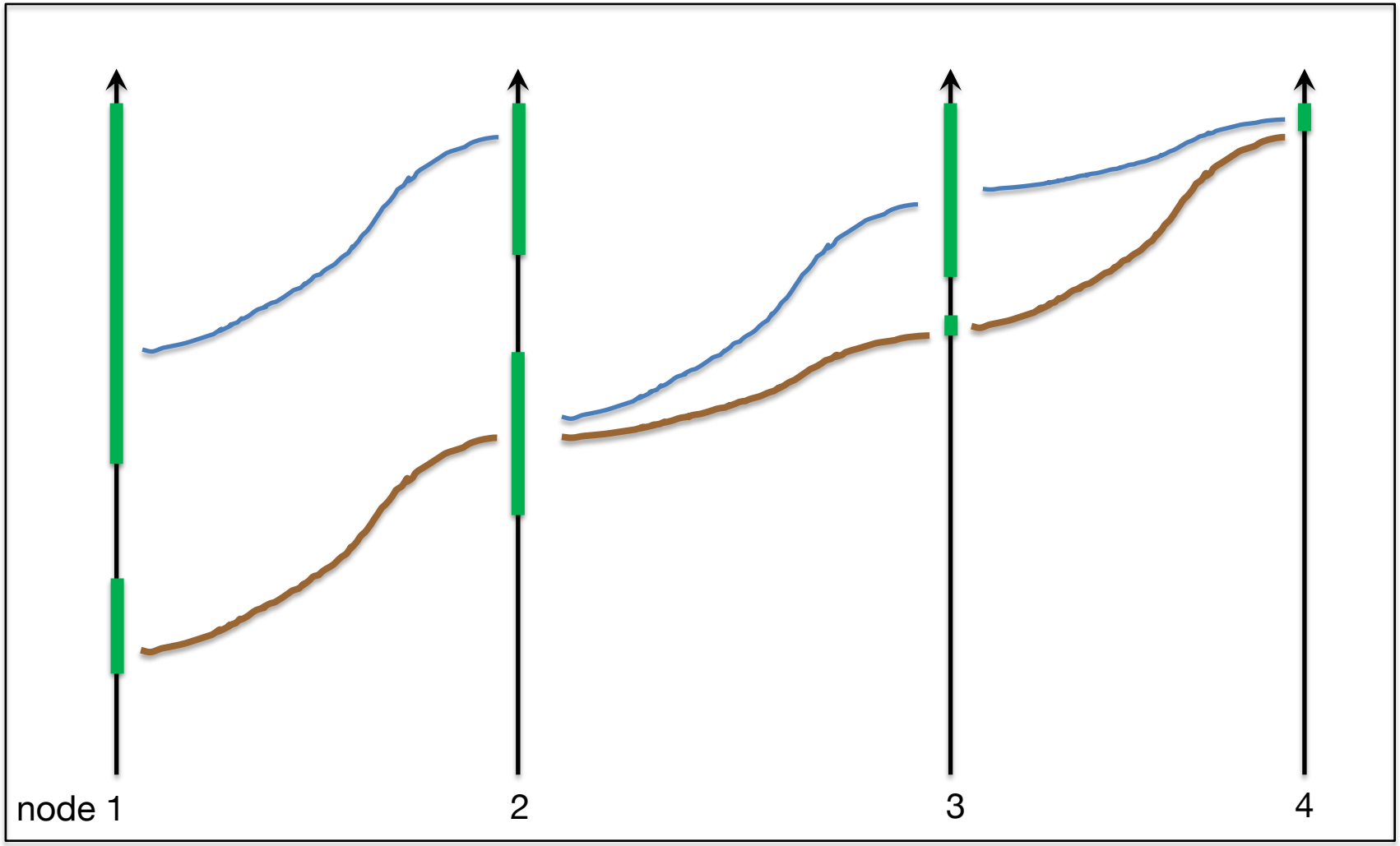


Scheduling Algorithm, Phase 4: Sequences of Time Intervals



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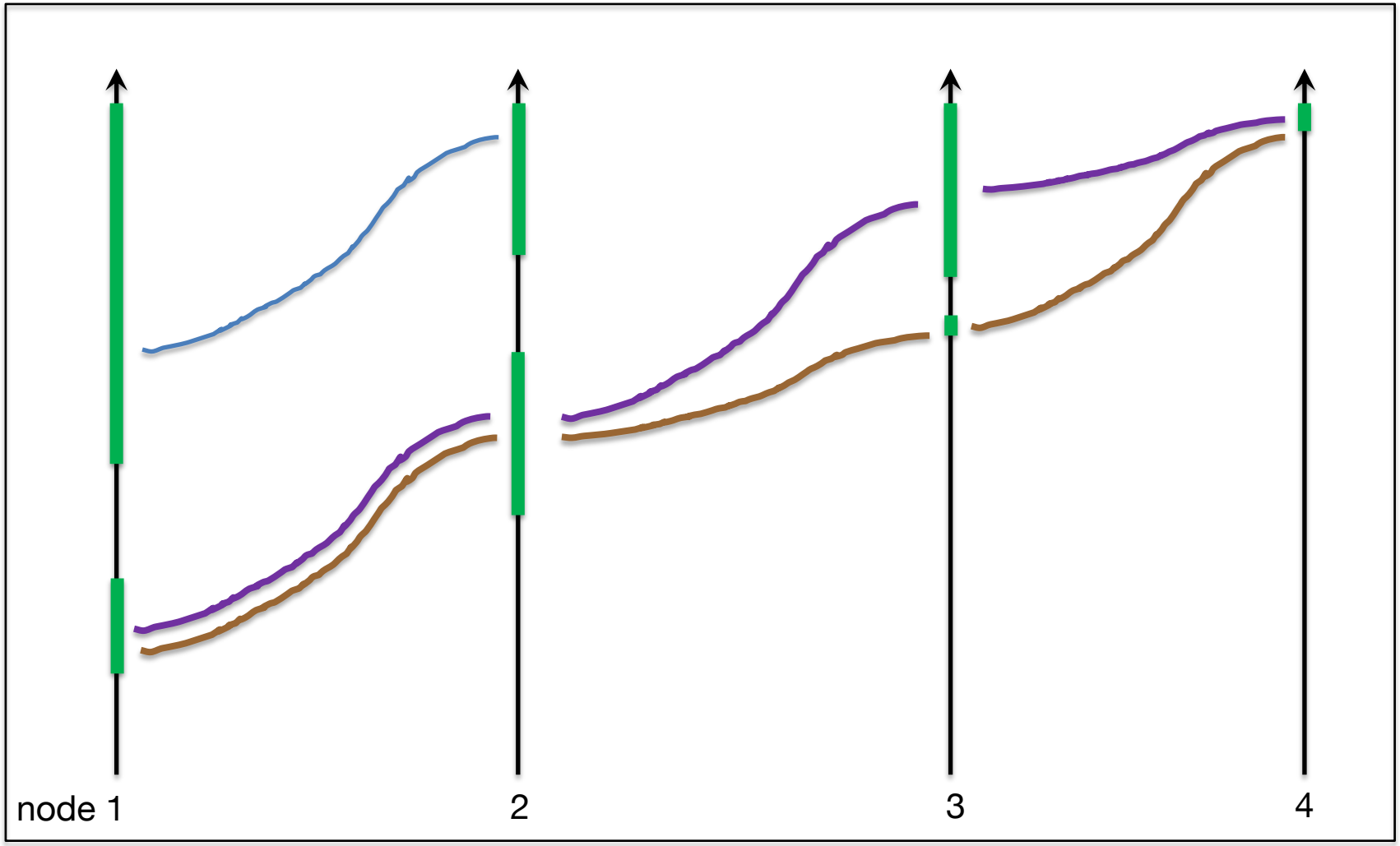
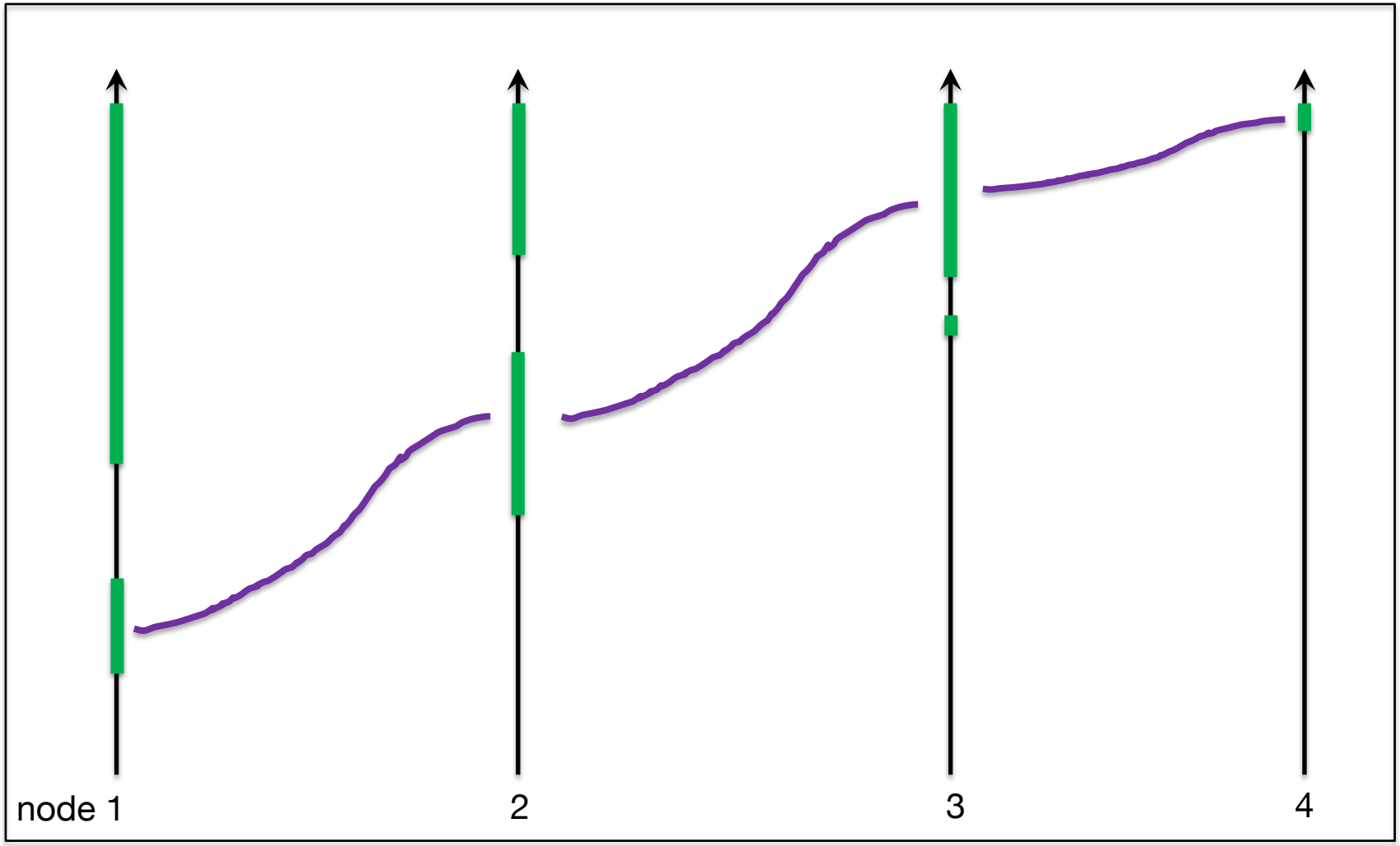


Scheduling Algorithm, Phase 5: Pick a Feasible Sequence



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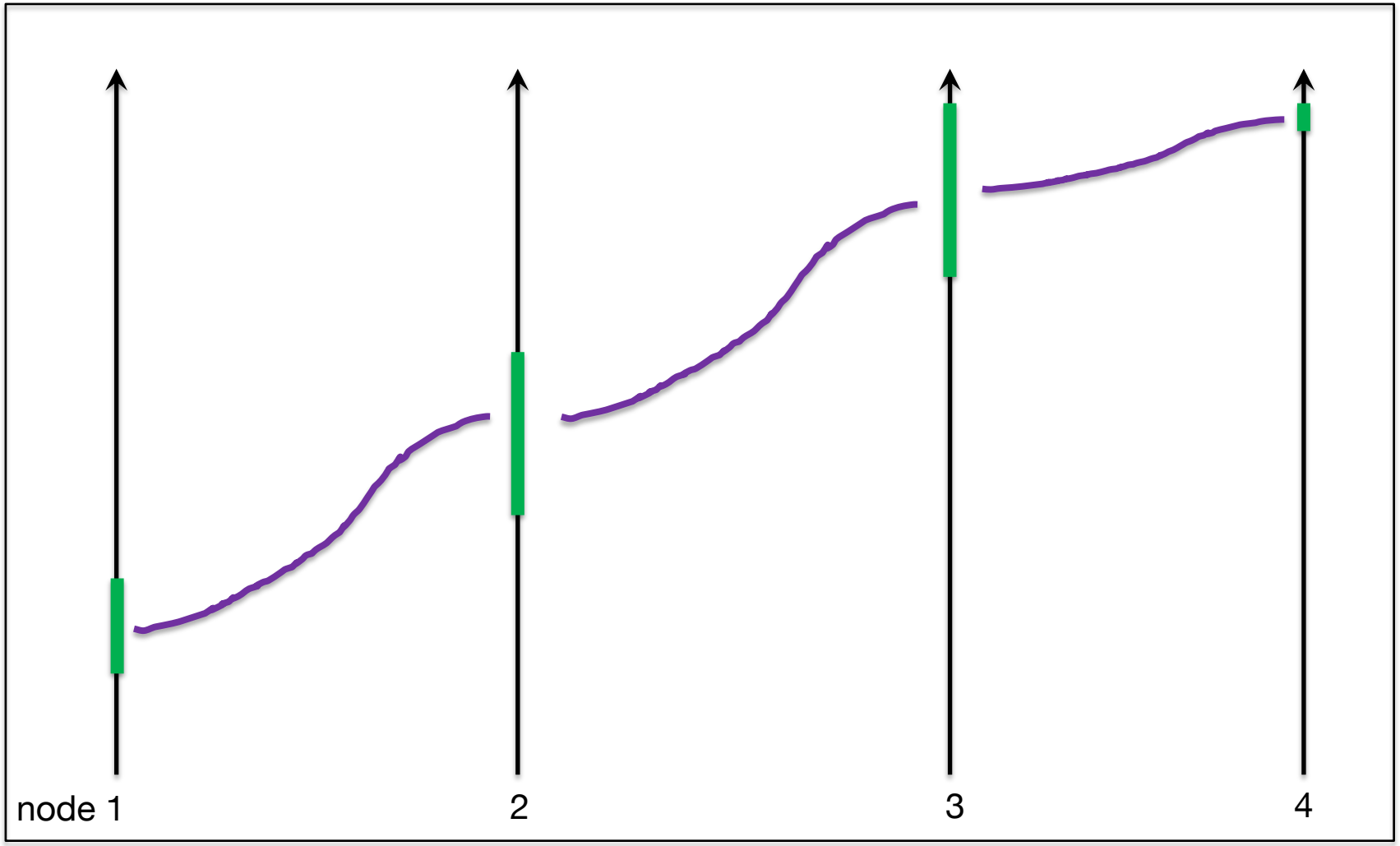
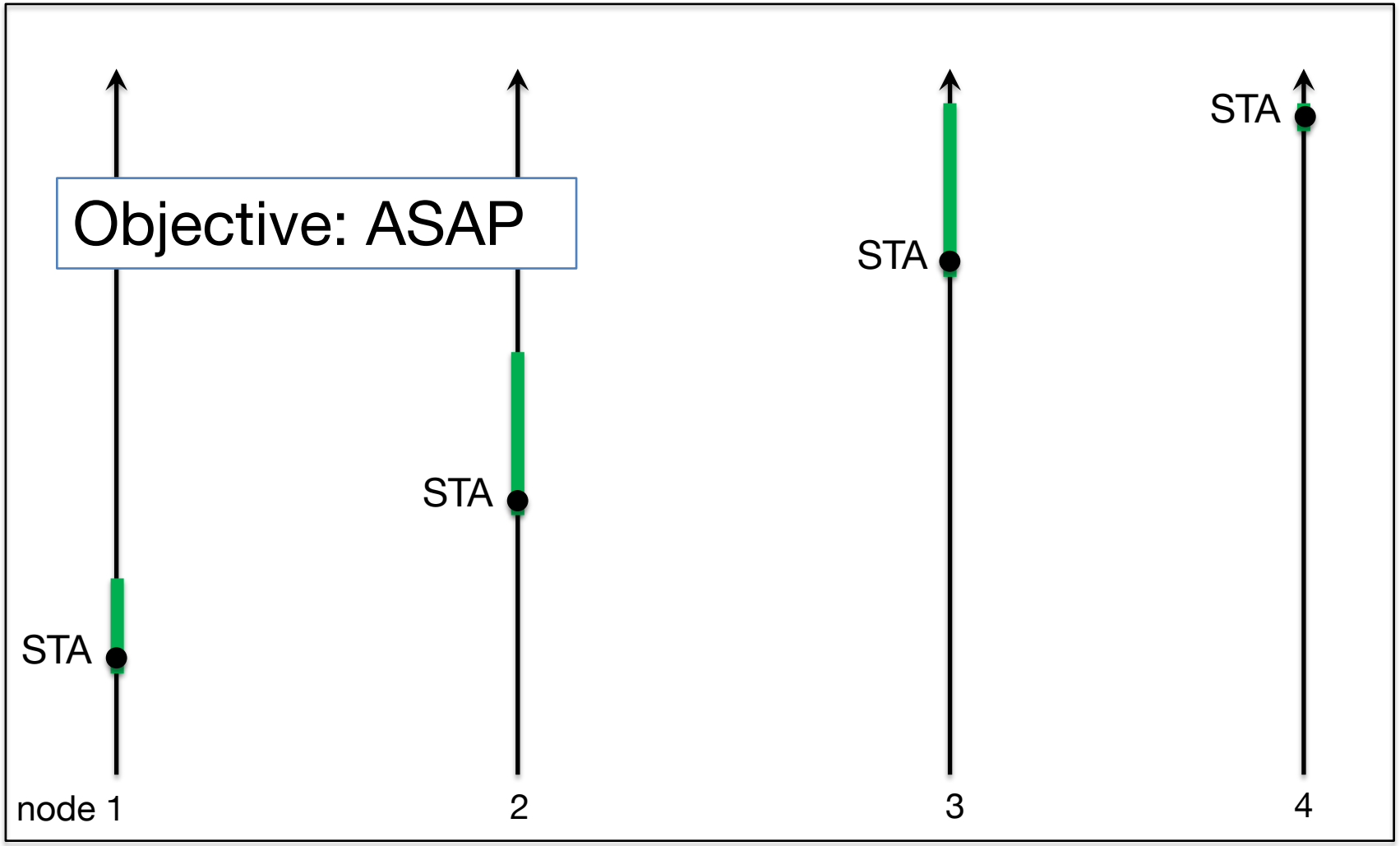


Scheduling Algorithm, Phase 6: Pick the STAs to objective



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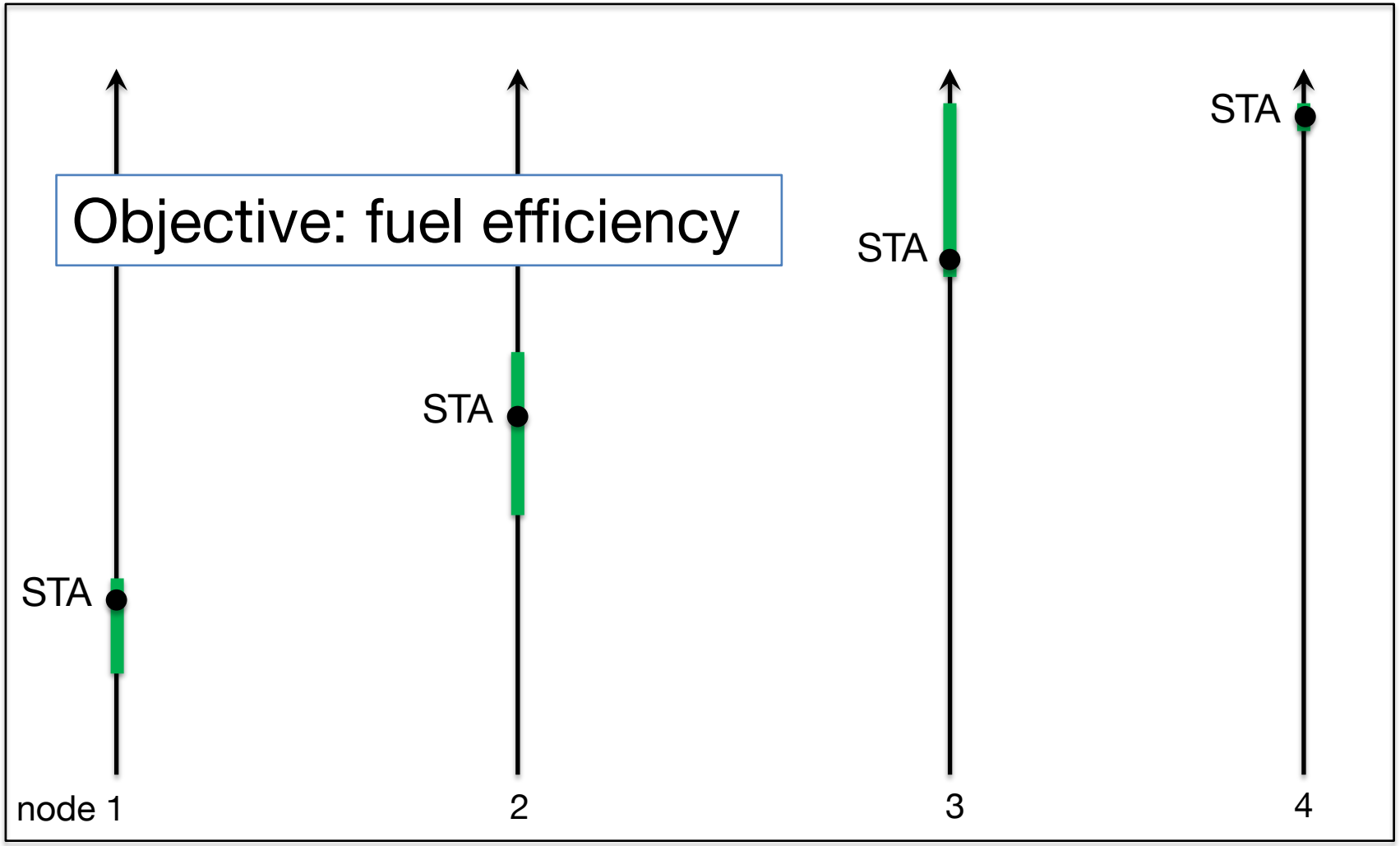
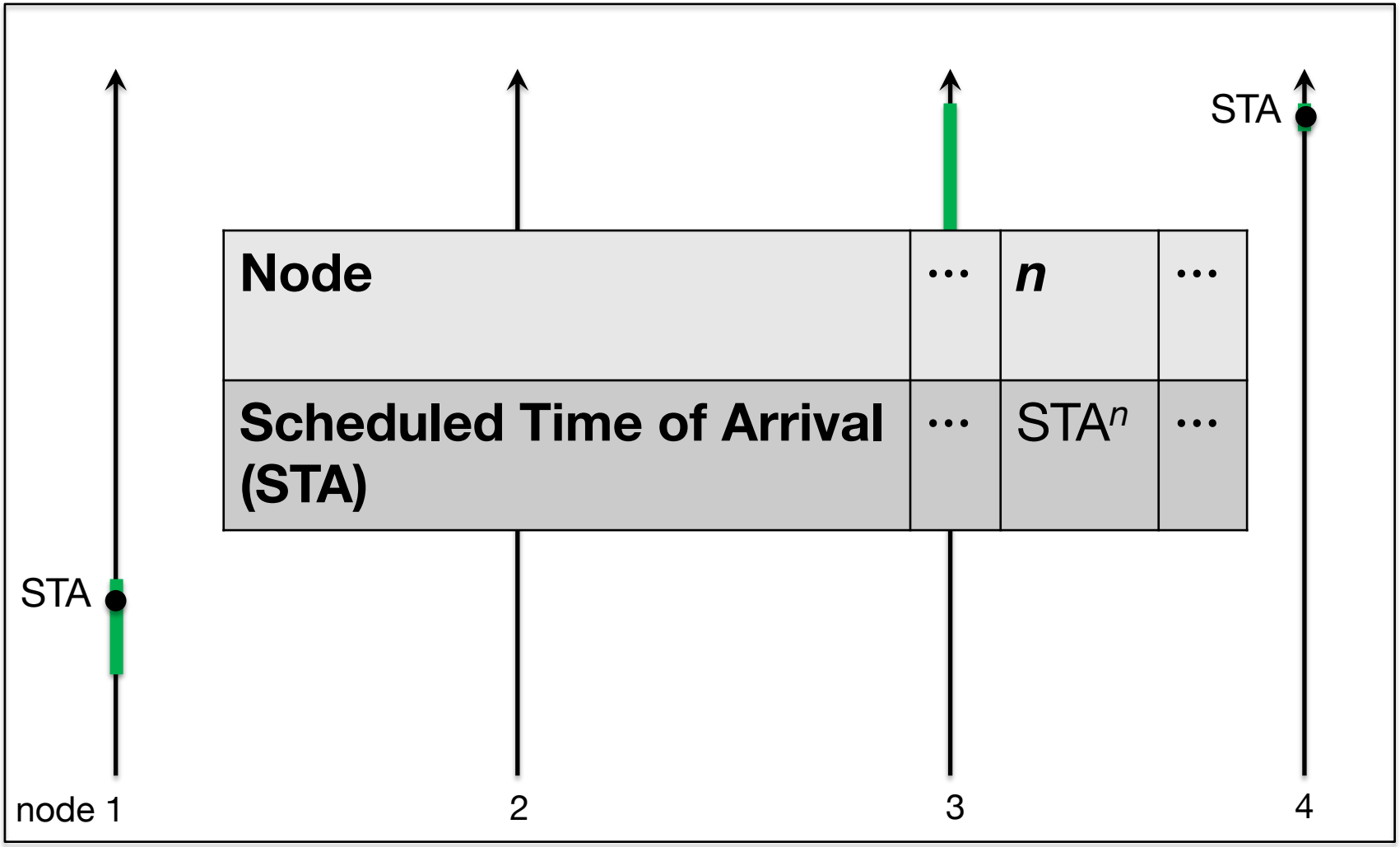
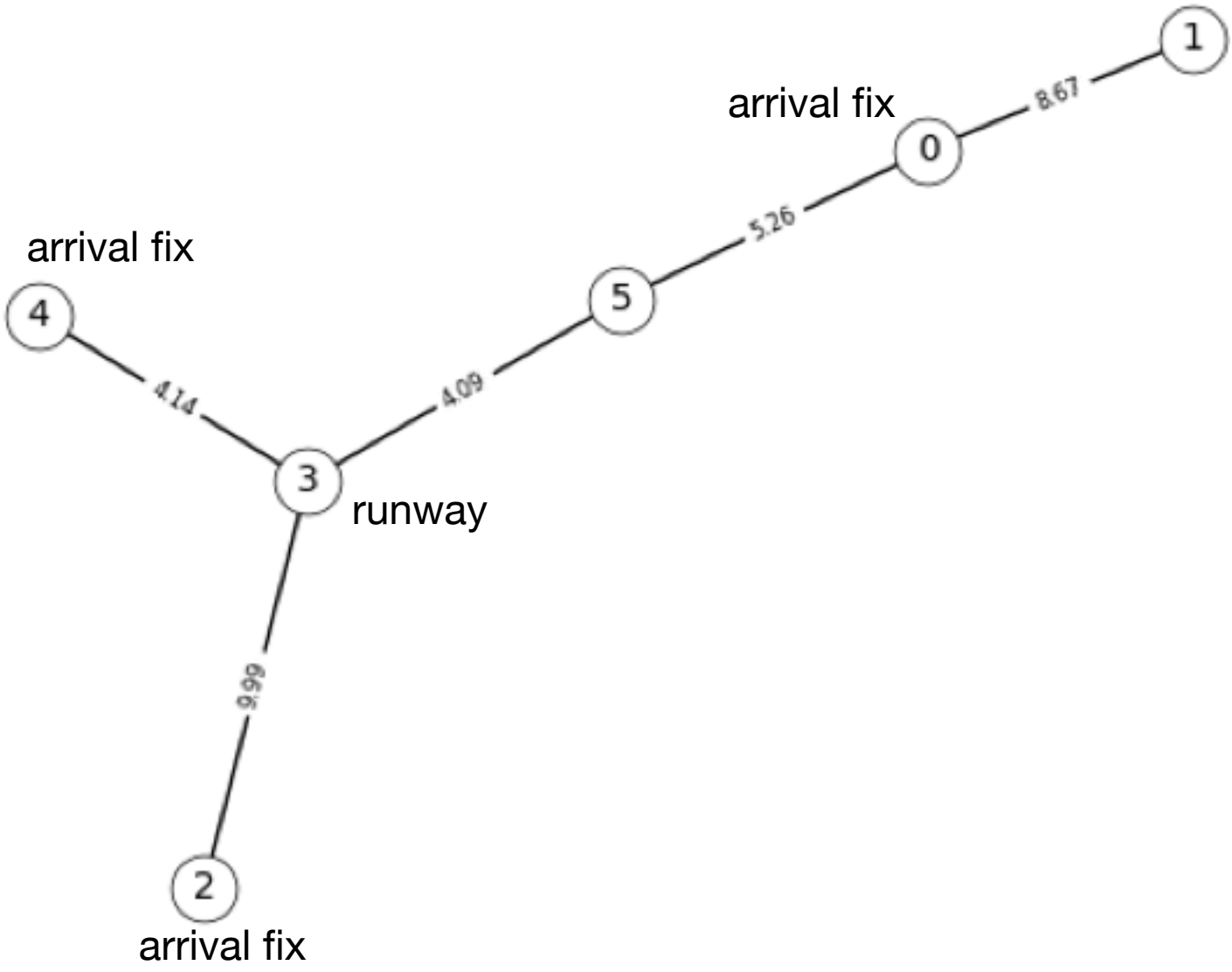


Scheduling Algorithm, Phase 6: Ensure constraint compliance



A Computed Example



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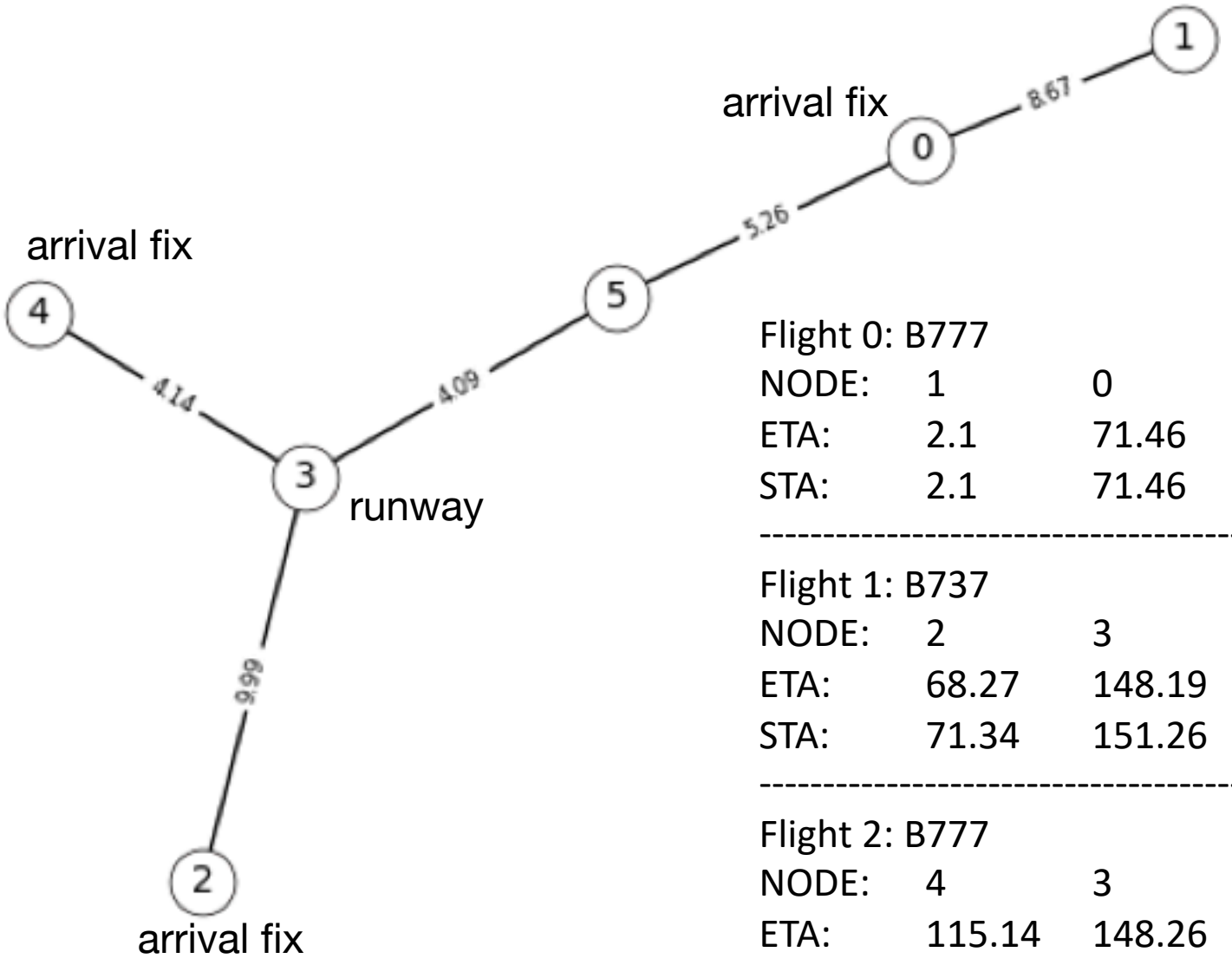

Flight 0: B777

NODE:	1	0	5	3
ETA:	2.1	71.46	113.54	146.26
STA:	2.1	71.46	113.54	146.26

Flight 1: B737

NODE:	2	3
ETA:	68.27	148.19
STA:	71.34	151.26

Flight 2: B777

NODE:	4	3
ETA:	115.14	148.26
STA:	123.14	156.26

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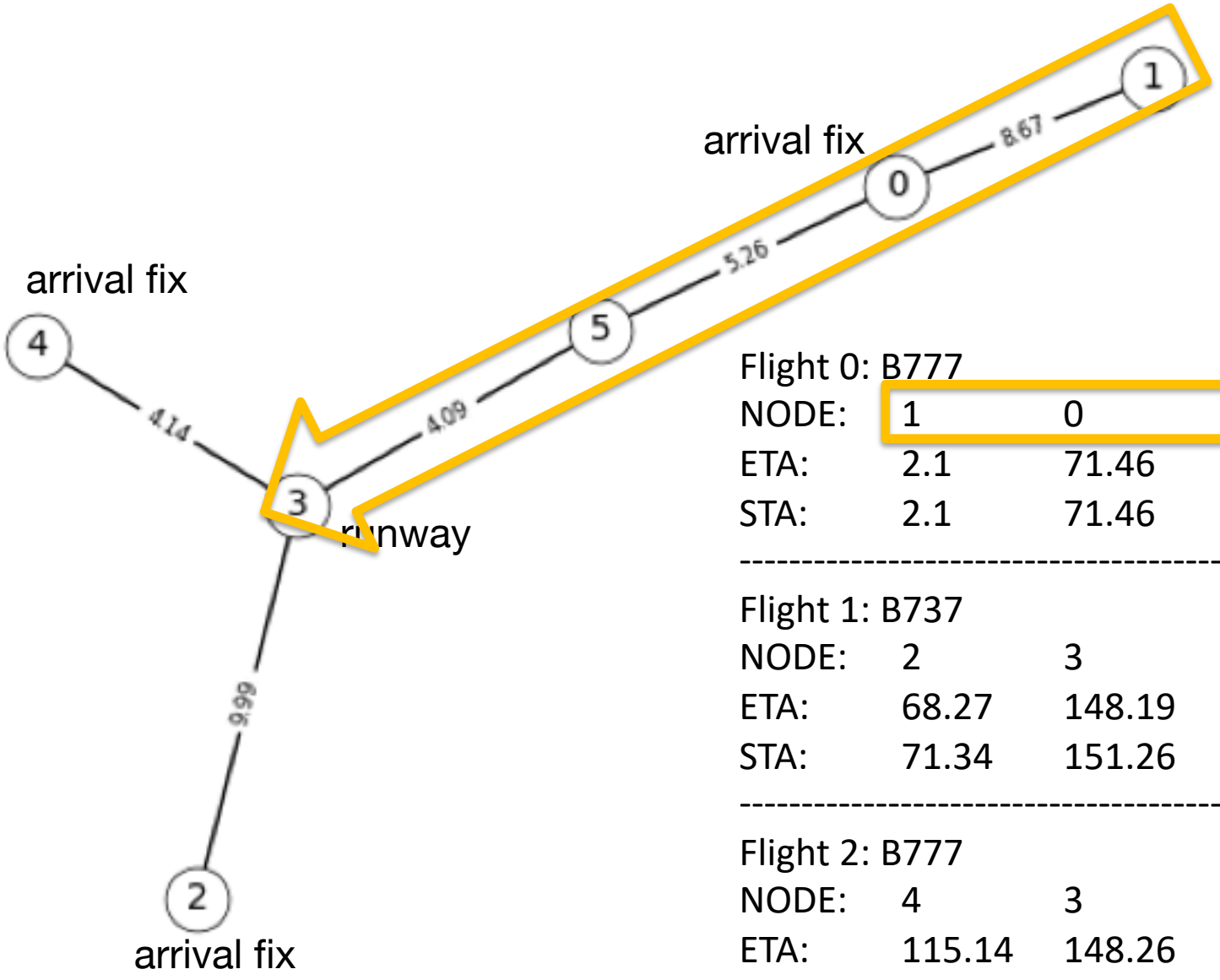

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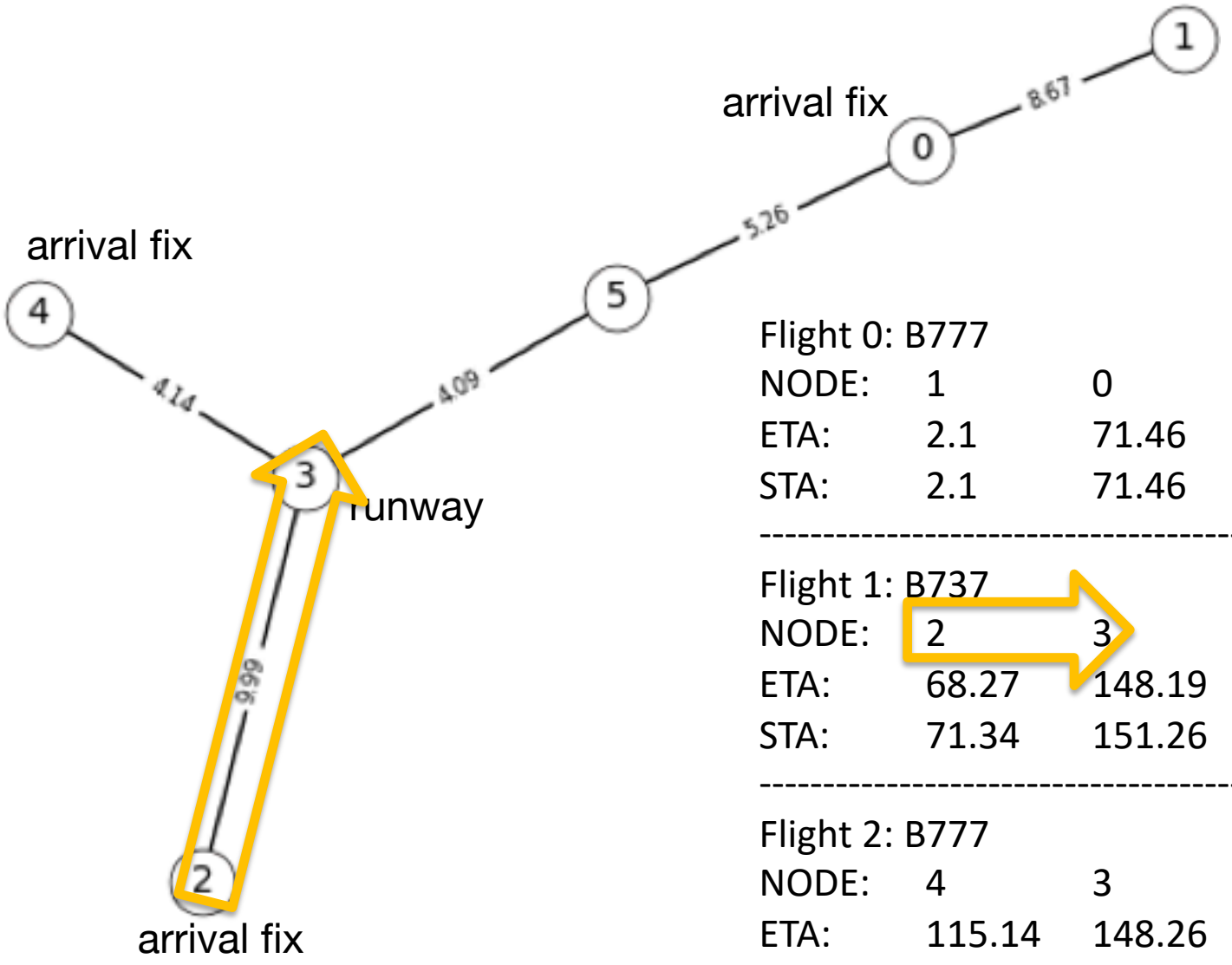

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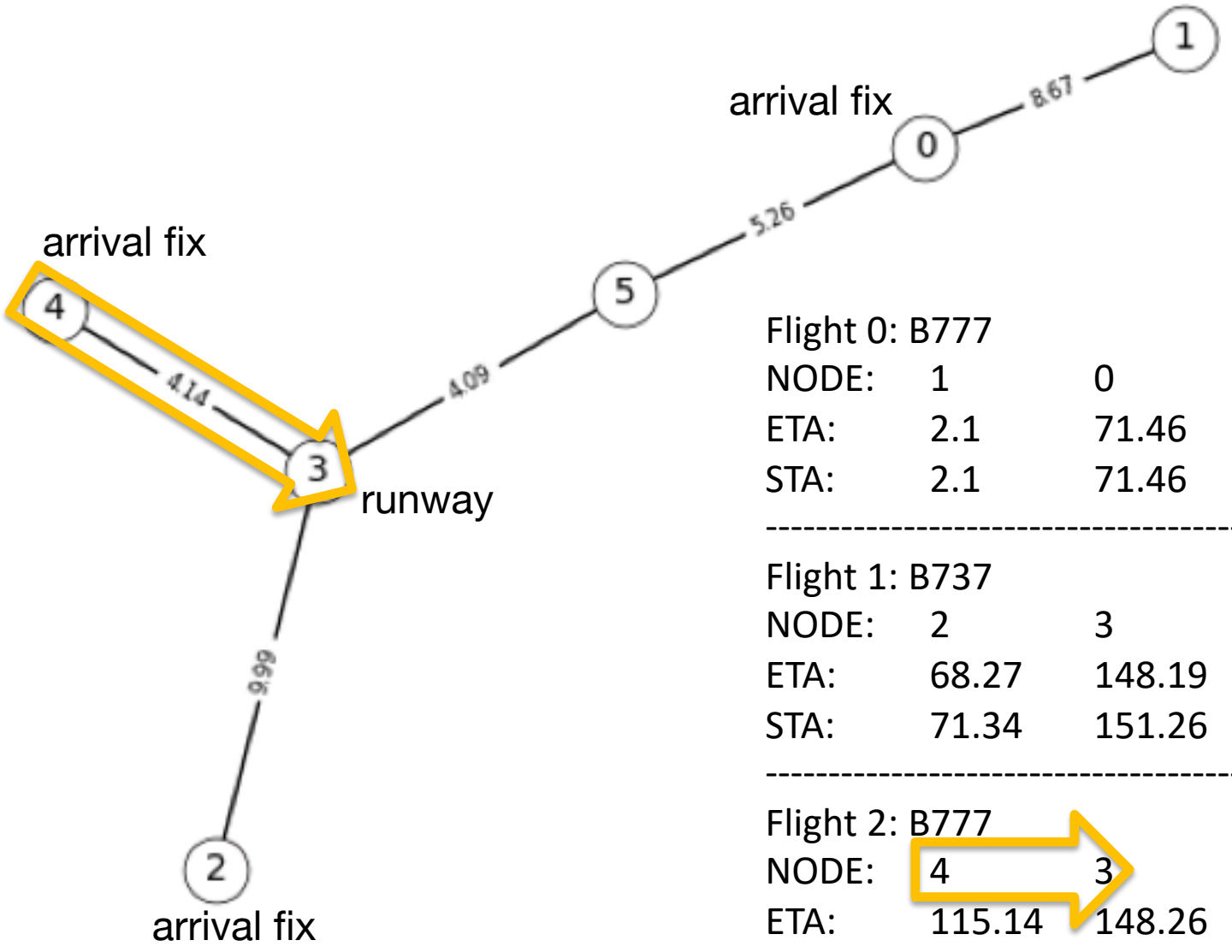

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Distributed System Functionality

distributed record of the already scheduled flights

node	used by flight	at STA
i	f_m	STA(i, f_m)
i	f_n	STA(i, f_n)
j	f_m	STA(j, f_m)
⋮	⋮	⋮

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Schedule Service Supplier
For the Operator of a Flight f

Distributed System Functionality

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i	f_n	STA(i, f_n)
j	f_m	STA(j, f_m)
⋮	⋮	⋮

Schedule Service Supplier
For the Operator of a Flight *f*

Which flights use nodes needed by *f*?

Distributed System Functionality

distributed record of the already scheduled flights

node	used by flight	at STA
i	f_m	STA(i, f_m)
i	f_n	STA(i, f_n)
j	f_m	STA(j, f_m)
⋮	⋮	⋮

Schedule Service Supplier
For the Operator of a Flight f

Schedule Service Supplier
For the Operator of another Flight

⋮

Summary

- An algorithm for the generic step in scheduling.
- Requires knowing prior schedules.
- Can be run by each agent in a distributed system.

Future research questions

- How to prioritize flights?
- Different operators' objectives:
  - Systemic inefficiencies?
  - Criteria of equity and fairness?
- How to implement re-negotiation of a schedule?
- How to ensure a negotiation ends?
- Race conditions between Service Suppliers accessing distributed record?

Thank you!

Q&A

Terminal Sequencing and Spacing

"The TMA-TM generates an arrival schedule that *conditions the* flow in the Center to facilitate sequencing and spacing in the TRACON. […] [The Center controllers'] radar displays show meter lists and delay countdown timers (DCTs) with a resolution of tenths of minutes. TRACON controllers are presented with CMS advisory tools to assist schedule conformance."

Thipphavong *et. al.*, 32nd DASC, Syracuse, NY, 2013.

Collaborative Decision Making

"XYZ AIRLINE: NEW YORK METROS SURROUNDED BY SIGNIFICANT AMOUNT OF CONVECTION FOR MANY HOURS. THEY TACTICALLY MOVED A LOT OF AIRPLANES, USED LIMITED GROUND STOPS AND HAD A GDP THAT SERVED THEM WELL. A VERY GOOD JOB AND WE APPRECIATE HELPING XYZ1234 DFW-LGA FROM DIVERTING."

Source: https://www.icao.int/SAM/Documents/2015-ACDM/8_CDM_ATFM_ACDM_Modification.pdf