NTN Days - Toulouse

Oct 1-2, 2025

Unraveling Temporal Challenges in Space Networking

Juan A. Fraire

Inria

Time

System Model

Standard Model written in Lagrangian Form

$$\mathcal{L}_{SM} = \underbrace{\frac{1}{4}W_{\mu\nu}\cdot W^{\mu\nu} - \frac{1}{4}B_{\mu\nu}B^{\mu\nu} - \frac{1}{4}G^{\alpha}_{\mu\nu}G^{\mu\nu}_{\alpha}}_{\text{kinetic energies and self-interactions of the gauge bosons}}$$

$$+ \underbrace{\bar{L}\gamma^{\mu}\left(i\partial_{\mu} - \frac{1}{2}g\tau\cdot W_{\mu} - \frac{1}{2}g'YB_{\mu}\right)L + \bar{R}\gamma^{\mu}\left(i\partial_{\mu} - \frac{1}{2}g'YB_{\mu}\right)R}_{\text{kinetic energies and electroweak interactions of fermions}}$$

Time

$$+ \underbrace{\frac{1}{2}\left|\left(i\partial_{\mu} - \frac{1}{2}g\tau\cdot W_{\mu} - \frac{1}{2}g'YB_{\mu}\right)\phi\right|^2 - V(\phi)}_{W^{\pm},Z,\gamma \text{ and Higgs masses and couplings}}$$

$$+ \underbrace{g''\left(\bar{q}\gamma^{\mu}T_a q\right)G^{\alpha}_{\mu}}_{\text{interactions between quarks and gluons}} + \underbrace{\left(G_1\bar{L}\phi R + G_2\bar{L}\phi_c R + h.c.\right)}_{\text{fermion masses and couplings to Higgs}}$$

Time

Forget it!

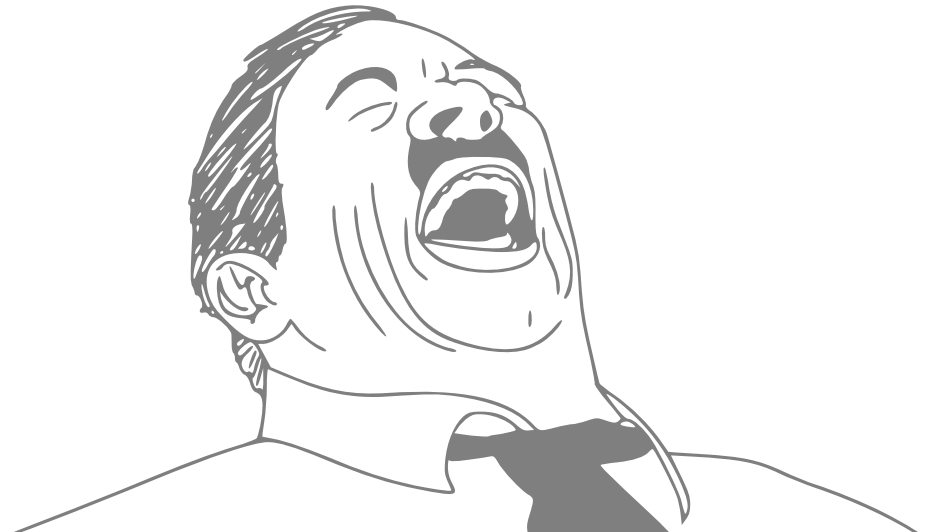
This presentation has

Time

No equations

No plots

No tables



Time

(Newton)

Time is

Absolute

Space ∩ Time

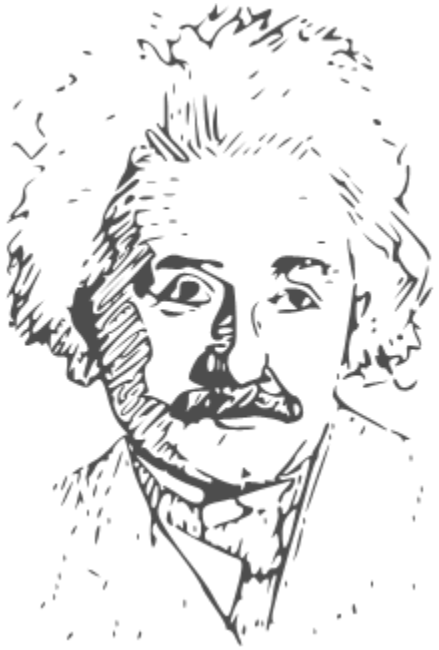
?

(Einstein)

Time is

Relative

Space ∪ Time



(Quantum)

Time is

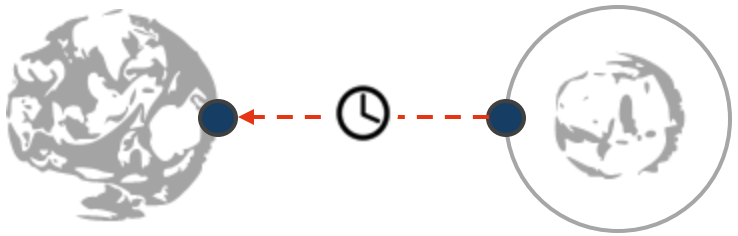
Unimportant

Having challenged humanity's greatest minds…

…How can time **not be** a controversial topic in **Space Networks**?

Delay

Light-Speed Propagation

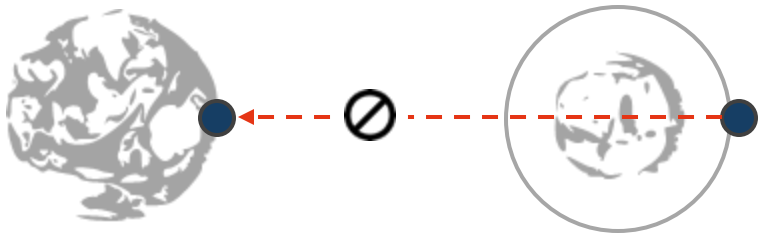


Very High Latency

(Temporarily)

Disruptions

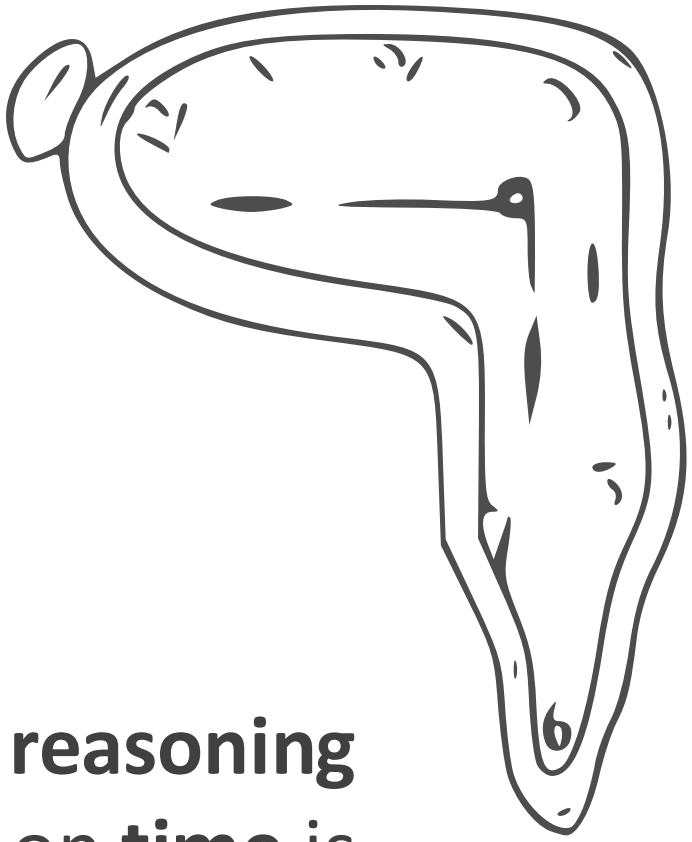
Planetary Occlusions



Fragmented Topologies

(Temporarily)

Disruption can be viewed as merely a **Delay** that extends to infinity…



∞

… proof of how tricky **reasoning** on **time** is

Space

Asynchronous

Very High Latency
(Temporarily)

Fragmented Topologies
(Temporarily)

Low Latency
(Stably)

Persistent Paths
(Stably)

Synchronous

Internet

Patches

Time

PEPs

Patch for **latency**

(break end-to-end principle)

GEO Network PEP Proxy

Space

GTP/MIP

Patch for **mobility**

(keeps static addressing)

Home Agent Foreign Agent

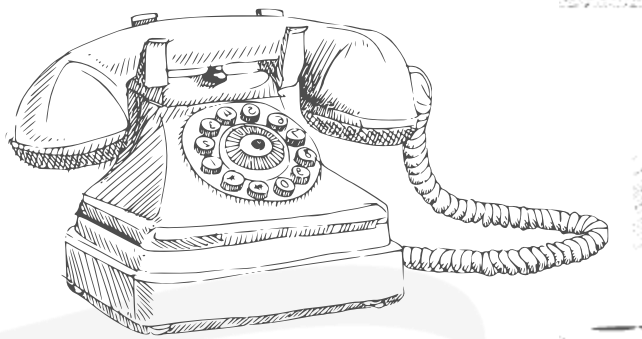
Mega-Constellations can also be seen as a Patch!

John Day

On the Internet

Built without a **theory**: **engineering** first, science later

Names, **addresses**, and **layers** confused



Space

Space Network Protocols

In **CCSDS** Since the 70s

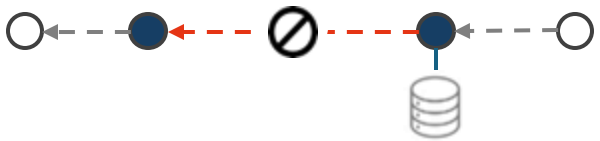
Very High Latency

Minimum Feedback

Bundle all info for decoding

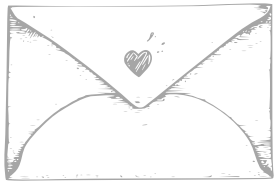
TM/TC
CFDP
…

Fragmented Topologies



Temporary Storage

Until links become available



A Postal Model!

Space

Space Network Protocols

In **CCSDS** Since the 70s

Very High Latency

Fragmented Topologies

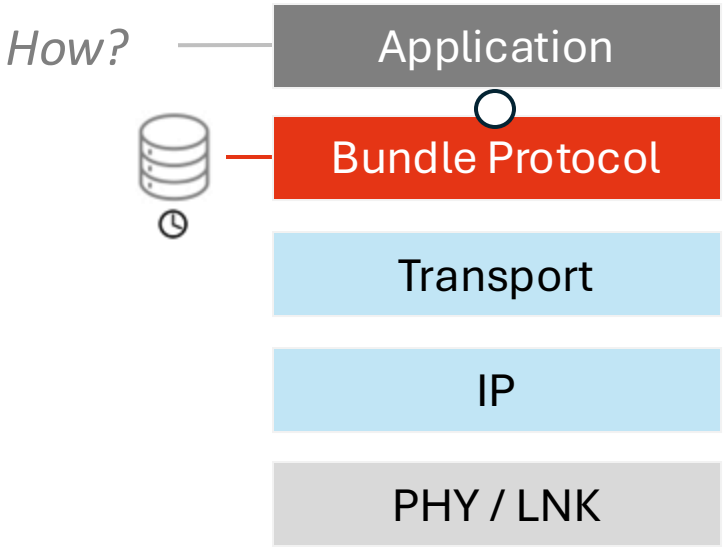
In **IETF** Since Recently

WG	WG	WG	RG
DTN	**TIPTOP**	**TVR**	**SPACE**
(Birrane / Taylor)	(Esnault / Sarker)	(Birrane / Li)	(Fraire / Ott)
Protocol	Protocol	Topology	Research
datatracker.ietf.org/wg/dtnwg/	datatracker.ietf.org/wg/tiptop	datatracker.ietf.org/wg/tvr	datatracker.ietf.org/rg/space

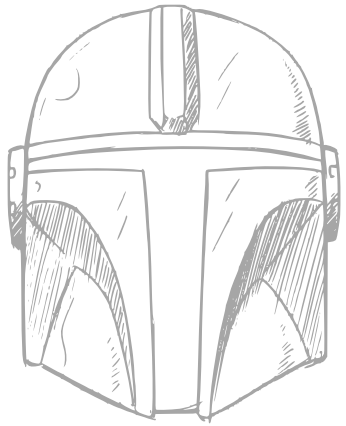
Space

Space Network Protocols

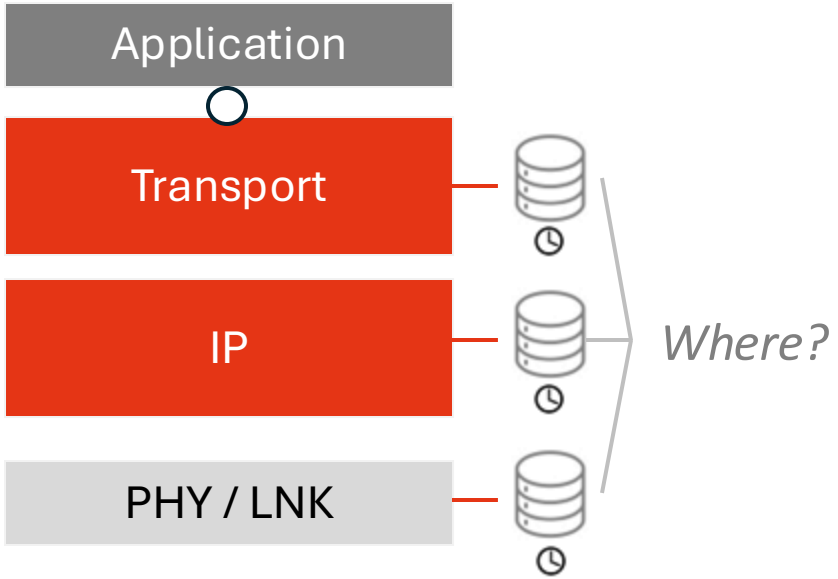
BP-Centric (DTN)



Which is The Way?



IP-Centric (TIPTOP)



For **Engineering**:
Go to **CCSDS** and **IETF WGs**

Our **Research**

Models and Methods

Topology Determination & Design
Routing, Forwarding, & Congestion,
Link Policies & Management

Time-Evolving

Evaluation

Simulation, Emulation, & Visualization

Mega-constellations
Satellite IoT
Deep Space

Application Domains

No time - Reach out!

Takeaways

Limitations

Decades of **technical excellence** in space tech hadn't been translated into a **time-embracing Internet**

We just keep patching the Internet!

Ambition

Open, **explainable**, and **implementable** time-aware network models and protocols for a **Space-Terrestrial Integrated Internet**

At Some Random Bar In TLS at 11pm

#TheBestTeamInTheWorld

Thu Oct 2nd | Morning

Session 5 – IoT NTN Simulation and Optimization (09h00 - 10h30) Session Chair: Congduc Pham (Univ. Pau)

09h00 (20 min) Generating and Visualising Realistic Interplanetary Topologies with ESA's Astrodynamics Lucas Poulhe & Alice Le Bihan (INSA Lyon)

ftware and IPN-v

RaSat 2: Simulating Cross-Linked Direct-to-Satellite IoT LEO Benoît Cougnet & Alexander Choquenaira (Inria)

tellations

tations, Optimizations, and Learning Approaches for Direct-to-Satellite IoT Diego Maldonado (INRIA / INSA Lyon)

Delay-Tolerant Routing: A-SABR, the Adaptive Library for SABR Longrui Ma (Inria)

Coffee Break - Poster Session

ry and DTN Networks (11h00 - 11h50) Session Chair: Emmanuel Lavinal (IRIT)

Unraveling Temporal Challenges in Space Networking Juan A. Fraire (Inria)

mentation of a Native Socket Interface for the Bundle Protocol Sylvain Pierrot (Polytech)

NTN DAYS

implemen

and protocols for a Space

ated Internet

https://stintworkshops.org/

Co-located with IEEE WiSEE 2025

STINT 2025

Space-Terrestrial Internetworking Workshop

The Forum for Delay-Tolerant and Space Networking Research

October 13–15, 2025 Halifax, NS, Canada

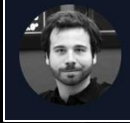
Hybrid Format

Speakers are expected to attend in person; remote participants may join online at a reduced fee.

Keynote Speakers

Rick Taylor
Aalyria

Felix Flentge
European Space Agency (ESA)



Jeremy Pierce-Mayer
GMV

Welcome Words by Vinton Cerf

The co-inventor of the Internet will open STINT 2025 with remote welcome remarks.

MISSION https://mission-project.eu/

STEREO https://stereo-project.space/

https://dorsaliot.space/

http://donuts-project.space/

IPNSIG http://ipnsig.org/

IETF https://www.ietf.org/

Consultative Committee CCSDS for Space Data Systems https://ccsds.org/

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Unraveling Temporal Challenges in Space Networking

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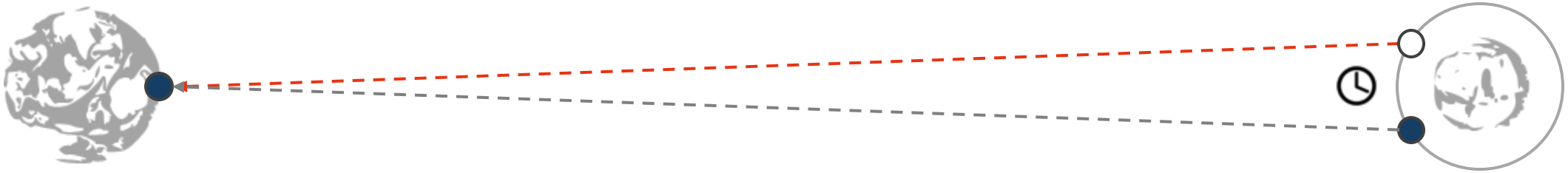
Topology

Determination

Signal received from where the spacecraft
was, not where **it is**



Determining **light time delay** involves iterative processes that converge on

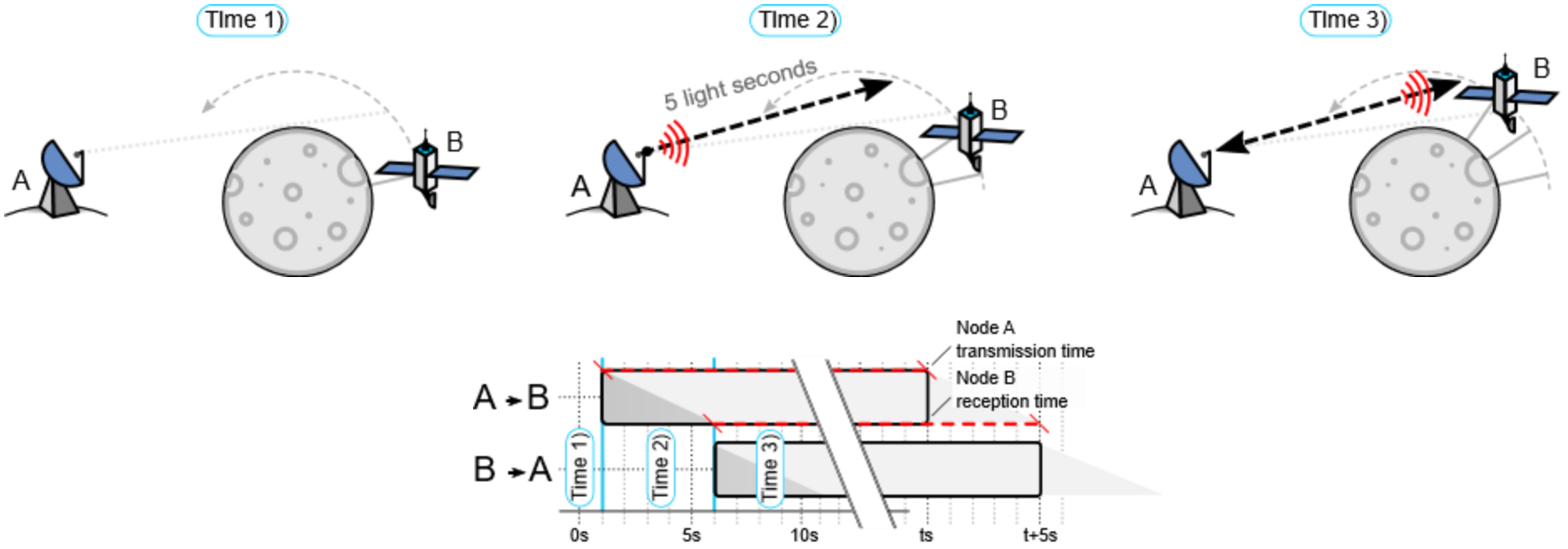
$$\Delta t = r(t)/c$$

(Apparent Position Problem)

Topology

Determination

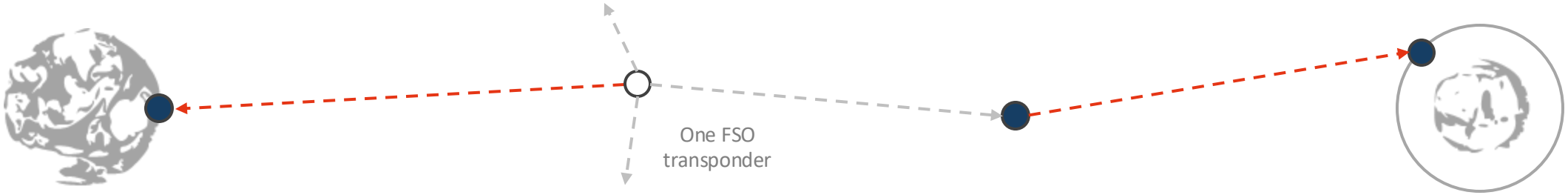
Contacts are time-wise **asymmetric,** thus better described as **unidirectional**



Topology

Design

Space is vast, links are mostly **point-to-point** (e.g., FSO)



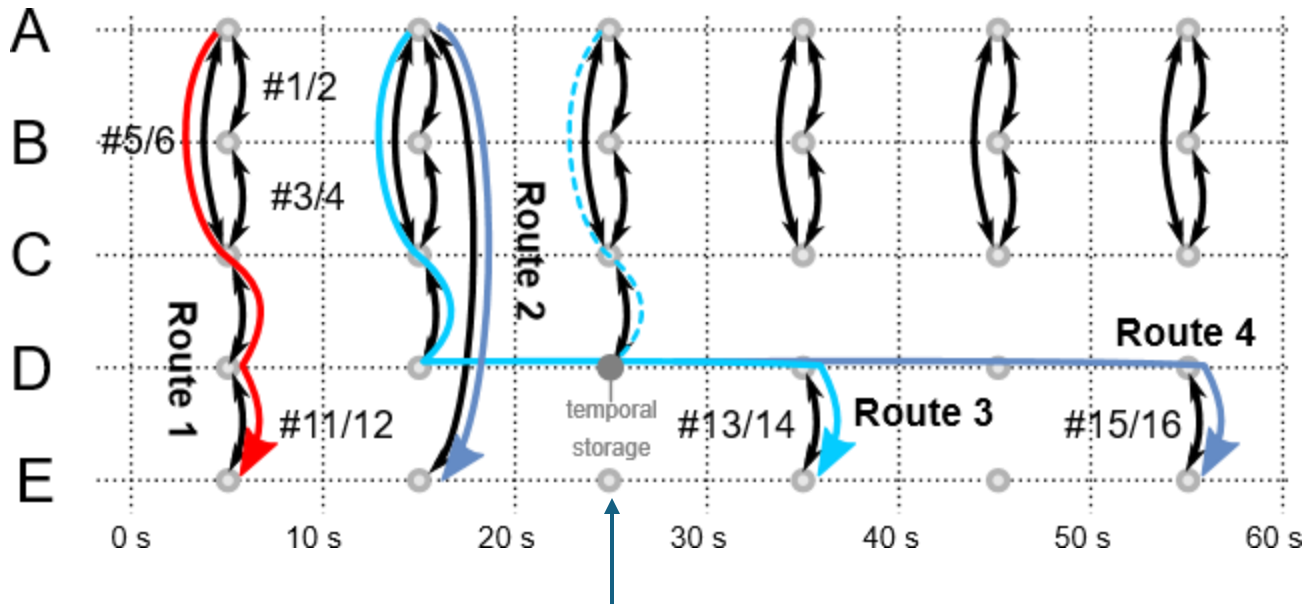
Designing a **contact plan** is a complex continuous optimization process

Models

Graphs

Time-Evolving Graph (TEG)

#	src	dst	st	end	rate	owlt
1/2	A	B	0	60	1	1
3/4	B	C	0	60	1	1
5/6	A	C	0	60	1	1
7/8	C	D	0	30	1	1
9/10	A	E	10	20	1	1
11/12	D	E	0	10	1	1
13/14	D	E	30	40	1	1
15/16	D	E	50	60	1	1



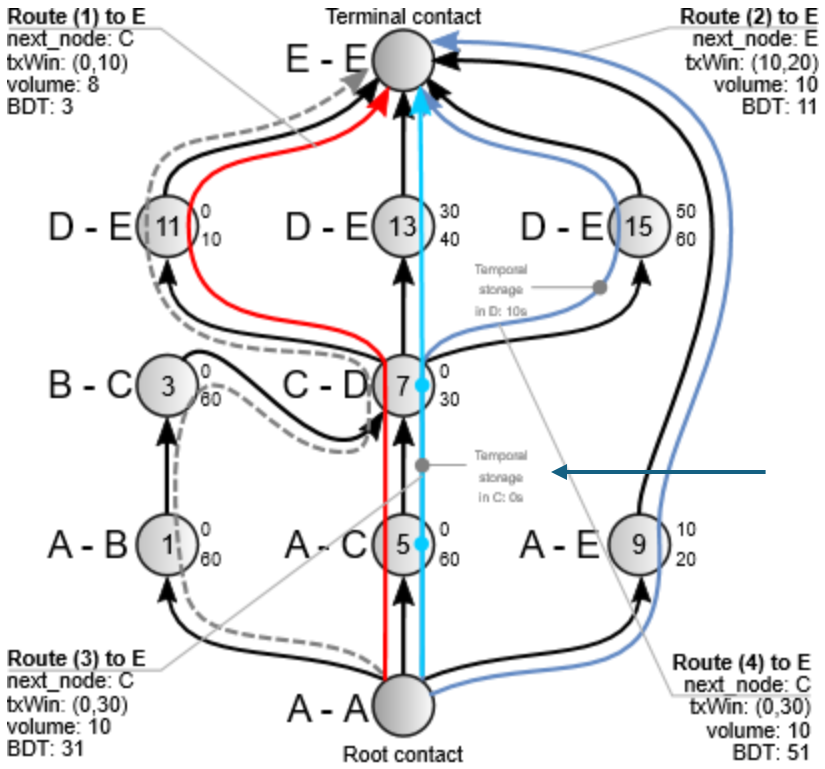
Time-Discrete

Models

Graphs

Contact Graph (CG)

#	src	dst	st	end	rate	owlt
1/2	A	B	0	60	1	1
3/4	B	C	0	60	1	1
5/6	A	C	0	60	1	1
7/8	C	D	0	30	1	1
9/10	A	E	10	20	1	1
11/12	D	E	0	10	1	1
13/14	D	E	30	40	1	1
15/16	D	E	50	60	1	1



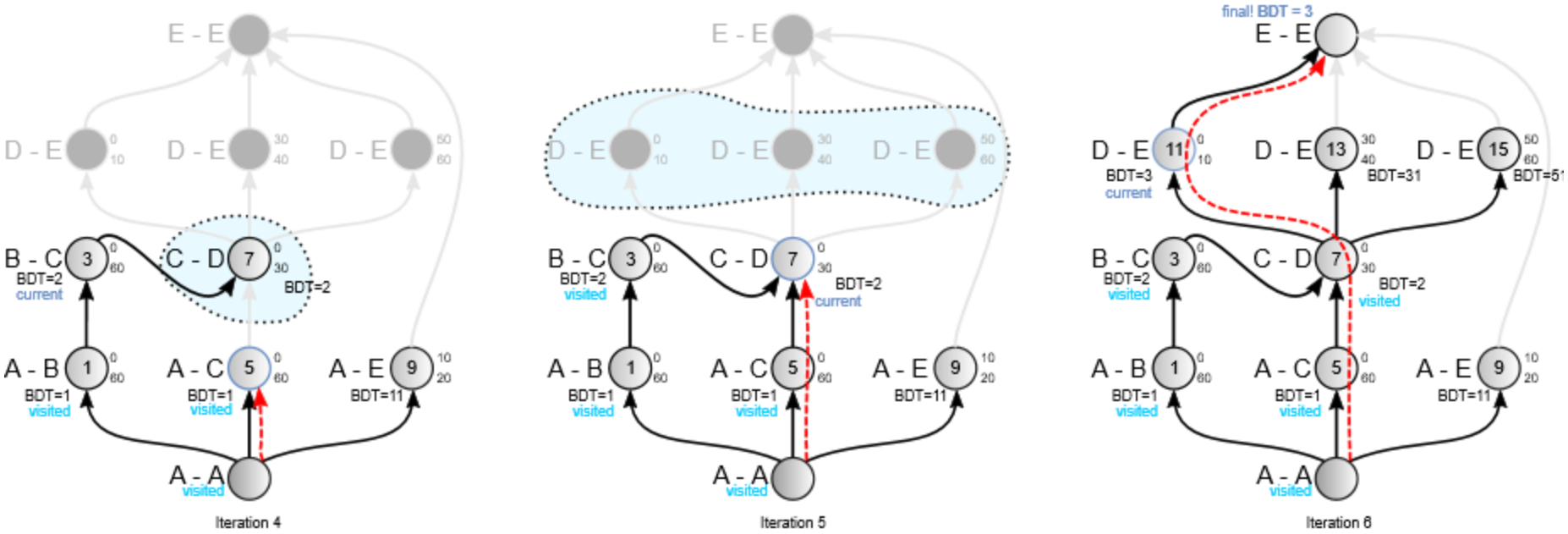
Retention Period

Contacts → Vertices

Models

Algorithms

Routing



Scalable Dijkstra Adaptations

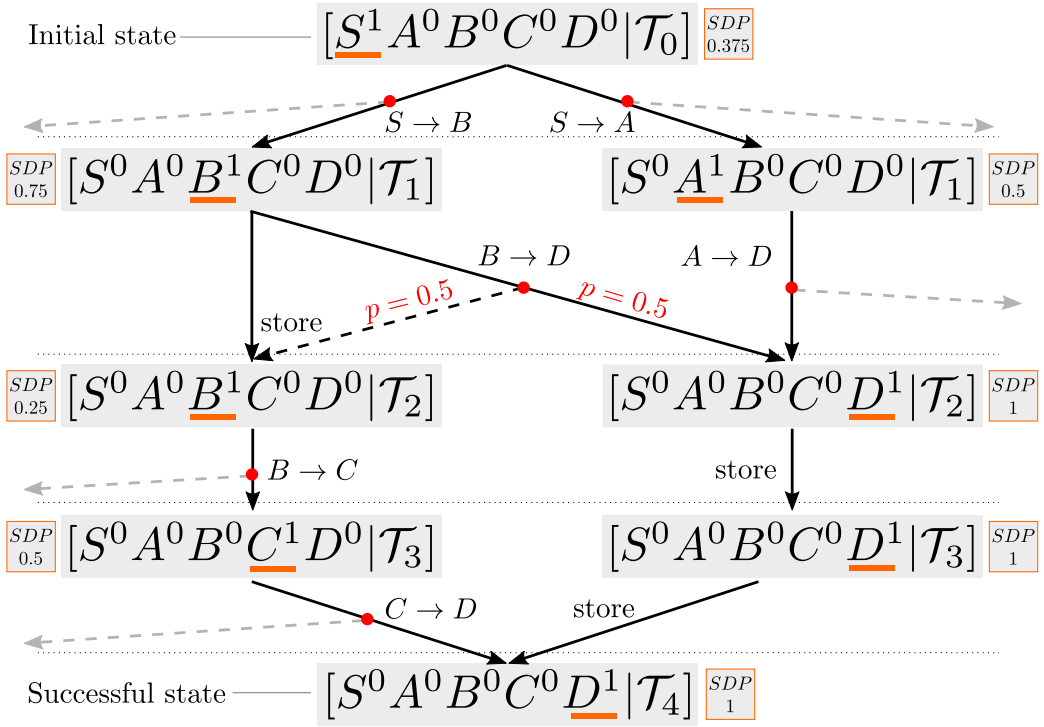
Models

Algorithms

Reliability & Congestion
(*Link –or storage- Overbooking*)

Proactive

(DTN)



Reactive

(TIPTOP)