Intersatellite Link (ISL) Networks: Topological Design, Routing and Network Dimensioning

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Outline of ISL Research within ATM-Sat

- Which ISL network topology ?
  - from the Iridium heritage to a modern (sustainable) design !
- "ATM-based" ISL routing concept:
  - a discrete-time dynamic routing framework derived from core ATM principles rather than an ATM implementation !
- Integrated ISL routing and network dimensioning
- Conclusions on work done
- Ongoing work and extensions

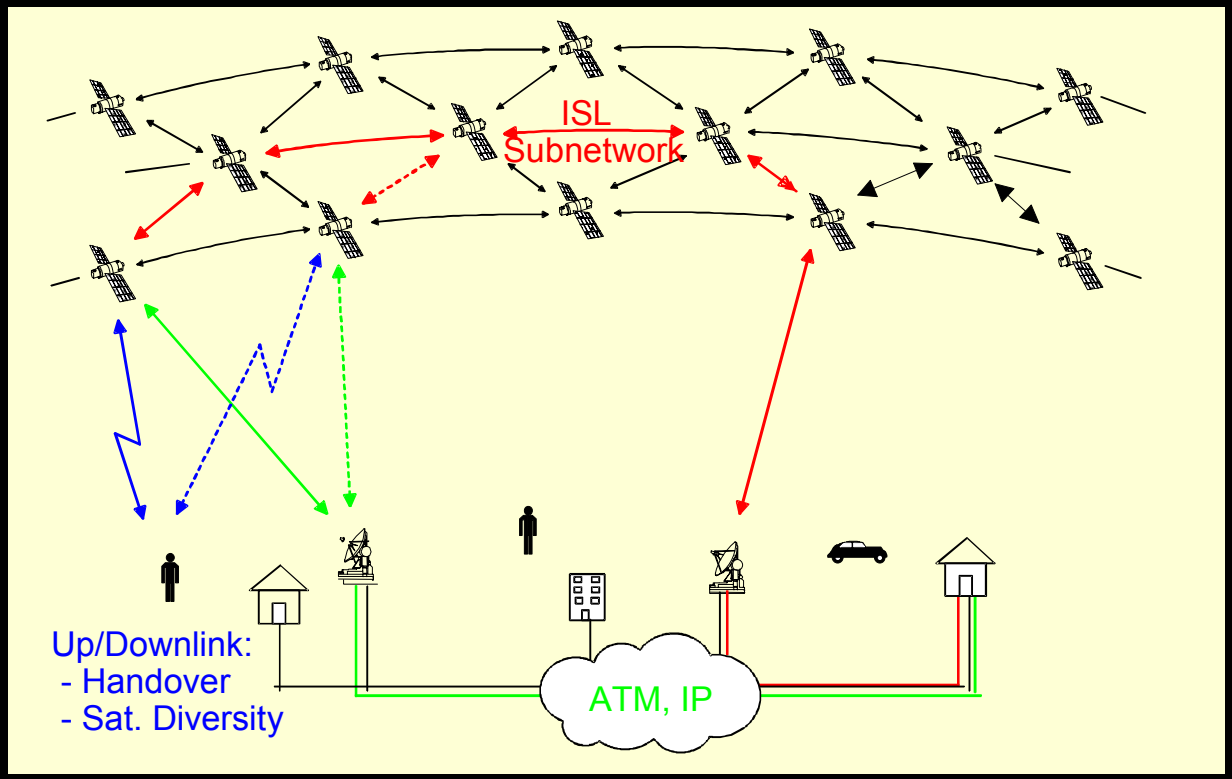
ISLs and ATM-Sat

- No “early-to-market” strategy, but strategic project ...
- ... consequently re-defining or just recalling the orientation/direction:

- “friendly” scenarios:
  - high-capacity multicast
  - fixed terminals
  - aggregated traffic ...
- prospective markets:
  - high quality Internet
  - particular global VPNs
  - high-speed and reliable global information distribution
  - trunking market niches ...

- driving technologies:
  - MPLS
  - optical networking
  - λ switching ...

Scenario



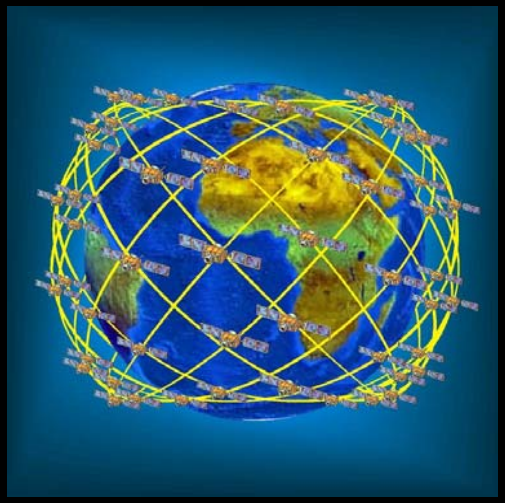
Space segment:
ISL trunk network

Air interface:
OD traffic

Earth segment:
Wireline backbones

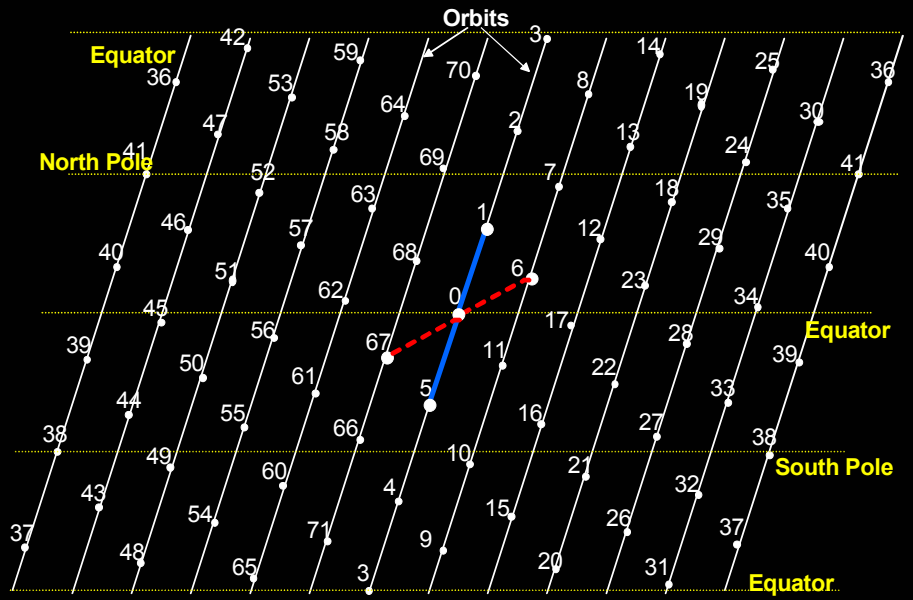
The Inclined Walker "Delta" Constellation M-Star

Constellation:



orbit altitude	1350 km
orbit period	113 min
# of satellites	72
# of orbits	12
inclination	47°

Planar projection (schematic):

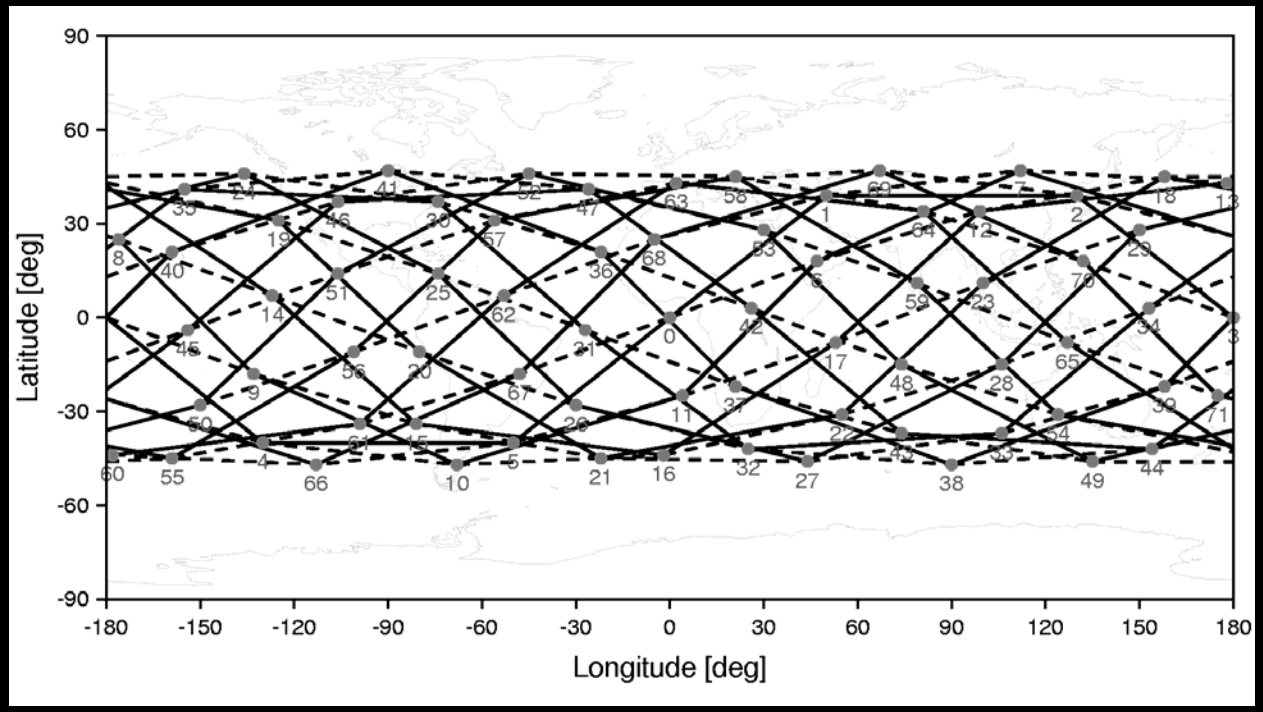


- regular phasing, phasing factor 5
- absolute symmetry of the orbital constellation
- no "seam" like in polar constellations

M-Star utilizes the promising combination of "delta" constellation pattern and optical ISLs

Reference ISL Topology for M-Star

Snapshot at *t*=0:



All links are permanently maintained over the whole orbit period !

Discrete-Time Dynamic Routing Framework

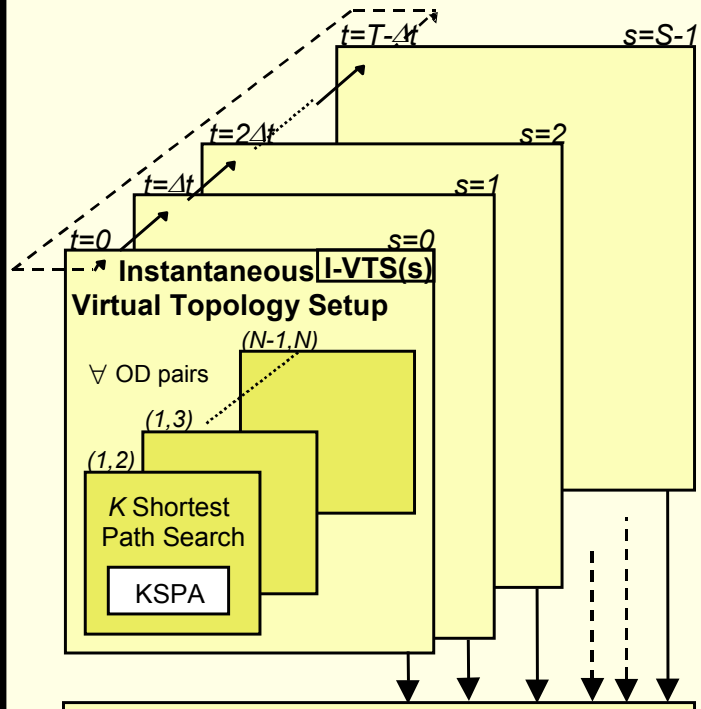
Topological Design

Permanent Physical Topology Design **P-PTD**

Topological design of ISL network
with permanent (non-switched) physical links
for Walker delta constellations

Off-line Routing Framework

Discrete-Time VirtualTopology Design **DT-VTD**



***K* → *k*(OD) Processing**

flexible *k* , path grouping / path reordering

Capacity Dimensioning

Discrete-Time Multi-Step Dimensioning **DT-MSD**

or *or*

Single-step dimensioning + post-processing	Linked single-step dimensioning	Multi-step dimensioning: Dynamic optimiz.

Network Dimensioning: Target Functions

ISL capacity requirements → Bandwidth & RF power

Satellite capacity requirements → Processing power & buffer sizes

Bandwidth & RF power, Processing power & buffer sizes → DC power → Size & weight of satellite → System costs

- LEO constellation dynamics --> every sat/link encounters worst case sometime
  --> all sats/links to be dimensioned accordingly

→ Candidate target functions: TF1: Minimize worst case link (WCL) load

TF2: Minimize worst case node (WCN) load

- positive "side effect": better utilization of installed network capacity

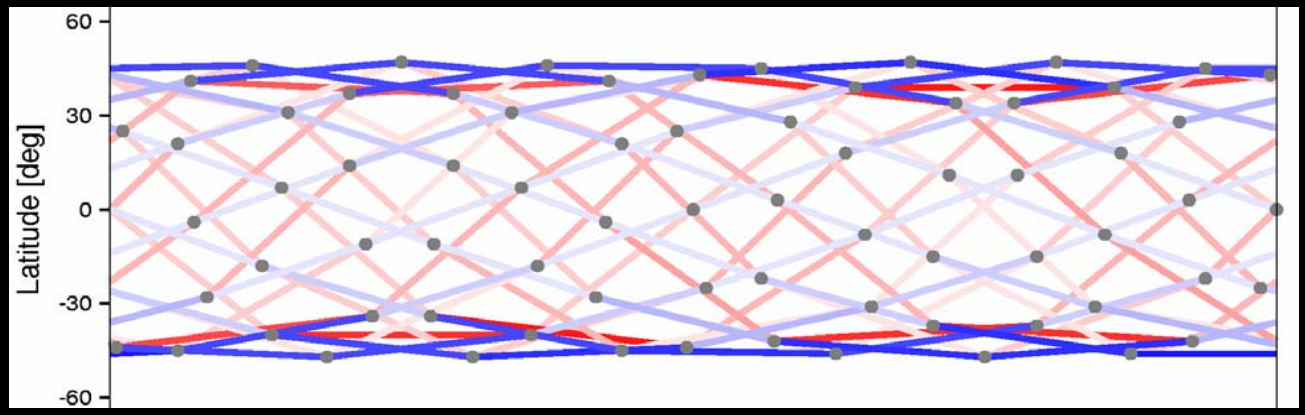
Performance of Isolated Step Optimization

from here, all numerical examples assume network-uniform traffic, i.e., a normalized symmetric traffic load of 1 between all OD pairs

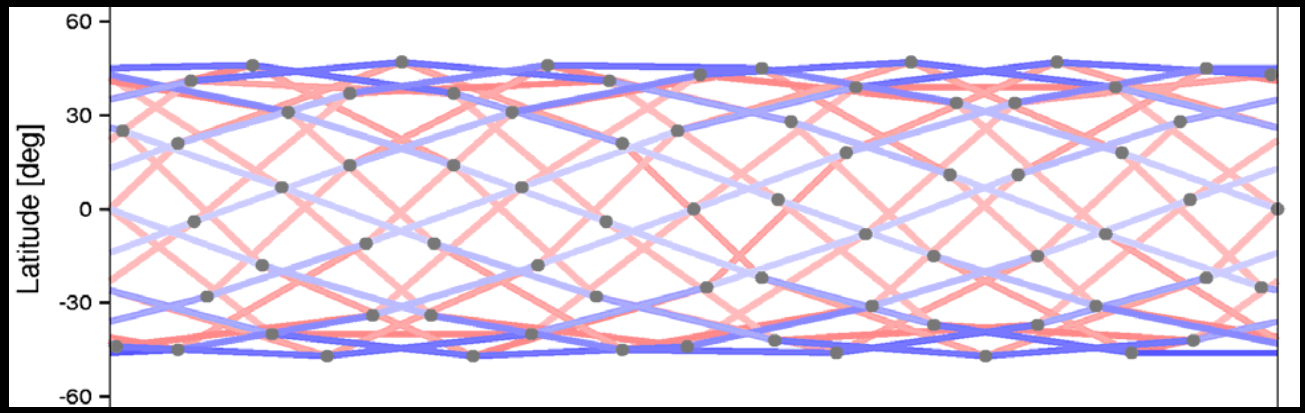
Worst Case Link (WCL) Load: EqualSharing - BoundedOptimization - FullOptimization

... and all that on the map:

without optimization (shortest path routing):



with optimization (multipath/alternate routing):



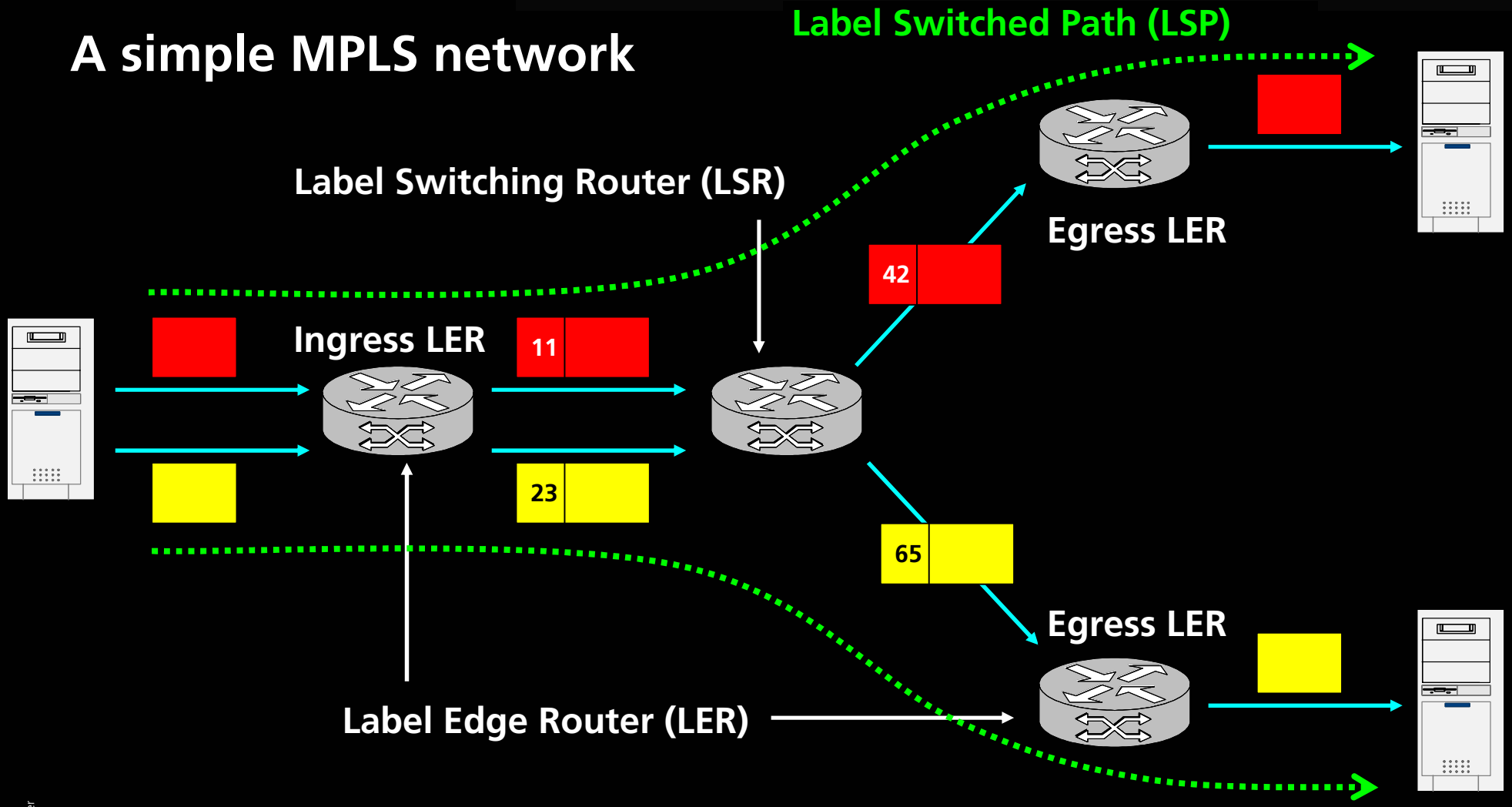
Conclusions (on Work Done)

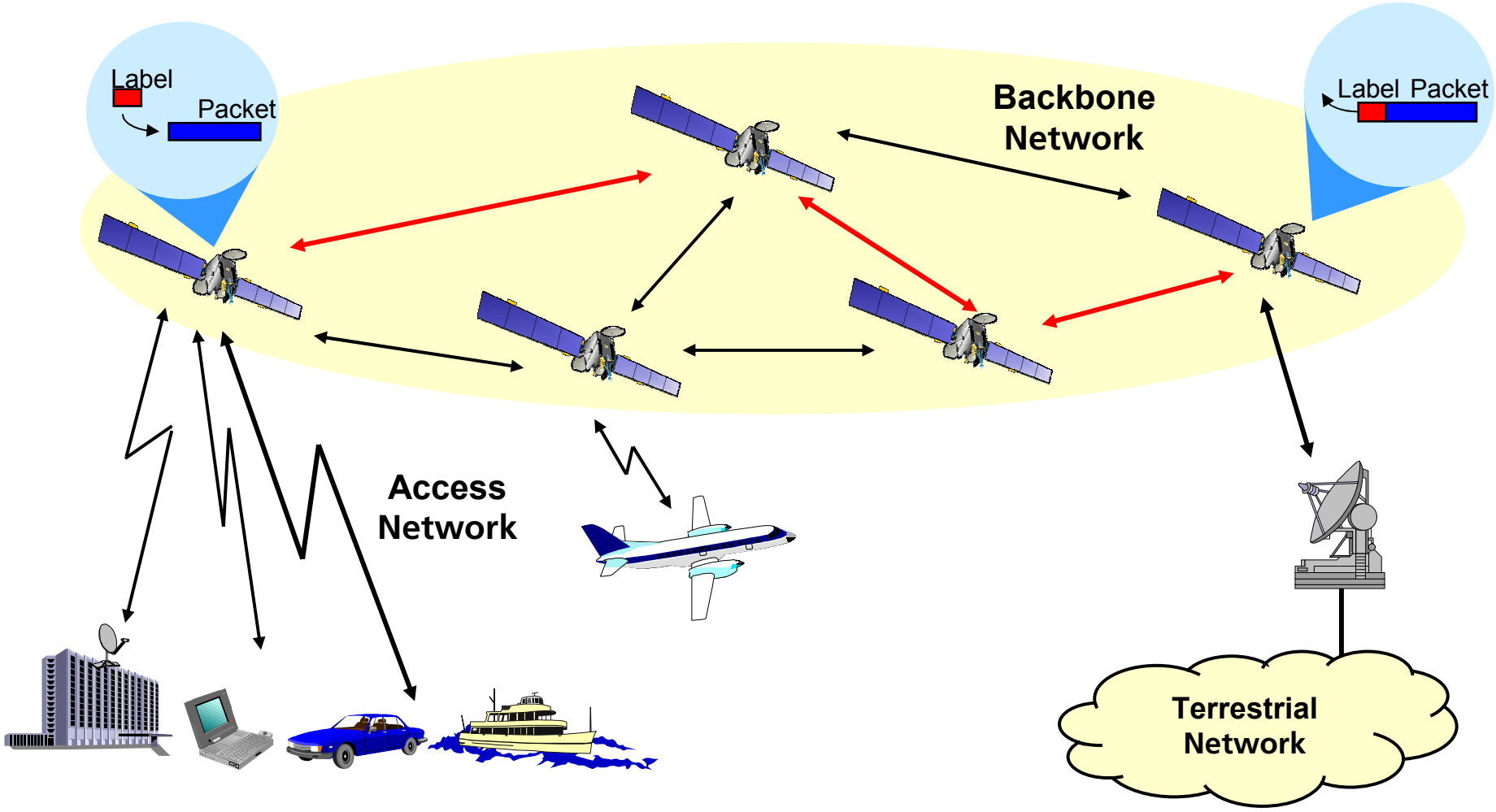
- ✓ <u>Network design process for LEO ISL networks</u>:
- ✓ Topological design of ISL segments with permanent link feature
- ✓ Discrete-time dynamic routing framework based on VPCs
- ✓ Network dimensioning: (a) heuristic design rules,
- ✓ (b) linear programming optimization approach
- ✓ (a) + (b) = efficient solution of routing/dimensioning task
  good performance
- ✓ Considerable reduction of worst case link loads can be achieved at the expense of an acceptable increase in both,
  - average link loads
  - average path delays

Possible Extensions (1): Multi-Protocol Label Switching (MPLS)

- A way to integrate ATM and IP, combining the benefits
- Appeal of and issues for MPLS-based ISL networking
  - MPLS is a technique **dedicated to backbones**
  - a “blue-sky” ISL network may be an ideal basis to exploit the full potential of MPLS in a **homogeneous global MPLS domain**
  - importance of traffic engineering; potential use of proposed dimensioning methods, alternate routing approaches ...
  - each satellite acts as edge router (serving ground) and core router (transit)

A simple MPLS network




Label
Packet
Backbone
Network
Label Packet
Access
Network
Terrestrial
Network

Possible Extensions (2): Optical ISL Networking

- Key role of optical communications for current/future backbone networks
  - (D)WDM - (dense) wavelength division multiplex
  - wavelength-routing or λ-switching
  - form optical transport network (OTN) by circuit-switched lightpaths
- For future ISL backbones:
  - low mass, size and power consumption of optical ISL terminals
  - PAT requirements for inter-plane ISLs can be met by laser technology
  - space OTN concepts are really close to the developed connection-oriented routing and dimensioning framework