An Efficient Scheduling Algorithm for Time-Driven Switching Networks

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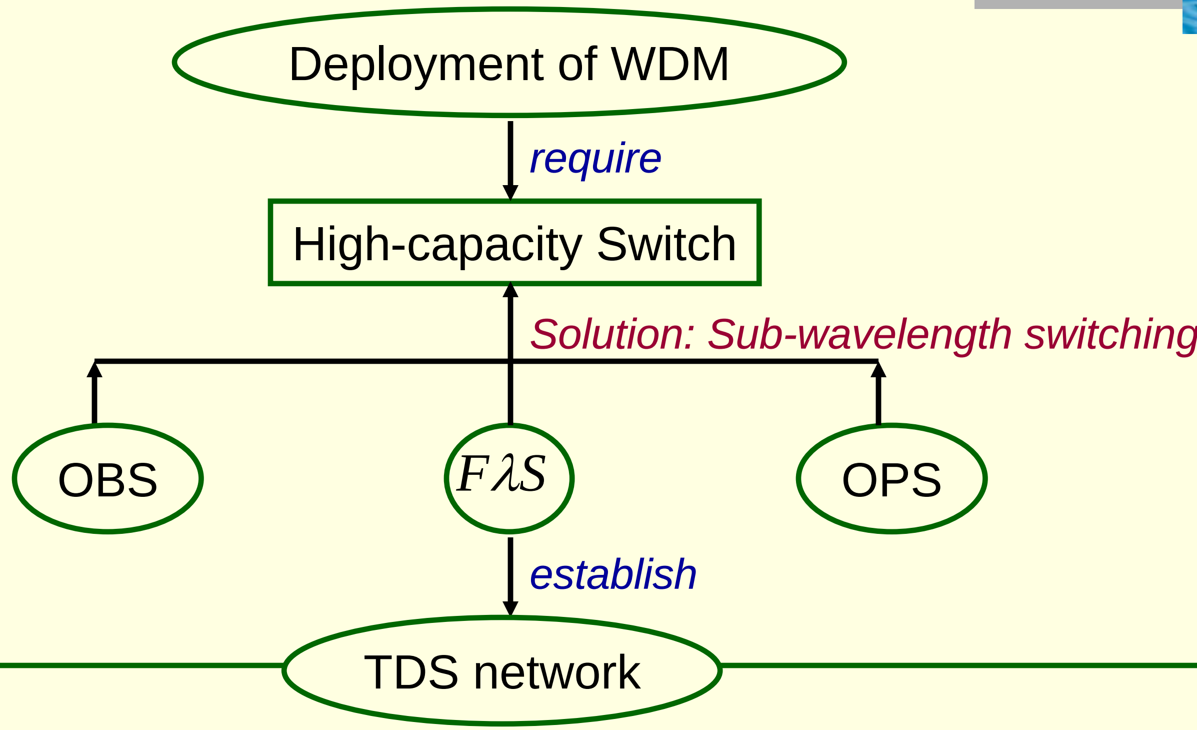
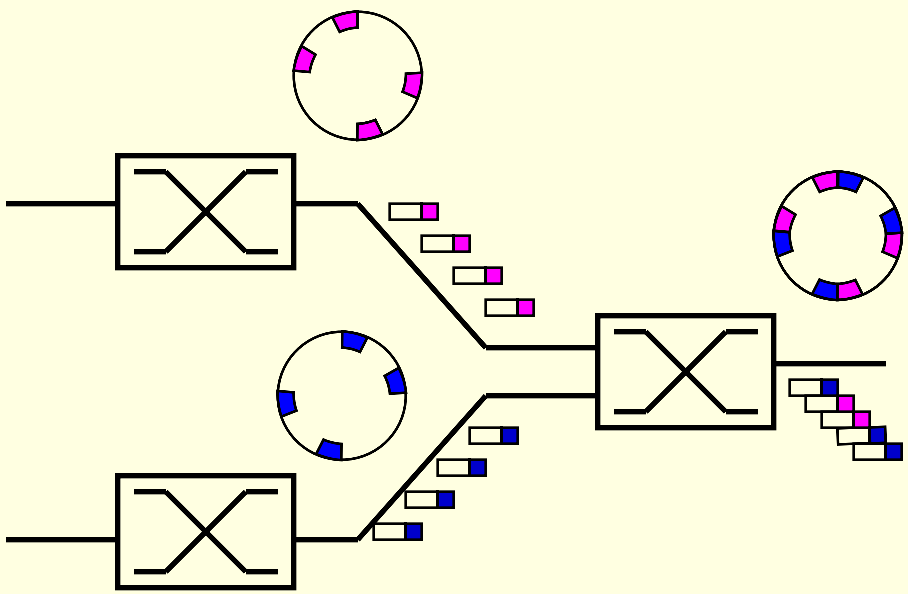
Why Time-Driven Switching (TDS)?

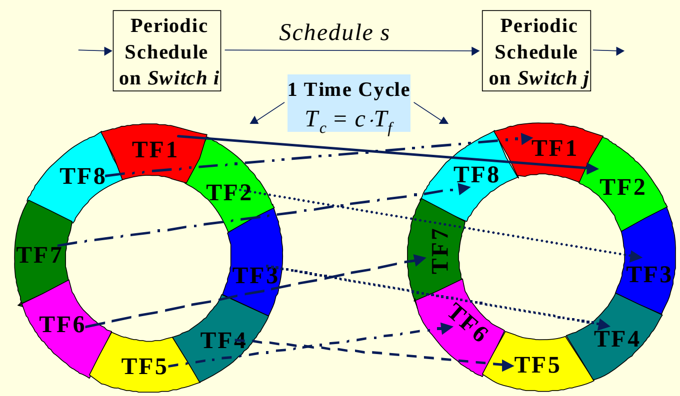


- Switches synchronized to a commen time reference CTR (e.g. UTC)
- Due to phase synchronization, pipeline forwarding is established

→No packet header processing → bring scalability of switch architectures
→Guarantees QoS such as: no loss, no jitter

Time-Driven Switching Network Principles





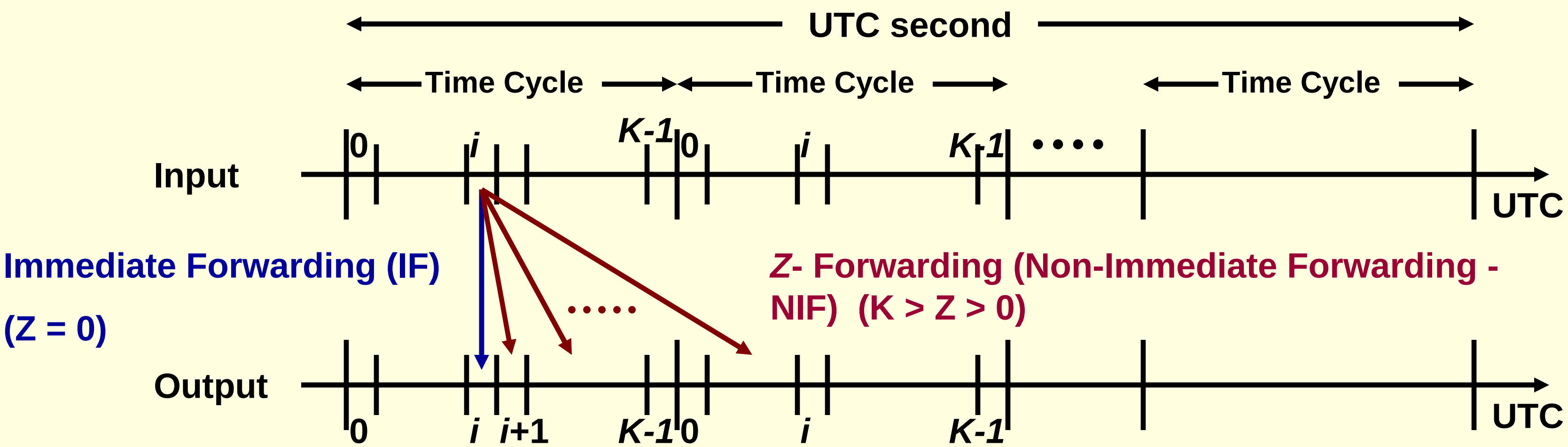
Always aligned with a bounded error (typically < 1 μsecond)
Thus, delay (optical memory) per switch = 1 T_f

Timing Principles and Pipeline Forwarding

$$D_{Pipeline} = D_{\Pr opagation} + D_{Alignment} + D_{Z-forwarding} \quad \text{where} \quad 0 \le D_Z \le Z$$

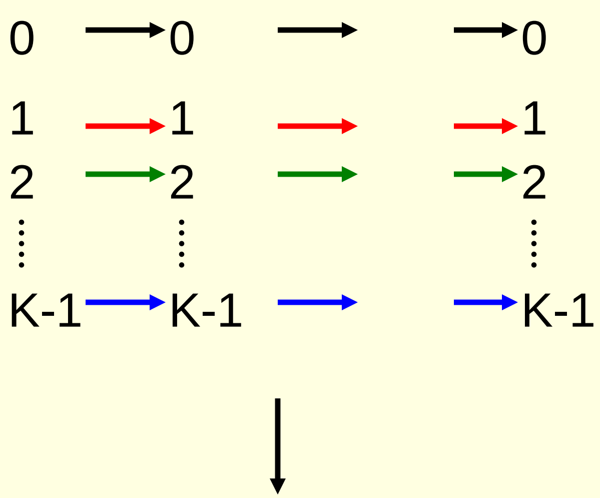
Without loss of generality, assume:

- Availability of the alignment operation $D_{Alignment} = 0$
- Ignore the propagation delay $D_{\Pr opagation} = 0$



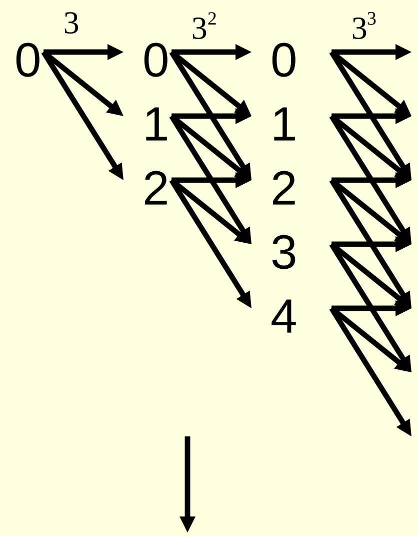
Scheduling Problem Formulation

Immediate Forwarding - IF



Space of K pipes/schedules

Non-immediate Forwarding - NIF



Exponential growth in space of schedules

NIF – Non-immediate Forwarding: Benefits and Problems

***Observation* 1**

For Z-forwarding ($0 < Z < K$-1), with the case of single channel links, the total number of possible schedules for a h-hop route is: $K \cdot (Z+1)^{h-1}$

***Observation* 2**

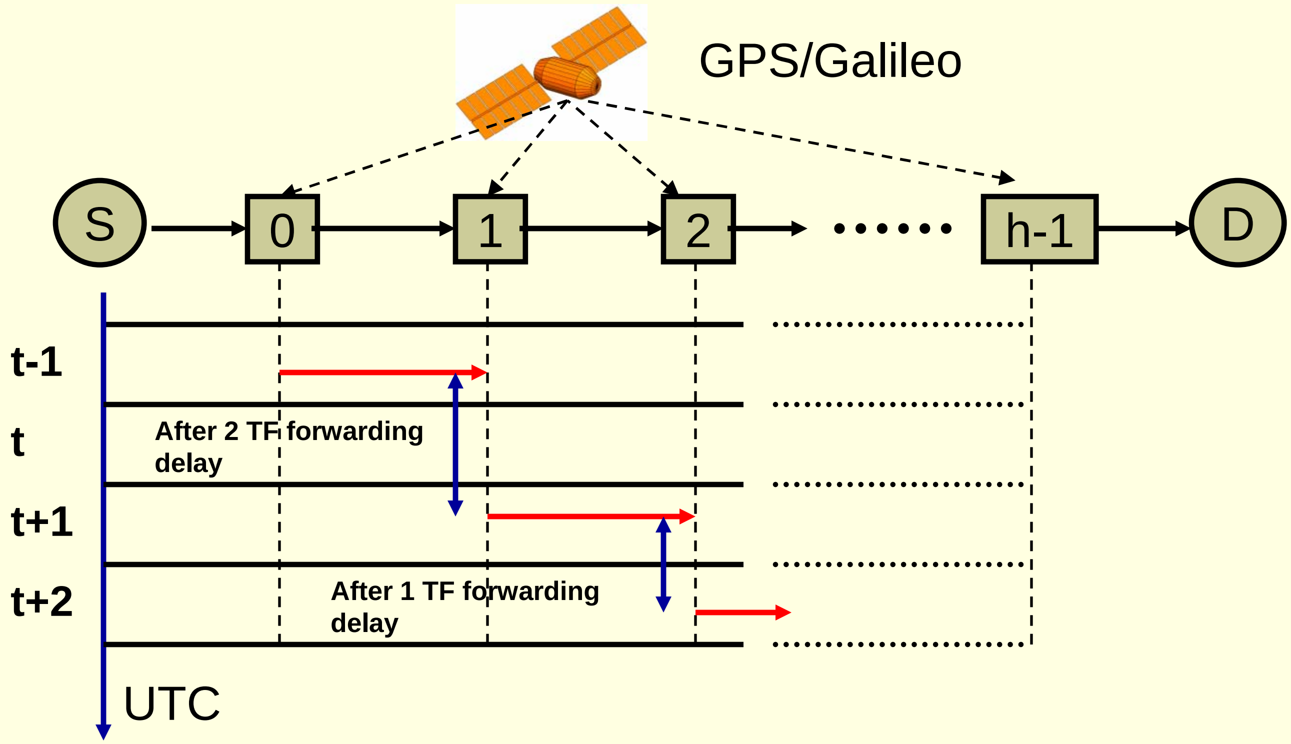
For Z-forwarding ($0 < Z < K$-1), with the case of multiple channel (C) links, the total number of possible schedules for a h-hop route is:

$$K \cdot (Z+1)^{h-1} \cdot C^h$$

- Benefits
  - Higher scheduling flexibility → pipeline blocking probabilty is reduced
- Problems:
  - Using NIF, due to Z-range restriction, sufficient bandwidth does not guarantee a non-blocking schedule
  - NIF introduces an exponential number of possible schedules

Network Model and Assumptions

- Homogeneous networks with various topologies
- A route of *h* switches synchronized by UTC: 0 → *h*-1
- Each time cycle TC consists of K TFs : 0 → *K*-1
- Z-forwarding
- A single-TF request



eSS – efficient Survivor-based Search

Trellis graph

{V,E}

Where: V=h.K

Stage = Switch *j* : 0→ *h*-1

State = TF *i* : 0→ K-1

Transition = a possible Z-forwarding from one state to another state of 2 consecutive stages

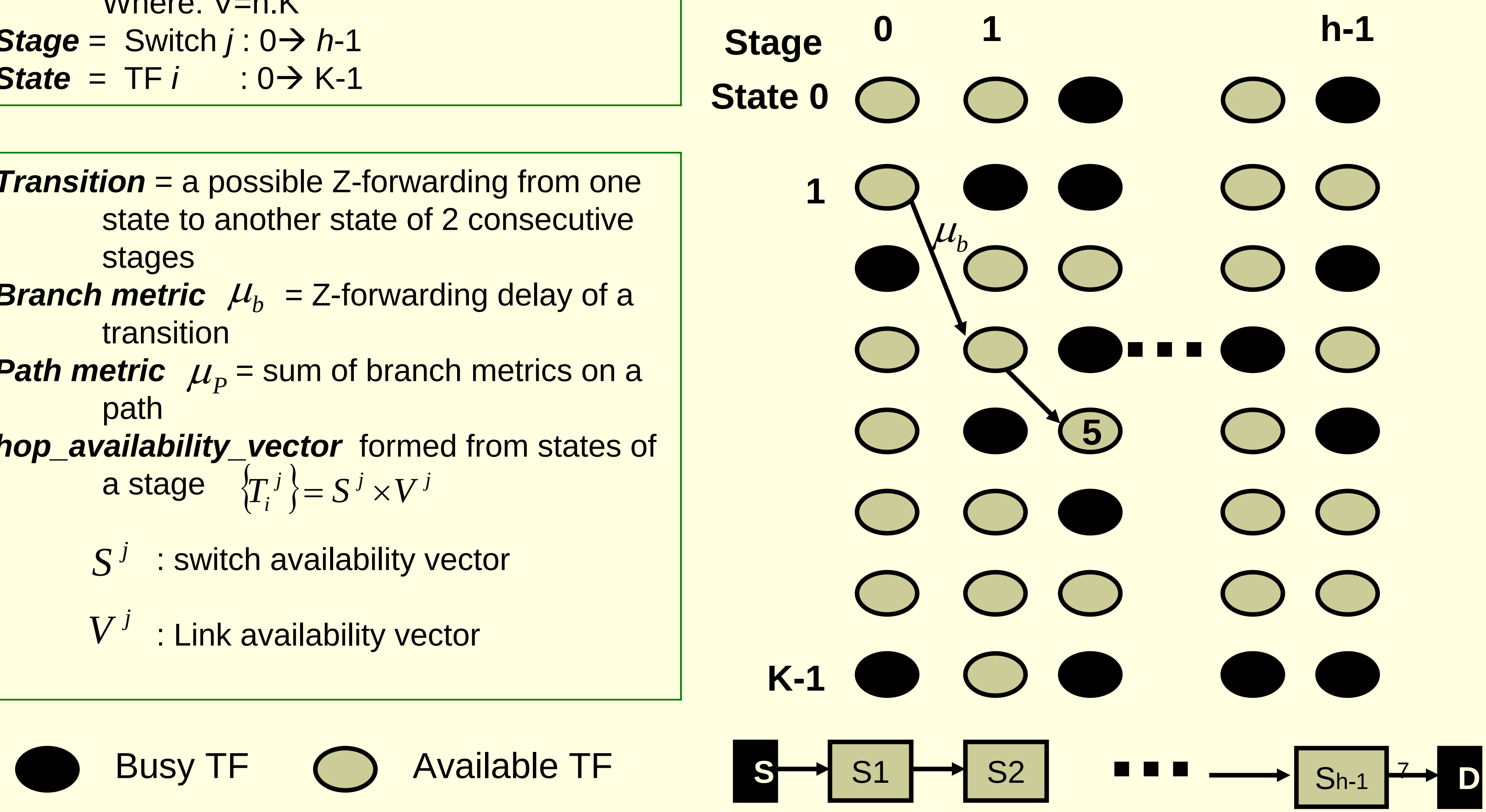
Branch metric μ_b = Z-forwarding delay of a transition

Path metric μ_P = sum of branch metrics on a path

hop_availability_vector formed from states of a stage $\{T_i^j\} = S^j \times V^j$

S^j : switch availability vector

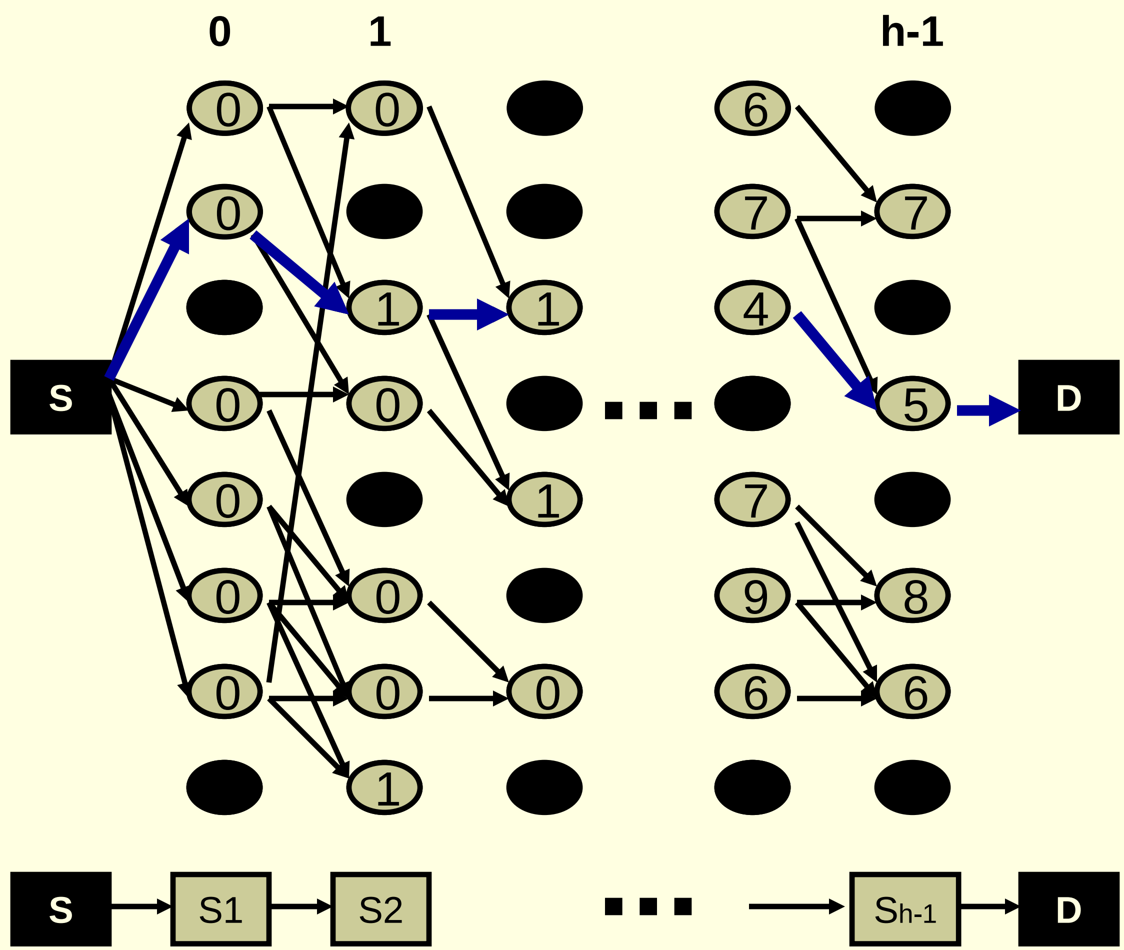
V^j : Link availability vector



eSS – efficient Survivor-based Search

Survivor-based Searching Algorithm

- Dynamic Programming.
- Memoryless process,computation is progressed stage by stage.
- A survivor kept for each state: survivor = smallest accumulated delay.
- At stage (*h*-1), a final schedule is yielded from existing survivors



eSS – efficient Survivor-based Search

Algorithm Property

- **Optimality**
  - eSS finds out an optimal solution alike exhaustive approach
- **Efficiency**
  - eSS yields a linear complexity instead of the exponential complexity introduced by exhaustive search

$$(h-1)\cdot K\cdot(Z+1) << K\cdot\left[\frac{(Z+1)^h-1}{Z}-1\right]$$

- **QoS: Delay criterion**

- eSS vs. Dijkstra
  - Smaller complexity
    - eSS $O(E)$
    - Dijkstra $O(V^2)$ or $O((V+E)\log V)$
  - Applied in both distributed and centralized manner

Scheduling in WDM Networks

No wavelength conversion

Disjoint Approach

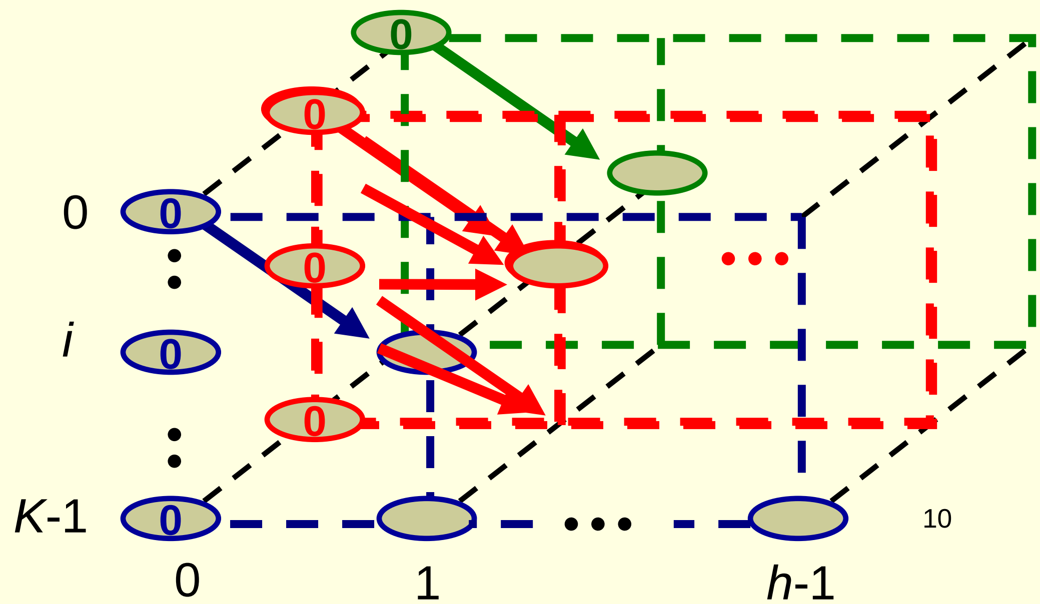
- A wavelength plane is selected based on least-loaded criterion

  Least Load-metric = minimum number of available TFs on the wavelength over the entire route

- On the selected wavelength plane, eSS searches for the best TF schedule

Complexity

$$X(h,K,Z,C)=(h-1)\cdot K\cdot(Z+1)\cdot C$$



Scheduling in WDM Networks

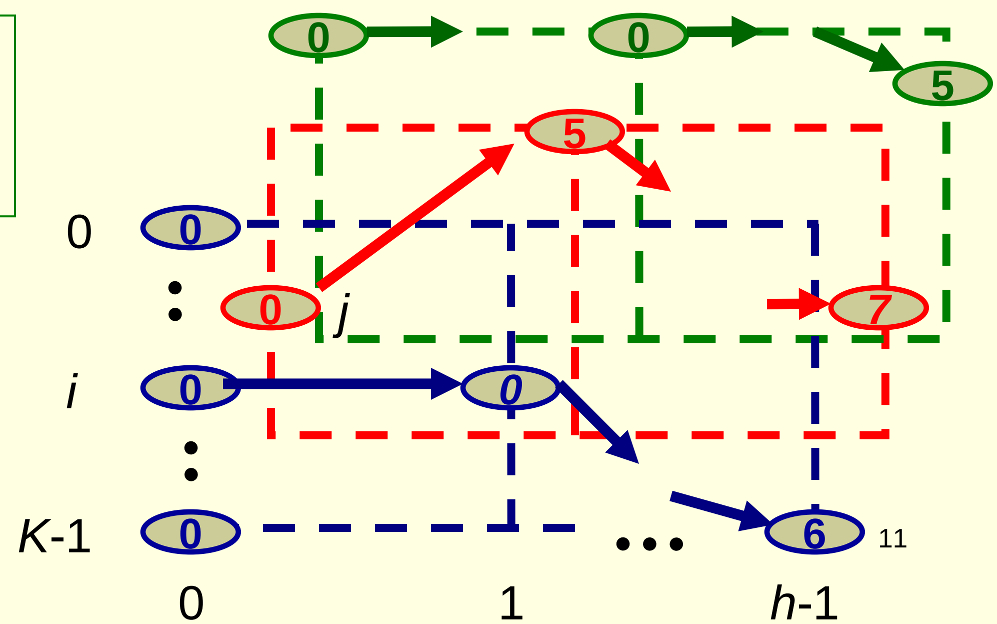
No wavelength conversion

Joint Approach

- eSS runs in each of all wavelength planes
  - *→ schedule in each planes is found*
- Those schedules are compared to select the best one
  - *→ WA is based on optimal delay criterion*

Complexity

$$X(h,K,Z,C) = (h-1)\cdot K\cdot(Z+1)\cdot C$$



Next Step

Network Type \ Requested BW	Single TF	Multiple TFs	Fraction of TF
Single channel -Homogeneous	**Case 1**	Case 5	Case 9
Multiple channel -Homogeneous	**Case 2**	Case 6	Case 10
Single channel -Heterogeneous	Case 3	Case 7	Case 11
Multiple channel -Heterogeneous	Case 4	Case 8	Case 12

Heterogeneous Network = links with different bit rates

Homogeneous Network = all links with the same bit rate