Tiered Service in Packet-Switched Networks

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Outline

- Motivation
- Service tier selection as a directional p-median problem:
  - deterministic demands
  - stochastic demands
  - multiple QoS parameters
  - TDM emulation
- Application: efficient WFQ implementations

Challenges at Data and Control Planes

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  - complexity of QoS functions increases with # of users/constraints

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- Data plane:
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$\longrightarrow$ Maintaining per-flow information poses severe scalability challenges

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As network capacity $\uparrow$, overhead also $\uparrow$

Example: Cable TV

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- But: only a few subscription levels offered
  - “basic”
  - “standard”
  - “premium”
  - plus a few “a la carte” channels

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- Demands mapped to next higher tier $\longrightarrow$ performance penalty
- Benefits: control and data plane operation simplified
  - traffic engineering
  - traffic grooming
  - billing, policing, etc.
  - TDM emulation
  - scheduling and QoS support

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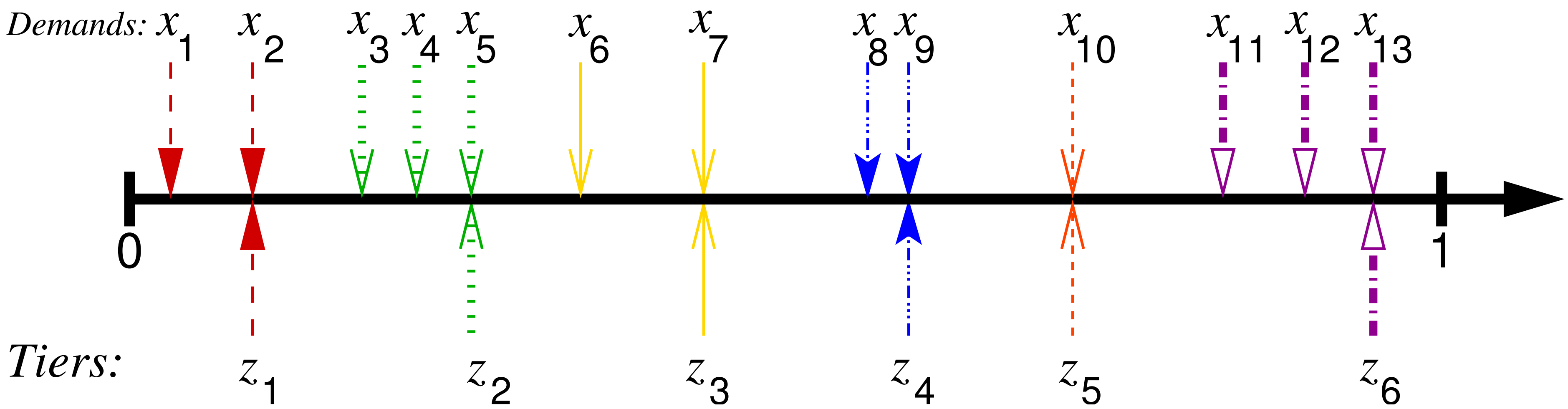
Tier Selection: Deterministic Demands

- Input: n bandwidth demands, $x_1 \leq x_2 \leq \cdots \leq x_n$
- Output: $p \ll n$ service tiers, $z_1 < z_2 < \cdots < z_p$
- Objective:
  - $x_i \longrightarrow z_j$ iff $z_{j-1} < x_i \leq z_j$
  - to minimize the total bandwidth penalty $\sum_{i=1}^{n}(z_j - x_i)$

Mapping of Bandwidth Demands to Service Tiers



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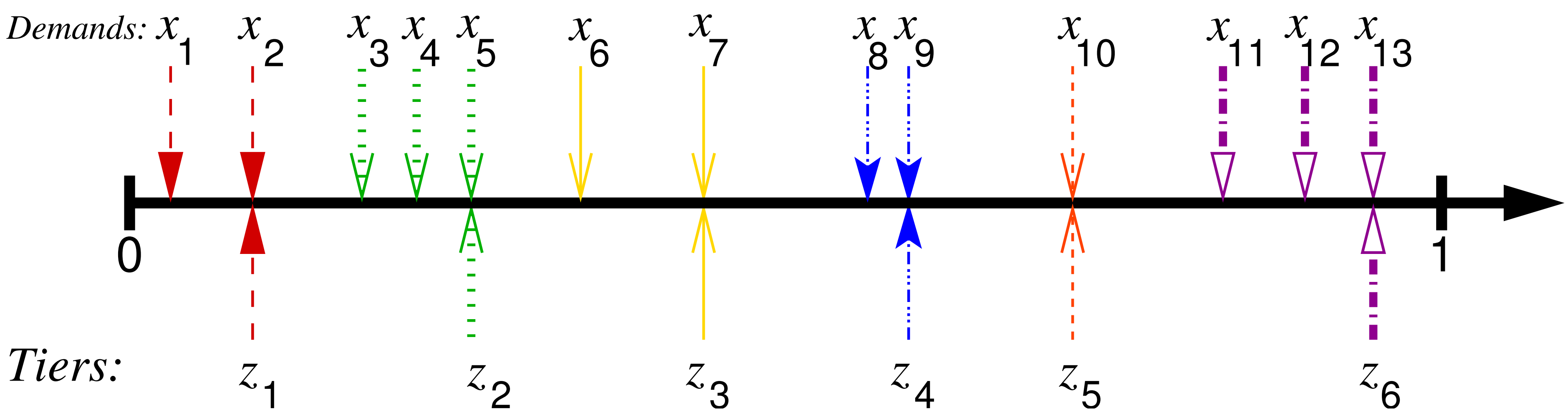
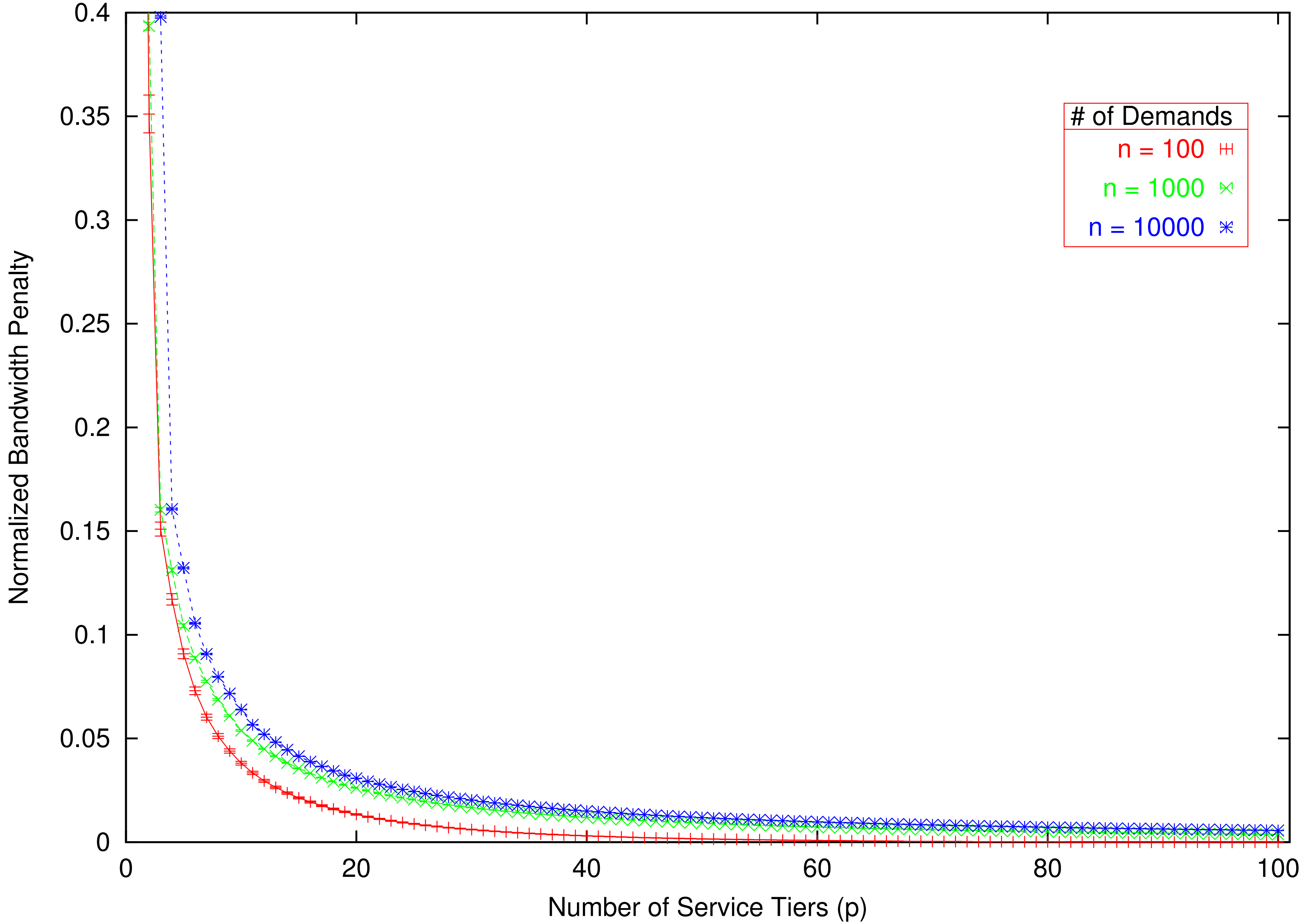


- Similar to p-median problem on the real line
- But: demands mapped to next higher tier
- Dynamic programming algorithm with complexity $O(pn)$

Results: Bandwidth Penalty



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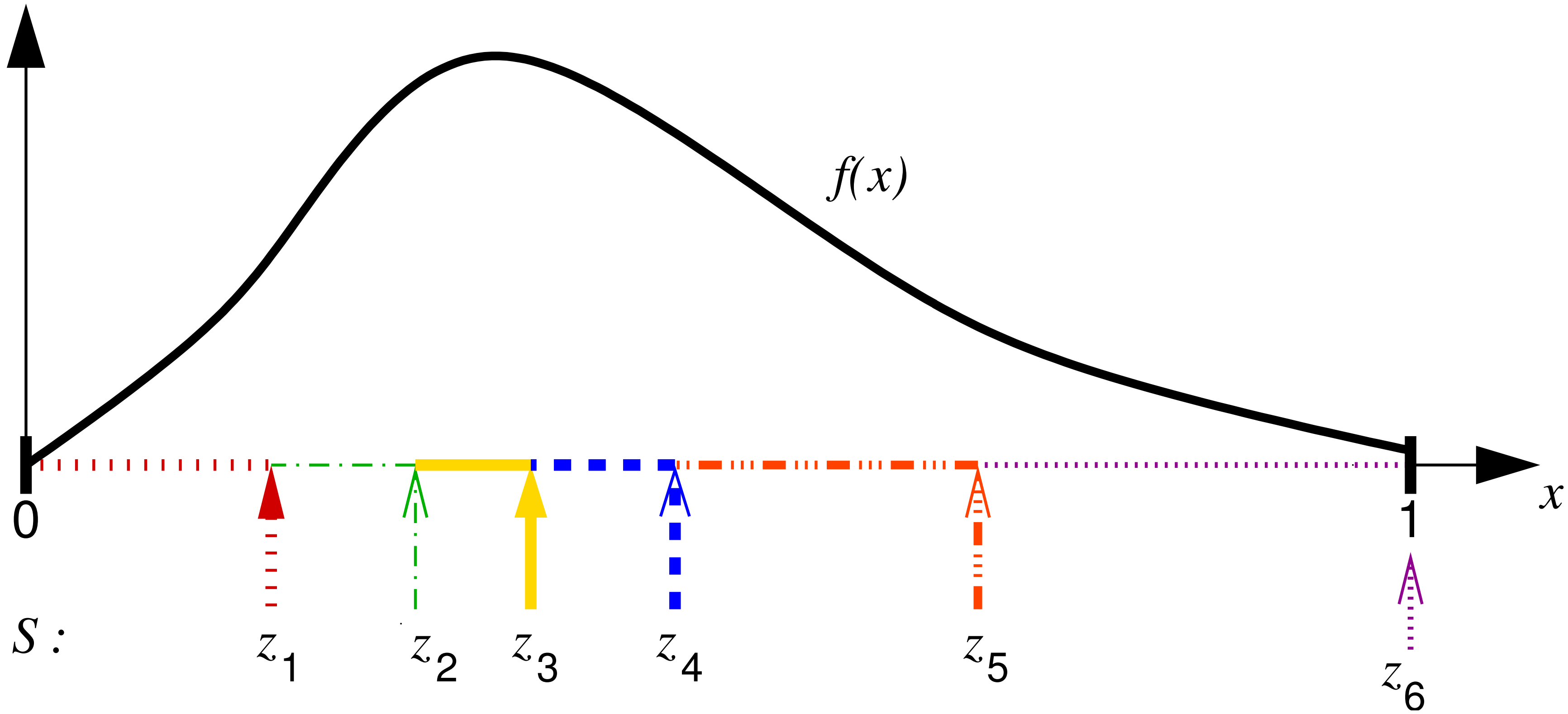
Tier Selection: Stochastic Demands

- Input: PDF $f(x)$ of bandwidth demands
- Output: p service levels, $z_1 < z_2 < \cdots < z_p$
- Objective:
  - $x \rightarrow z_j$ iff $z_{j-1} < x \leq z_j$
  - to minimize the expected bandwidth penalty $\sum_{i=1}^{L} \int_{z_{i-1}}^{z_i} (z_i - x) f(x) dx$

Mapping of Bandwidth Demands to Service Tiers



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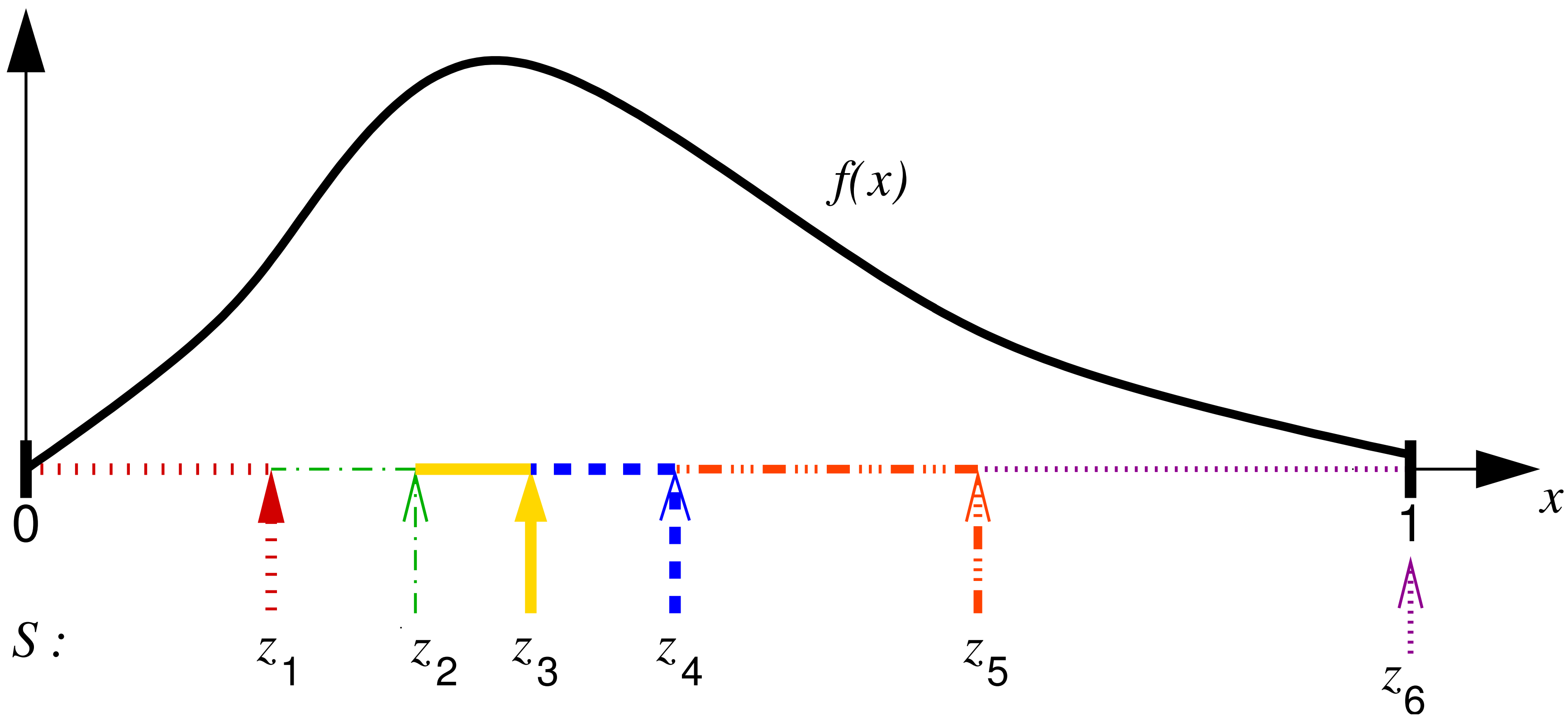
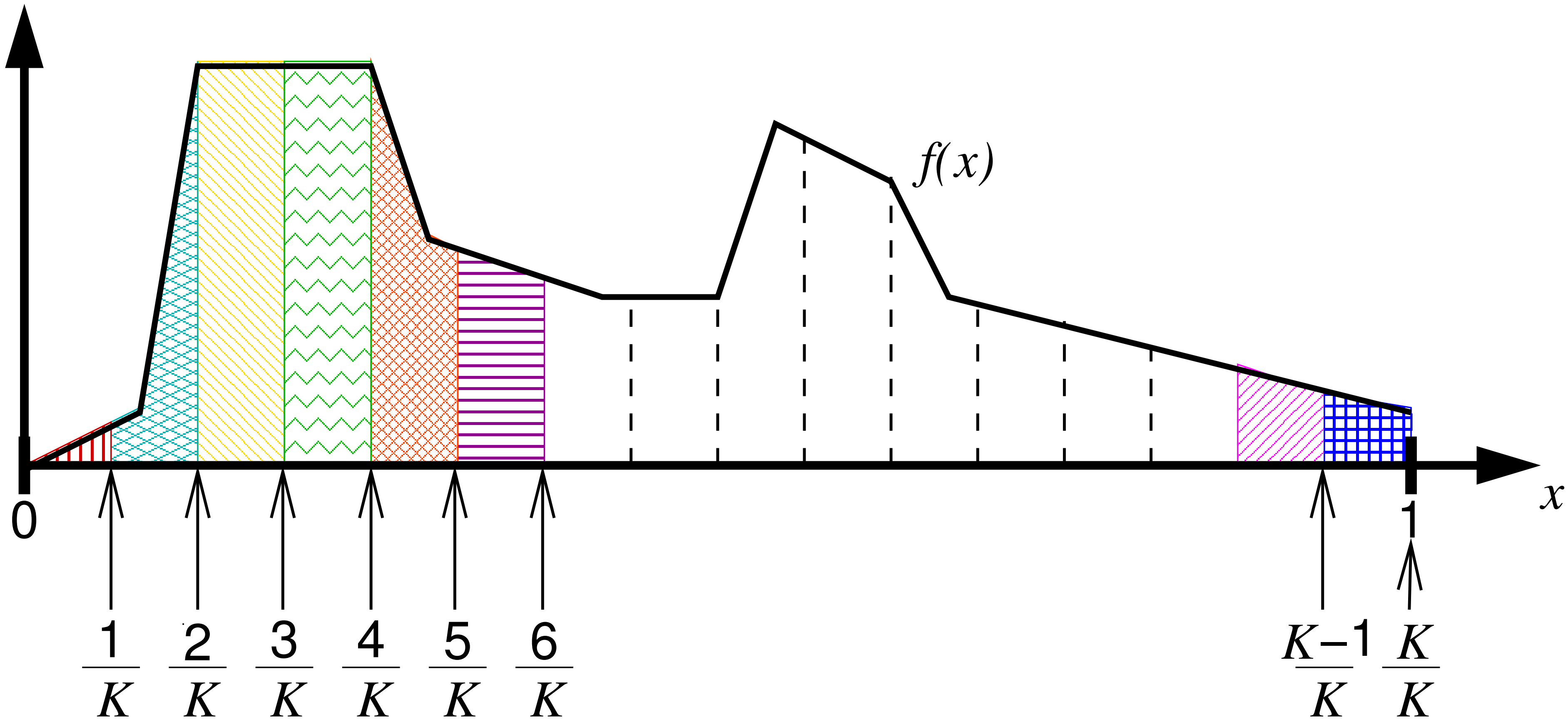


1. Optimal solution through nonlinear programming
2. Discretize the PDF → reuse previous algorithm

Discretizing the PDF



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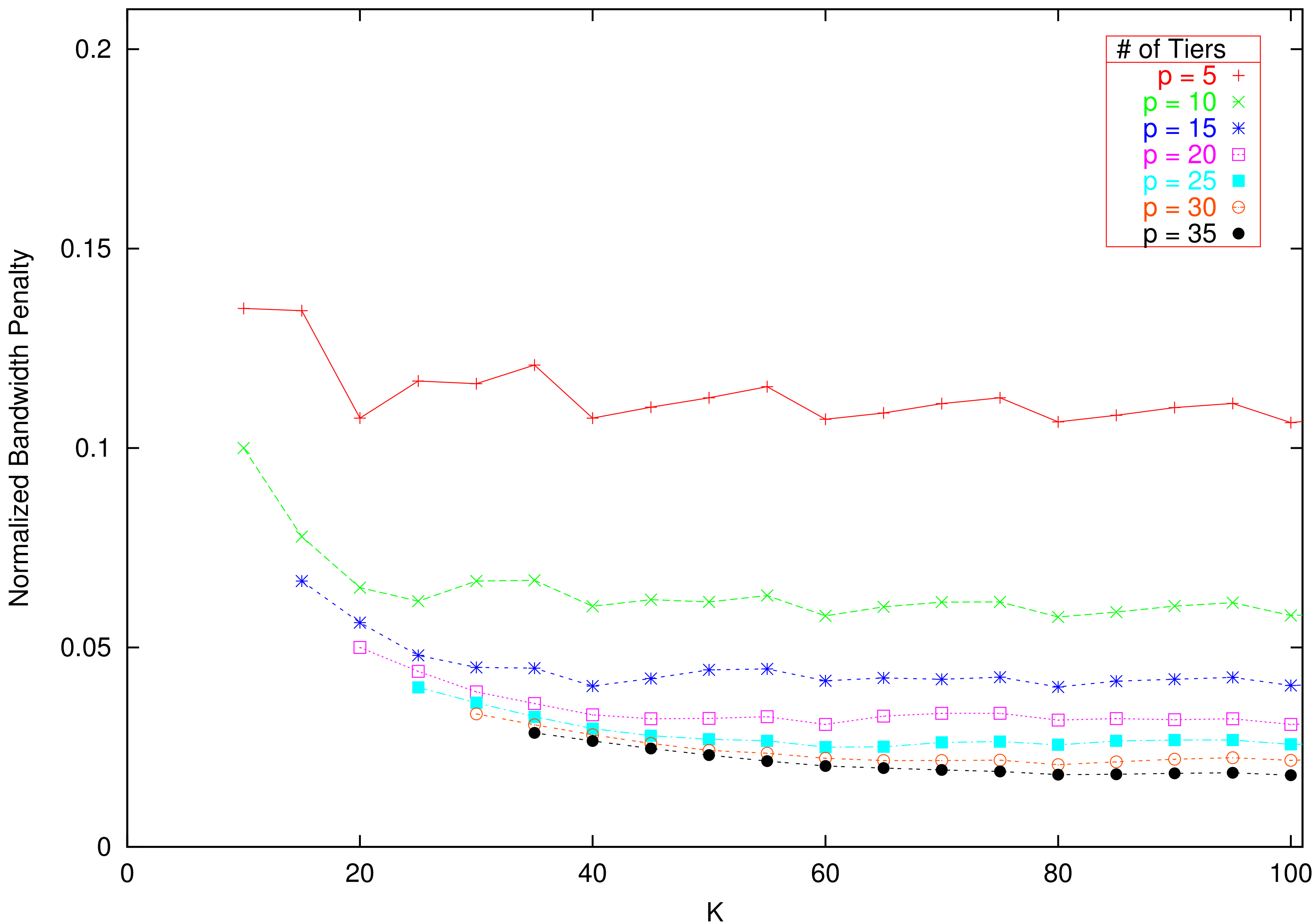

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Tier Selection with Multiple Parameters

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  - bandwidth
  - maximum burst size
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  - etc...

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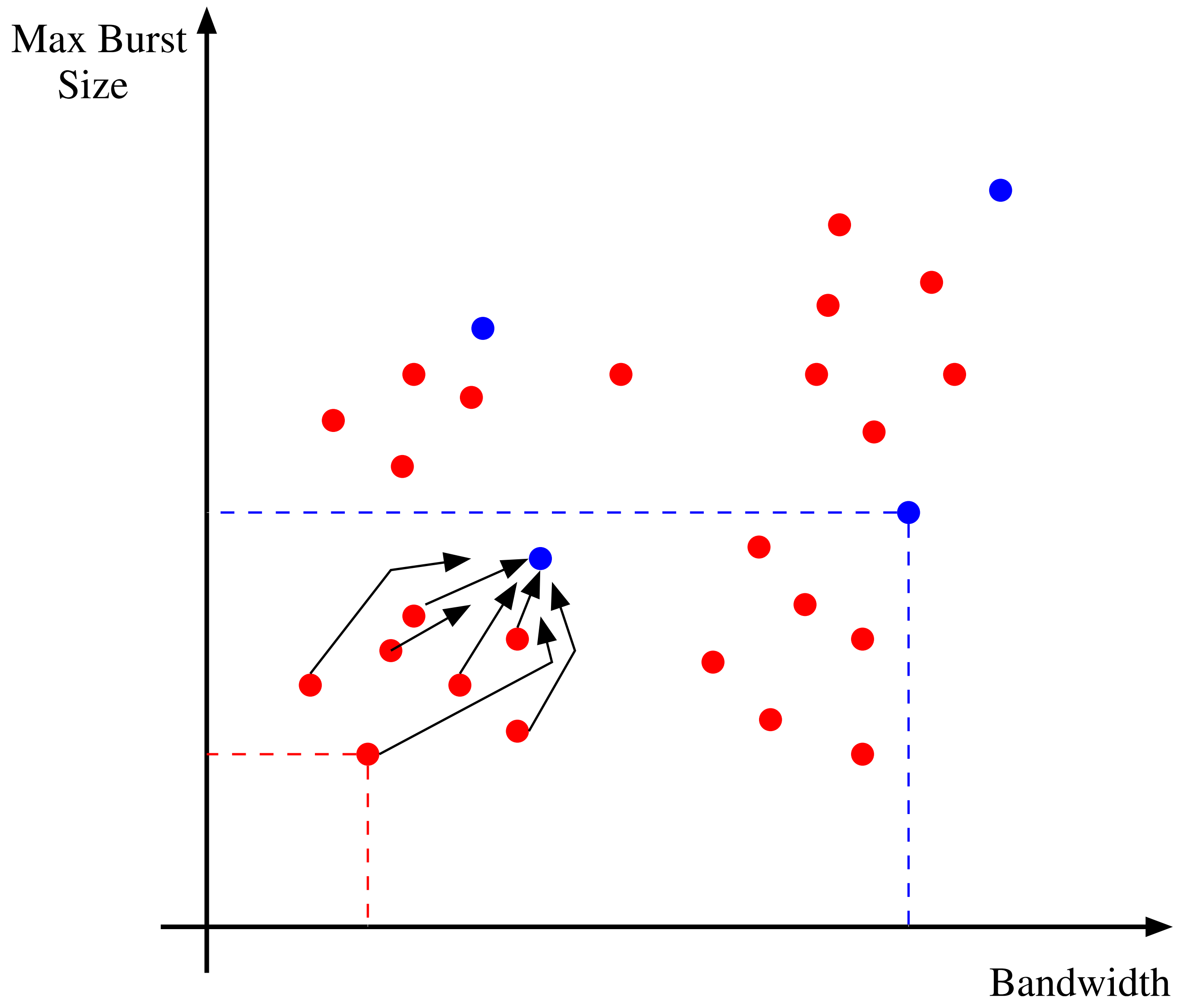
  - bandwidth
  - maximum burst size
  - delay bound
  - etc...
- Service tiers in multiple dimensions
  - jointly optimal for a vector of parameters
- Problem is NP-Complete for ≥ 2 dimensions
  - reduction from planar 3-SAT, non-polar version

The Directional p-Median Problem in the Plane



Decomposition Heuristic

- Our heuristic:
  - run 1-dimensional algorithm twice
    - once on x-values $\longrightarrow$ p best x's
    - once on y-values $\longrightarrow$ p best y's
  - cross two sets $\longrightarrow$ p^2 candidate points
  - run the Teitz & Bart (TB) exchange heuristic
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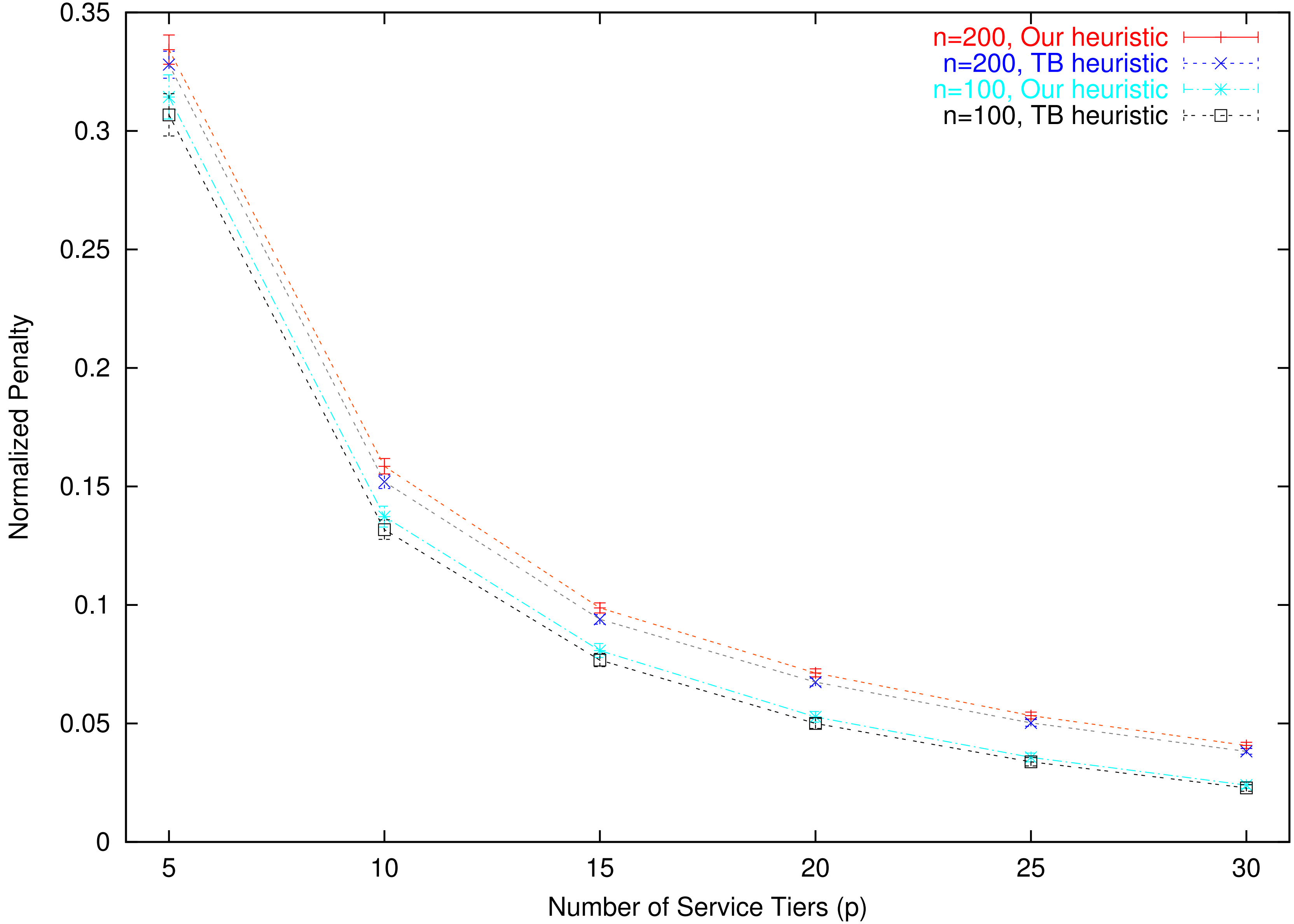
    - popular, well-studied, extremely robust
- Complexity: $O(p^3 n)$

Results: Normalized Penalty



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- Output:
  - $p \ll n$ service tiers, $z_1 < z_2 < \cdots < z_p$
  - $z_i \;=\; k_i\, r$ $\longleftarrow$ additional constraint
- Objective:
  - $x_i \longrightarrow z_j$ iff $z_{j-1} < x_i \leq z_j$
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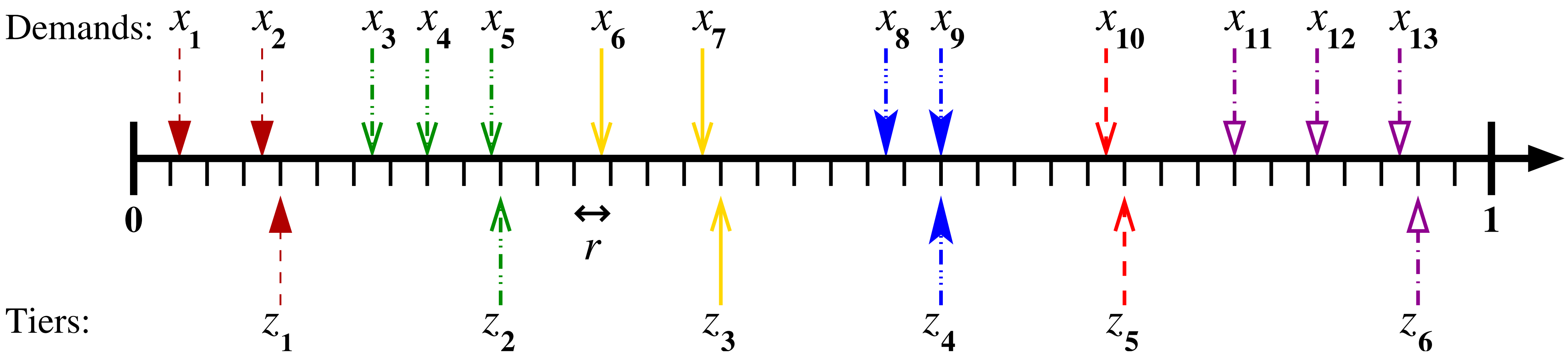
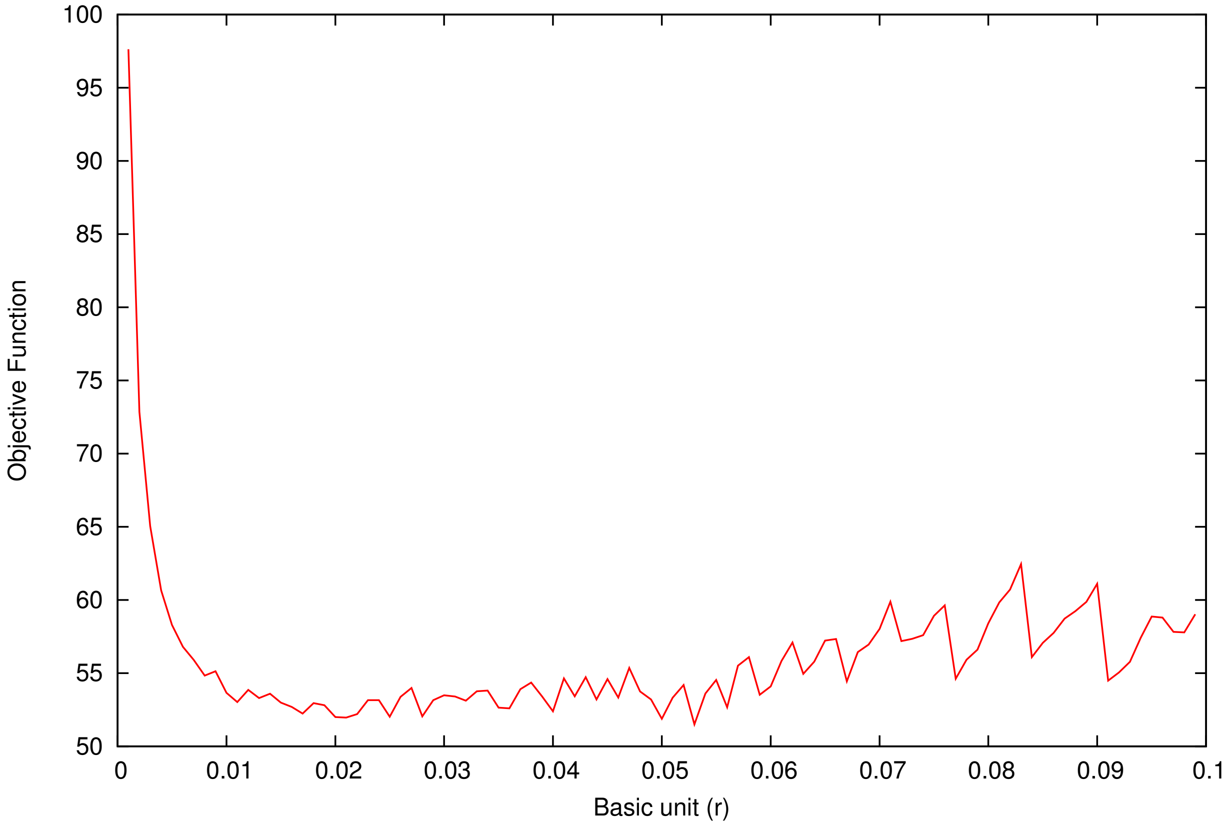


Why TDM Emulation?

- Reuse robust control/management functions
- Configurable bandwidth unit (slot) $\longrightarrow$ may be optimized
- Data plane operation not affected
  - no “wasted” slots
  - reuse of excess bandwidth

Behavior of the Objective Function



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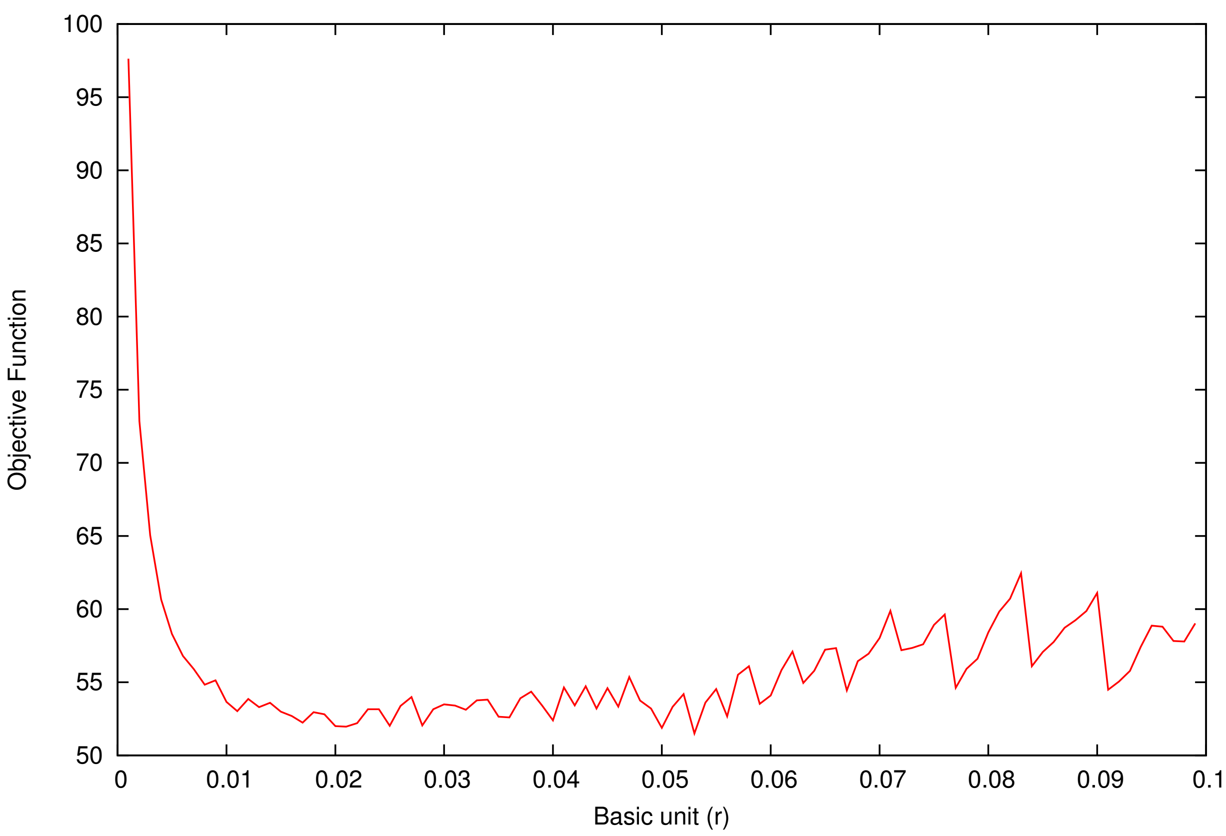
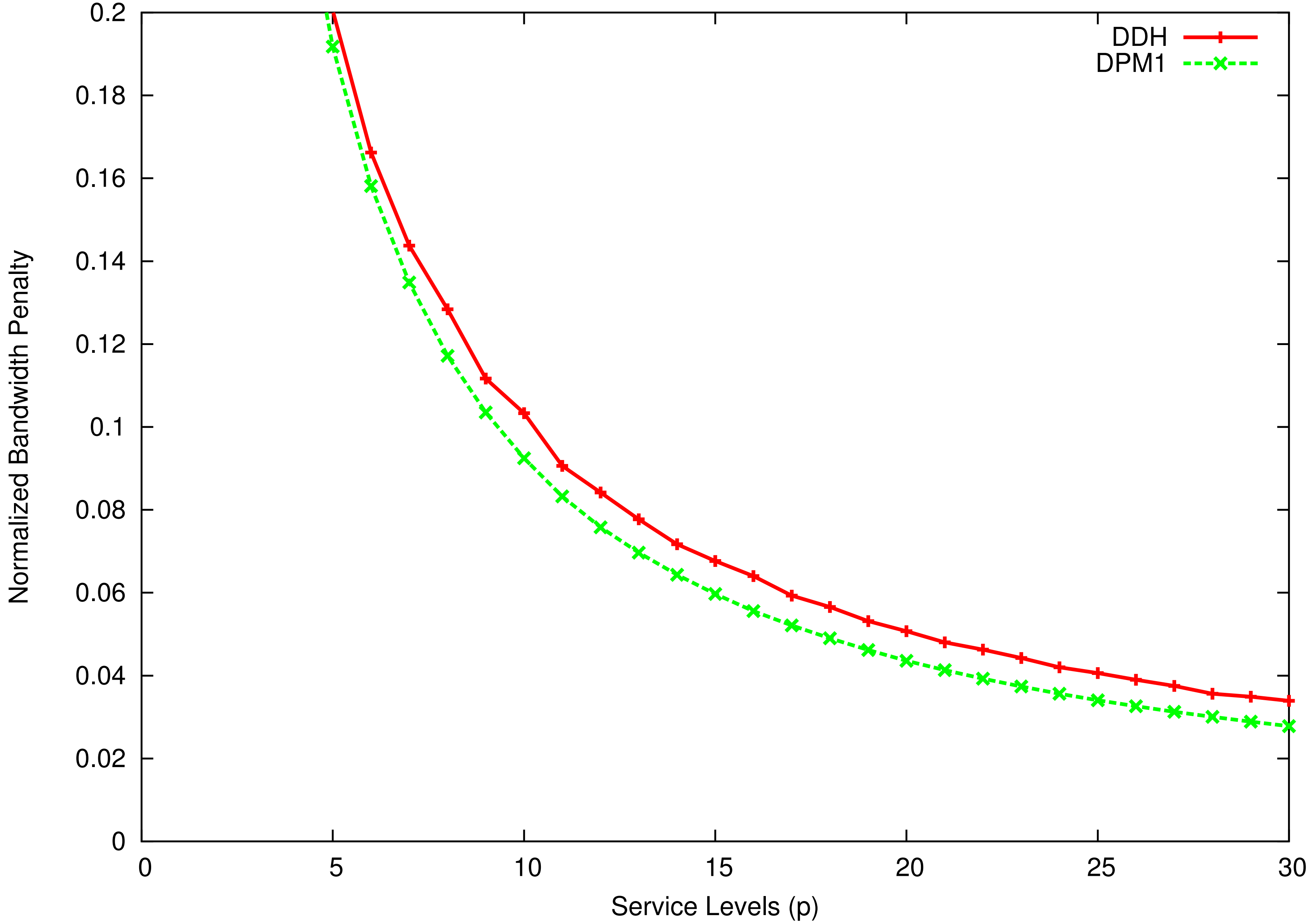


We have developed efficient heuristics

Results: Bandwidth Penalty



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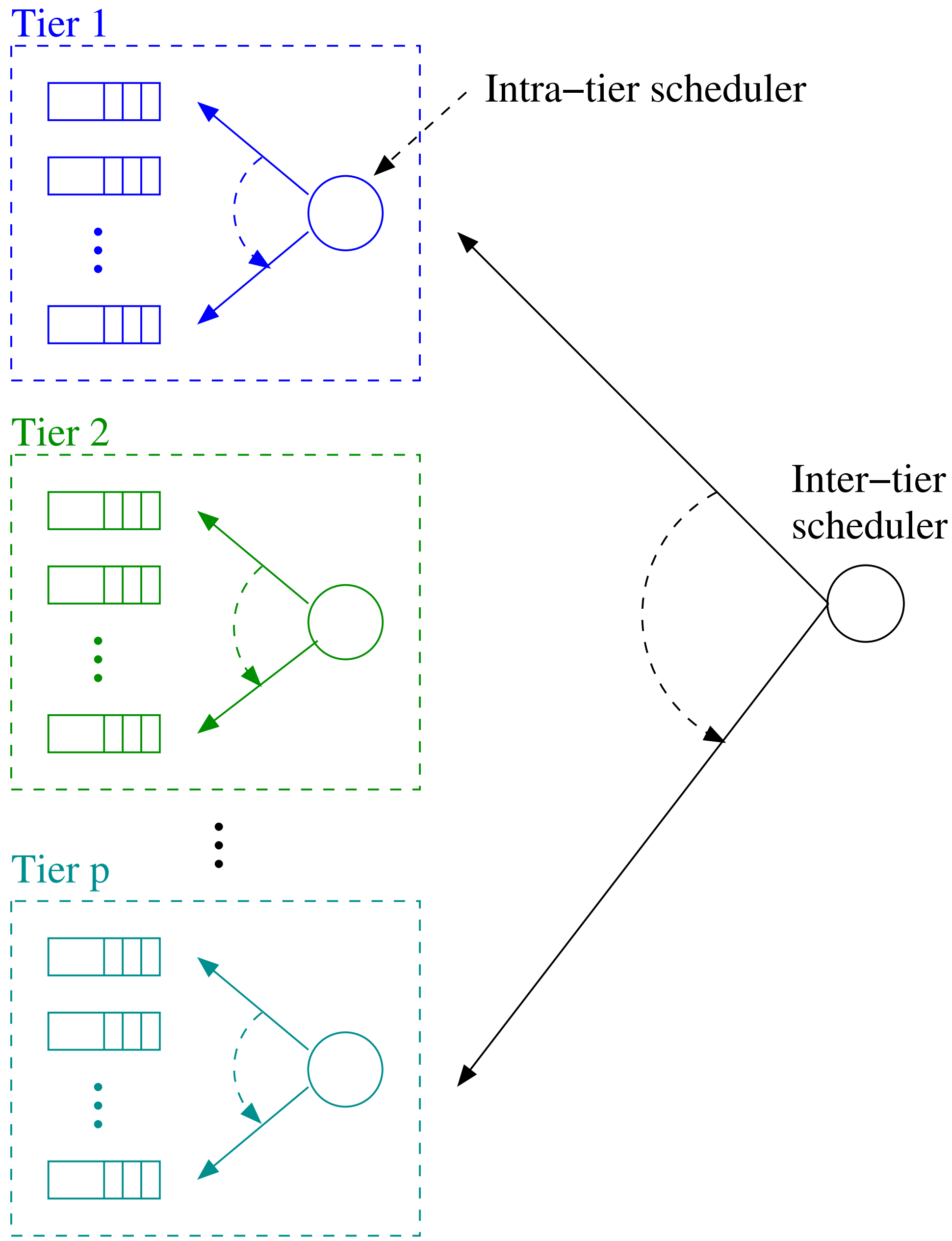
WFQ Packet Scheduling

- Packet departure time based on fluid-flow fair queueing algorithm

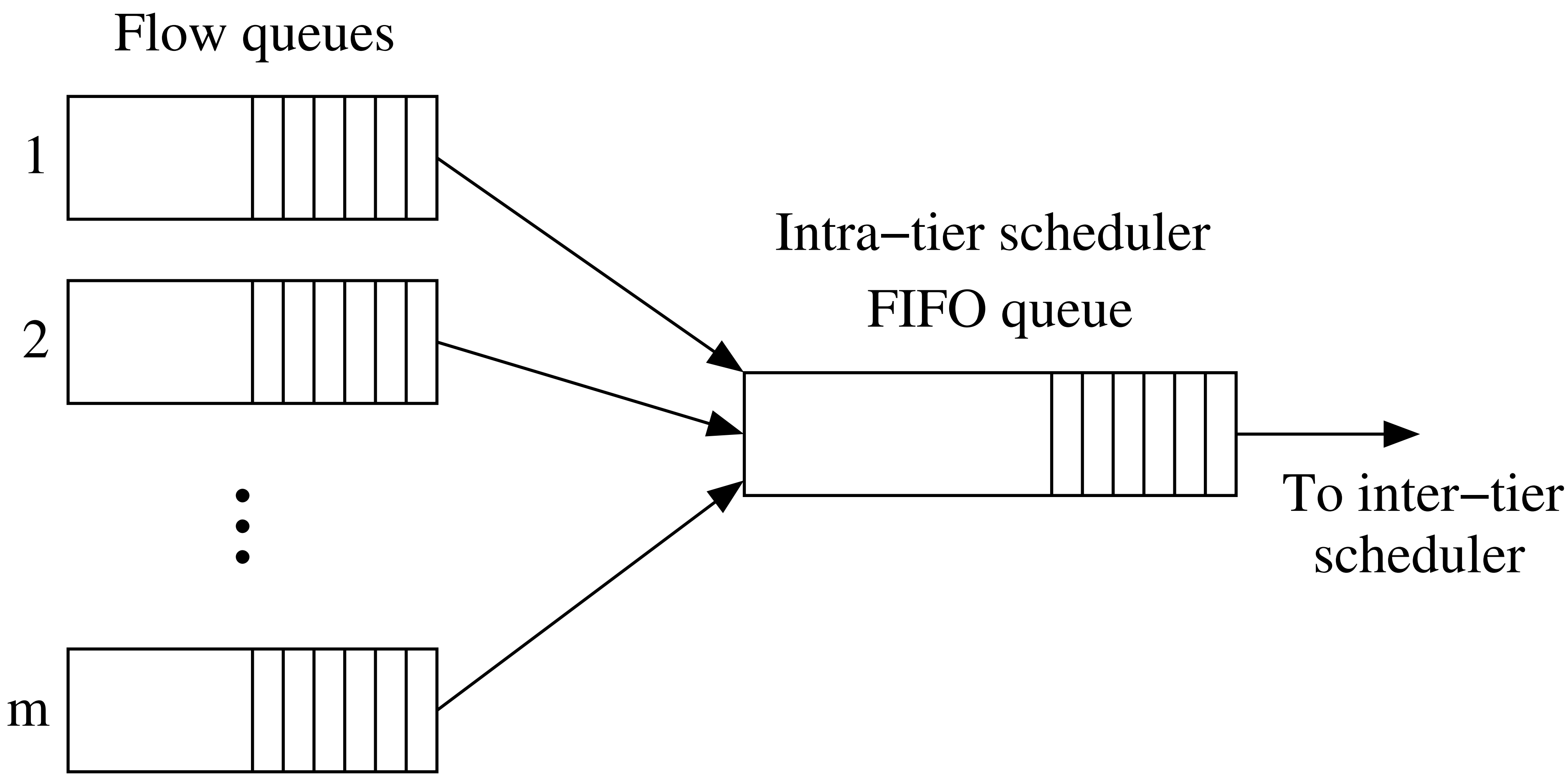
$$F_i^k = \max\{F_i^{k-1}, V(a_i^k)\} + \frac{L_i^k}{\phi_i}$$

- Packet inserted in logical queue
- Queue is sorted with respect to departure times
- Complexity:
  - $O(\log n)$ for selecting next packet
  - $O(n)$ for computation of virtual function

TSFQ Inter-Tier Scheduling



TSFQ Intra-Tier Scheduling: Fixed Packets



TSFQ Intra-Tier Scheduling: Variable Packets