Optimal Scheduling of Real Time traffic in Wireless Networks with Delayed Feedback

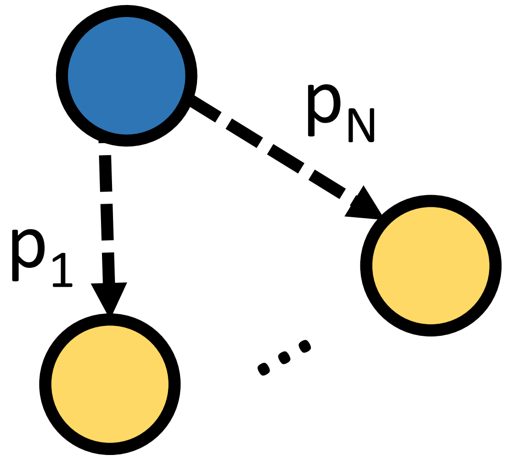
Kyu Seob Kim, Chih-Ping Li, **Igor Kadota** and Eytan Modiano

Allerton Conference, October 1, 2015

Contributions / Topics

- Network Model
- DP Solution
- Feasible Region
- Feasibility Optimal Dynamic Algorithm
- Low-complexity Heuristic Algorithm

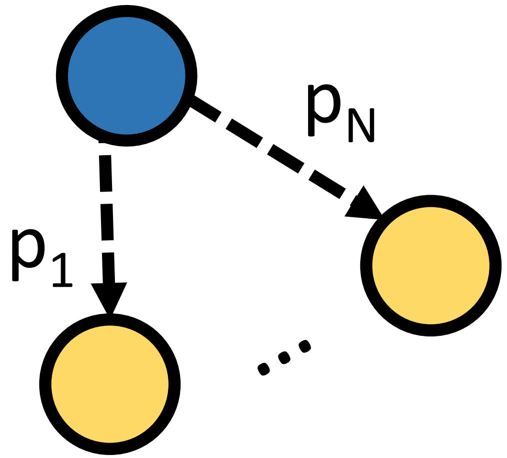
Wireless Single-Hop Network

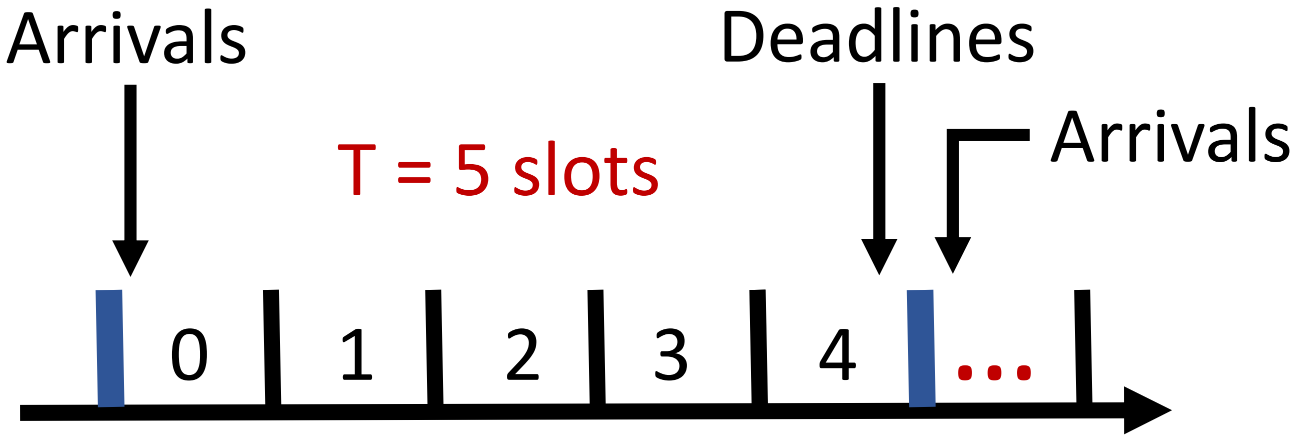


[5] I.-H. Hou, V. Borkar, and P. R. Kumar, “A theory of QoS for wireless,” IEEE INFOCOM, Apr. 2009.

Network Model

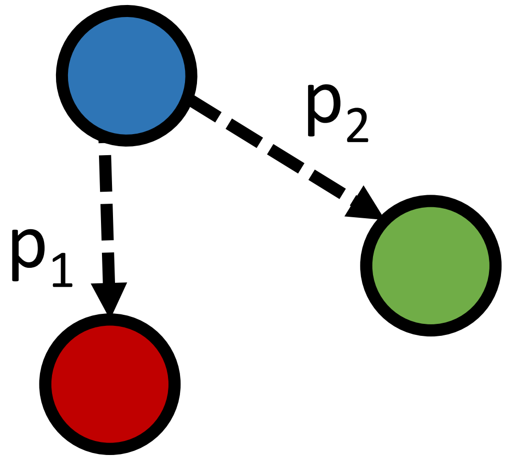
Wireless Single-Hop Network

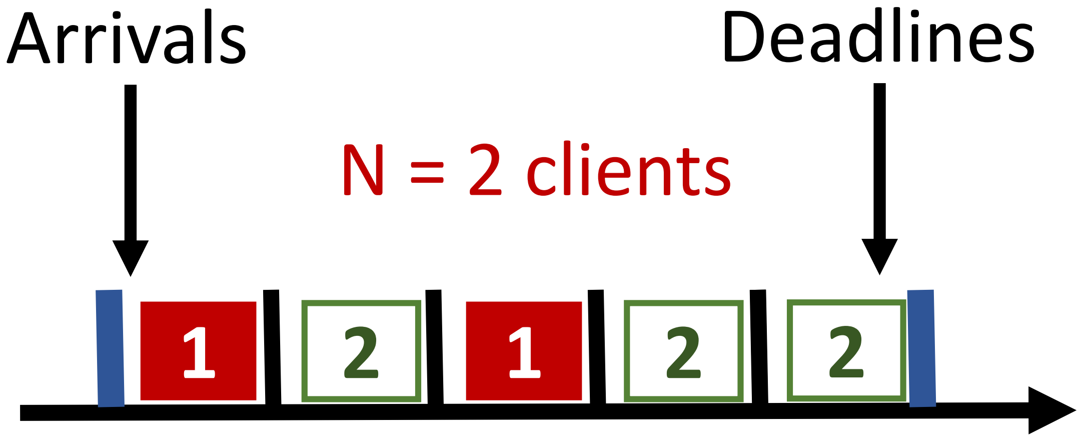




Network Model

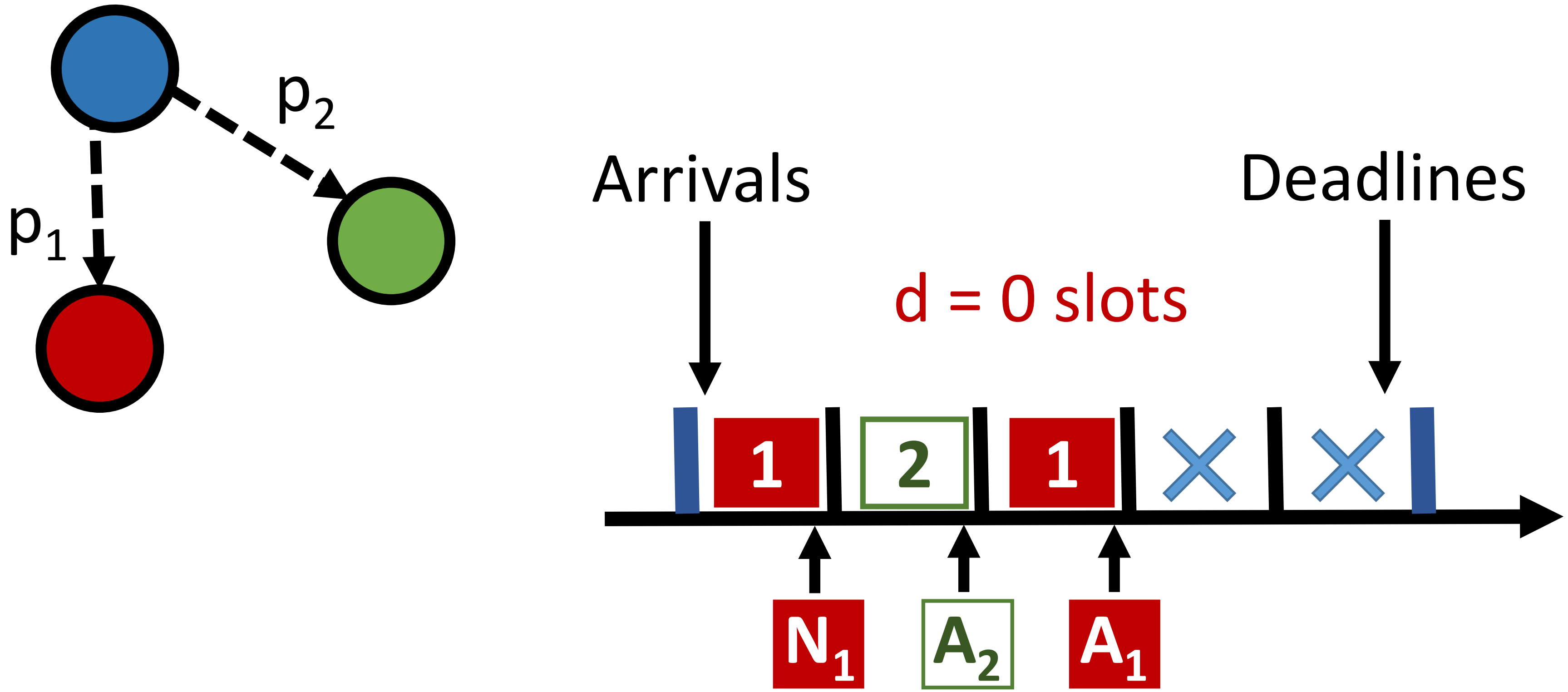
Wireless Single-Hop Network





Network Model

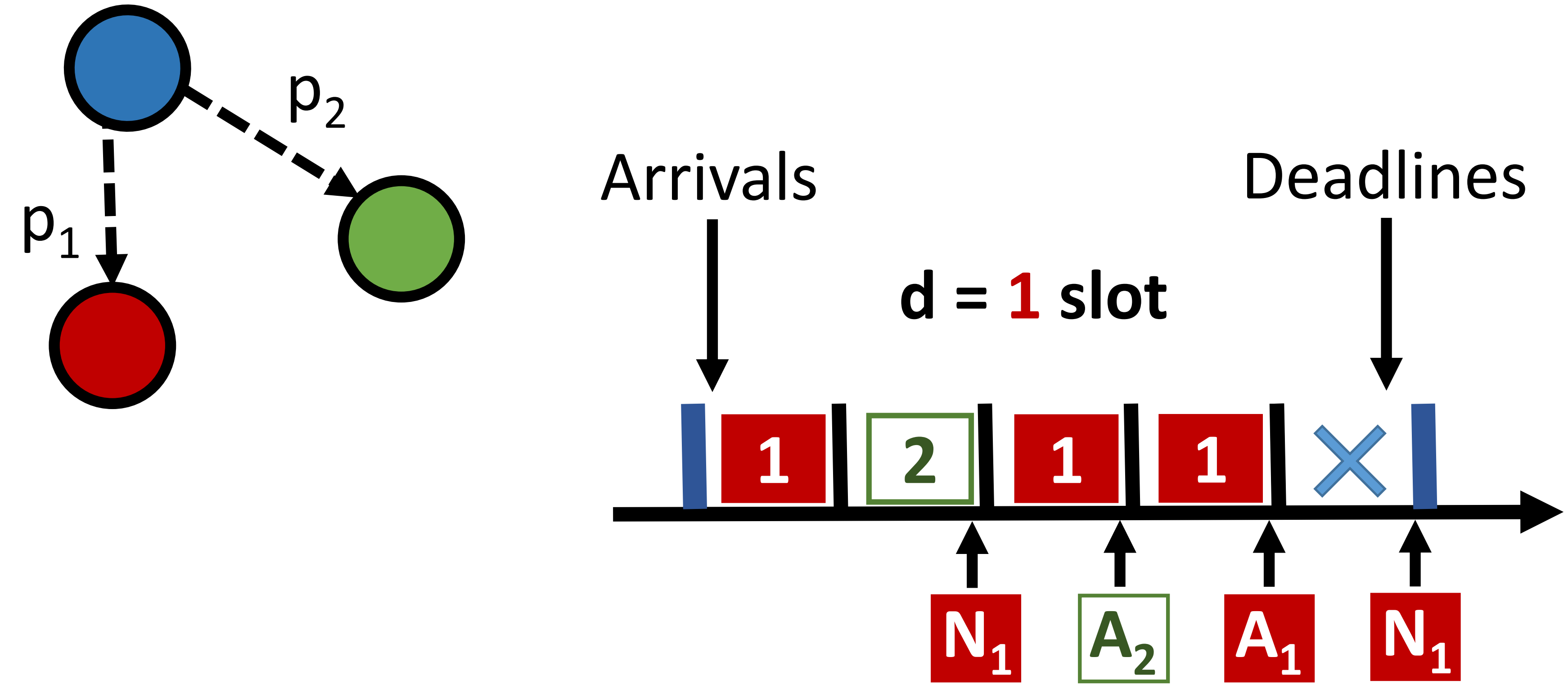
Wireless Single-Hop Network



[6] I-Hong, Kumar, **var.-bit-rate**, 2009.
[7] I-Hong, Kumar, **fading channels**, 2010.
[8] Kyu, Chih-Ping, Eytan, **multicast**, 2014.

Delayed Feedback

Network Model



Network Model

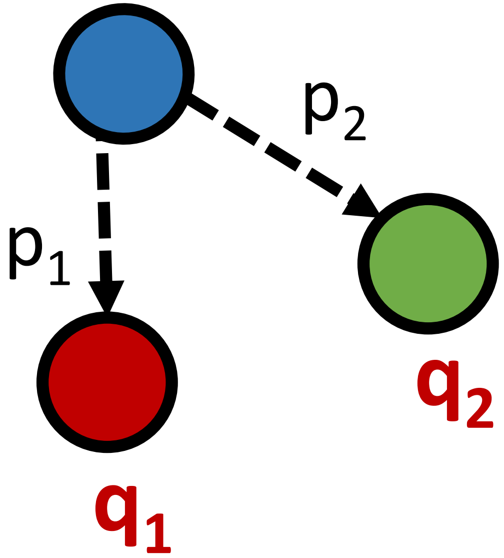
QoS Requirements and Goal

- $\eta \in \Pi$
- $D_i^{\eta}(k) = 1 \text{ or } 0$

Throughput "i": $\hat{q}_i^{\eta} \triangleq \liminf_{K \to \infty} \frac{1}{K} \sum_{k=0}^{K-1} D_i^{\eta}(k)$

QoS Requirements: $P\left(\hat{q}_i^{\eta} \geq q_i\right) = 1, \forall i$

Goal is to find η → EWST (Expected Weighted Sum Throughput)



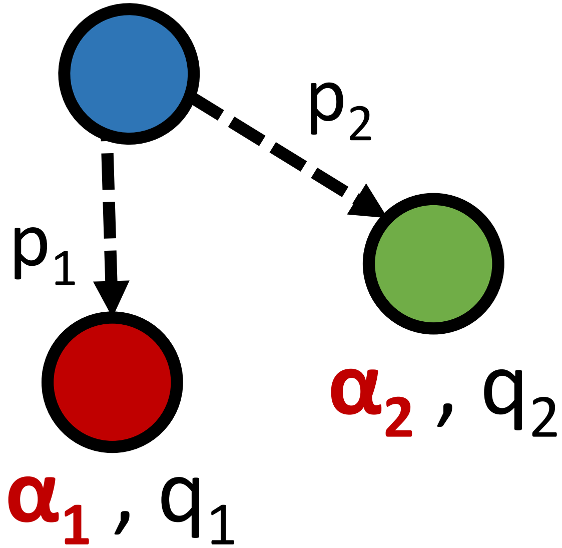
QoS Requirements and Goal

Network Model

- $\eta \in \Pi$
- $D_i^{\eta}(k) = 1 \text{ or } 0$

Optimization Problem:

$$EWST(\vec{\alpha}) = \max_{\eta \in \Pi} \sum_{i=1}^{N} \alpha_i E[D_i^{\eta}(0)]$$



Solution

Dynamic Program

For t and for $\tilde{s}_t$:

$$J_t(\tilde{s}_t) = \max_{u_t \in U_t(.)} E[g_t(.) + J_{t+1}(.)]$$

Result:

$$J_0(\emptyset) = \max_{\eta \in \Pi} \sum_{i=1}^{N} \alpha_i E\left[D_i^{\eta}(0)\right] \quad \text{and} \quad \eta^*$$

Dynamic Program

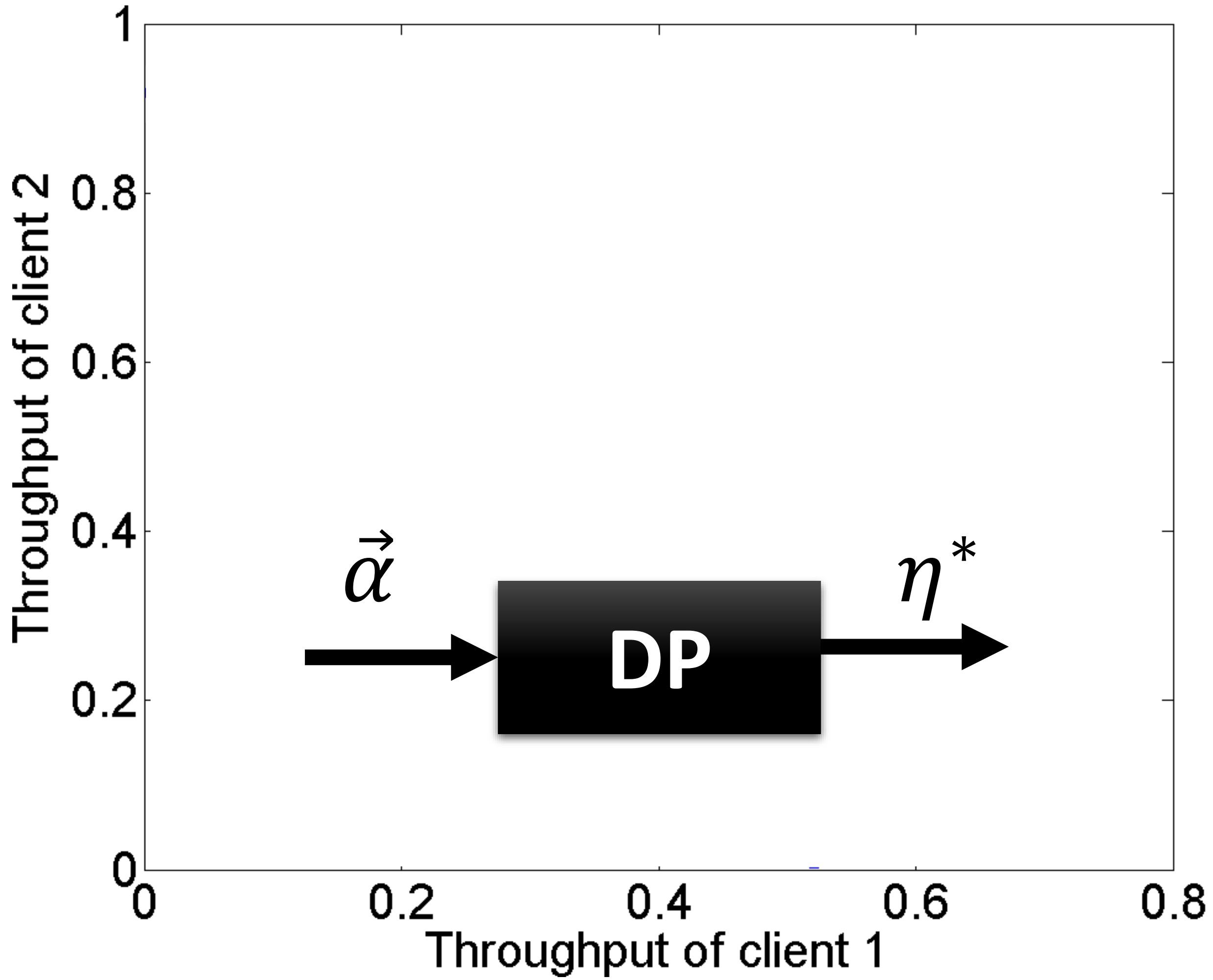
For t and for $\tilde{s}_t$:

$$J_t(\tilde{s}_t) = \max_{u_t \in U_t(.)} E[g_t(.) + J_{t+1}(.)]$$

$O(T\, 2^N N^d)$

Feasible Region

Feasible Throughput Region



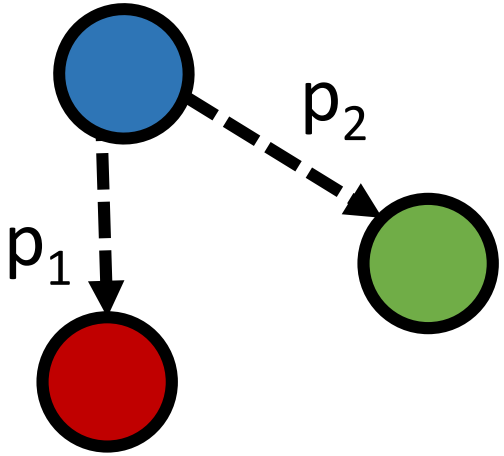
N = 2

T = 7

d = 2

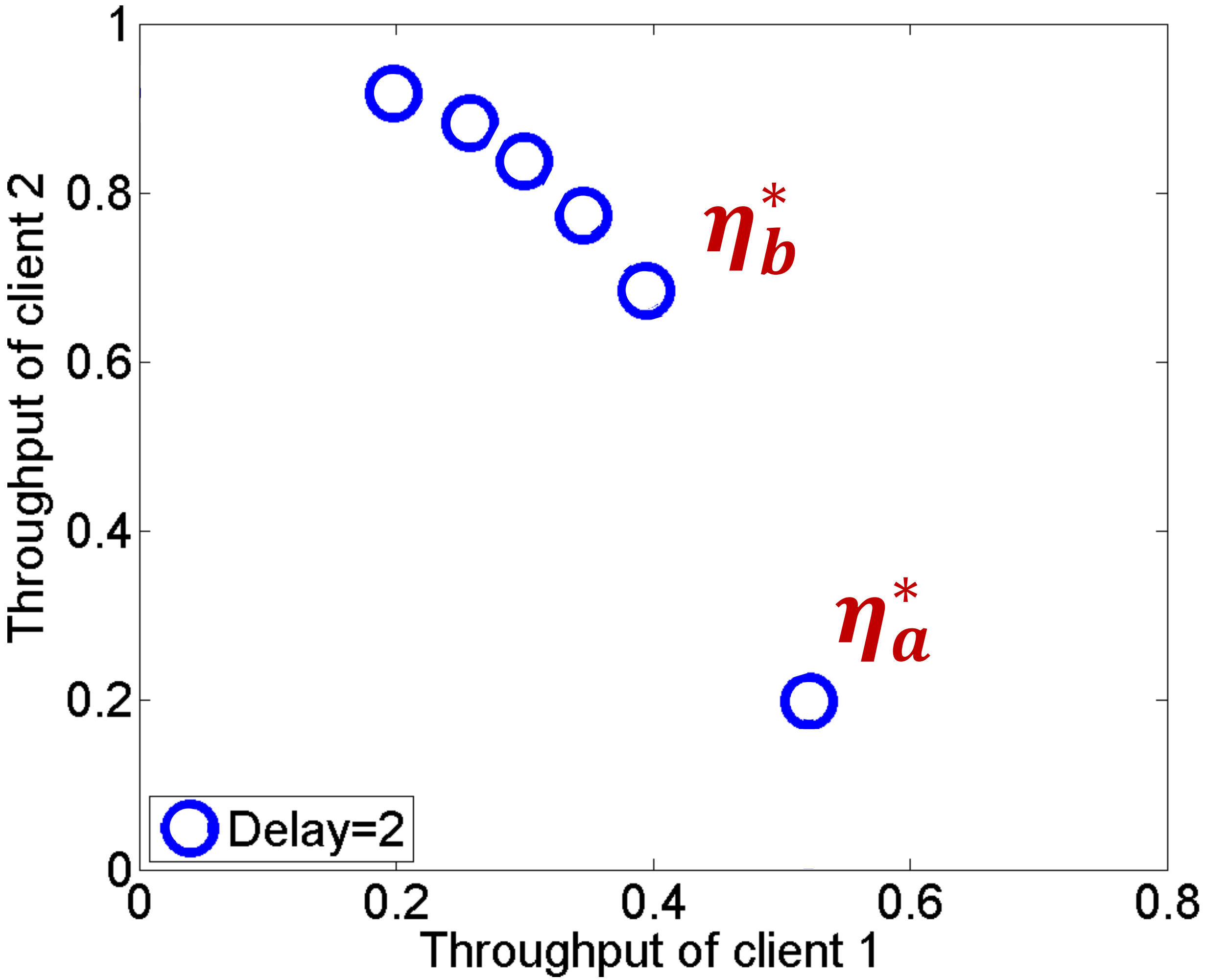
$p_1 = 0.1$

$p_2 = 0.3$



Feasible Region

Feasible Throughput Region



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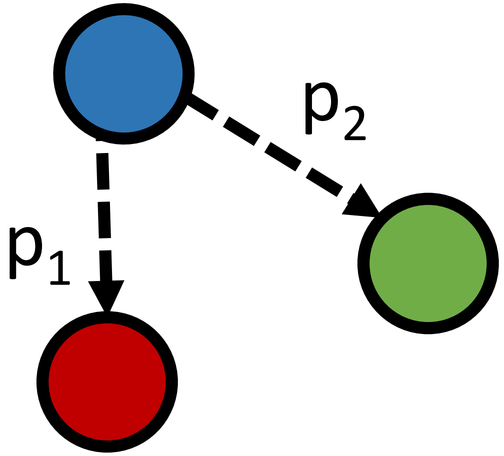
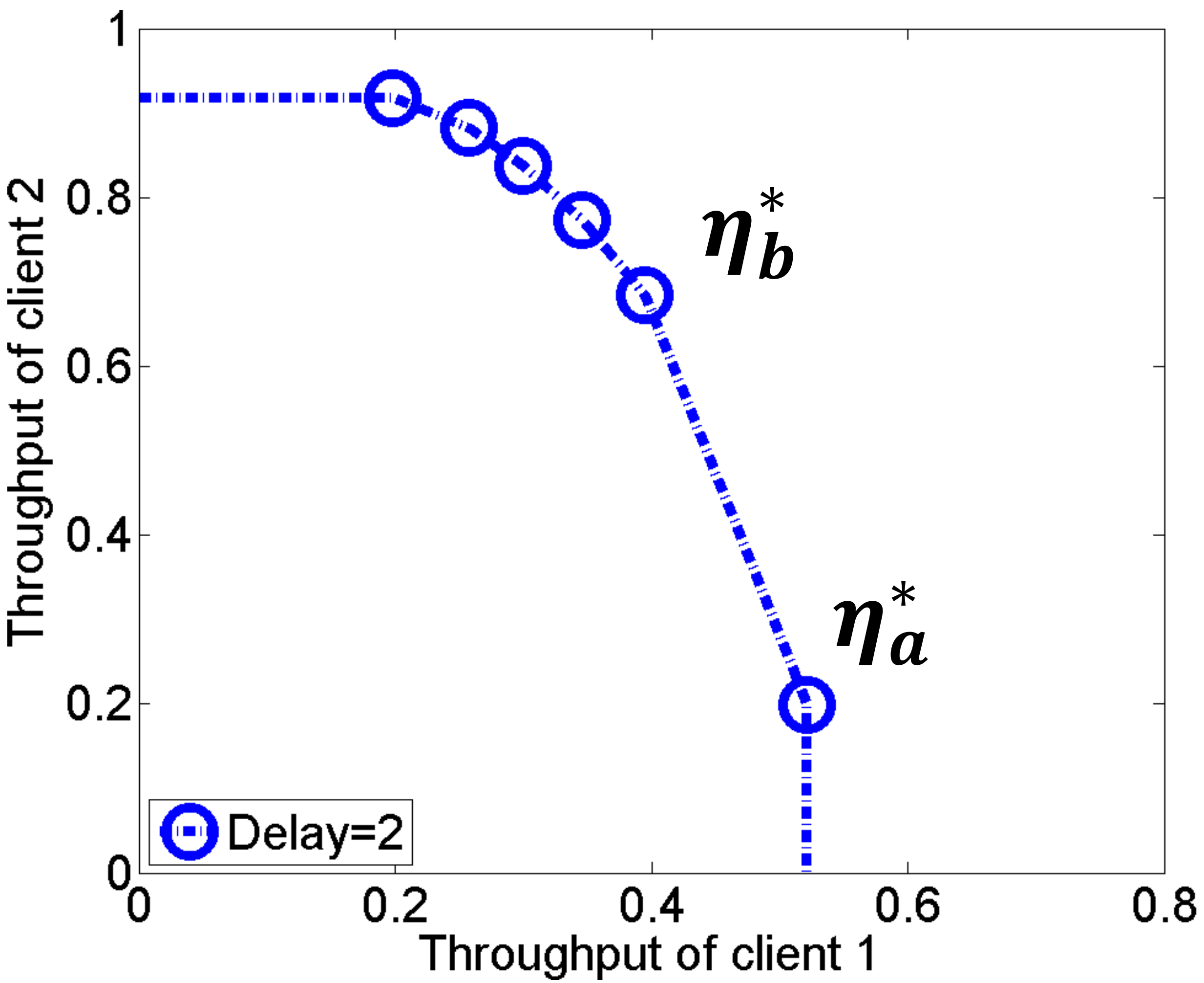


Feasible Throughput Region

Feasible Region



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d = 2

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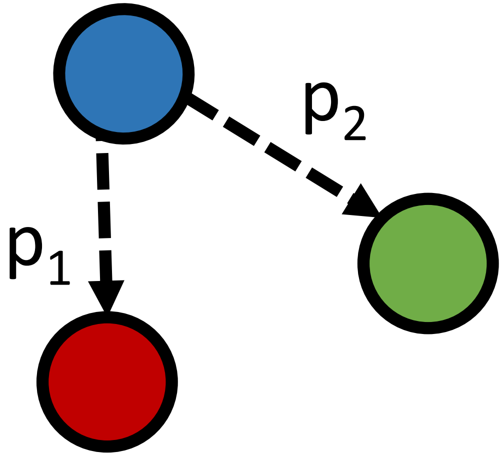
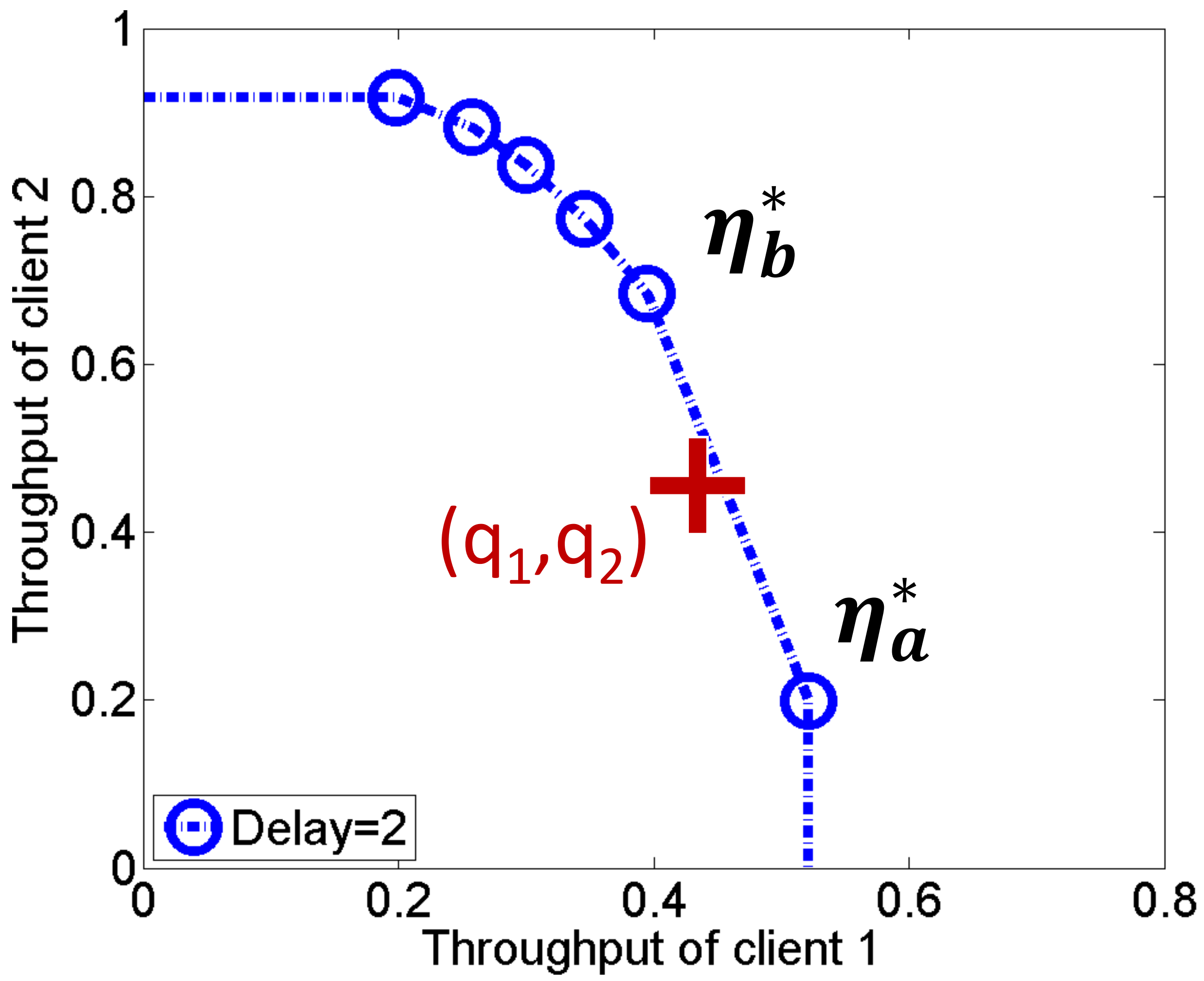


Feasible Throughput Region



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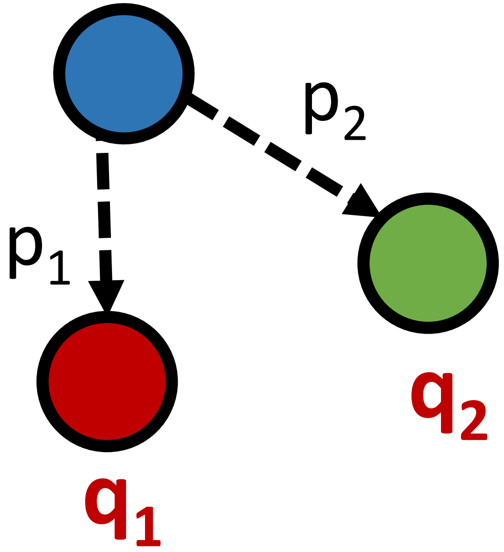
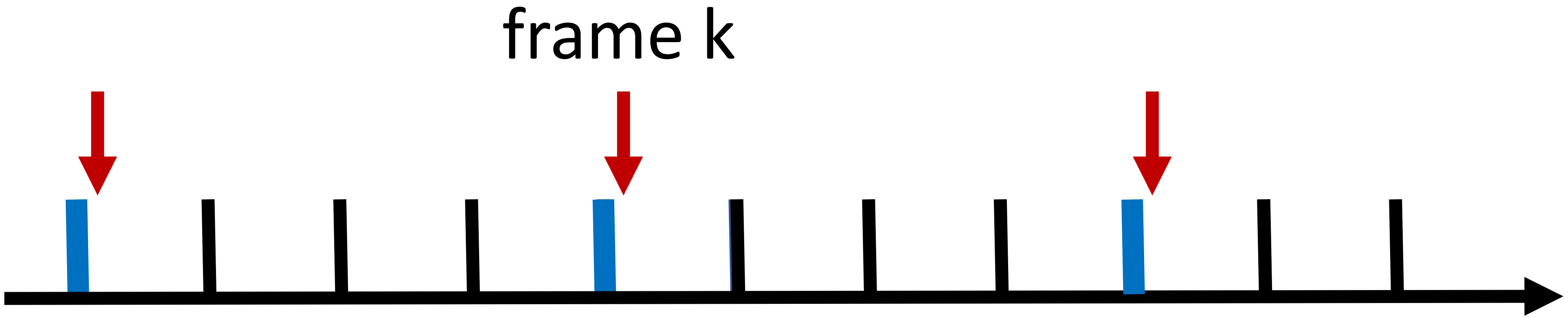


Feasibility Optimal Algorithm

Optimal Algorithm

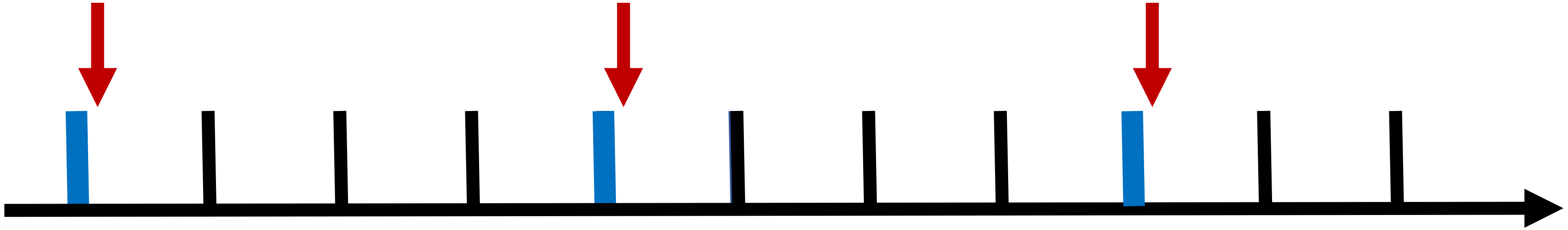
$$d_i(k) = kq_i - Q_i(k)$$



Feasibility Optimal Algorithm

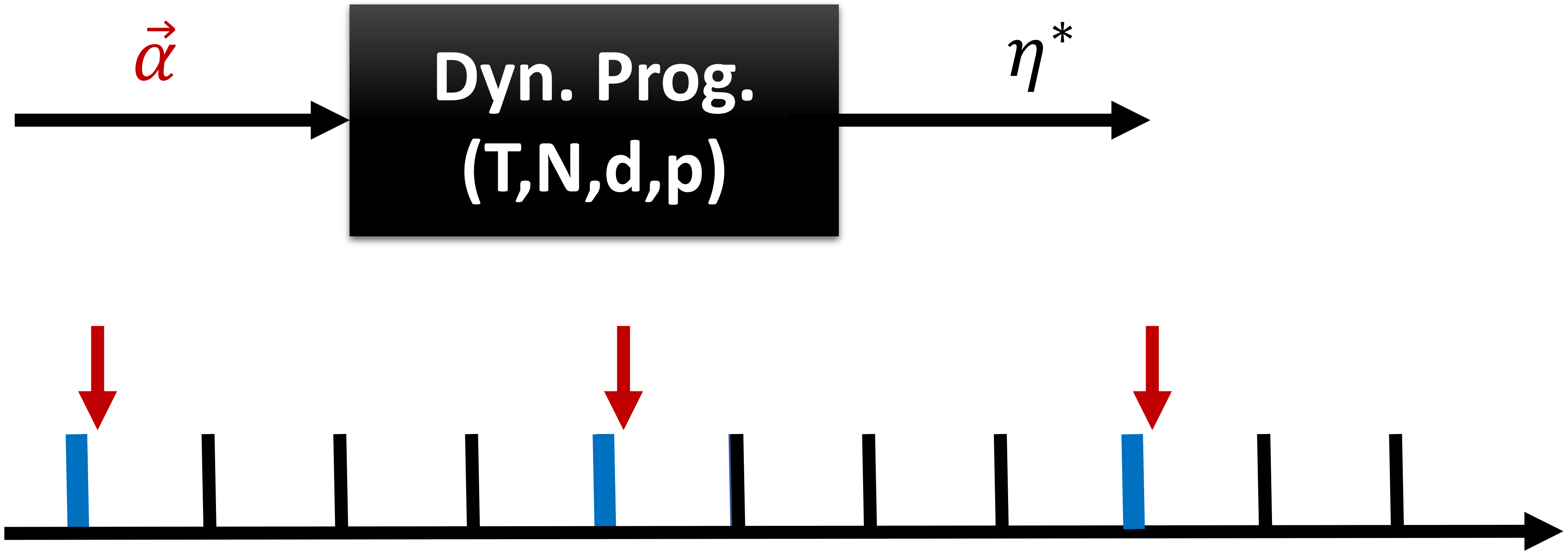
Optimal Algorithm

$$\alpha_i = \max\{d_i(k), 0\} \rightarrow \vec{\alpha}$$



Optimal Algorithm

Feasibility Optimal Algorithm

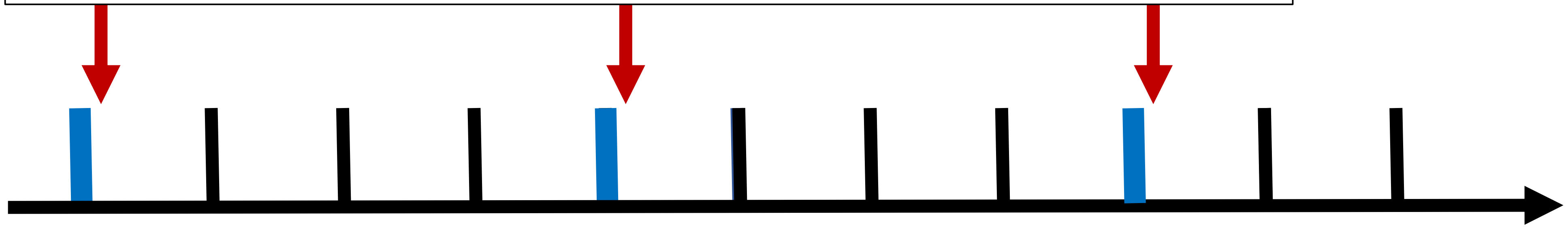


Feasibility Optimal Algorithm

Optimal Algorithm

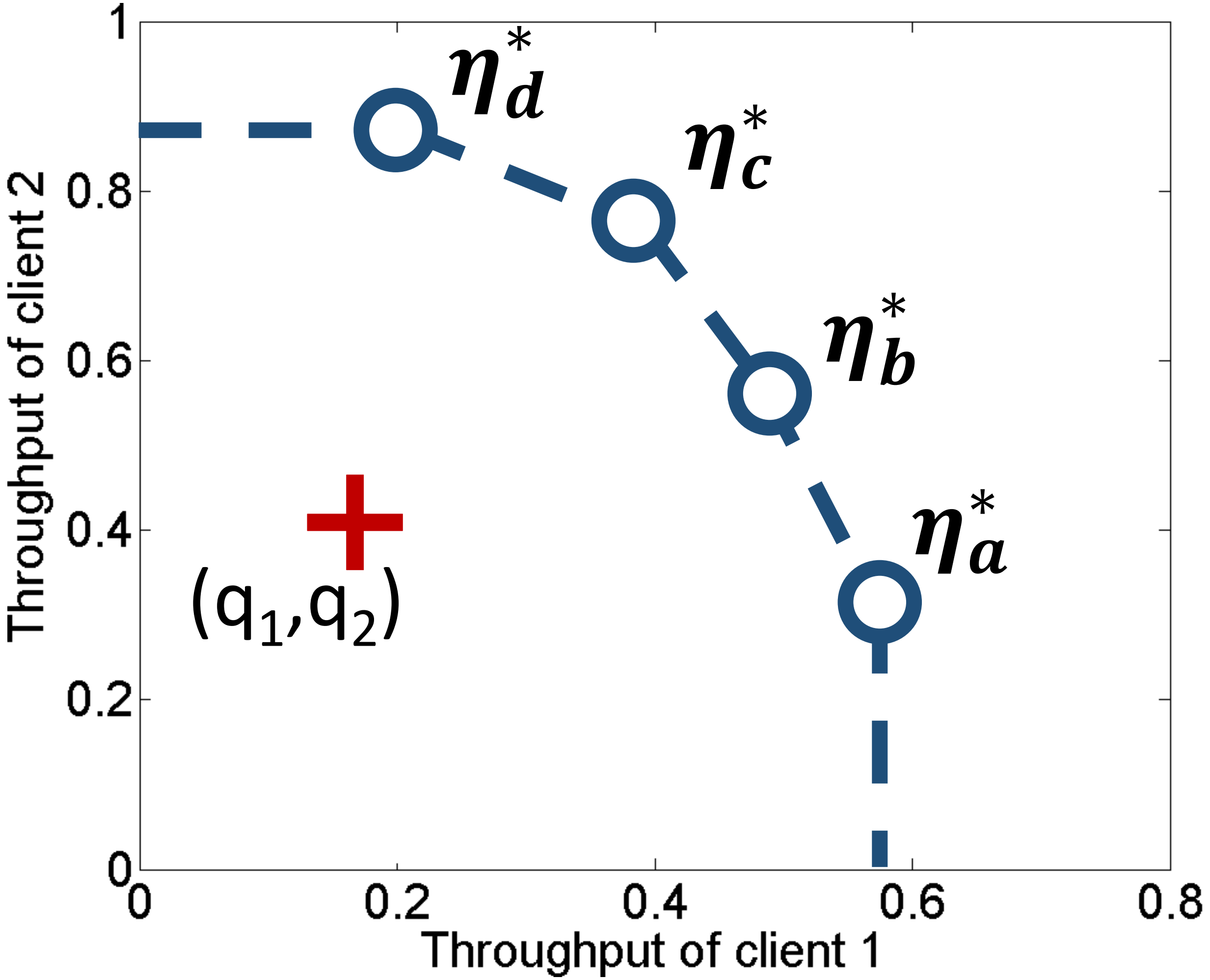
<u>Frame-Based Max-Weight Algorithm</u>

- $d_i(k) = kq_i - Q_i(k)$
- $\alpha_i = \max\{d_i(k), 0\}$
- Employ η^*

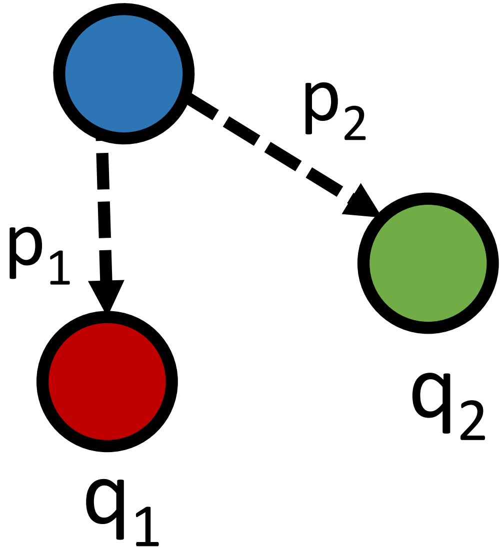


Feasibility Optimal Algorithm

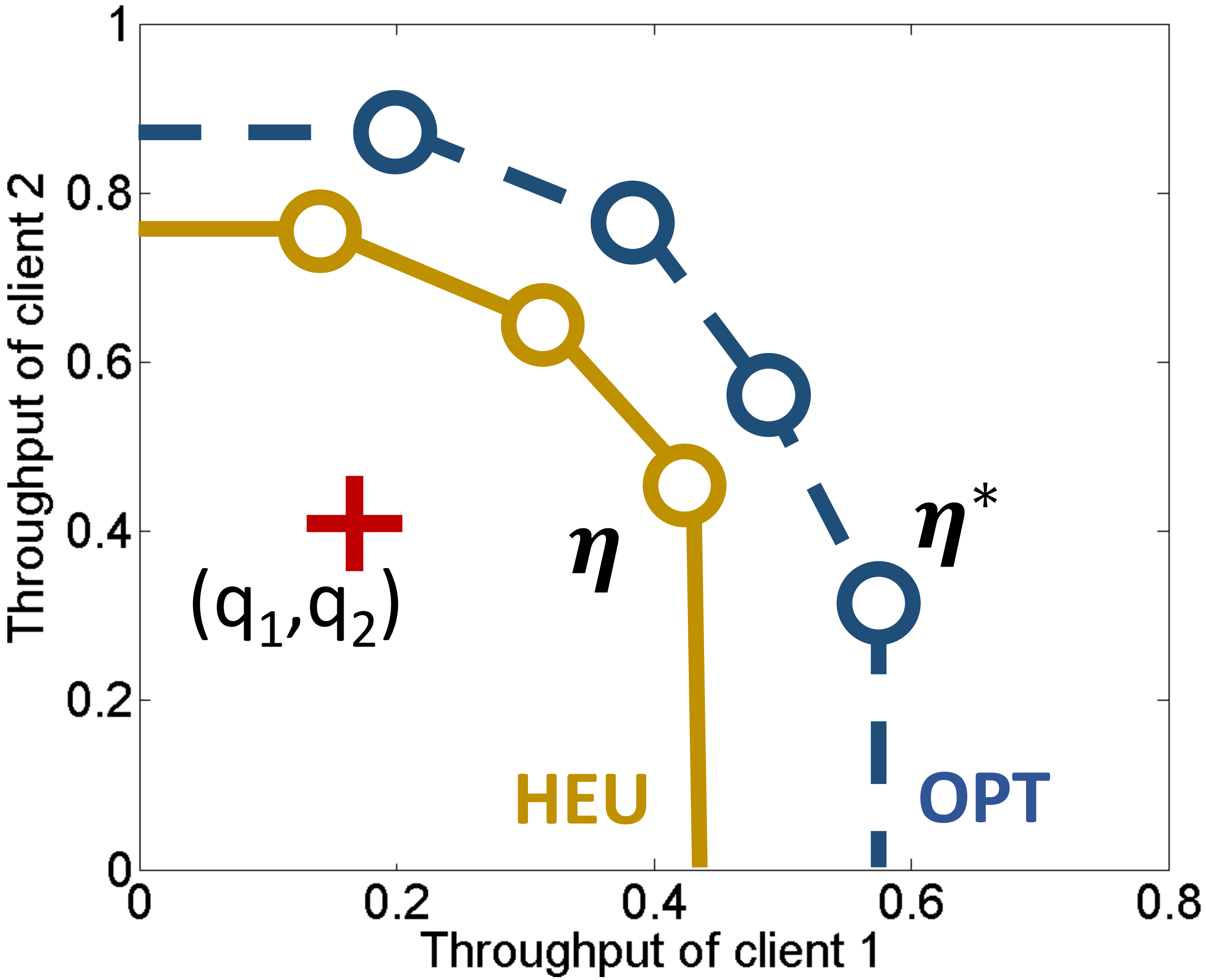
Optimal Algorithm



N
T
d
p_1
p_2



Heuristic Algorithm



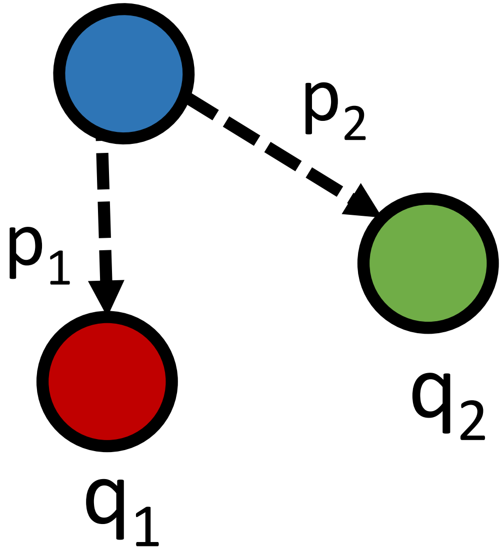
N

T

d

p_1

p_2



Heuristic Algorithm

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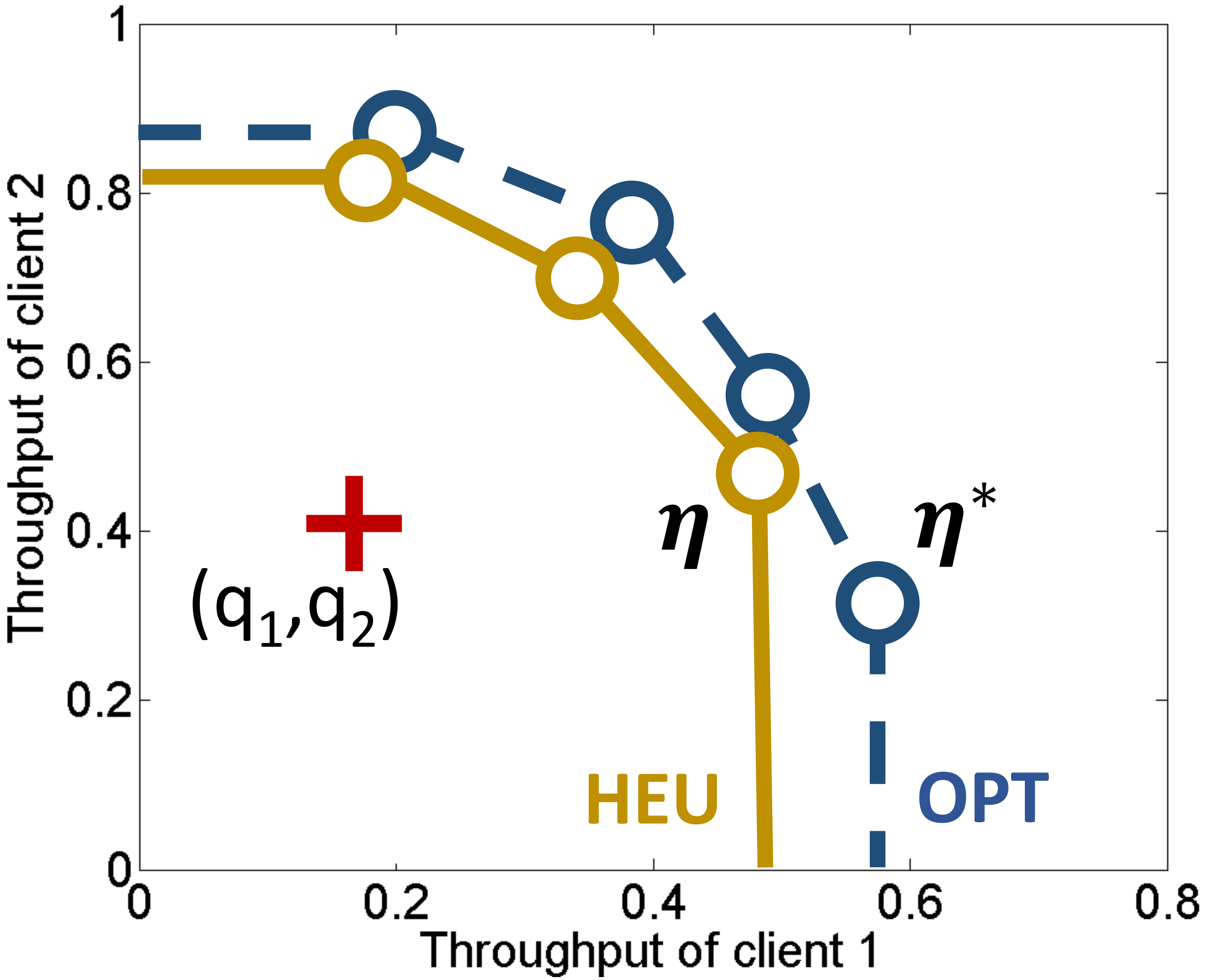


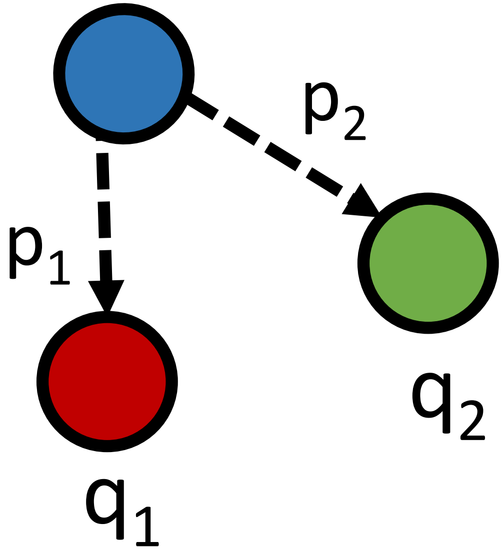
N

T

d

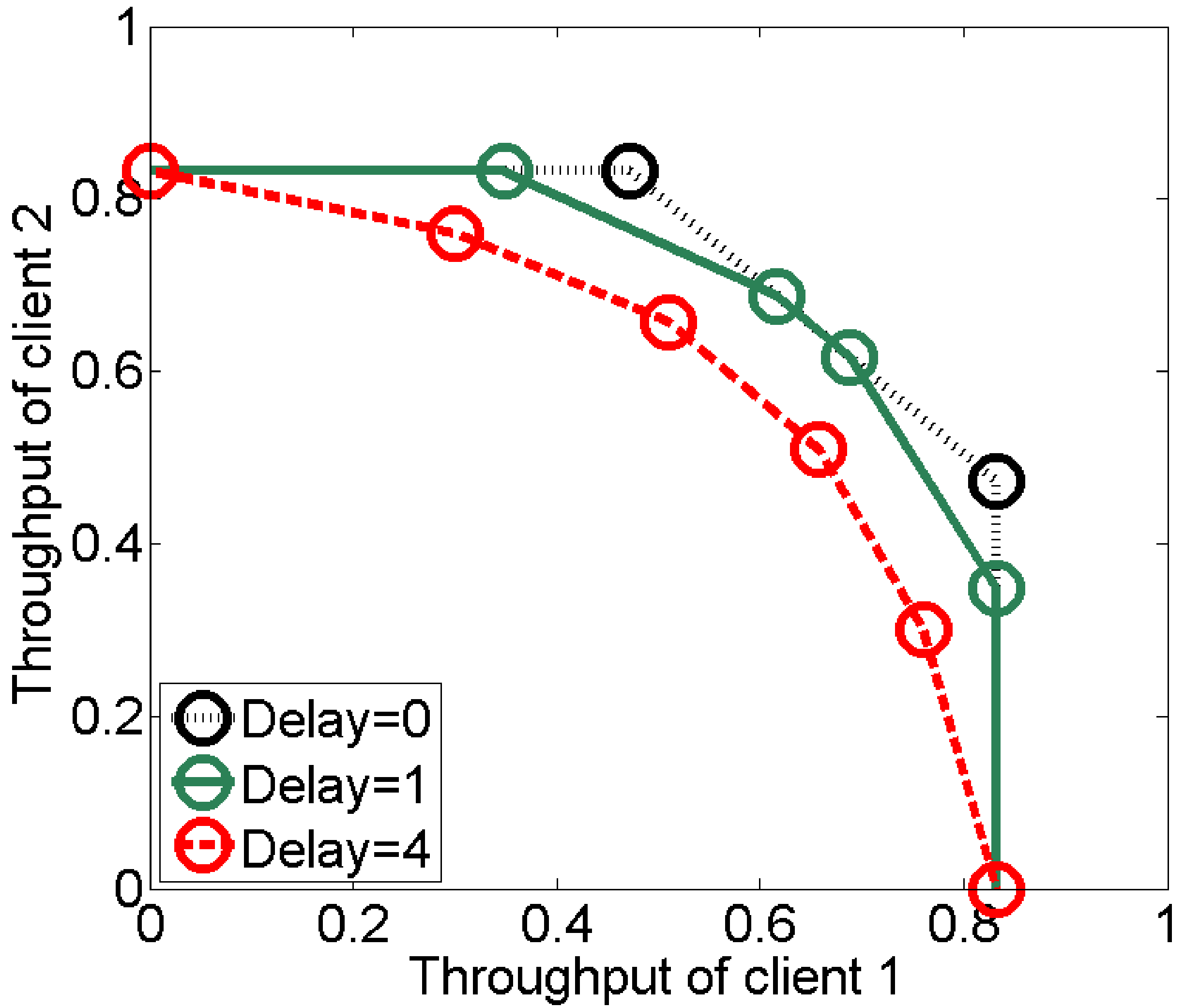
p_1

p_2



Heuristic Algorithm

Insights into the Optimal Policies



$N = 2$

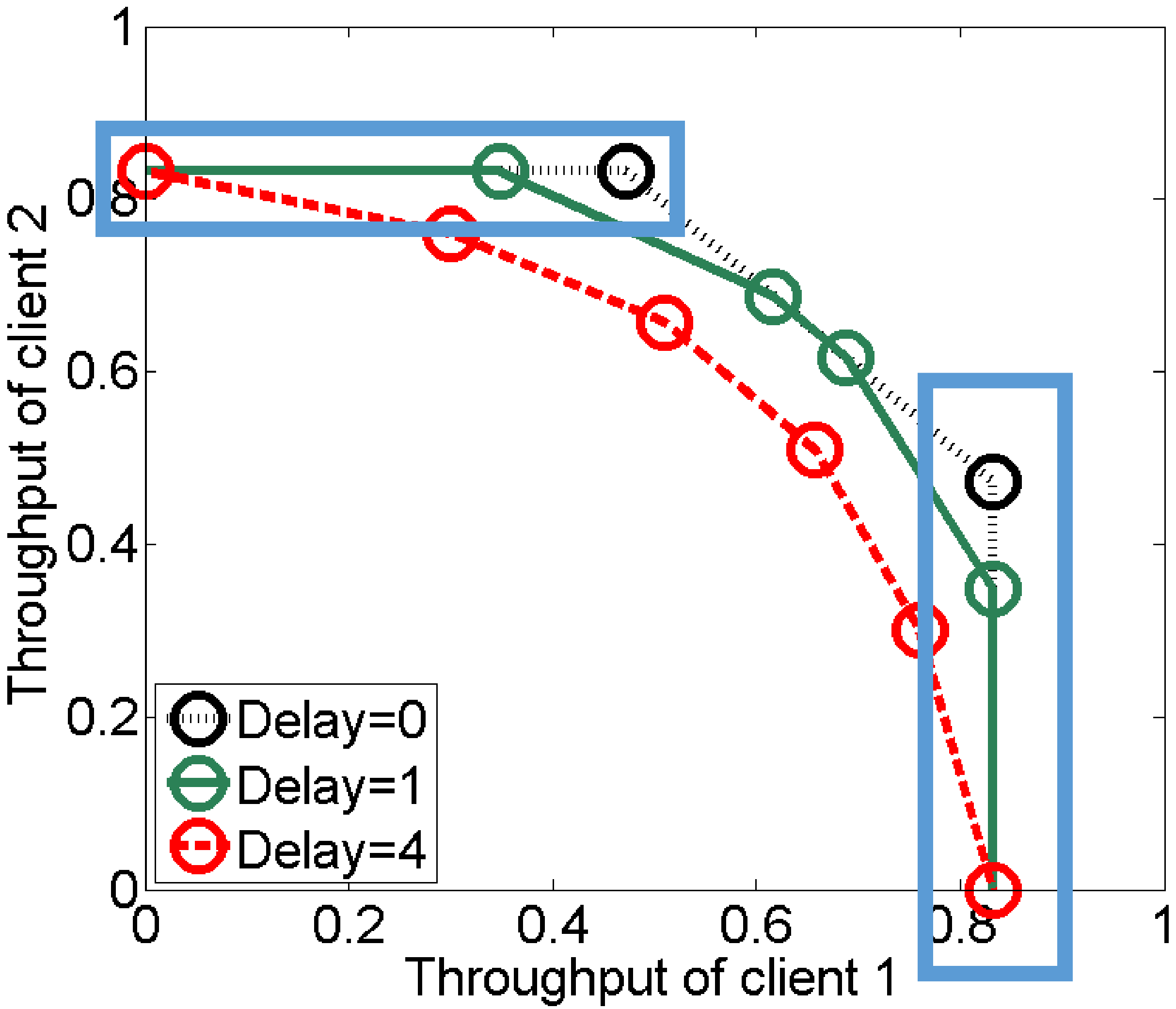
$T = 5$

$d = 0,1,4$

$p_1 = p_2 = 0.3$

Heuristic Algorithm

Insights into the Optimal Policies



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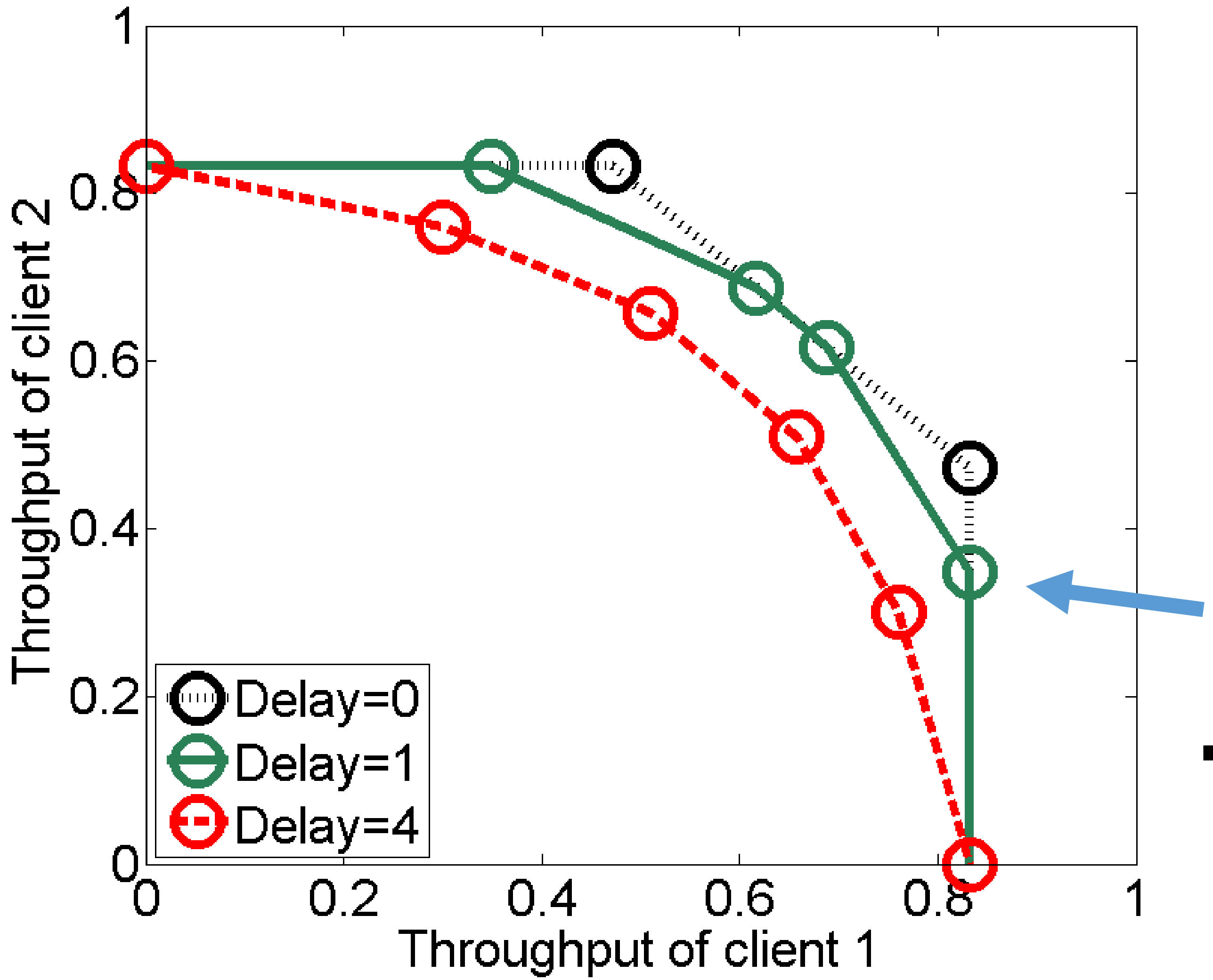

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d = 0,1,4

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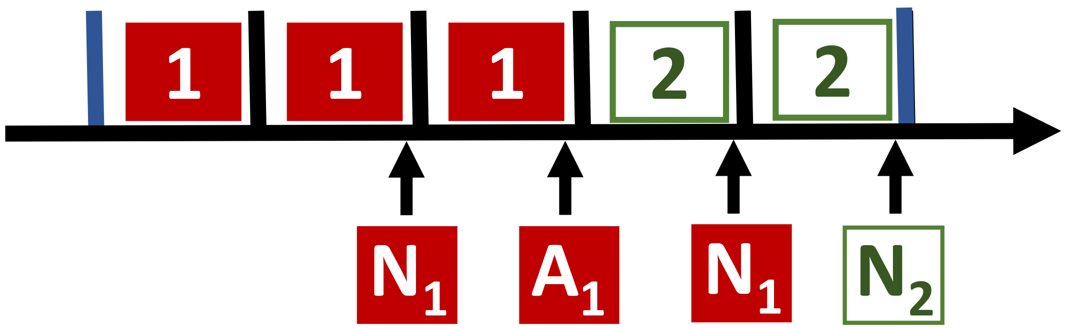

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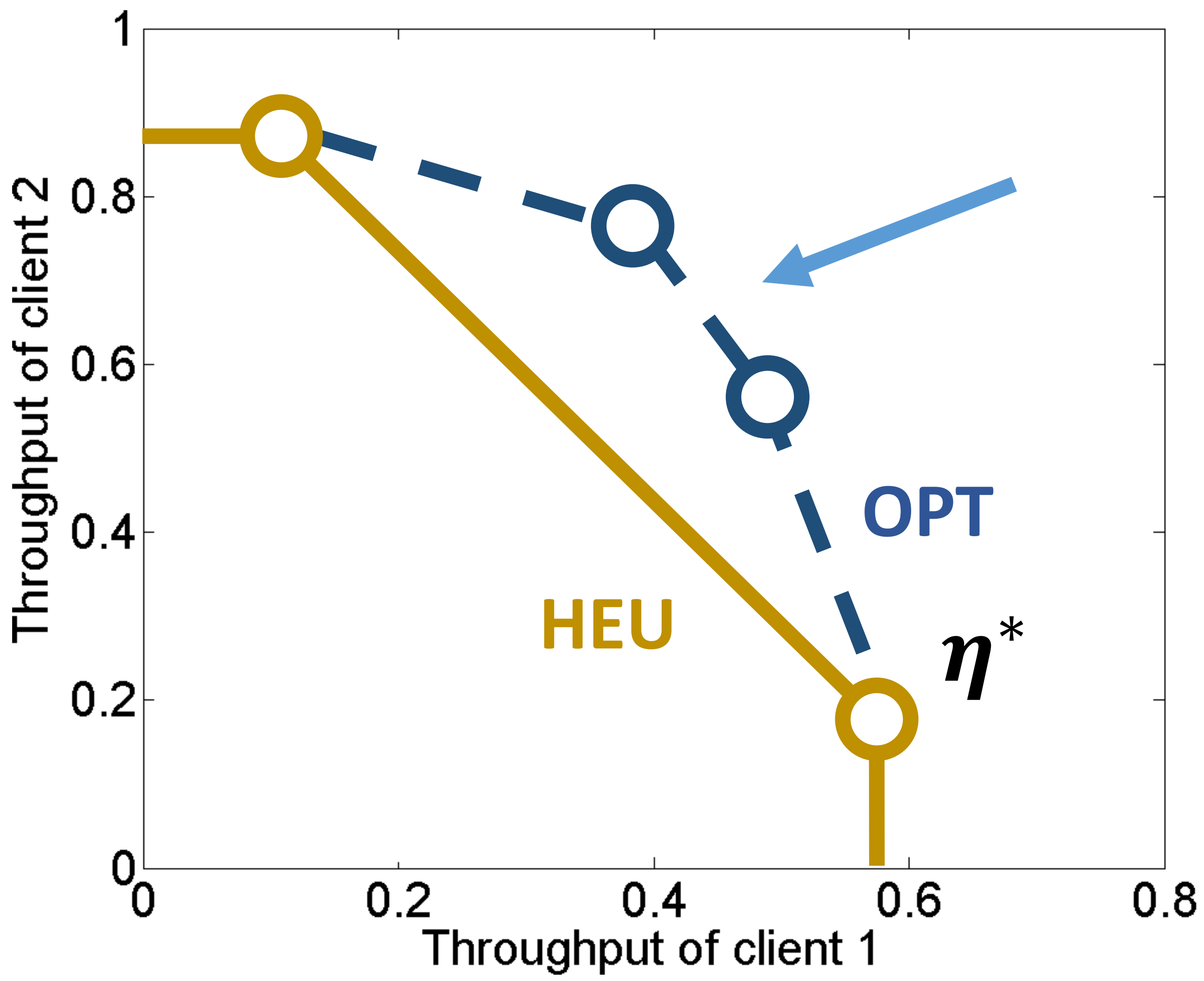

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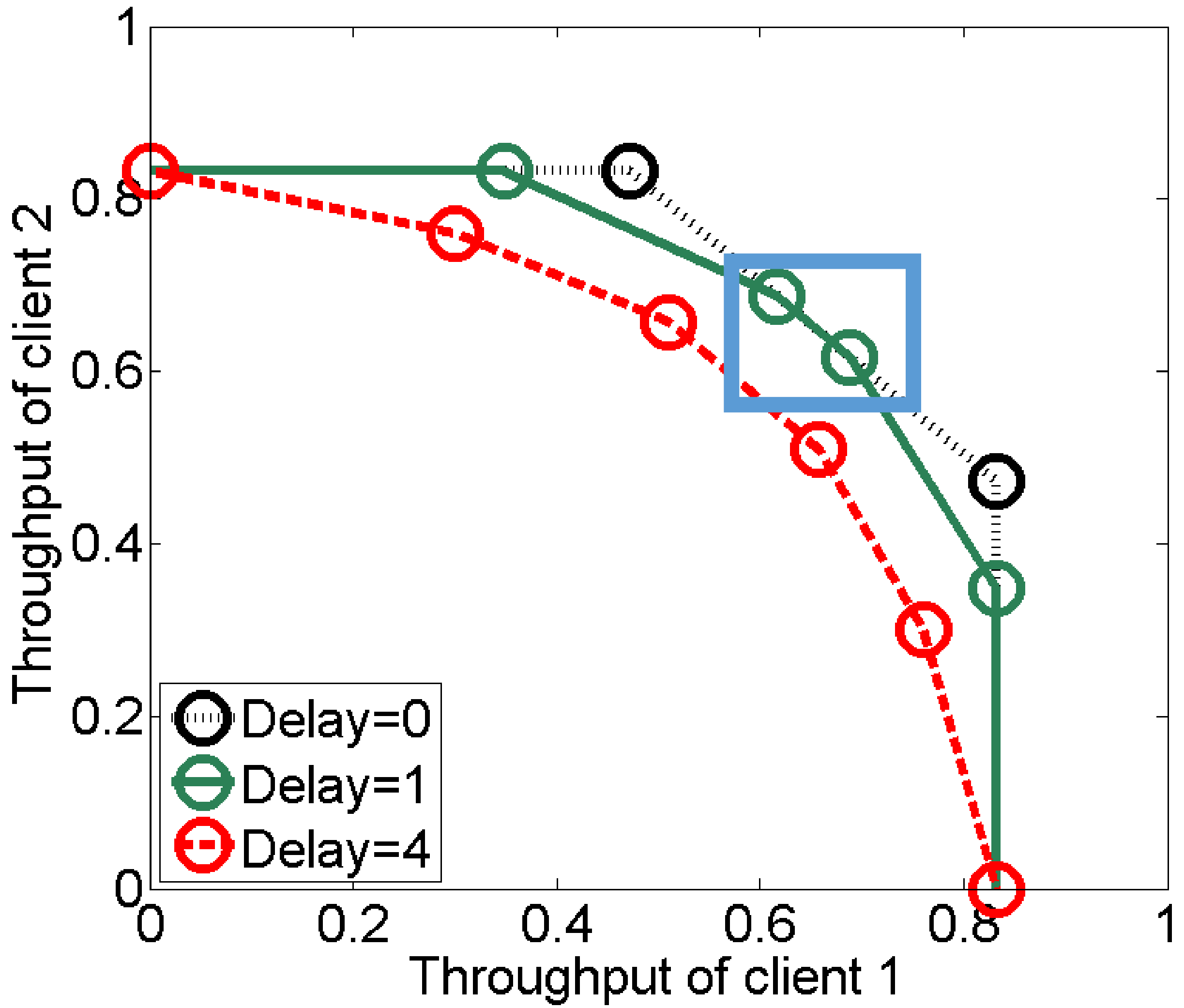

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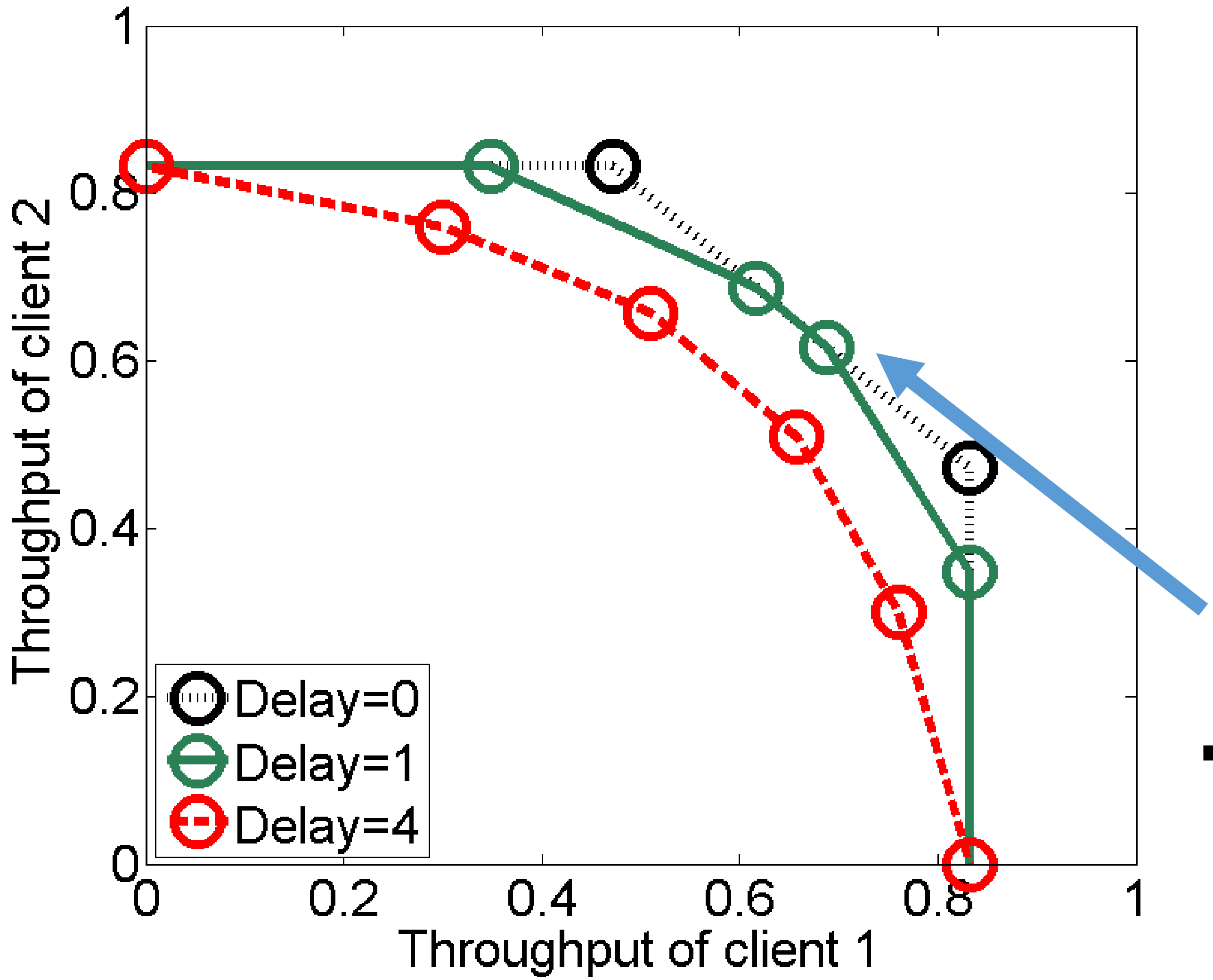

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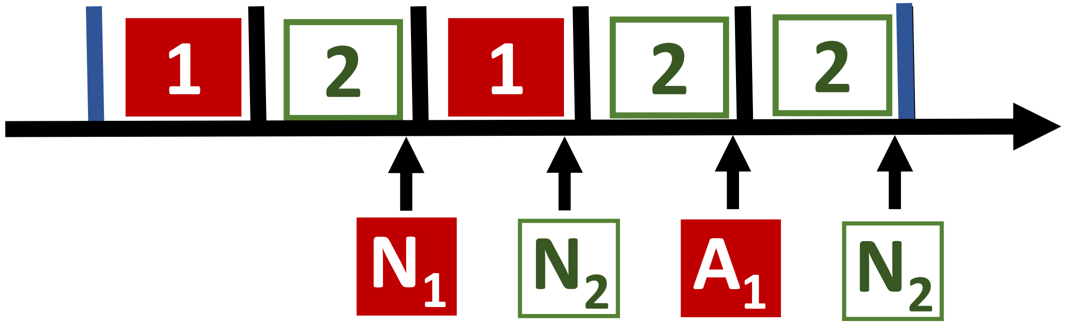
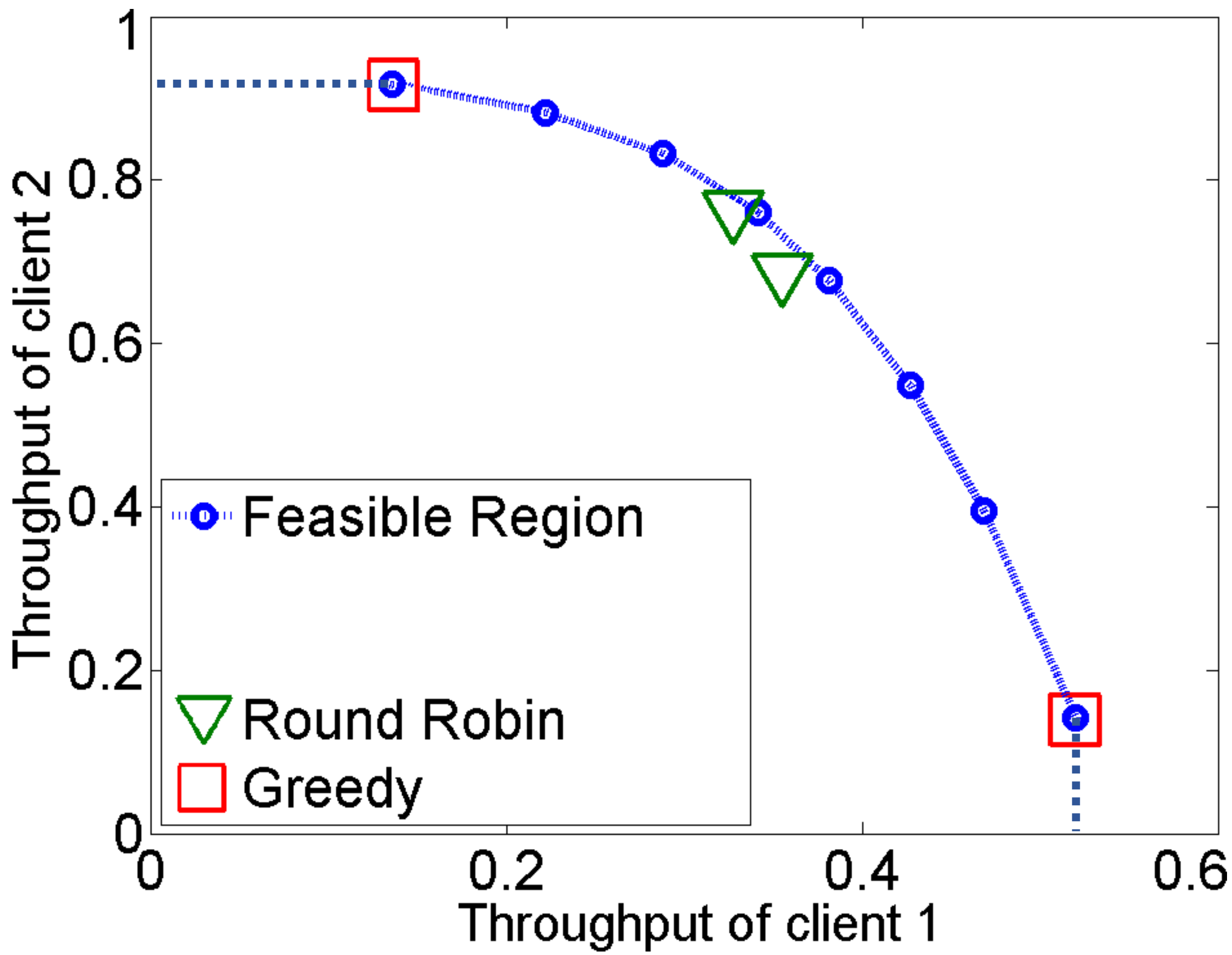


Optimal vs Heuristic

Heuristic Algorithm



N = 2

T = 7

d = 3

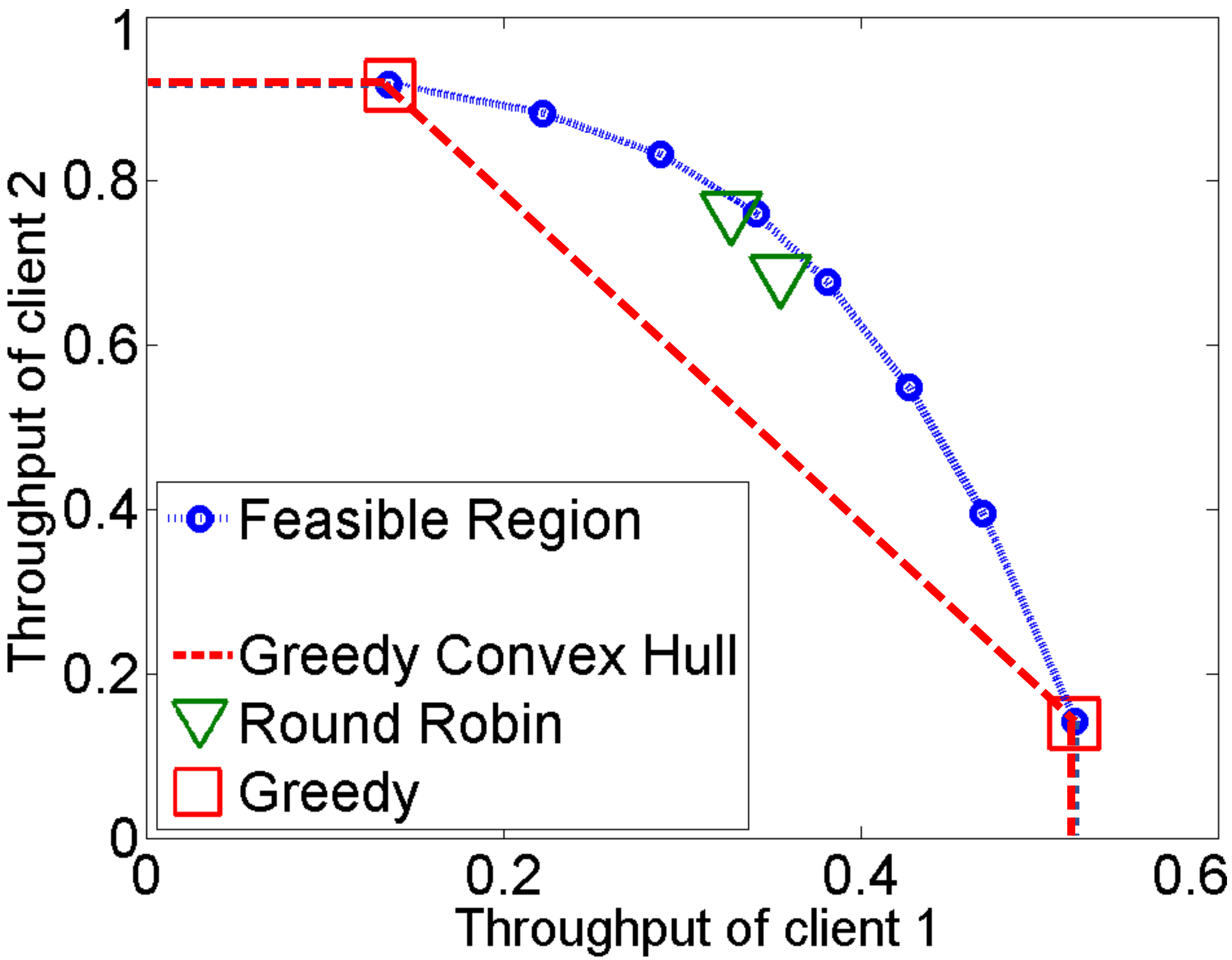
$p_1 = 0.1$

$p_2 = 0.3$

frames = $5x10^4$

Heuristic Algorithm

Optimal vs Heuristic



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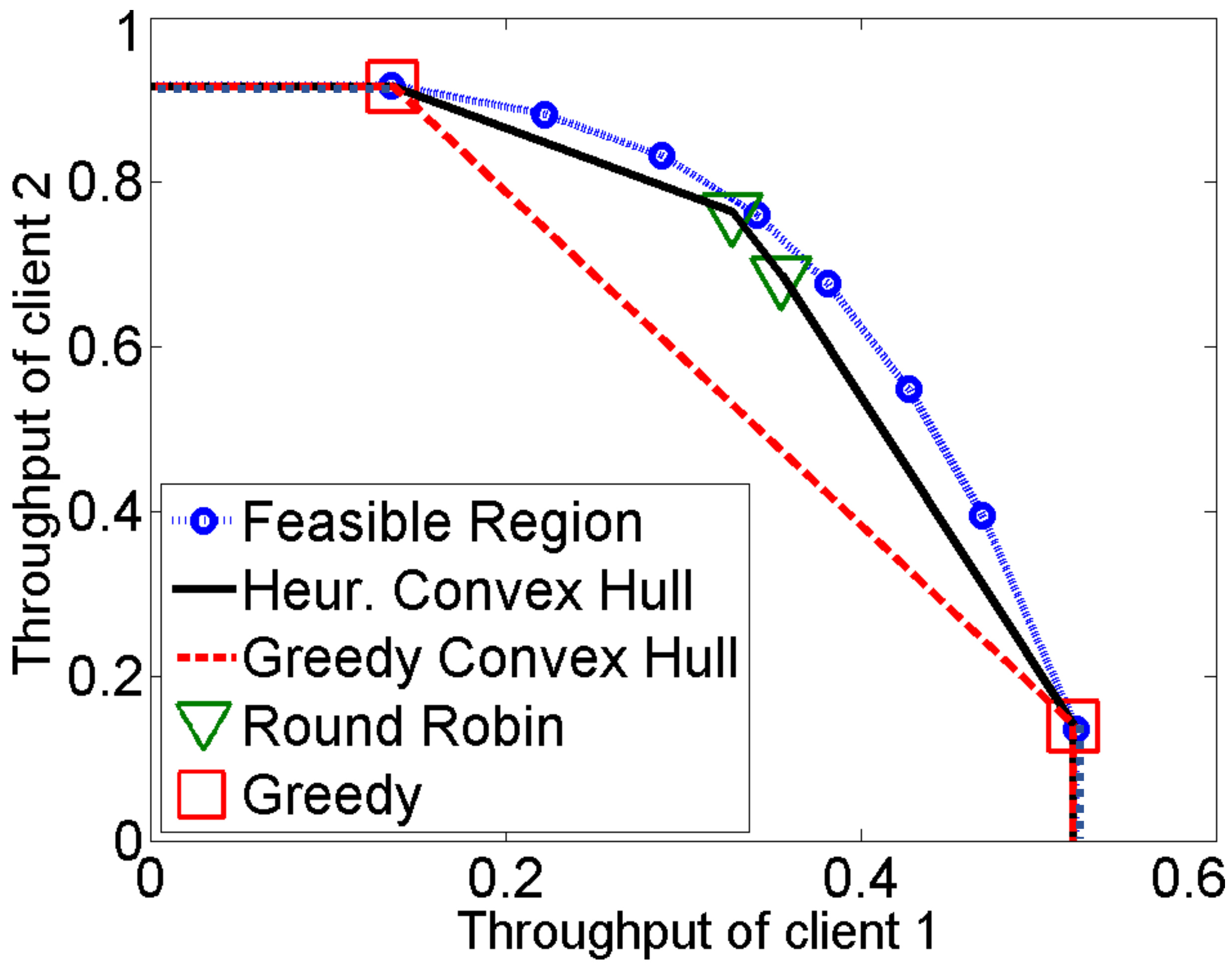
frames = 5×10^4

Heuristic Algorithm

Optimal vs Heuristic



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T = 7

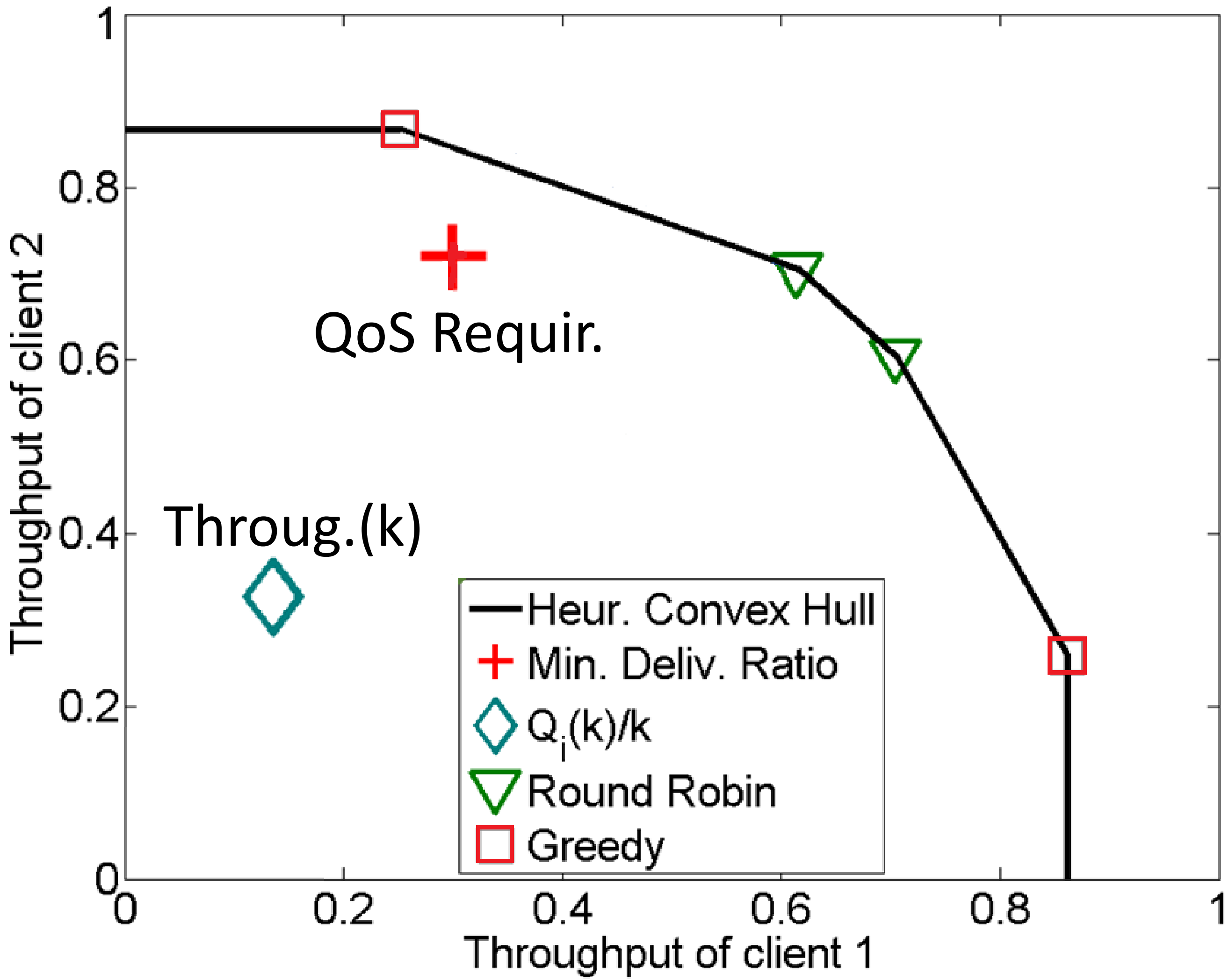
d = 3

$p_1 = 0.1$

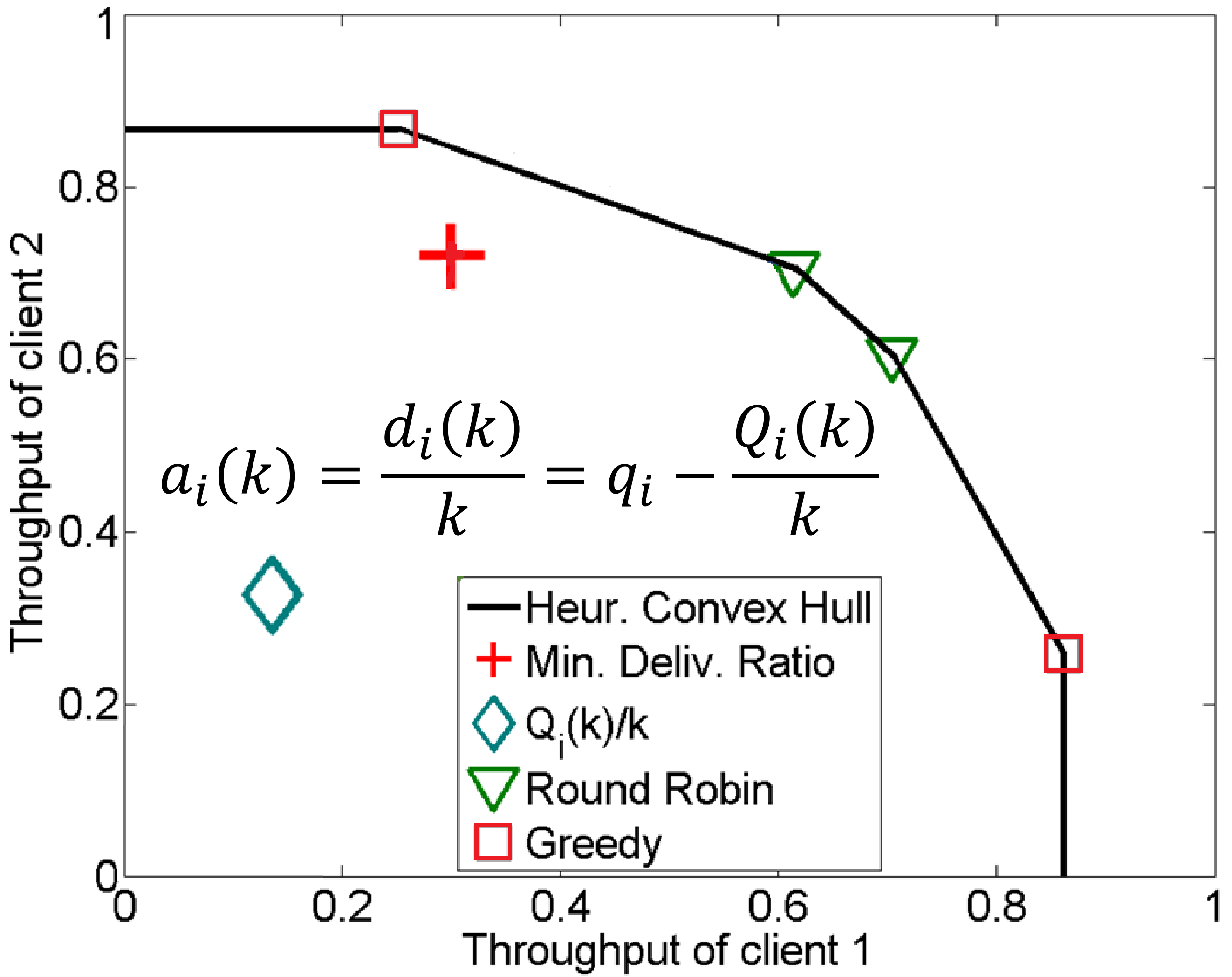
$p_2 = 0.3$

frames = 5×10^4

Heuristic Algorithm

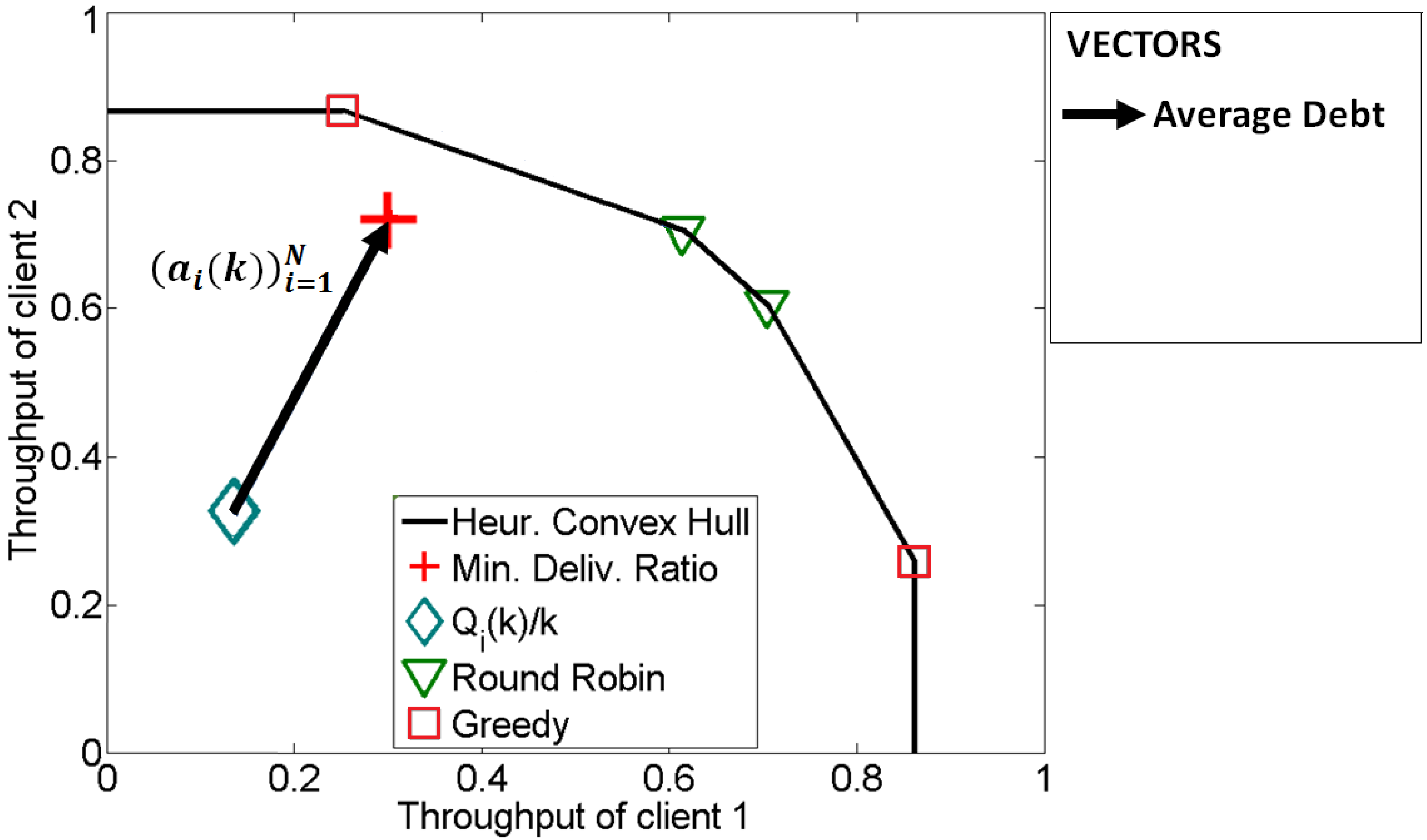


Heuristic Algorithm



$$a_i(k) = \frac{d_i(k)}{k} = q_i - \frac{Q_i(k)}{k}$$

Heuristic Algorithm



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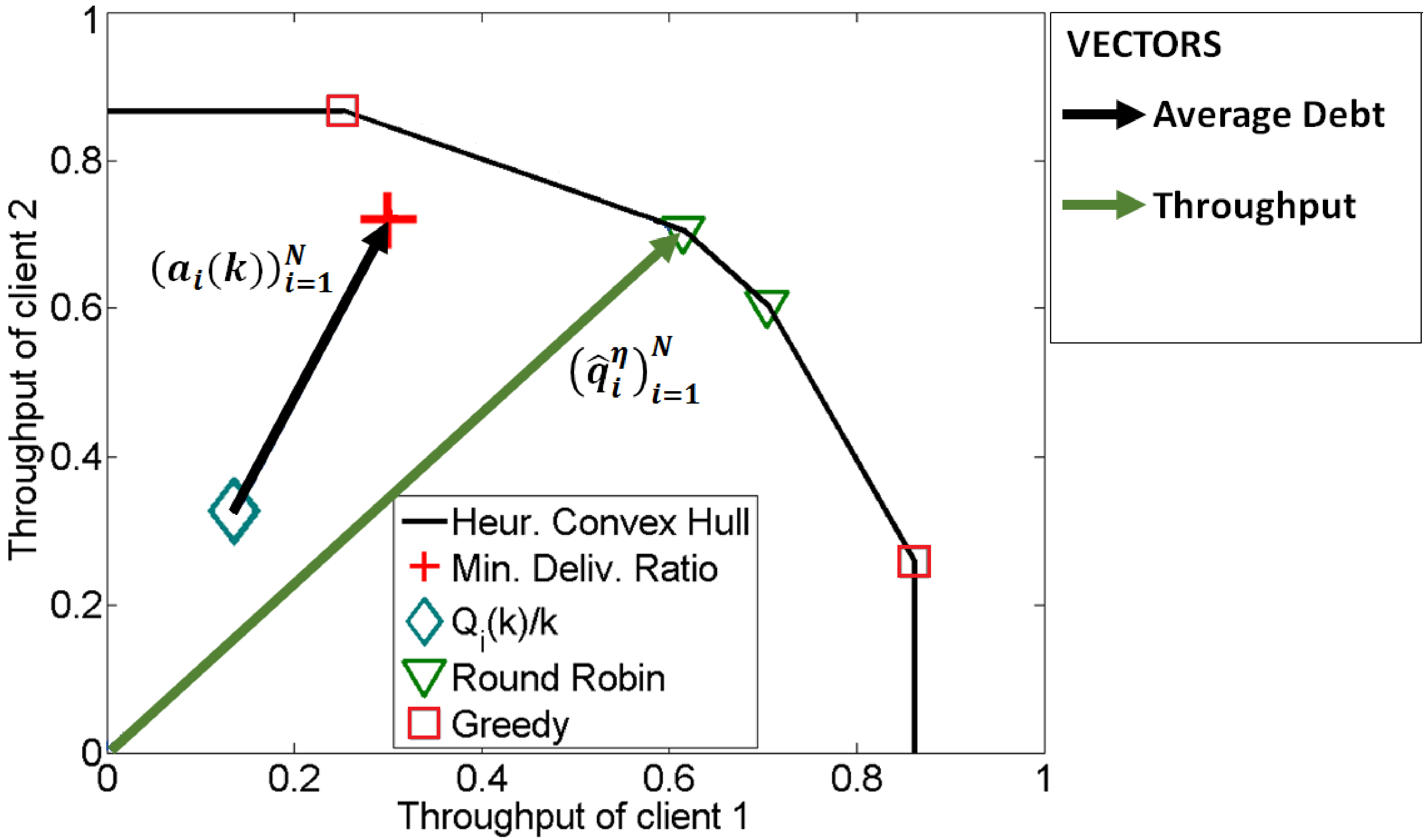
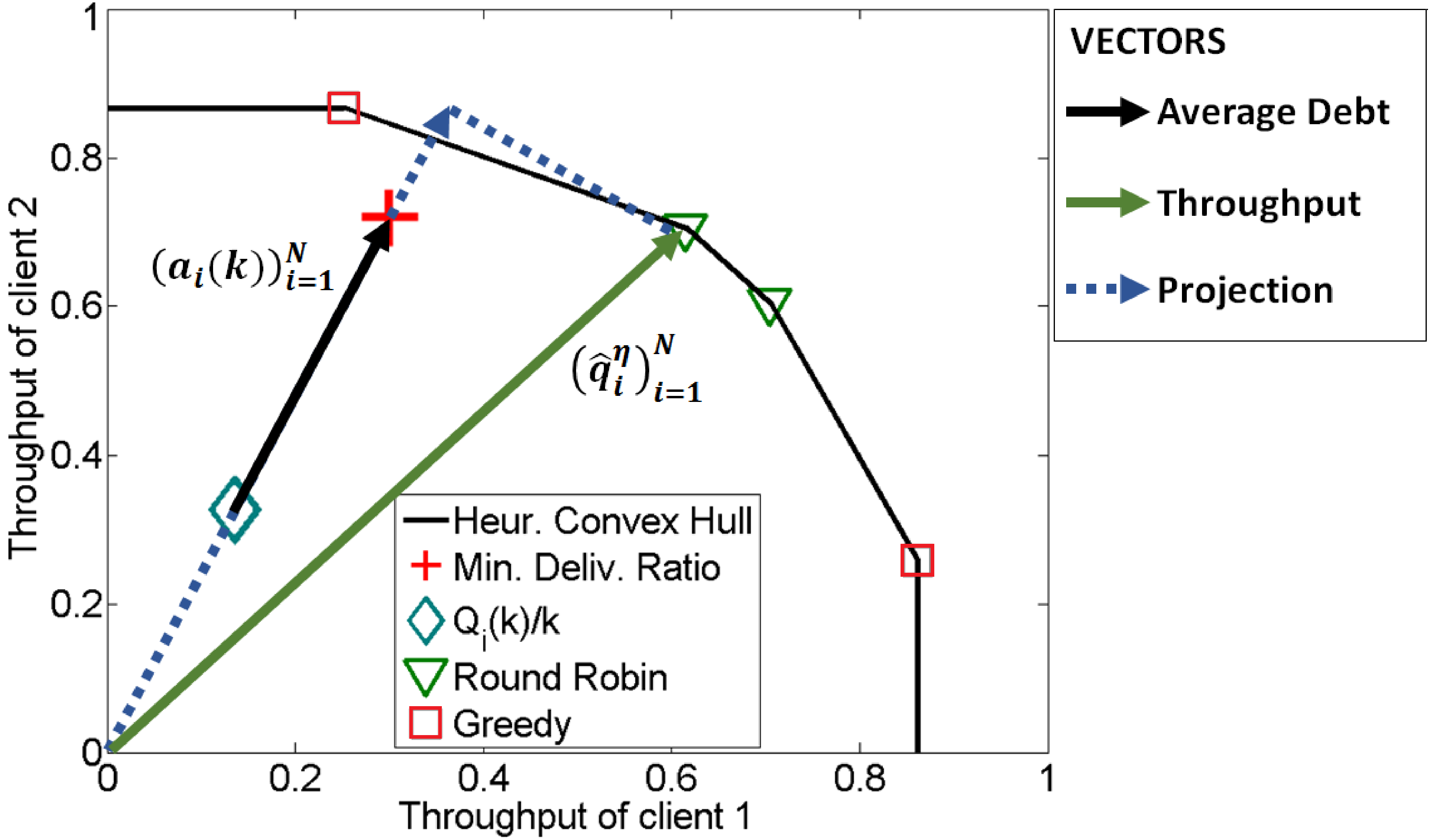


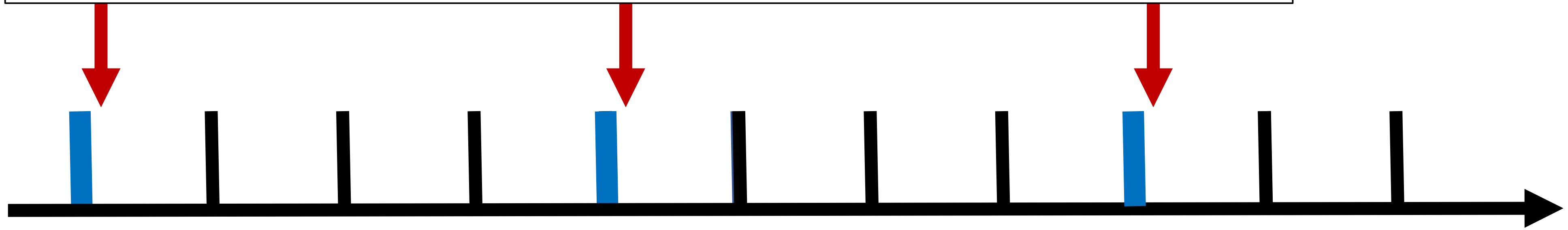
Heuristic Algorithm



Heuristic Algorithm

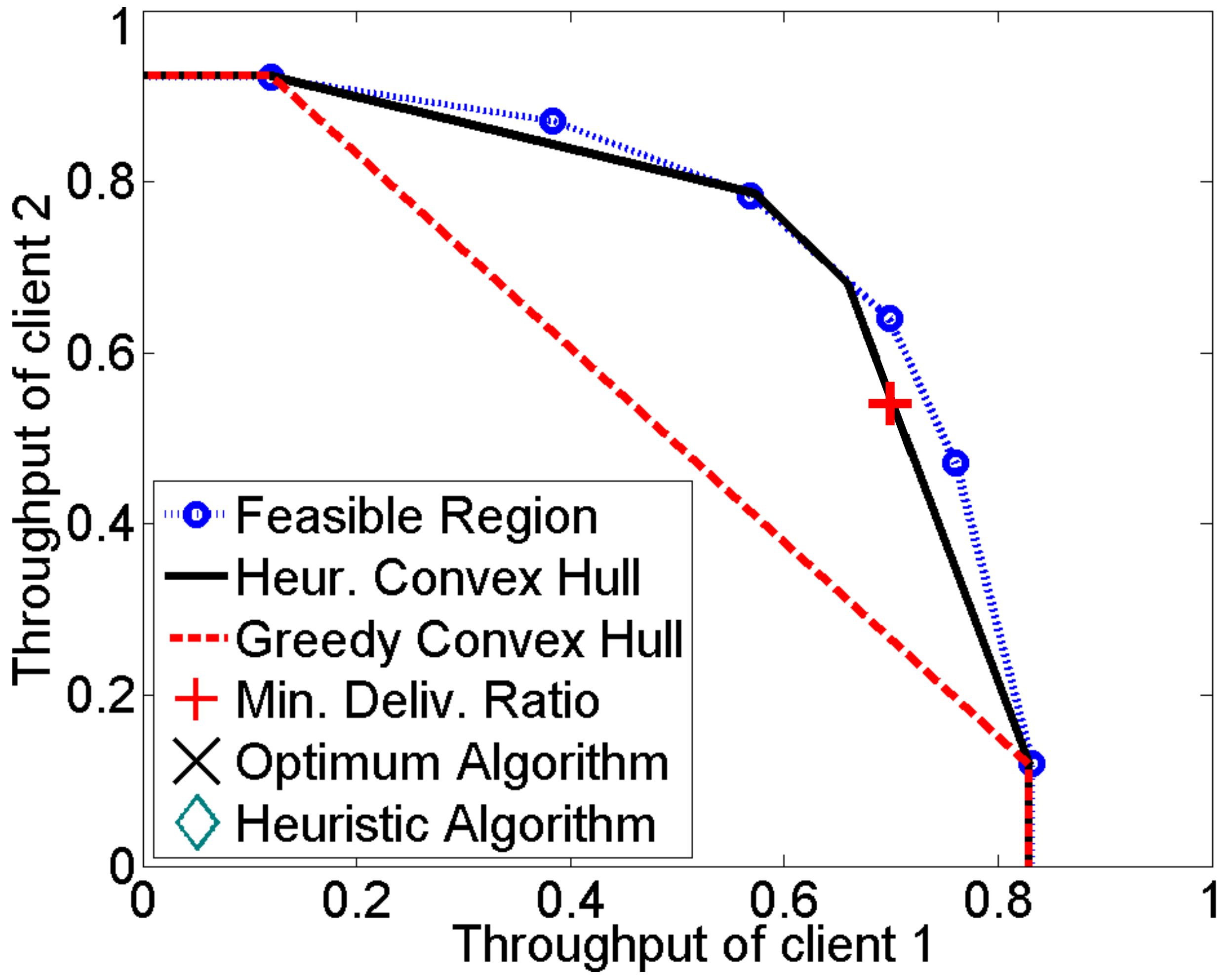
Heuristic Algorithm

- $a_i(k) = q_i - Q_i(k)/k$
- $\max_{\eta \in \text{set}} \{\text{projection}\}$
- Employ η



Heuristic Algorithm

Simulations – Opt. and Heur.



$N = 2$

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$d = 3$

$p_1 = 0.3$

$p_2 = 0.4$

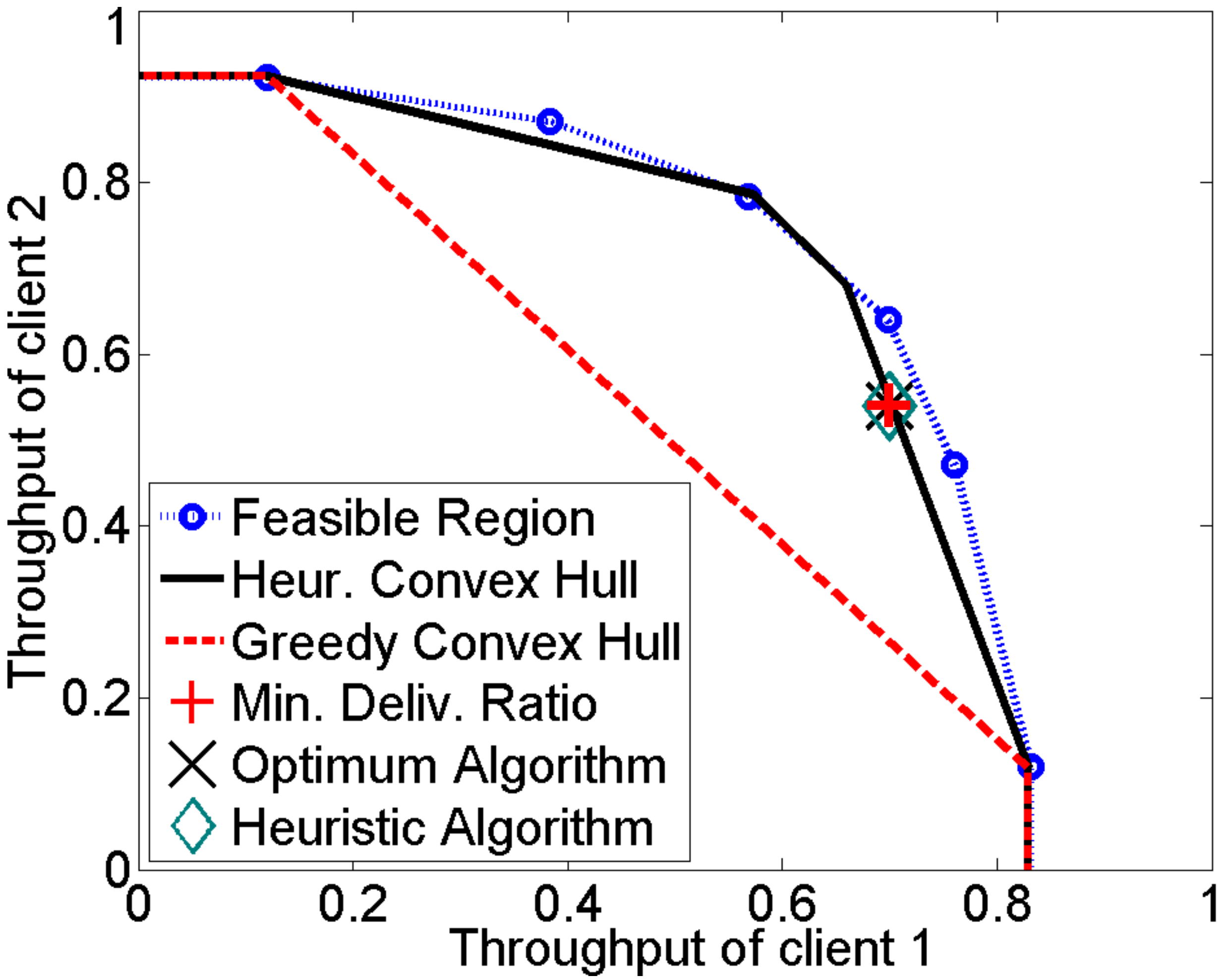
$q_1 = 0.7$

$q_2 = 0.54$

frames = 5×10^4

Heuristic Algorithm

Simulations – Opt. and Heur.



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$p_2 = 0.4$

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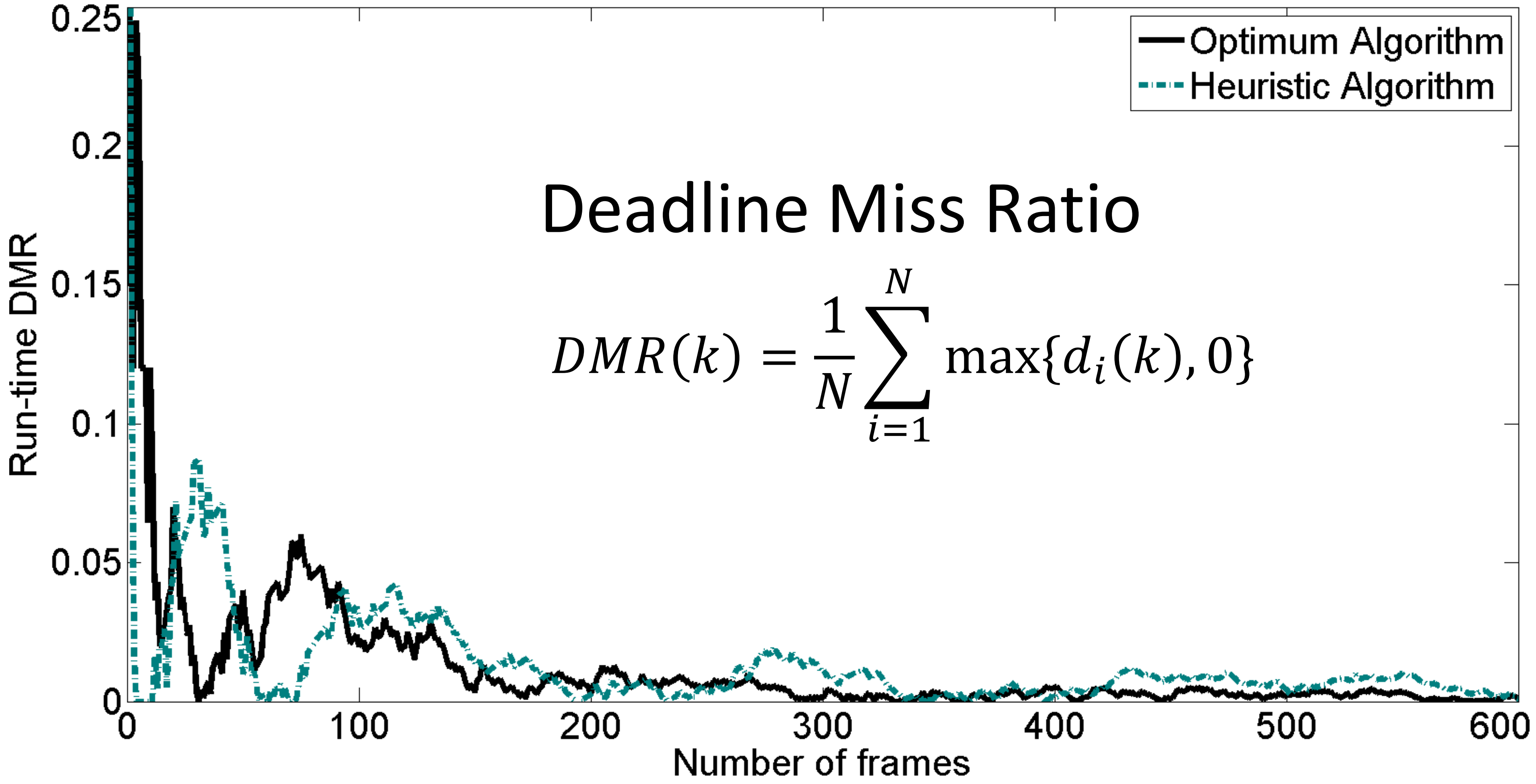
$q_2 = 0.54$

frames = $5\text{x}10^4$

Simulations – Opt. and Heur.

Heuristic Algorithm

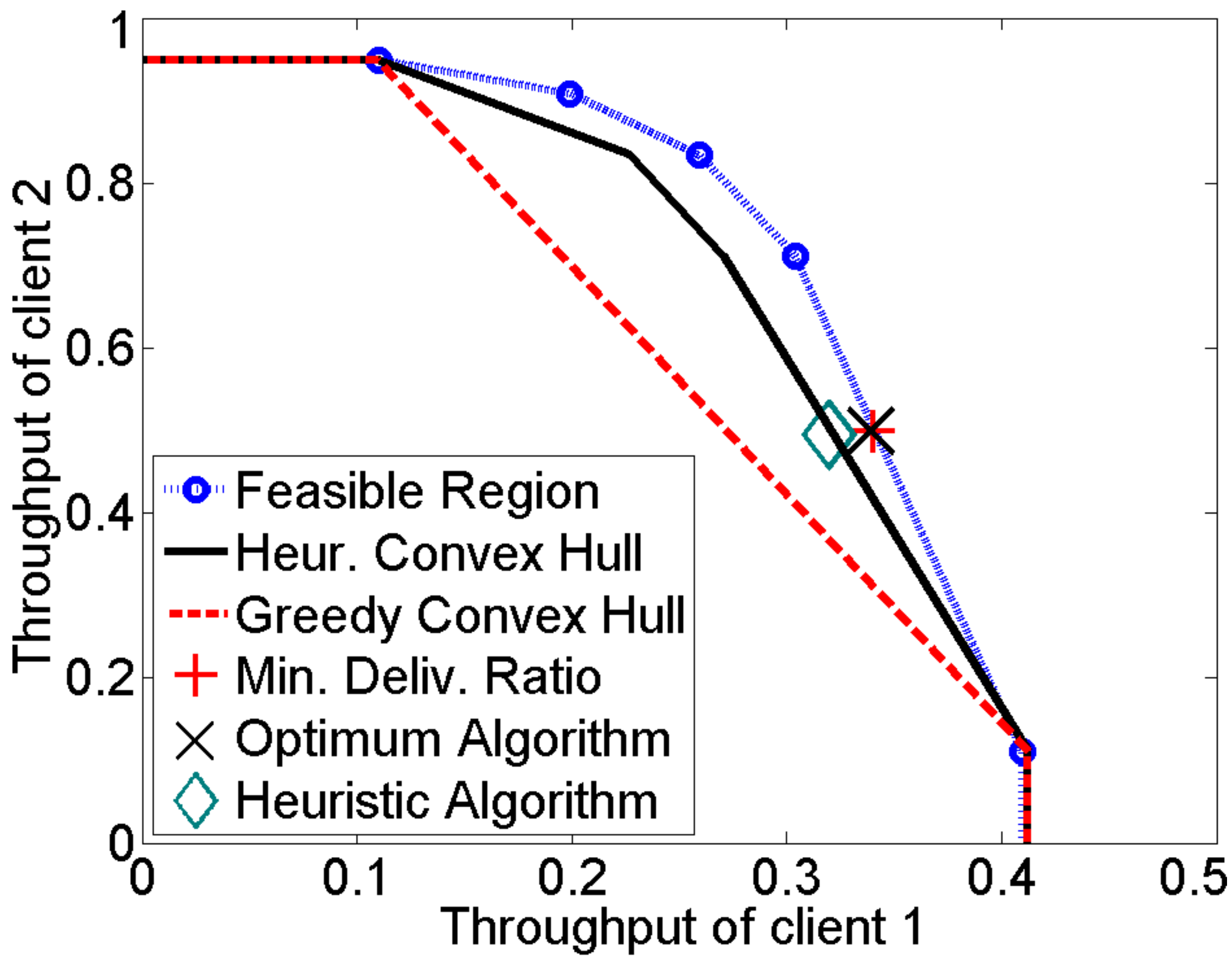


Deadline Miss Ratio

$$DMR(k) = \frac{1}{N}\sum_{i=1}^{N} \max\{d_i(k), 0\}$$

Heuristic Algorithm

Simulations – Opt. and Heur.



N = 2

T = 5

d = 2

$p_1 = 0.1$

$p_2 = 0.45$

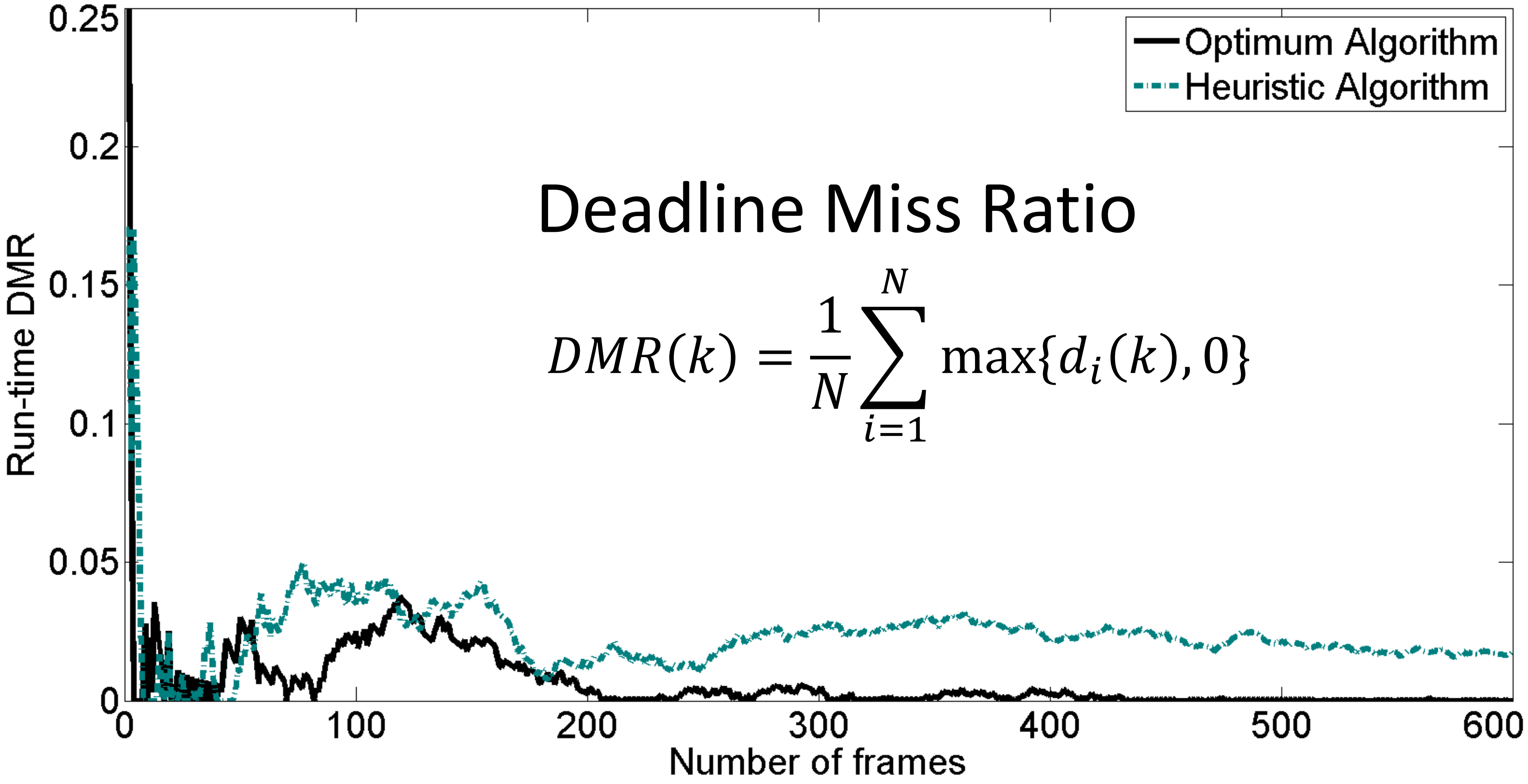
$q_1 = 0.34$

$q_2 = 0.5$

frames = 5×10^4

Simulations – Opt. and Heur.

Heuristic Algorithm



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