Aalto University
School of Electrical
Engineering

Load Balancing of Elastic Data Traffic in Heterogeneous Wireless Networks

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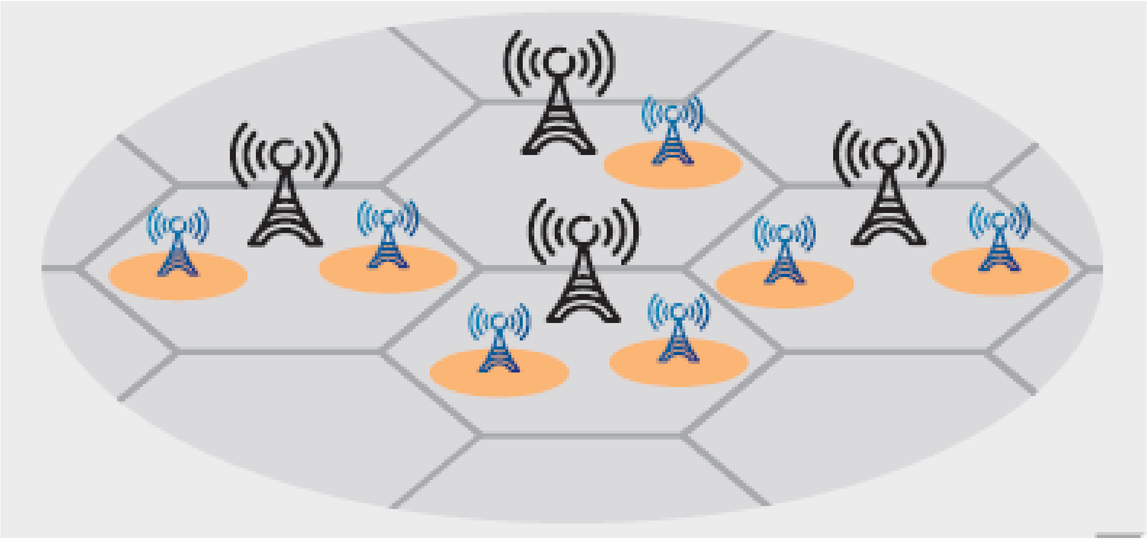
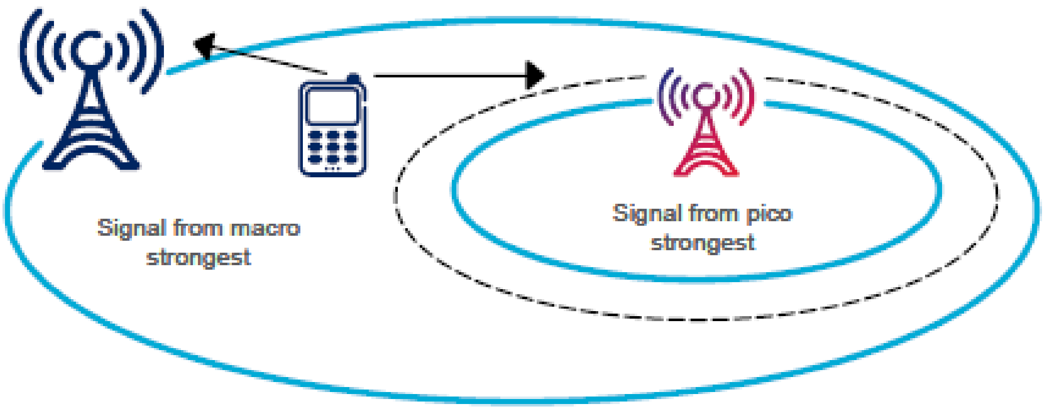
Part I
Introduction

Heterogeneous Network



Source: Parkvall & al. (2011)

Load Balancing



Source: Ericsson White Paper (2012)

Elastic Traffic

Bandwidth sharing and admission control for elastic traffic

J. W. Roberts and L. Massoulié
France Telecom - CNET
CNET/DAC/GTR
38 rue du Général Leclerc
92794 Issy-Moulineaux Cedex 9
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"Elastic flows, on the other hand, are established for the transfer of digital objects which can be transmitted at any rate up to the limit imposed by link and system ca-pacity."

"For an elastic flow, quality of service is manifested es-sentially by the time it takes to complete the document transfer."

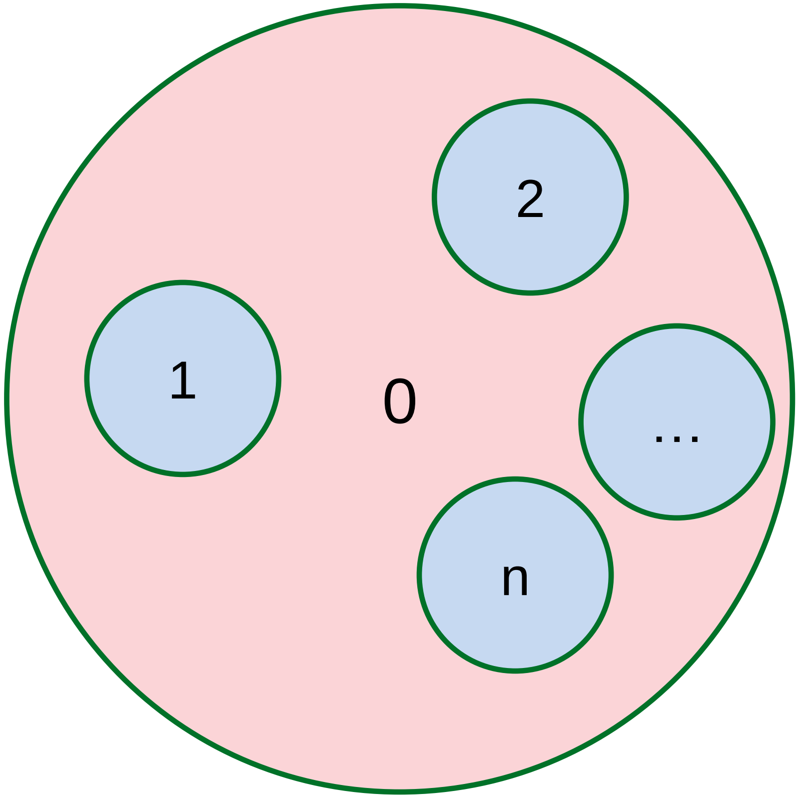
= flow delay (in our paper)

Source: Roberts & Massoulie (1998)

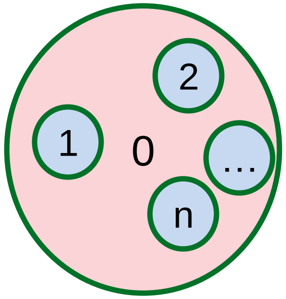
Part II
Model

Scenario

- Single macro cell (index 0) with multiple outband and separate micro cells (1,…,n)
- No interference between cells
- Traffic consists of elastic DL data flows
- Resources of each cell time-shared uniformly between the active flows



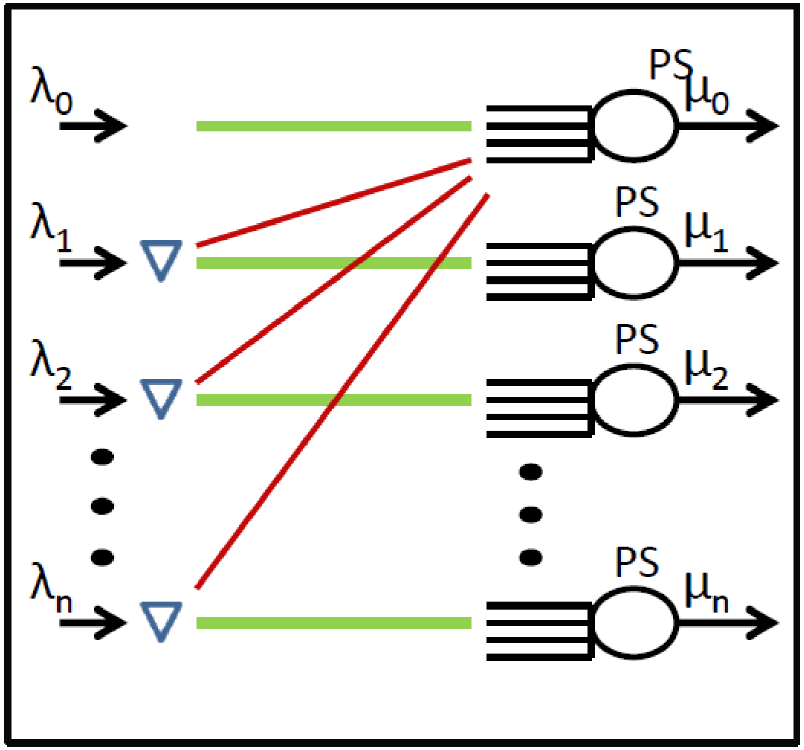
Queueing Model



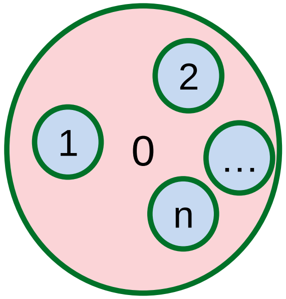
- Single macro cell (index 0) with multiple micro cells (1,…,n)
- Traffic: elastic DL data flows
- Poisson arrivals in each cell
- Generally distributed flow sizes
- Cells modeled as M/G/1-PS servers

- Assumption: Micro cells faster than the macro cell

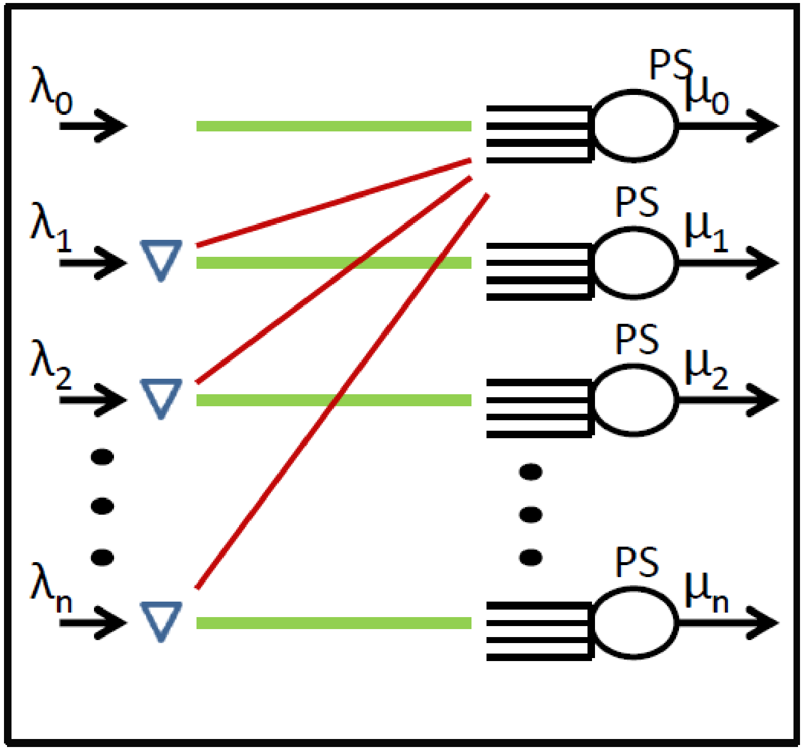
$$\mu_i \geq \mu_0 \quad \forall i$$



Dispatching Policy



- Dispatching policy decides for each arriving flow (belonging to any traffic class i) whether it should be served by
  - the "local" micro cell i or
  - the "global" macro cell 0

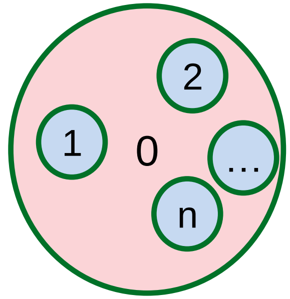


- Maximal stability region:

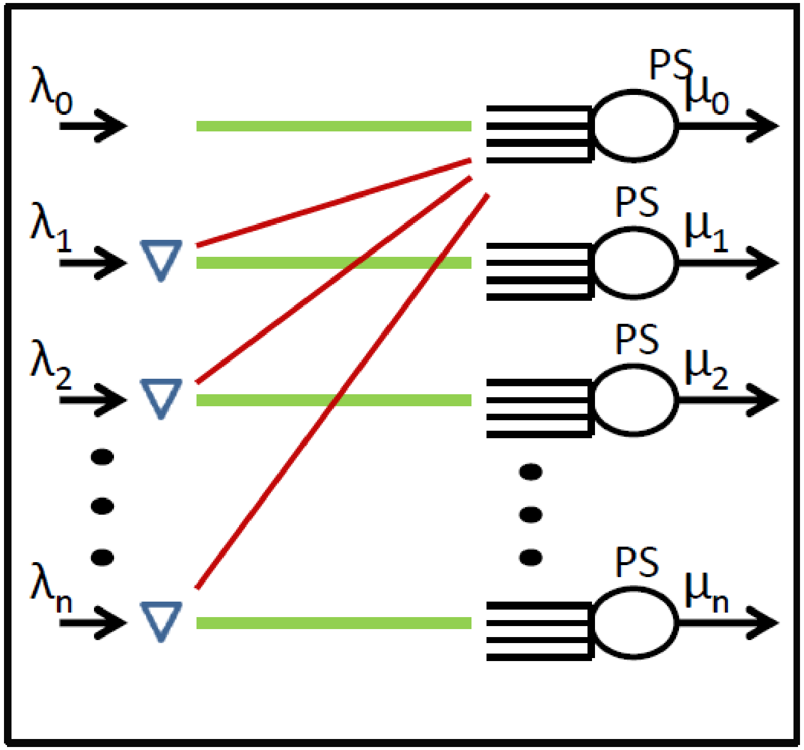
$$\lambda_0 + \sum_{i=1}^{n} \max\{\lambda_i - \mu_i, 0\} < \mu_0$$

Part III
Problem

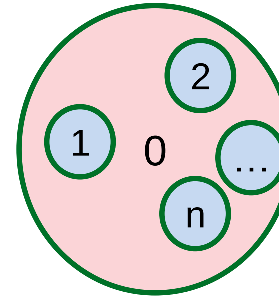
Optimal Dispatching Problem



- Optimal dispatching policy minimizes the mean flow delay
- Static policies
  - state-independent
  - analytical/numerical approach
  - optimal static policy used as a baseline in performance comparisons
- Dynamic policies
  - state-dependent
  - JSQ, MJSQ, LWL, MP, and FPI
  - performance evaluation based on simulations
  - better performance?



Static Dispatching Policies



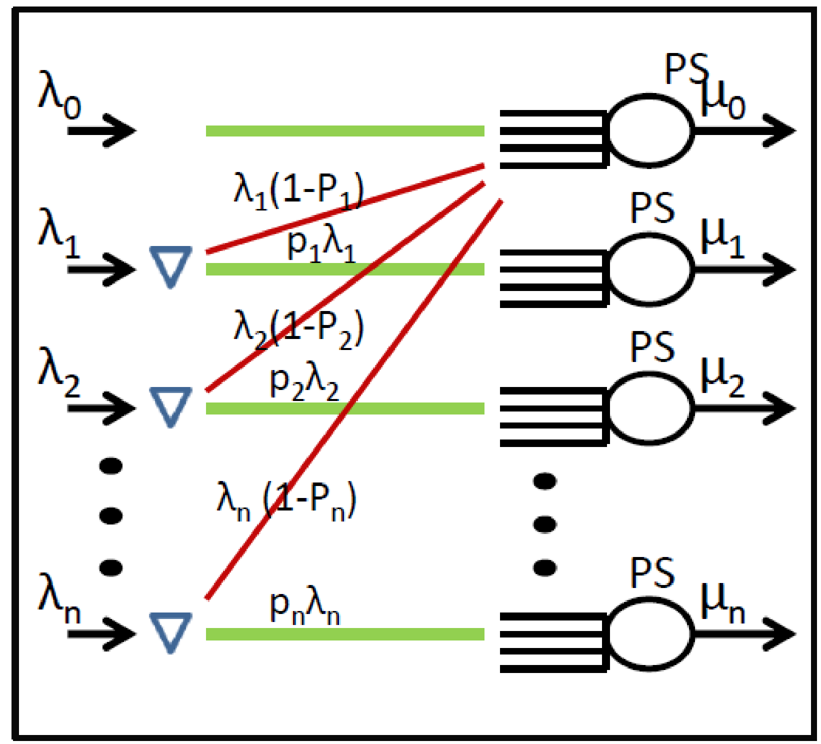
- Static (probabilistic) dispatching policy defined by vector

$$\mathbf{p} = (p_1, \ldots, p_n)$$

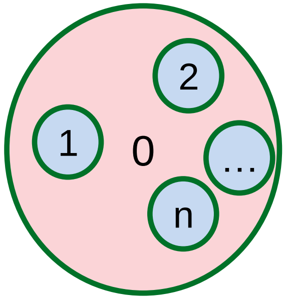
- Results in independent parallel M/G/1-PS queues
- Stable if and only if

$$\lambda_i p_i < \mu_i \quad \forall i$$

$$\lambda_0 + \sum_{i=1}^{n} \lambda_i (1 - p_i) < \mu_0$$



Mean Flow Delay



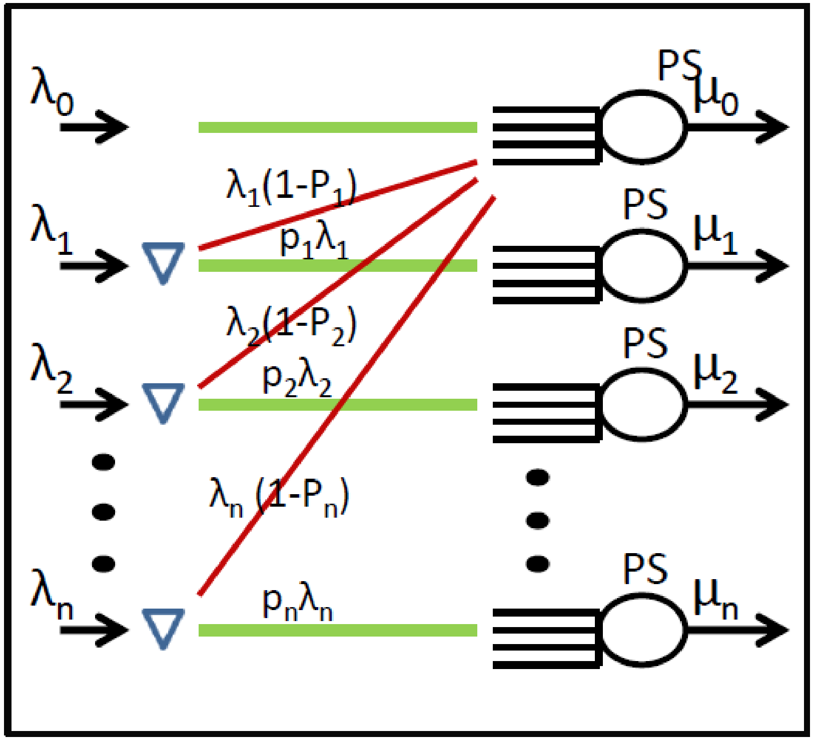
- For a stable static policy, the mean flow delay given by

$$E[T] = \frac{1}{\lambda_0 + \sum_{i=1}^{n} \lambda_i} \left(\sum_{i=1}^{n} \frac{p_i \lambda_i}{\mu_i - p_i \lambda_i} + \frac{\lambda_0 + \sum_{i=1}^{n} \lambda_i (1 - p_i)}{\mu_0 - \lambda_0 - \sum_{i=1}^{n} \lambda_i (1 - p_i)} \right)$$

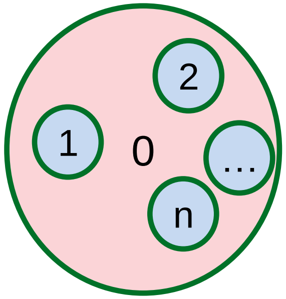
- Optimal static policy:

$$E[T] = \min_{\mathbf{p}}!$$

- By numerical methods



Symmetric Traffic Scenario



- Traffic scenario is symmetric if

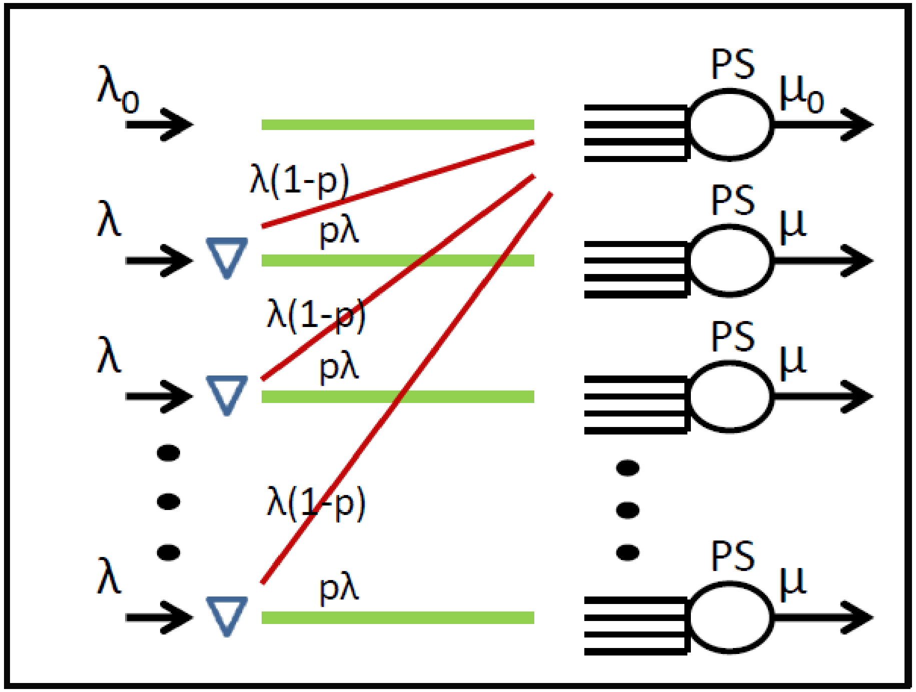
$$\lambda_1 = \ldots = \lambda_n = \lambda$$

$$\mu_1 = \ldots = \mu_n = \mu$$

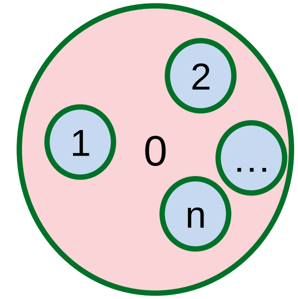
- It is sufficient to consider symmetric static policies defined by scalar p
- Optimal symmetric static policy:

$$p^* = \min\left\{ \frac{\mu\sqrt{\mu_0} + (\lambda_0 + n\lambda - \mu_0)\sqrt{\mu}}{\lambda\sqrt{\mu_0} + n\lambda\sqrt{\mu}}, 1 \right\}$$

- Analytic solution



Dynamic Dispatching Policies (1)



- JSQ (Join the Shortest Queue)

$$\arg\min\{n_0, n_i\}$$

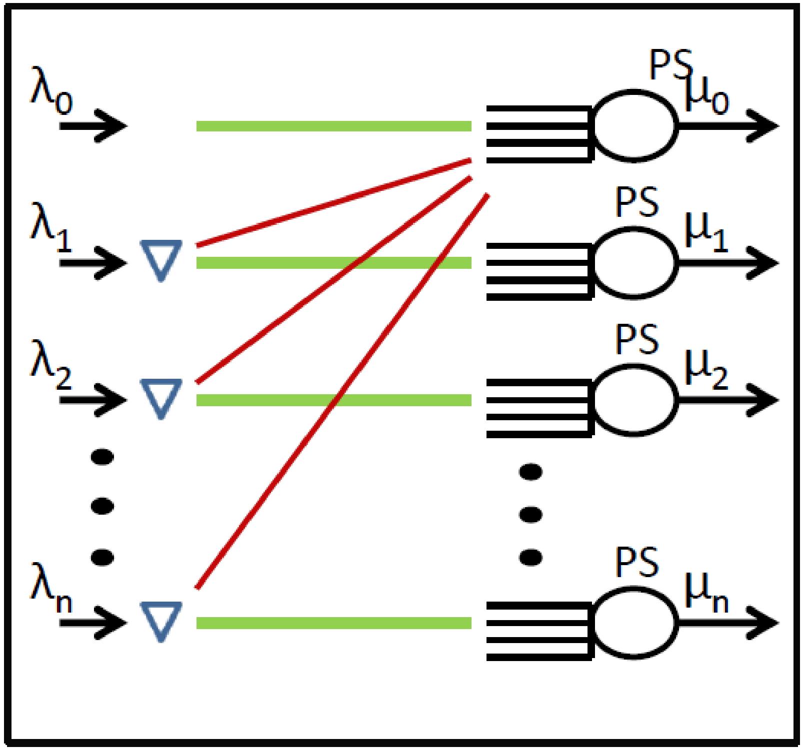
  - n = number of flows
- MJSQ (Modified JSQ)

$$\arg\min\{n_0/\mu_0, n_i/\mu_i\}$$

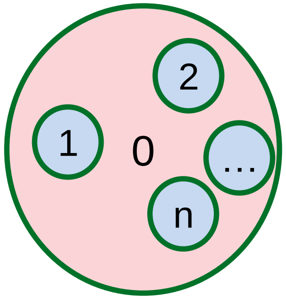
  - n/μ = expected workload
- LWL (Least Work Left)

$$\arg\min\{u_0, u_i\}$$

  - u = workload



Dynamic Dispatching Policies (2)



- MP (Myopic Policy)

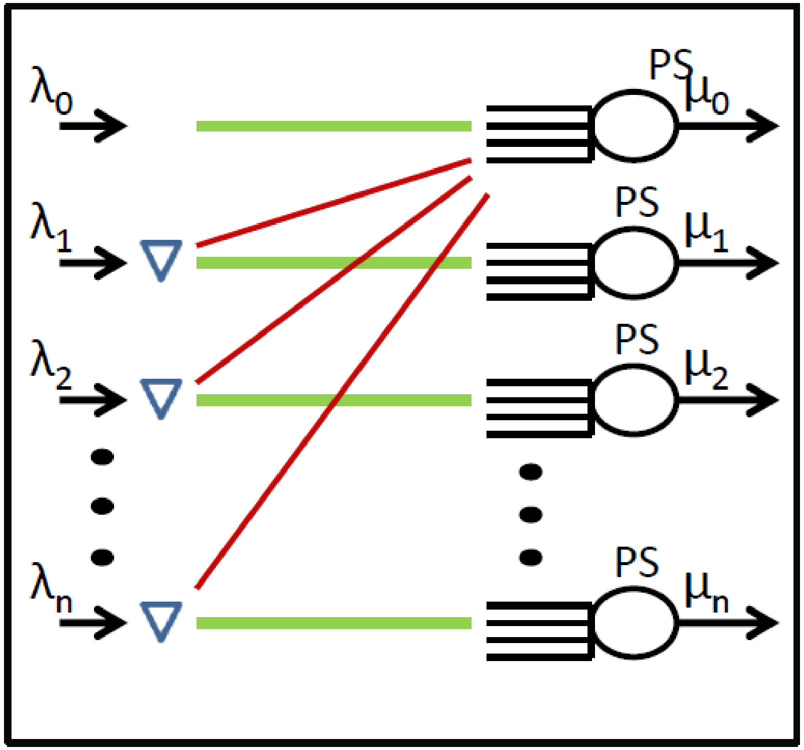
$$\arg\min\{\sigma_0, \sigma_i\}$$

  - minimizes mean additional delay costs without any new arrivals
  - Bonomi & Kumar (1990)

- FPI (First Policy Iteration)

$$\arg\min\{\sigma_0, \sigma_i\}$$

  - minimizes mean additional delay costs with future arrivals handled by the optimal static policy
  - Hyytiä & al. (2011)

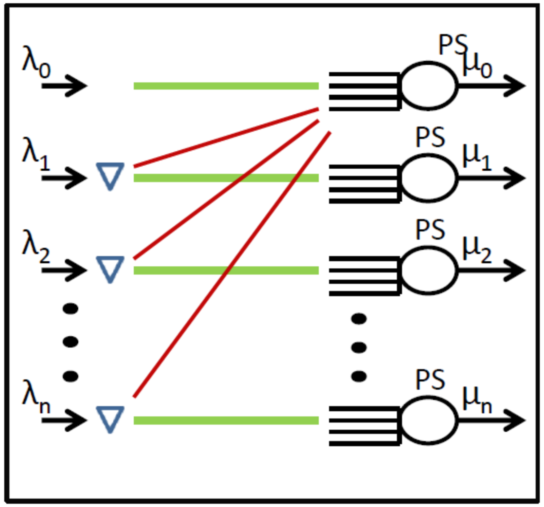


Part IV
Results

Traffic Scenarios

- Exp flow sizes (2nd experiment: bdd Pareto)
- n = 2 (3rd experiment: n = 2,…,10)
- $\mu_0 = 1$
- $\mu_1 = \mu_2 = 2$ (4th experiment: $\mu_1 = \mu_2 = 4$)

Scenario	Fixed	Varied
1 (symmetric)	$\lambda_0 = 0$	$\lambda_1 = \lambda_2 = \lambda$
2 (symmetric)	$\lambda_1 = \lambda_2 = 2$	$\lambda_0 = \lambda$
3 (asym.)	$\lambda_0 = 0, \lambda_2 = 2$	$\lambda_1 = \lambda$
4 (asym.)	$\lambda_1 = 1, \lambda_2 = 2$	$\lambda_0 = \lambda$



Mean Flow Delay Ratio

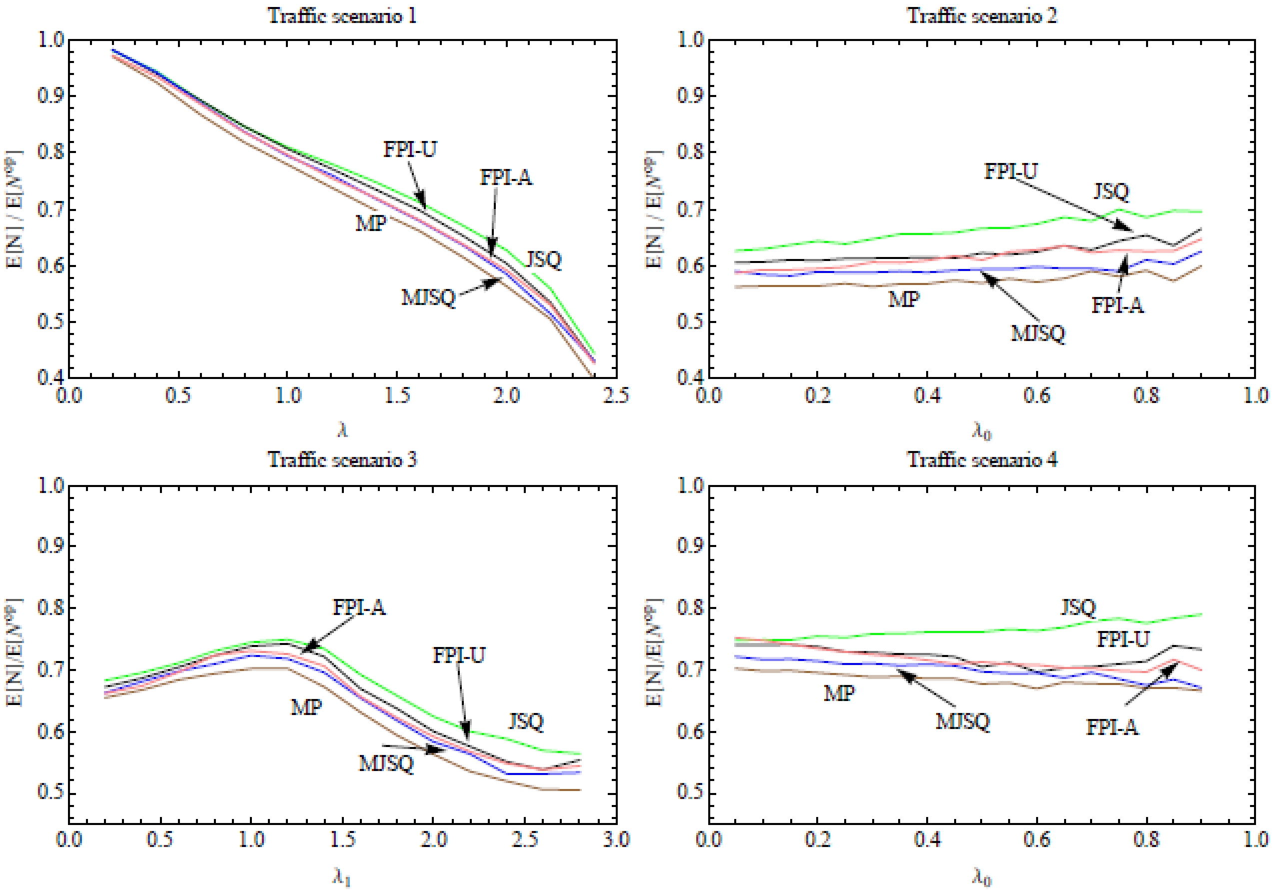


Fig. 3. Ratio of the mean number of flows in the system between the dynamic policies and the base line optimal static policy for Traffic scenarios 1-4

Effect of Flow Size Variation (Scenario 2)

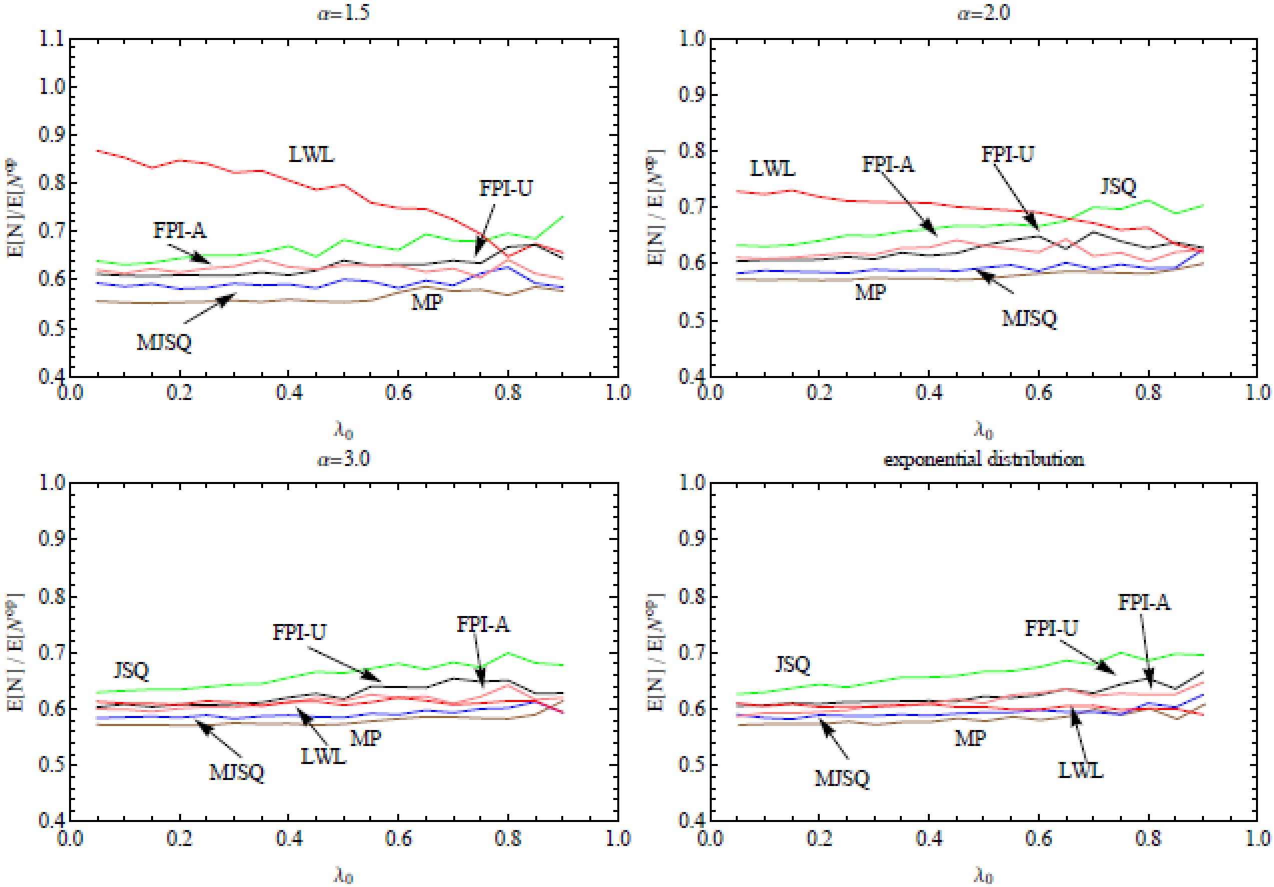


Fig. 4. Illustration of effect of the flow size variation: (a) bounded Pareto flow size distribution: $\alpha = 1.5$ (top left), (b) bounded Pareto flow size distribution: $\alpha = 2.0$. (top right), (c) bounded Pareto flow size distribution: $\alpha = 3.0$ (bottom left) and (d) exponential flow size distribution (bottom right)

Effect of Nmbr of Microcells (Scenario 2)

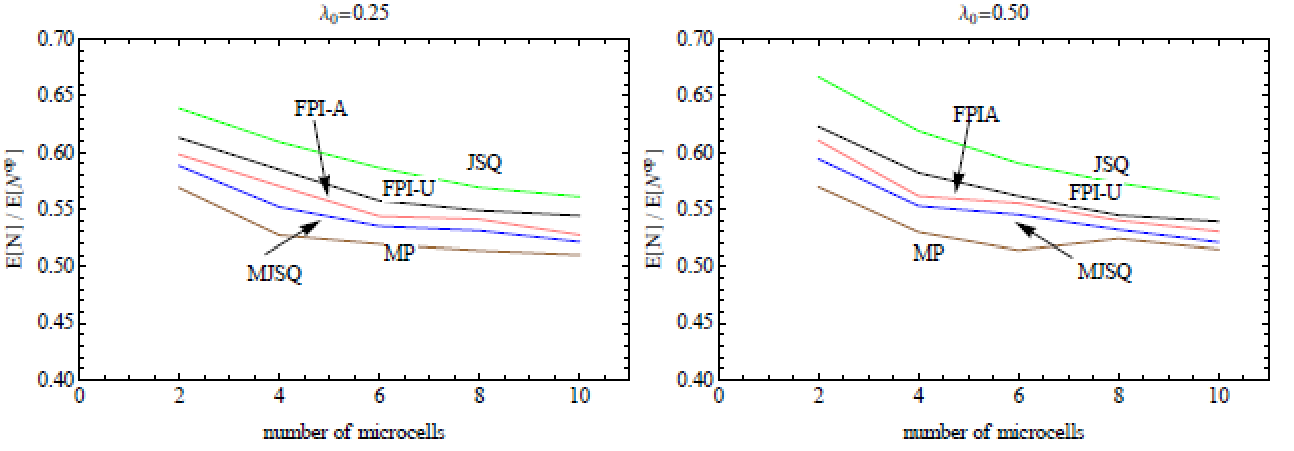


Fig. 5. Impact of the number of microcells on the performance gain of load balancing policies

Impact of Service Rate Difference

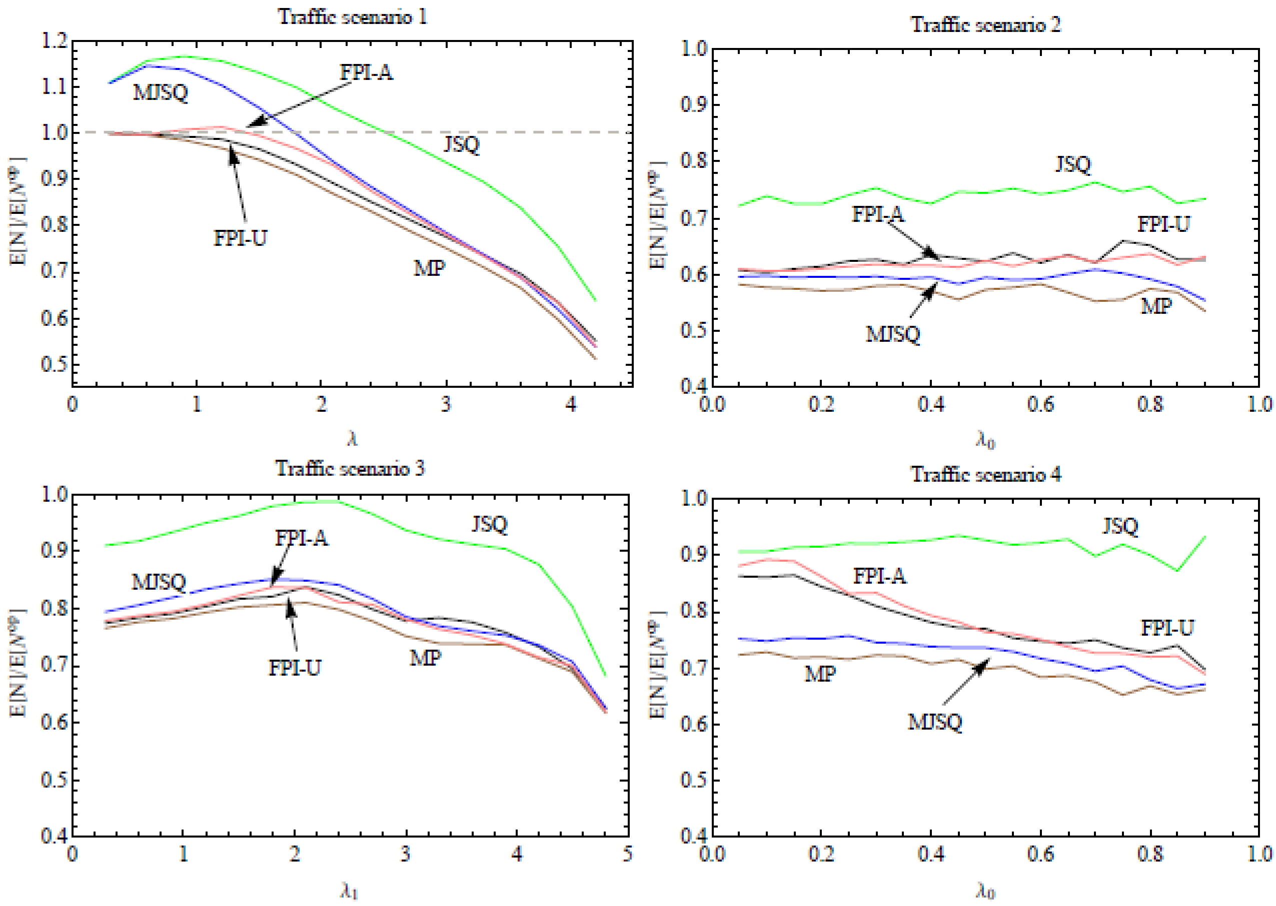


Fig. 6. Impact of service rate difference between macrocell and microcells for Traffic scenarios 1-4

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Conclusions

- All dynamic policies improve significantly the flow-level performance compared to the optimal static policy
  - best performance gain achieved with high load
  - gain increased when more micro cells
- Among the implemented dynamic policies,
  - myopic MP appears to be systematically the best;
  - MP may even be close to optimal in minimizing the mean flow delay;
  - more robust MJSQ is typically able to achieve almost the same performance;
  - FPI policies are not able to give any essential improvements over MJSQ;
  - classical JSQ typically performs worst
- Performance gain of dynamic polices (except LWL) approximately insensitive with respect to the flow size distribution

The End