Seminar in Distributed Computing

Task assignment with unknown duration

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Overview

- Model
- Performance goals
- Common task assignment policies
- Heavy tails
- Pareto Distribution
- Bounded Pareto Distribution
- TAGS Algorithm
- Results for the case of 2 hosts
- Results for more than 2 hosts
- Effect of the range of task sizes
- Server expansion metric
- Conclusion

Model

Model:

- Distributed server system with identical machines
- No cost for dispatching jobs
- Jobs **not** preemptible
- Service demand **not** known

Performance goals

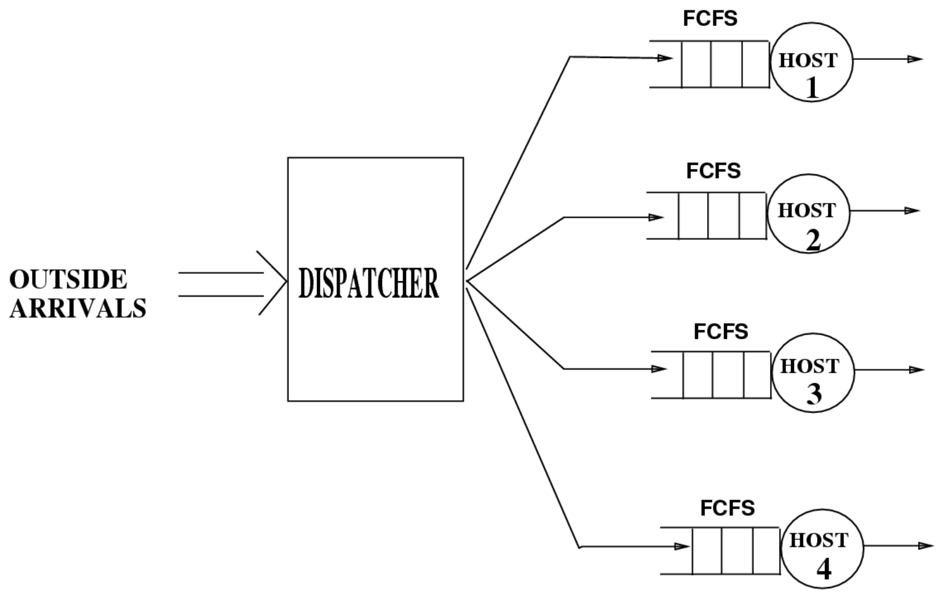
Goals to achieve:

Primary:
- Minimize mean response time.
- Minimize mean slowdown
  slowdown = (waiting time/ service requirement)

Secondary:
- Guarantee fairness
  All jobs should experience the same expected slowdown.

(Note: Minimizing the total running time of all the jobs is not a goal)

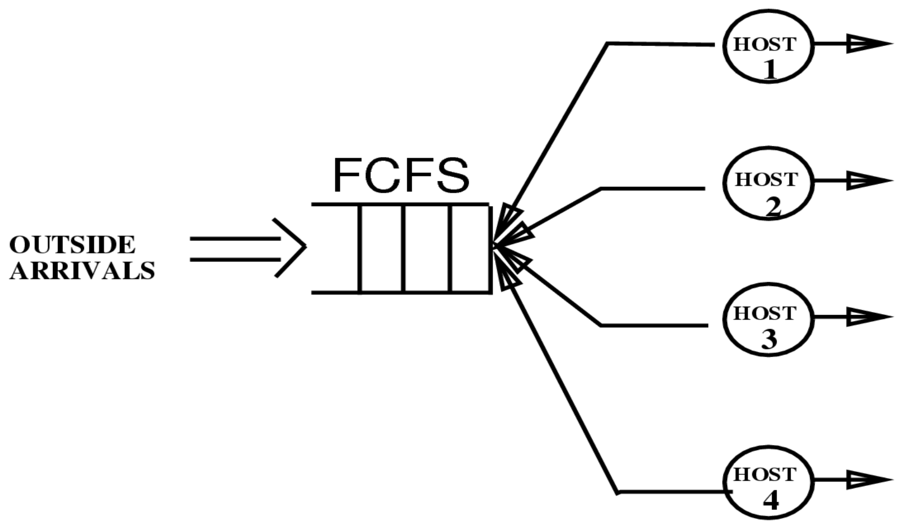
Common task assignment policies



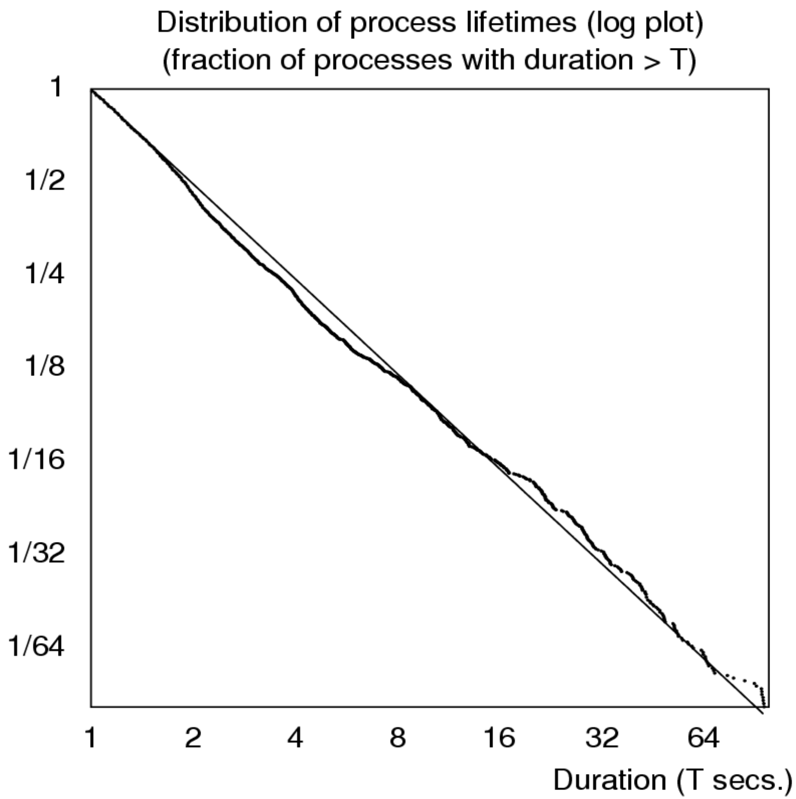
- **Random:**
  h hosts, each job gets assigned to a host with probability 1/h.
- **Round robin:**
  *i*th job assigned to host i mod h.
- **Shortest-queue:**
  job immediately dispatched to the host with the shortest queue.

Common task assignment policies

- **Least-work-remaining:**
  Send the job to the host with the least remaining work.
  -> However, we don't know the job size.
- **Central-queue:**
  Keep one global queue and dispatch job to the next free host.
  This policy is equal to the **least-work-remaining** policy and the **optimal solution** for **exponential job size distribution.**



Heavy tails



- Measurements indicate that the job distribution is not exponential, but **heavy-tailed**.
- Heavy tailed distribution: $\Pr\{X > x\} \sim x^{-\alpha}$

Pareto distribution

- **Pareto** probability mass function approximates heavy-tail property:

$$f(x) = \alpha x^{-\alpha-1} \qquad x \geq 1, 0 \leq \alpha \leq 2$$

- The lower α, the more variable the distribution

3 Properties:

- Decreasing failure rate: The longer a job has run, the longer it is expected to continue running.
- Infinite or near infinite variance
- **Heavy tail-property**: One tiny fraction of the very largest jobs comprise more than half of the total load.

Bounded Pareto distribution

- Empirical results show that job size distributions often have $\alpha \approx 1$.
- Upper bound on process size
- We can approximate the distribution of job sizes with the **Bounded Pareto** distribution probability density function B(k,p,α):

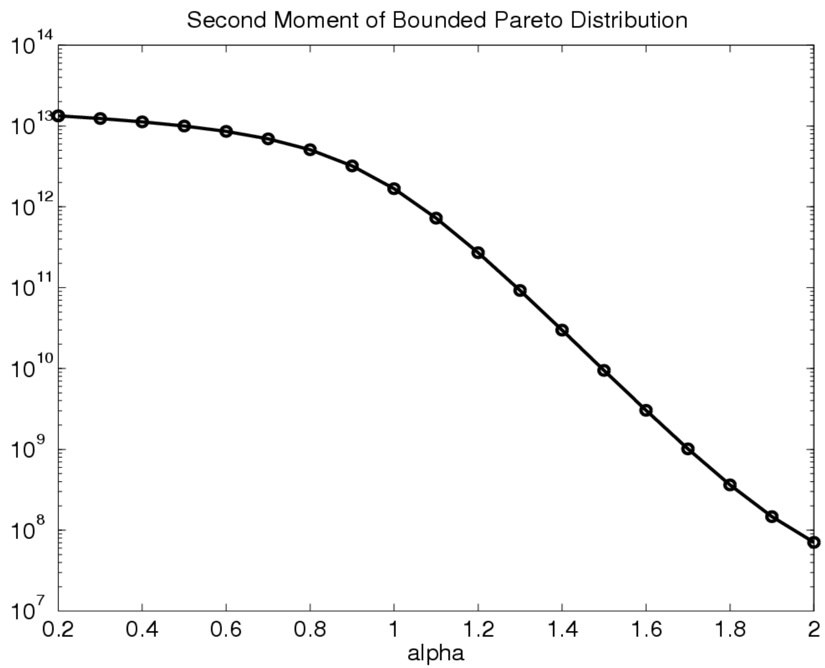
$$f(x) = \frac{\alpha k^{\alpha}}{1 - (k/p)^{\alpha}} x^{-\alpha-1} \qquad k \le x \le p \,,\ 0 \le \alpha \le 2$$

k: shortest possible job
p: longest possible job
α: variance parameter

Bounded Pareto distribution (ctd.)

- Heavy-tail property and decreasing failure rate still valid.
- We will vary α from 0 to 2. E(X) will be fixed to 3000 and p to 10^{10}.

- If workload heavy-tailed, the second moment "explodes".

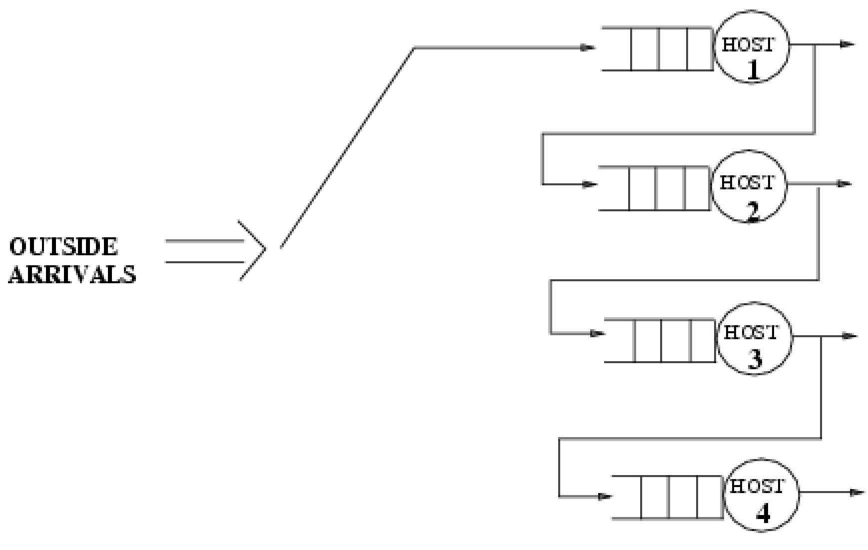


$E(X^2)$

The TAGS algorithm

h is the number of hosts (numbered 1..h). The *i*th host has a number s_i associated with it, where $s_1 < s_2 < \ldots < s_h$

All jobs are immediately dispatched to Host 1 where they are serviced in FCFS order. If the job hasn't finished after s_1 amount of time, it is canceled, and queued at host 2, where it is restarted from scratch.



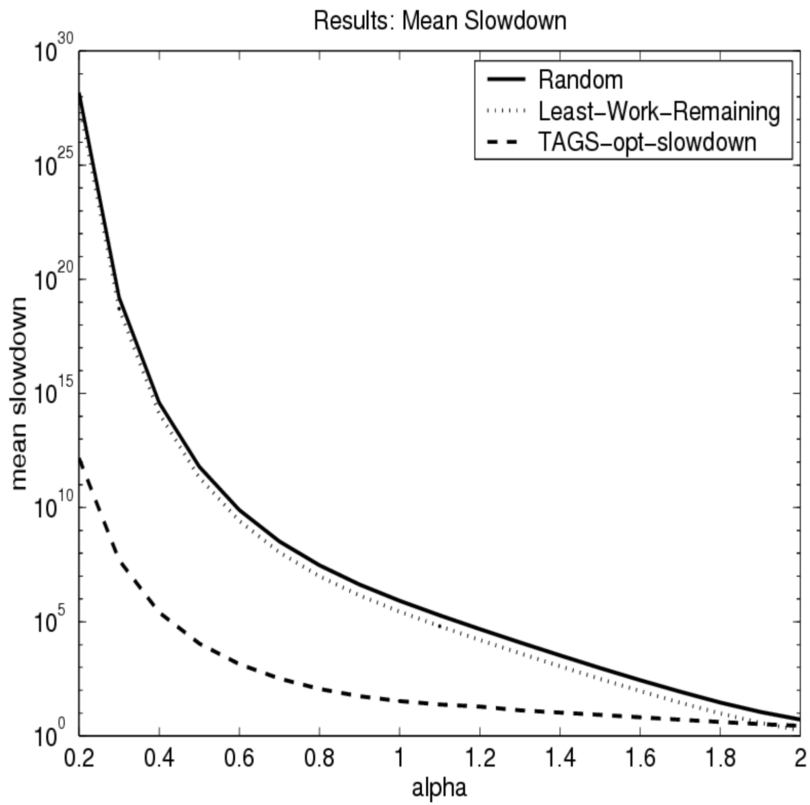
The TAGS algorithm (ctd.)

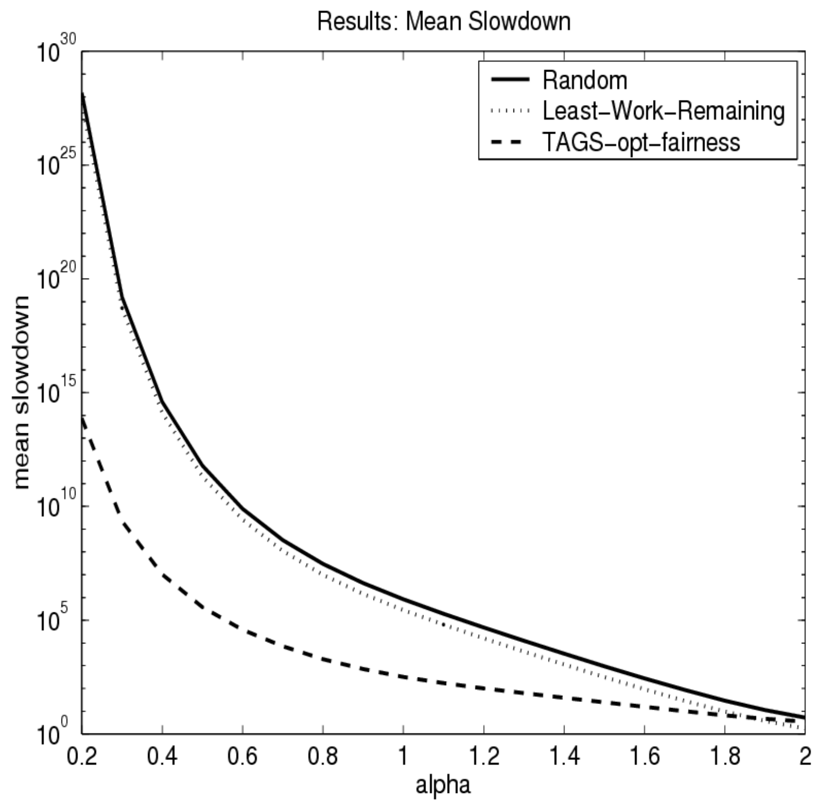
3 flavors:
- TAGS-optimize-slowdown
- TAGS-optimize-waitingtime
- TAGS-optimize-fairness

Each one of those has a different cutoff times s_i. s_i depends on the parameters α, k, p and λ (the arrival rate) and optimize the mean slowdown, waiting time, or fairness.

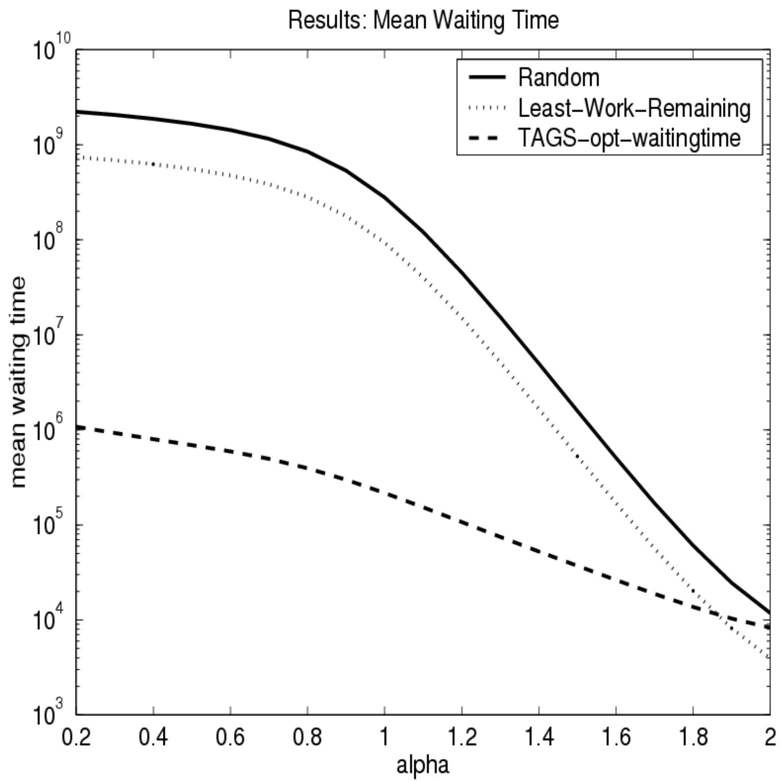
Analytic results for the case of 2 hosts

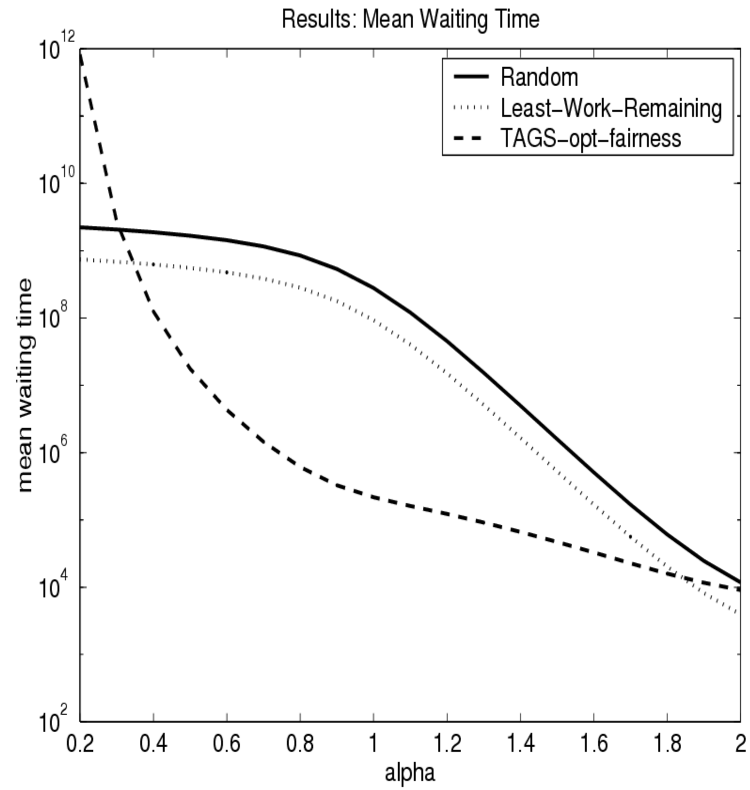
System load = Outside arrival rate * Mean job size / number of hosts
System load **fixed** to 0.5





Analytic results for the case of 2 hosts (ctd.)





Why does it perform so well?

- **Variance reduction**
- **Load unbalancing** instead of **load balancing**

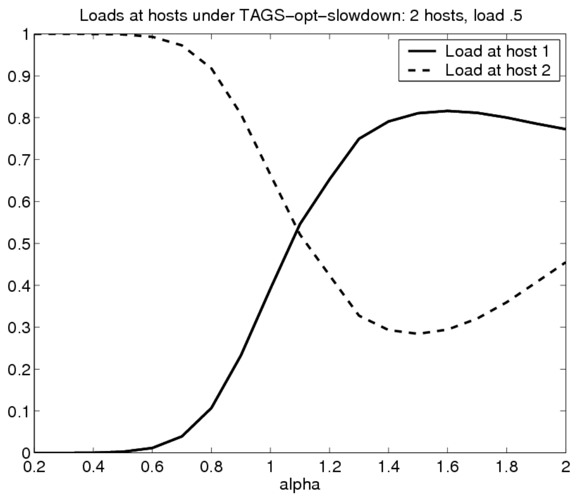
Variance reduction

Variance reduction reduces the variances of job sizes that share the same queue. This improves performance since it reduces the chance of a small job getting stuck behind a long job in the same queue.

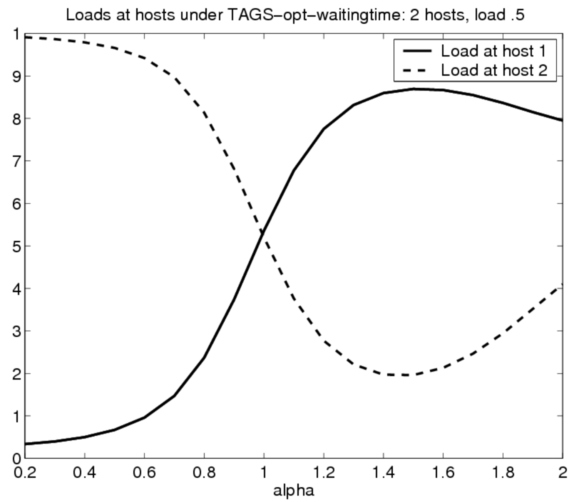
- Property: For a single FCFS queue, mean queue waiting time, slowdown and queue length are all proportional to $E(X^2)$.
- **Random task assignment:**
  Performance metrics stay proportional to $E(X^2)$ of $B(k,p,\alpha)$. Since $E(X^2)$ is high, performance is poor.
- **Least-work-remaining (central-queue):**
  Mean queue length, and therefore mean waiting time and mean slowdown proportional to $E(X^2)$.
- **TAGS:**
  Reduces the variance of job sizes at the individual hosts. Since the service time of host i is capped at s_i, $E(X^2)$ of each host i is lower than $E(X^2)$ of the original $B(k,p,\alpha)$ distribution. (Except for the last host)

Load unbalancing

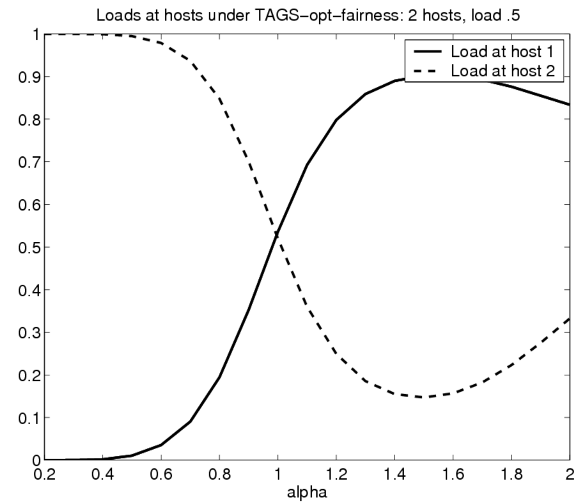
- TAGS tries to unbalance load.
- All other policies try to balance load.



TAGS-opt-slowdown



TAGS-opt-waitingtime



TAGS-opt-fairness

Observations:

- $\alpha < 1$: host 1 is underloaded
- $\alpha \approx 1$: Load is balanced
- $\alpha > 1$: host 2 is underloaded

Load unbalancing (ctd.)

Why is load balancing favorable for the mean system slow down?
-> Heavy-tail property.

- $\alpha < 1$: Very small fraction of jobs is needed to make up half the load. Because of the heavy-tail property, the load at Host 2 will be extremely high. Since most jobs run at host 1, the mean slowdown is very low.
- $\alpha \approx 1$: Distribution not as heavy tailed. Again we would like to underload host 1. A larger fraction of jobs must have host 2 as destination to create high load at host 2. But jobs at host 2 will impact more on the mean slowdown. This implies higher load at host 1 to reduce slowdown.

$\alpha > 1$: No matter how we choose the cutoff s1, a significant number of jobs will still have host 2 as their destination. So we need to keep performance of host 2 in check.

Load unbalancing (ctd.)

- How does load unbalancing optimize fairness?

- Under TAGS-optimize-fairness, the mean slowdown experienced by short jobs is equal to the mean slowdown experienced by long jobs.
- One might think of unfairness on 2 counts:

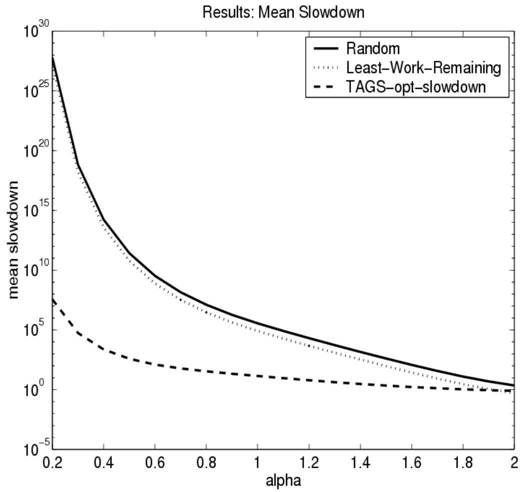
  -short jobs run on host 1 which has very low load (for low α) and very low $E(X^2)$

  -short jobs don't have to be restarted from scratch and wait on a second line

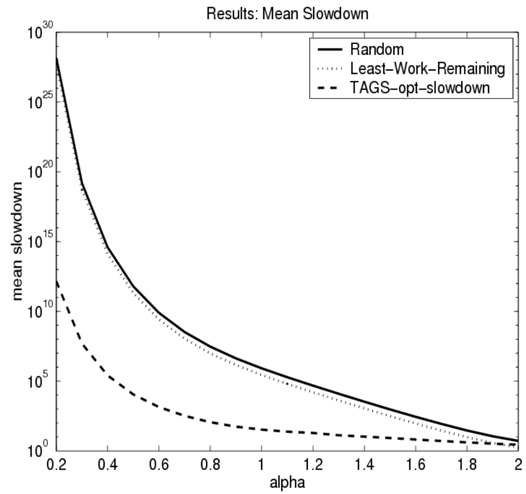
However short jobs are short. They don't need much time to complete. Since we have a heavy-tailed distribution, longer jobs are really longer ("elephants") and can afford the longer wait.

Different loads

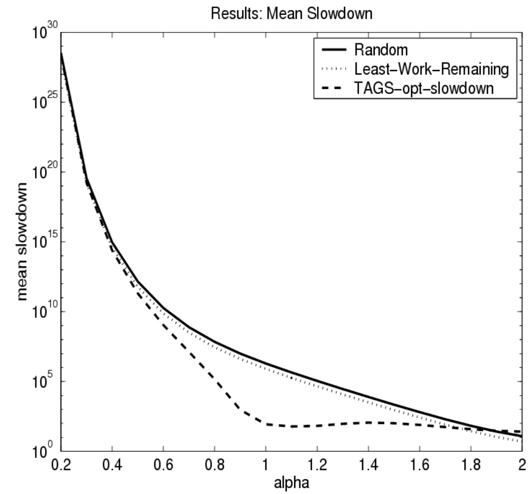
- Still distributed server with **2** hosts, but load varies.



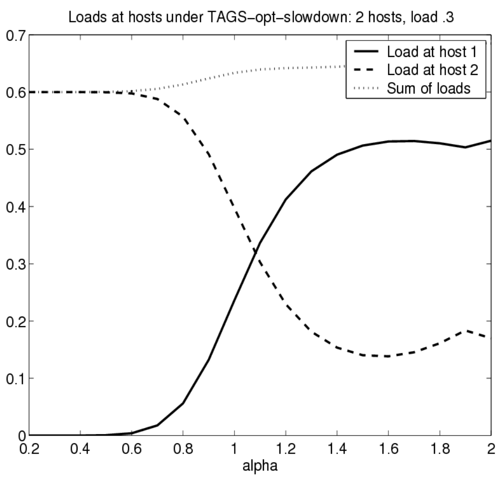
(a) System load 0.3

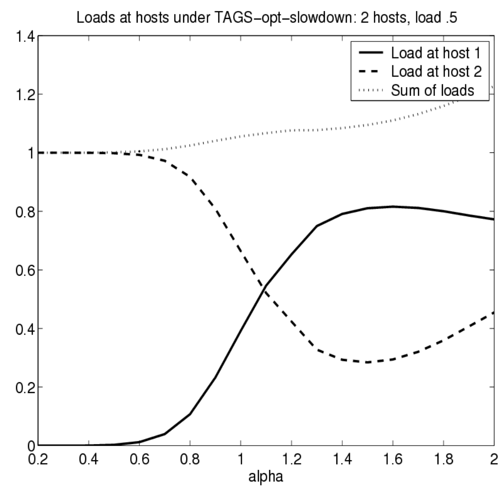


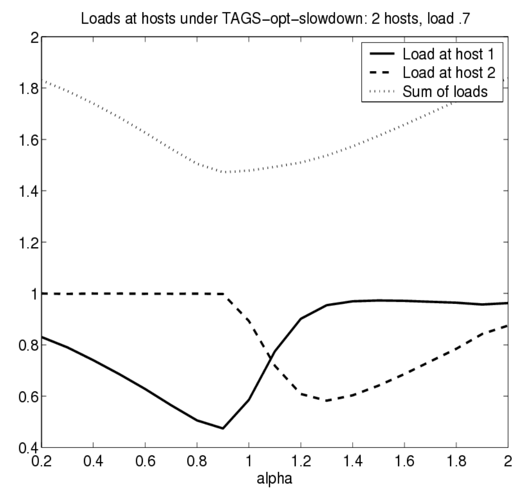
(b) System load 0.5



(c) System load 0.7







Different loads (ctd.)

Observation:

- performance of TAGS correlates with load

2 Reasons:

- The higher the load, the less TAGS can unbalance the jobs.
  For lower α's, TAGS can't pile as much work at host 2 and underload host 1, since the load at host 2 must not exceed 1.
- Excess = Extra work created by restarting jobs from scratch
  The excess is the difference between the sum of the loads on the hosts and h * system load.

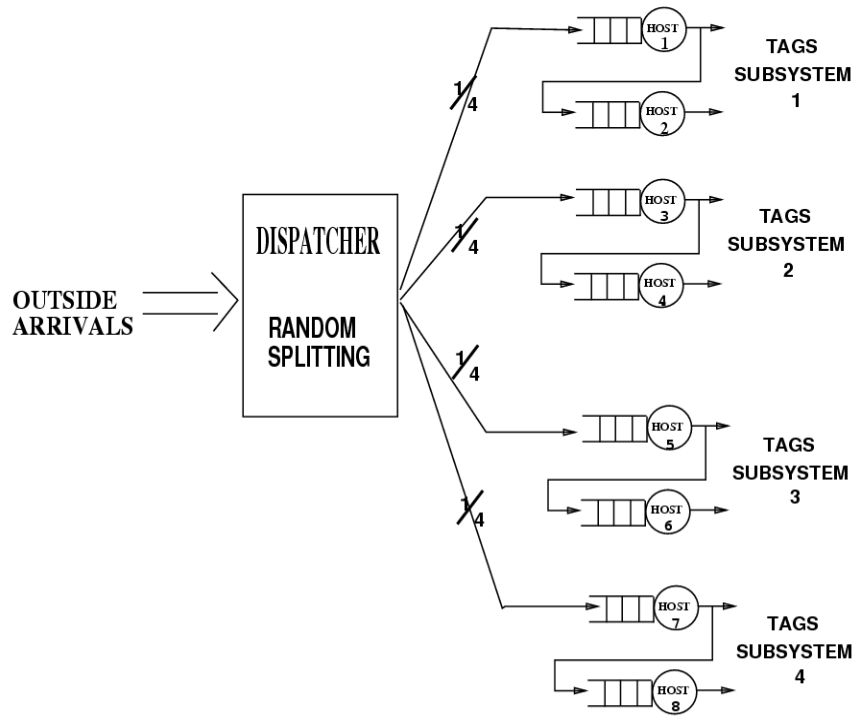
Analytical results for more than 2 hosts

Observation:

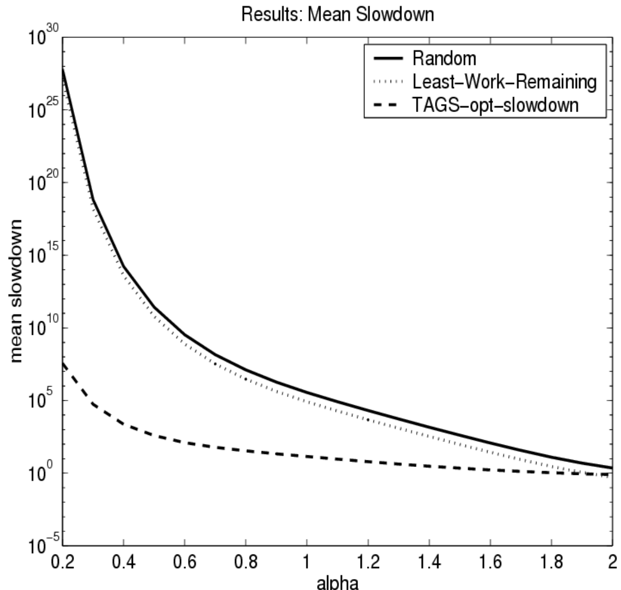
- For 2 hosts, TAGS-optimize-slowdown was good if system load was 0.5 or less.

Claim:

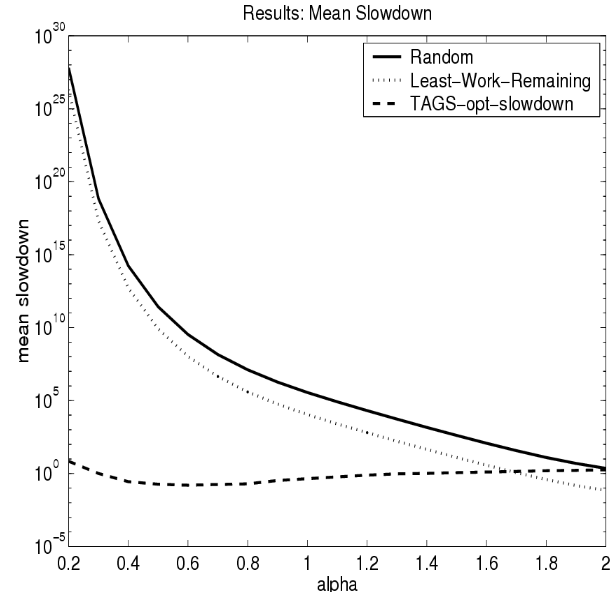
- h host system with a system load ρ can always be configured to produce performance which is at least as good as the best performance of a 2-host system with system load ρ.



Analytical results for more than 2 hosts (ctd.)



2 hosts, 0.3 load



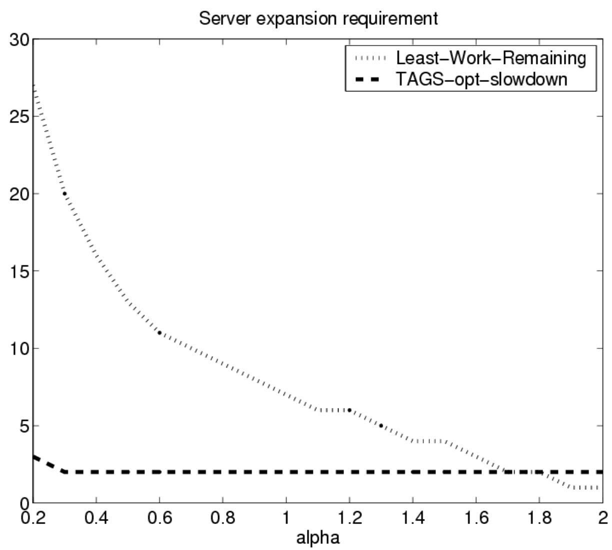
4 hosts, 0.3 load

Observations:

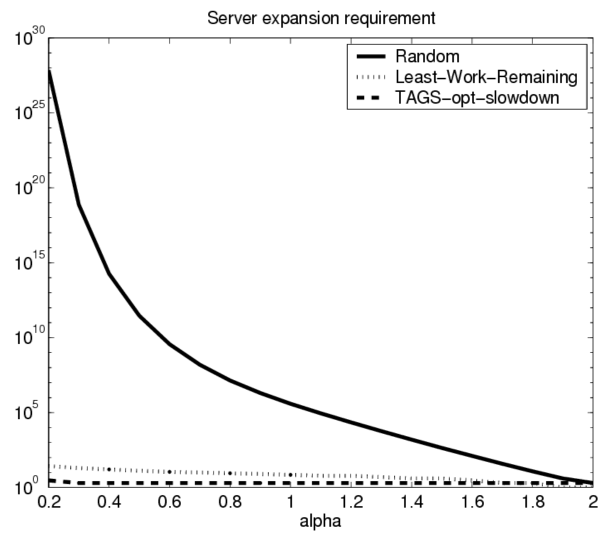
- Performance of **random** stays the same
- Performance of **Least-work-remaining** improved a little
- Huge improvement in performance for **TAGS.** Greater flexibility for choosing cutoff points.

Server expansion performance metric

- No one would run a system with slowdown of 10^5.
- **Server expansion metric:**
  How many new hosts do we have to add to bring the mean slowdown to a reasonable level (arbitrary set to < 3).



Non-log scale



Log scale

(We start with a 2 host system and system load 0.7)

(example: α= 0.6, 2 hosts -> TAGS: 10^9 ;4 hosts -> TAGS: 2, LWR: 10^8 ;13 hosts -> LWR < 3)

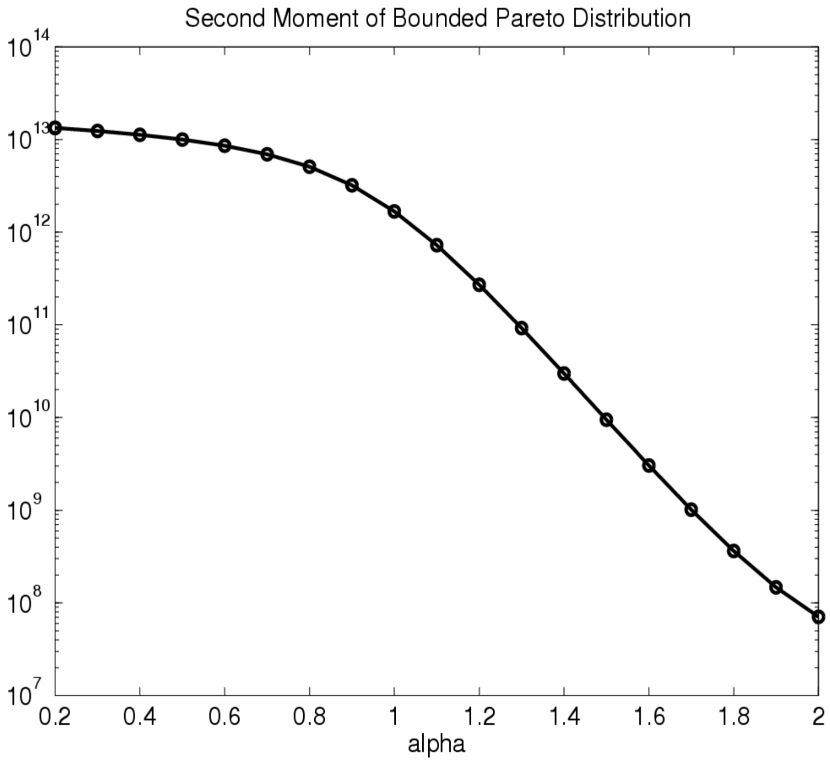
Server expansion performance metric (ctd.)

Observations:

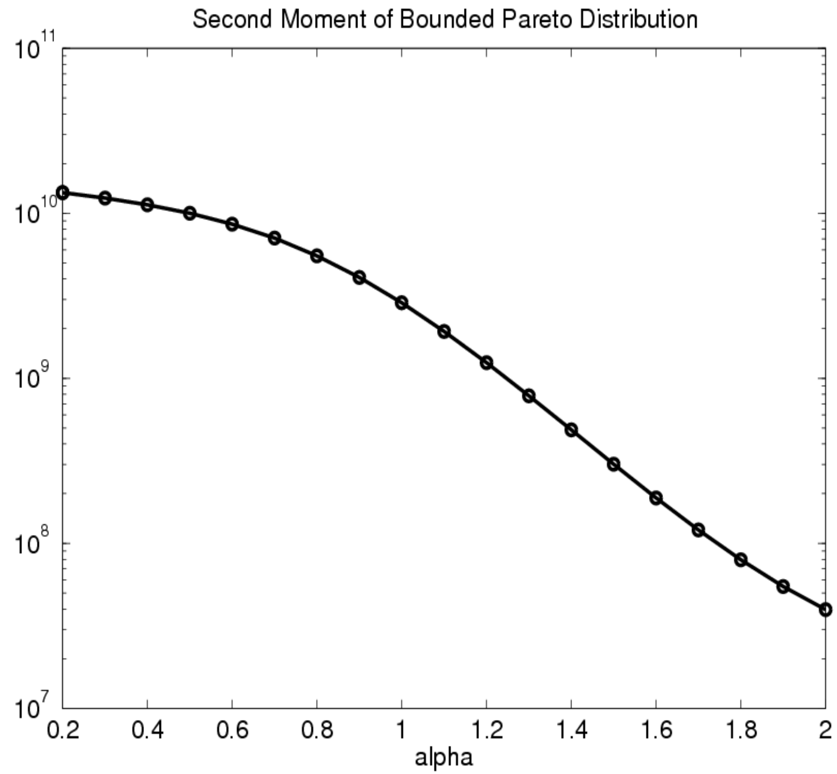
- For TAGS, the server expansion requirement is at most 3.
- For Least-work-remaining the server expansion ranges from 1 to 27. Still somehow good since performance increases when hosts are added.
- Random is exponentially worse than the others.

Effect of the range of task sizes

- Previous assumption was to set upper bound to $p=10^{10}$.
- What if we lower this bound to $p=10^{7}$.



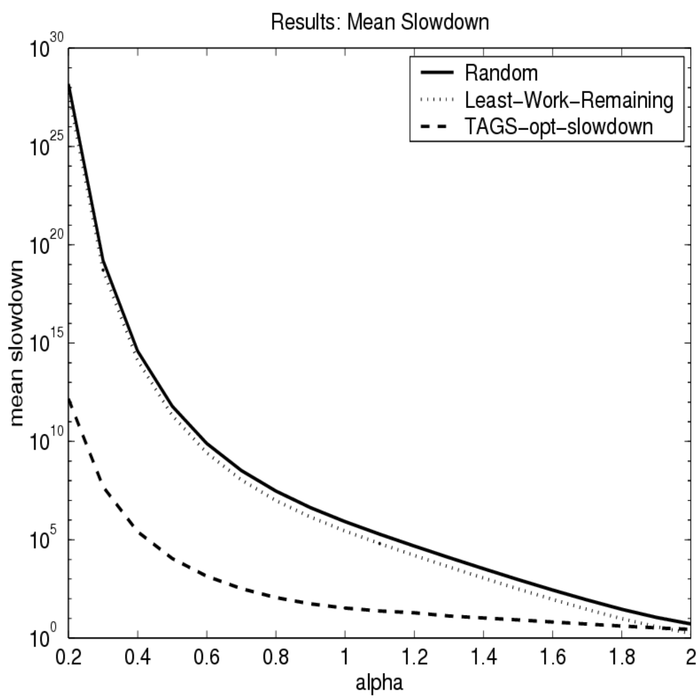
$p=10^{10}$



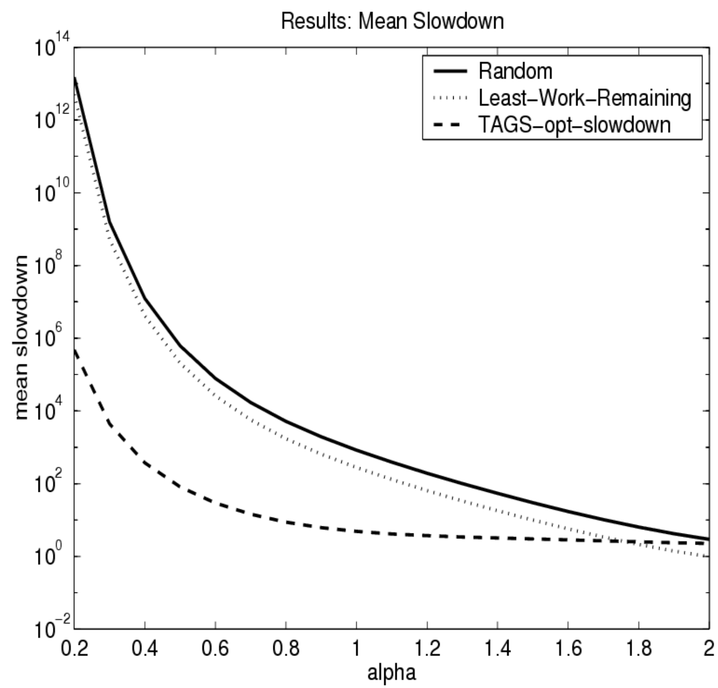
$p=10^{7}$

Effect of the range of task sizes (ctd.)

- Lower variance might suggest that TAGS improvement won't be so dramatic over the other assignment policies where p was set to $p=10^{10}$
- But still good performance.



2 hosts, system load 0.5, $p=10^{10}$



2 hosts, system load 0.5, $p=10^{7}$

Conclusion

- Interesting algorithm that challenges natural intuitions (eg load balancing, killing jobs).
- TAGS is outperforming other policies by several orders of magnitude if the system load is not too high.
- Normally fairness and performance conflicting goals, here they are quiet close.
- TAGS outperforms all other policies with respect to the server expansion metric.
- Raises interesting questions in out of scope fields:
  - Scheduling jobs at CPUs
  - Area of network routing