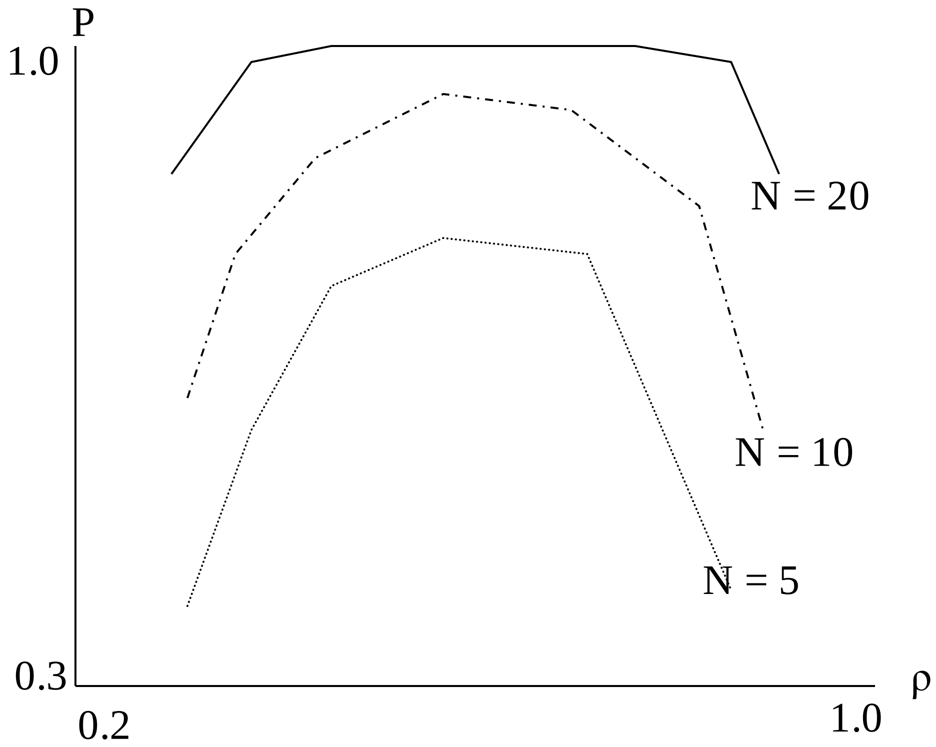
Distributed Scheduling

- Motivation: A distributed system may have a mix of heavily and lightly loaded systems. Hence, migrating a task to share or balance load can help.
- Let P be the probability that the system is in a state in which at least 1 task is waiting for service and at least 1 server is idle.
- Let ρ be the utilization of each server.
- We can estimate P using probabilistic analysis and plot a graph against system utilization.
- For moderate system utilization, value of P is high, i.e., at least 1 node is idle.
- Hence, performance can be improved by sharing of tasks.

Distributed Scheduling ...



What is Load?

- Load on a system/node can correspond to the queue length of tasks/ processes that need to be processed.
- Queue length of waiting tasks: proportional to task response time, hence a good indicator of system load.
- Distributing load: transfer tasks/processes among nodes.
- If a task transfer (from another node) takes a long time, the node may accept more tasks during the transfer time.
- Causes the node to be highly loaded. Affects performance.
- Solution: artificially increment the queue length when a task is accepted for transfer from remote node (to account for the proposed increased in load).
- Task transfer can fail? : use timeouts.

Types of Algorithms

- *Static load distribution algorithms*: Decisions are hard-coded into an algorithm with a priori knowledge of system.
- *Dynamic load distribution*: use system state information such as task queue length, processor utilization.
- *Adaptive load distribution*: adapt the approach based on system state.
  - (e.g.,) Dynamic distribution algorithms collect load information from nodes even at very high system loads.
  - Load information collection itself can add load on the system as messages need to be exchanged.
  - Adaptive distribution algorithms may stop collecting state information at high loads.

Balancing vs. Sharing

- *Load balancing*: Equalize load on the participating nodes.
  - Transfer tasks even if a node is not heavily loaded so that queue lengths on all nodes are approximately equal.
  - More number of task transfers, might degrade performance.
- *Load sharing*: Reduce burden of an overloaded node.
  - Transfer tasks only when the queue length exceeds a certain threshold.
  - Less number of task transfers.
- *Anticipatory task transfers*: transfer from overloaded nodes to ones that are likely to become idle/lightly loaded.
  - More like load balancing, but may be less number of transfers.

Types of Task Transfers

- *Preemptive task transfers*: transfer tasks that are partially executed.
  - Expensive as it involves collection of task states.
  - Task state: virtual memory image, process control block, IO buffers, file pointers, timers, ...
- *Non-preemptive task transfers*: transfer tasks that have not begun execution.
  - Do not require transfer of task states.
  - Can be considered as task placements. Suitable for load sharing not for load balancing.
- Both transfers involve information on user's current working directory, task privileges/priority.

Algorithm Components

- *Transfer policy*: to decide whether a node needs to transfer tasks.
  - Thresholds, perhaps in terms of number of tasks, are generally used. (Another threshold can be processor utilization).
  - When a load on a node exceeds a threshold T, the node becomes a *sender*. When it falls below a threshold, it becomes a *receiver.*
- *Selection Policy*: to decide which task is to be transferred.
  - Criteria: task transfer should lead to reduced response time, i.e., transfer overhead should be worth incurring.
  - Simplest approach: select newly originated tasks. Transfer costs lower as no state information is to be transferred. Non-preemptive transfers.
  - Other factors for selection: smaller tasks have less overhead. Location-dependent system calls minimal (else, messages need to be exchanged to perform system calls at the original node).

Algorithm Components...

- *Location Policy*: to decide the receiving node for a task.
  - *Polling* is generally used. A node polls/checks whether another is suitable and willing.
  - Polling can be done serially or in parallel (using multicast).
  - Alternative: broadcasting a query, sort of invitation to share load.
- *Information policy*: for collecting system state information. The collected information is used by transfer, selection, and location.
    - *Demand-driven Collection*: Only when a node is highly or lightly loaded, i.e., when a node becomes a potential sender or receiver.
      - Can be sender-initiated, receiver-initiated, or both(symmetric).
  - *Periodic*: May not be adaptive. Collection may be done at high loads worsening system performance.
  - *State-change driven*: only when state changes by a certain degree.

System Stability

- *Unstable system*: long term arrival rate of work to a system is greater than the CPU power.
- Load sharing/balancing algorithm may add to the system load making it unstable. (e.g.,) load information collection at high system loads.
- *Effectiveness of algorithm*: Effective if it improves the performance relative to that of a system not using it. (Effective algorithm cannot be unstable).
- Load balancing algorithms should avoid fruitless actions. (e.g.,) *processor thrashing*: task transfer makes the receiver highly loaded, so the task gets transferred again, perhaps repeatedly.

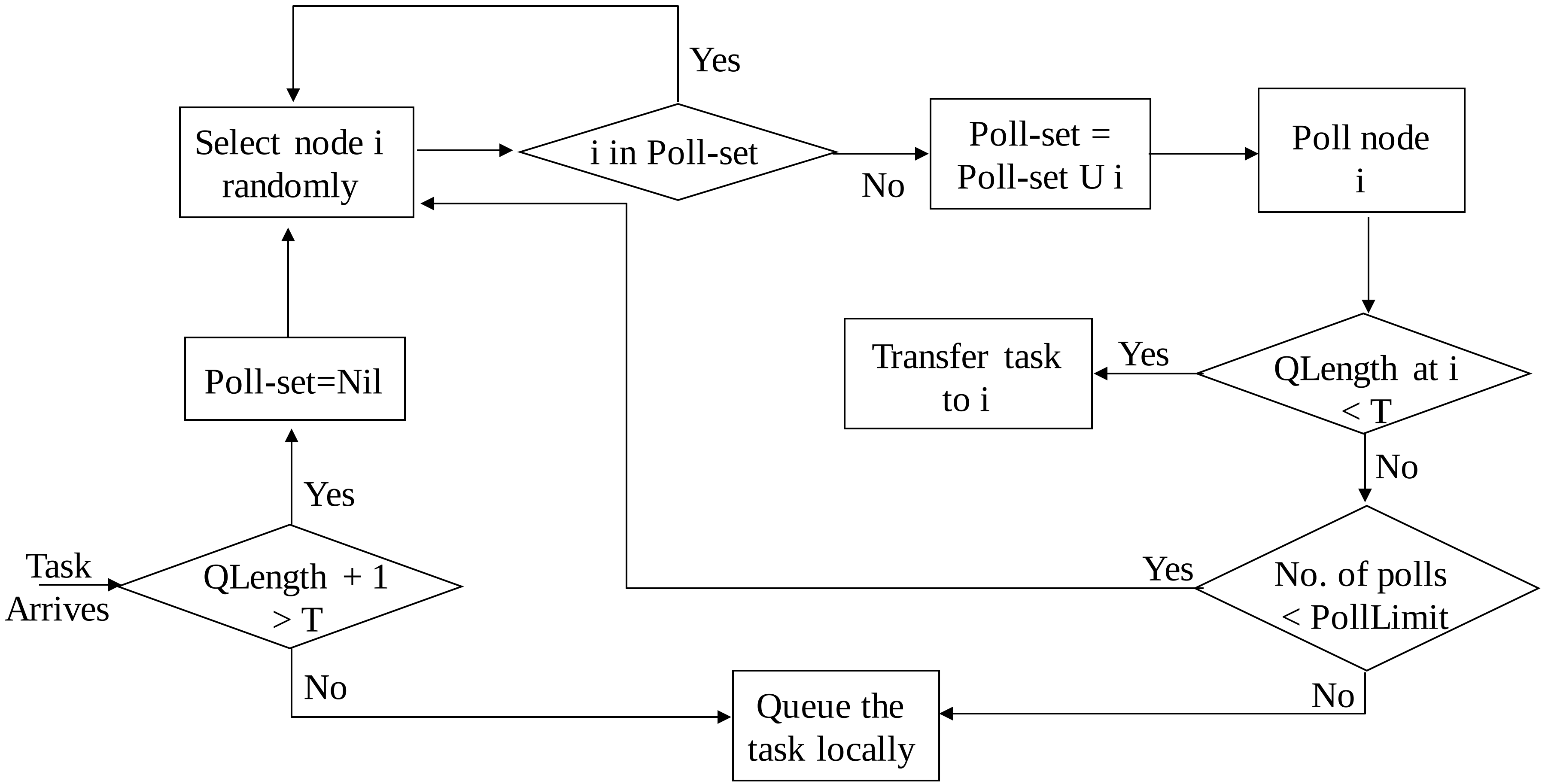
Load Distributing Algorithms

- Sender-initiated: distribution initiated by an overloaded node.
- Receiver-initiated: distribution initiated by lightly loaded nodes.
- Symmetric: initiated by both senders and receivers. Has advantages and disadvantages of both the approaches.
- Adaptive: sensitive to state of the system.

Sender-initiated

- *Transfer Policy*: Use thresholds.
  - Sender if queue length exceeds T.
  - Receiver if accepting a task will not make queue length exceed T.
- *Selection Policy*: Only newly arrived tasks.
- *Location Policy*:
  - Random: Use no remote state information. Task transferred to a node at random.
    - No need for state collection. Unnecessary task transfers (processor thrashing) may occur.
  - Threshold: poll a node to find out if it is a receiver. Receiver must accept the task irrespective of when it (task) actually arrives.
    - *PollLimit,* ie., the number of polls, can be used to reduce overhead.
  - Shortest: Poll a set of nodes. Select the receiver with shortest task queue length.

Sender-initiated



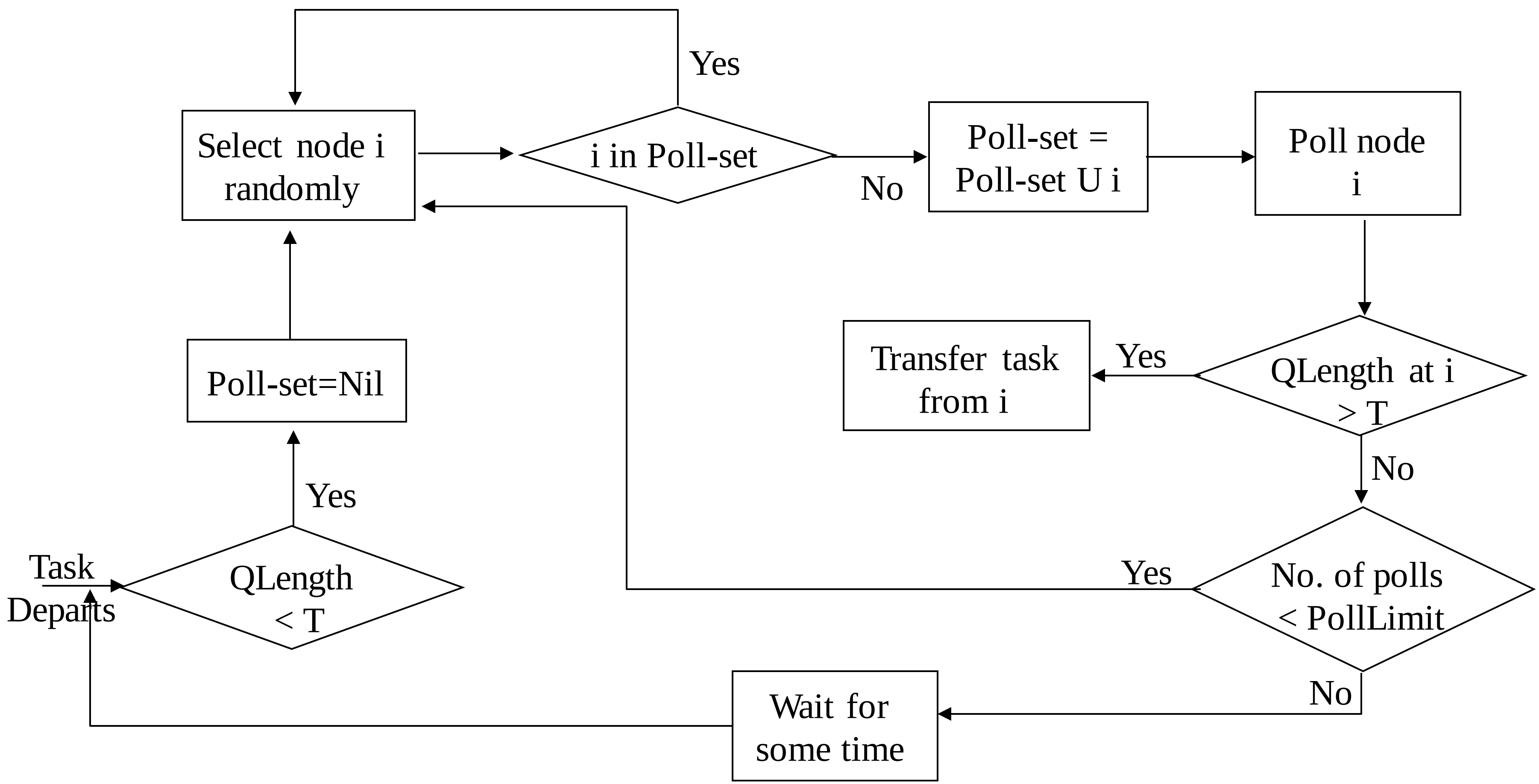
Sender-initiated

- *Information Policy*: demand-driven.
- *Stability*: can become unstable at high loads.
  - At high loads, it may become difficult for senders to find receivers.
  - Also, the number of senders increase at high system loads thereby increasing the polling activity.
  - Polling activity may make the system unstable at high loads.

Receiver-initiated

- *Transfer Policy*: uses thresholds. Queue lengths below T identifies receivers and those above T identifies senders.
- *Selection Policy*: as before.
- *Location Policy*: Polling.
  - A random node is polled to check if a task transfer would place its queue length below a threshold.
  - If not, the polled node transfers a task.
  - Otherwise, poll another node till a static PollLimit is reached.
  - If all polls fail, wait until another task is completed before starting polling operation.
- Information policy: demand-driven.
- Stability: Not unstable since there are lightly loaded systems that have initiated the algorithm.

Receiver-initiated



Receiver-initiated

- Drawback:
  - Polling initiated by receiver implies that it is difficult to find senders with new tasks.
  - Reason: systems try to schedule tasks as and when they arrive.
  - Effect: receiver-initiated approach might result in preemptive transfers. Hence transfer costs are more.
  - Sender-initiated: transfer costs are low as new jobs are transferred and so no need for transferring task states.

Symmetric

- Senders search for receivers and vice-versa.
- Low loads: senders can find receivers easily. High loads: receivers can find senders easily.
- May have disadvantages of both: polling at high loads can make the system unstable. Receiver-initiated task transfers can be preemptive and so expensive.
- Simple algorithm: combine previous two approaches.
- Above-average algorithm:
  - Transfer Policy: Two adaptive thresholds instead of one. If a node's estimated average load is A, a higher threshold *TooHigh* > A and a lower threshold *TooLow* < A are used.
  - Load < TooLow -> receiver. Load > TooHigh -> sender.

Above-average Algorithm

- Location policy:
- Sender Component
  - Node with *TooHigh* load, broadcasts a *TooHigh* message, sets *TooHigh* timer, and listens for an *Accept* message.
  - A receiver that gets the (TooHigh) message sends an *Accept* message, increases its load, and sets *AwaitingTask* timer.
  - If the *AwaitingTask* timer expires, load is decremented.
  - On receiving the Accept message: if the node is still a sender, it chooses the best task to transfer and transfers it to the node.
  - When sender is waiting for Accept, it may receive a *TooLow* message (receiver initiated). Sender sends *TooHigh* to that receiver. Do step 2 & 3.
  - On expiration of *TooHigh* timer, if no Accept message is received, system is highly loaded. Sender broadcasts a *ChangeAverage* message.

Above-average Algorithm...

- Receiver Component
  - Node with *TooLow* load, broadcasts a *TooLow* message, sets a *TooLow* timer, and listens for *TooHigh* message.
  - If *TooHigh* message is received, do step 2 & 3 in Sender Component.
  - If *TooLow* timer expires before receiving any *TooHigh* message, receiver broadcasts a *ChangeAverage* message to decrease the load estimate at other nodes.
- Selection Policy: as discussed before.
- Information policy: demand driven. Average load is modified based on system load. High loads may have less number of senders progressively.
  - Average system load is determined individually. There is a range of acceptable load before trying to be a sender or a receiver.

Adaptive Algorithms

- Limit Sender's polling actions at high load to avoid instability.
- Utilize the collected state information during previous polling operations to classify nodes as: Sender/overloaded, receiver/underloaded, OK (in acceptable load range).
- Maintained as separate lists for each class.
- Initially, each node assumes that all others are receivers.
- Location policy at sender:
  - Sender polls the head of the receiver list.
  - Polled node puts the sender at the head of it sender list. It informs the sender whether it is a receiver, a sender, or a OK node.
  - If the polled node is still a receiver, the new task is transferred.
  - Else the sender updates the polled node's status, polls the next potential receiver.
  - If this polling process fails to identify a receiver, the task can still be transferred during a receiver-initiated dialogue.

Adaptive Algorithms…

- Location policy at receiver
  - Receivers obtain tasks from potential senders. Lists are scanned in the following order.
    - Head to tail in senders list (most up-to-date info used), tail to head in OK list (least up-to-date used), tail to head in receiver list.
    - Least up-to-date used in the hope that status might have changed.
  - Receiver polls the selected node. If the node is a sender, a task is transferred.
  - If the node is not a sender, both the polled node and receiver update each other’s status.
  - Polling process stops if a sender is found or a static PollLimit is reached.

Adaptive Algorithms…

- At high loads, sender-initiated polling gradually reduces as nodes get removed from receiver list (and become senders).
  - Whereas at low loads, sender will generally find some receiver.
- At high loads, receiver-initiated works and can find a sender.
  - At low loads, receiver may not find senders, but that does not affect the performance.
- Algorithm dynamically becomes sender-initiated at low loads and receiver-initiated at high loads.
- Hence, algorithm is stable and can use non-preemptive transfers at low loads (sender initiated).

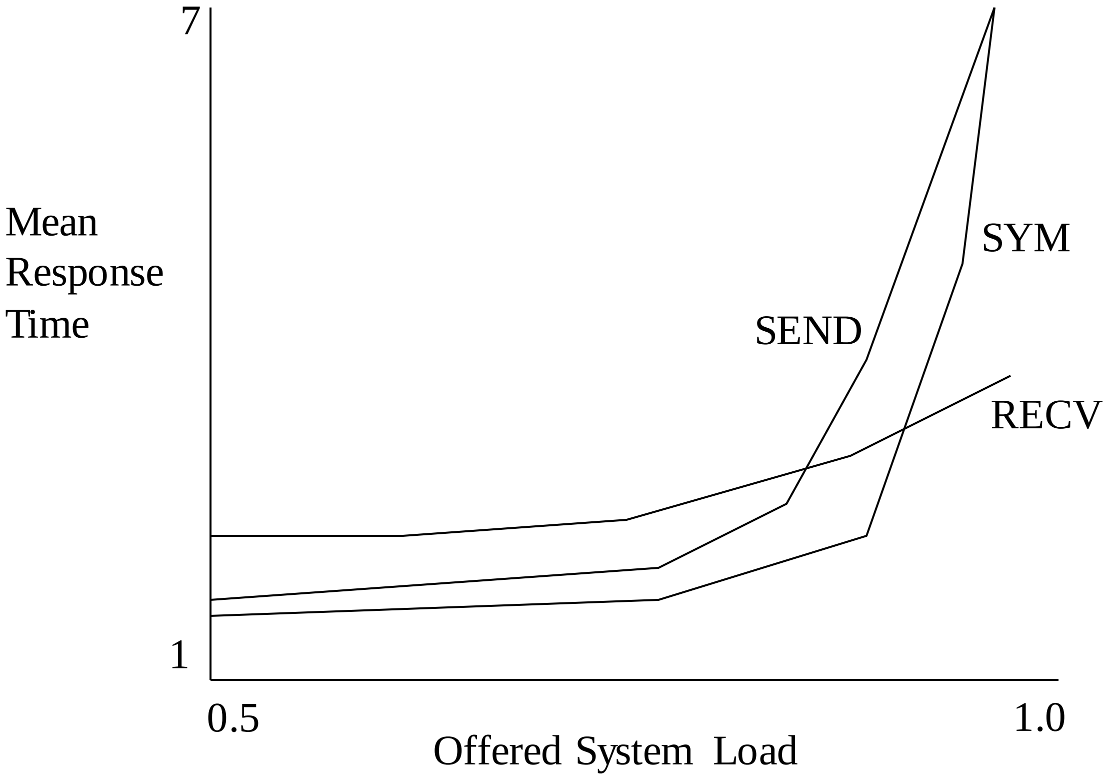
Selecting an Algorithm

- If a system never gets highly loaded, sender-initiated algorithms work better.
- Stable, receiver-initiated algorithms better for high loads.
- Widely fluctuating loads: stable, symmetric algorithms.
- Widely fluctuating loads + high migration cost for preemptive transfers: stable, sender-initiated algorithms.
- Heterogeneous work arrival: stable, adaptive algorithms.

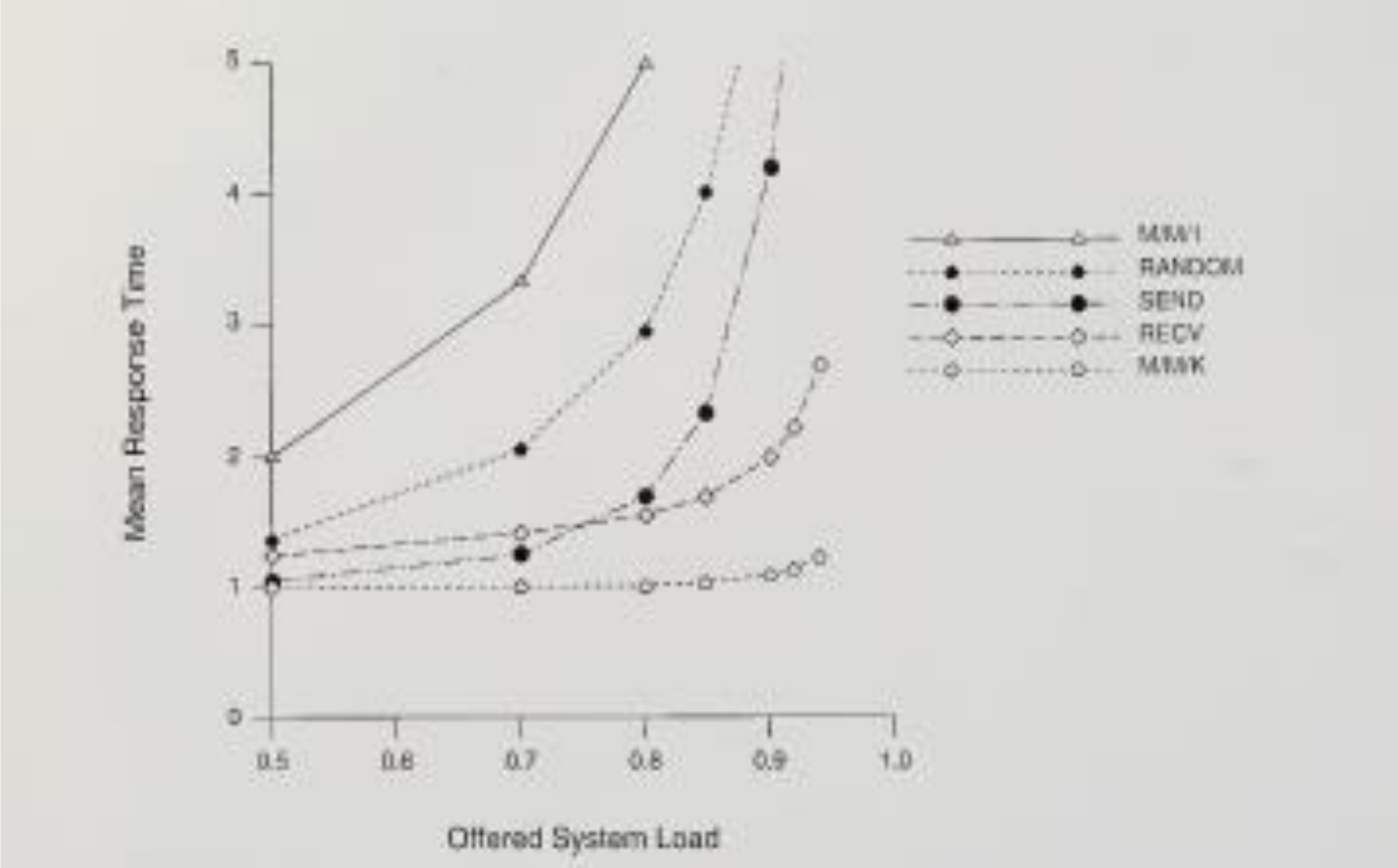
Performance Comparison

- Notations used in algorithm comparison:
  - M/M/1 -- a distributed system that performance no load distributing
  - RECV --- Receiver- initiated algorithm
  - RAND ---Sender – initiated algorithm with random location policy
  - SEND --- Sender – initiated algorithm with threshold location policy
  - ADSEND –Stable sender- initiated algorithm
  - SYM – Symmetrically initiated algorithm
  - ADSYM – Stable symmetrically initiated algorithm
  - M/M/K – A distributed system that performs ideal load distributing without incurring any overhead.

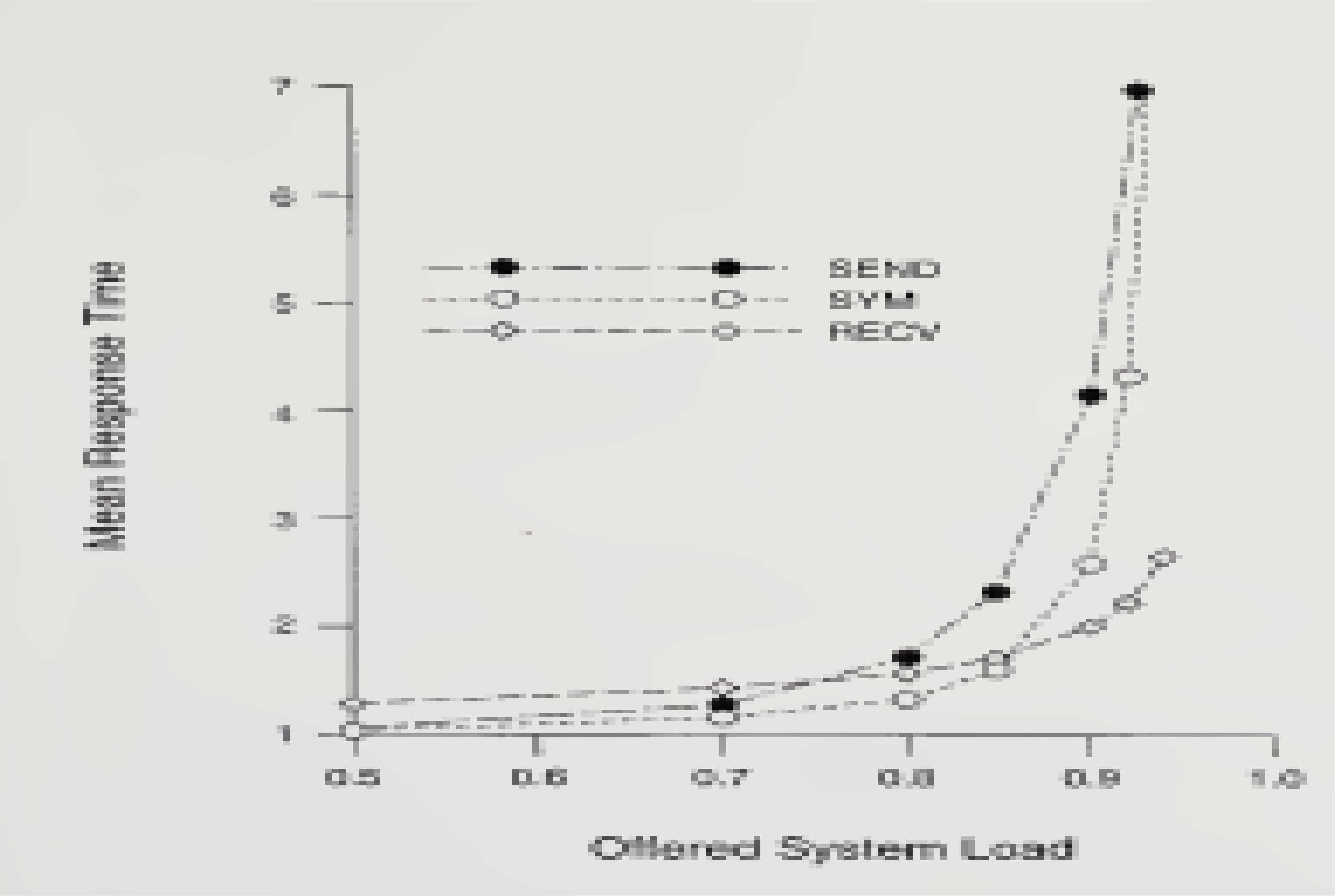
Performance Comparison



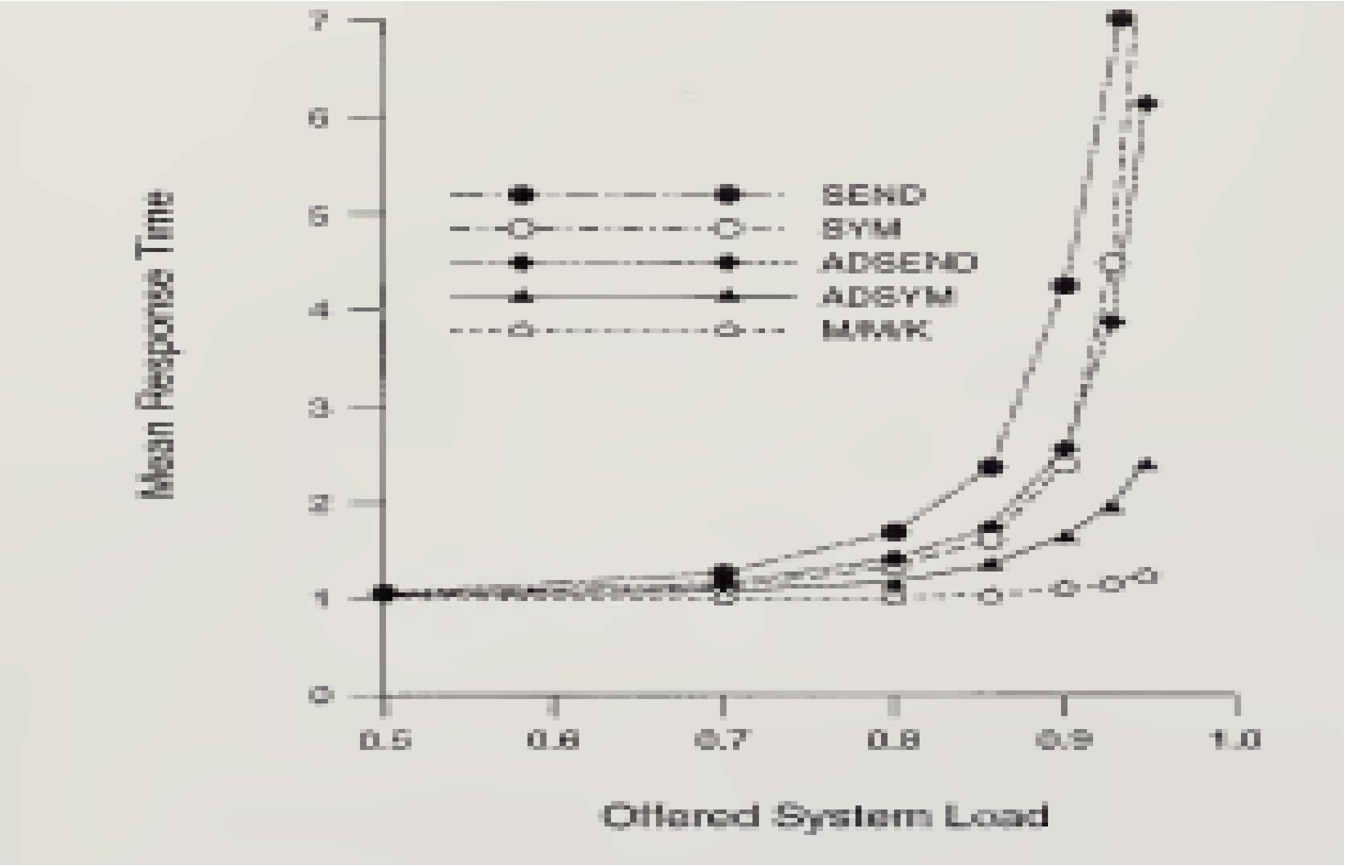
Reciver-initiated vs sender-initiated load sharing



Symmetrically initiated load sharing



Stable load sharing algorithms



Performance under heterogeneous workloads