Toward Fault-tolerant P2P Systems: Constructing a Stable Virtual Peer from Multiple Unstable Peers

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Background

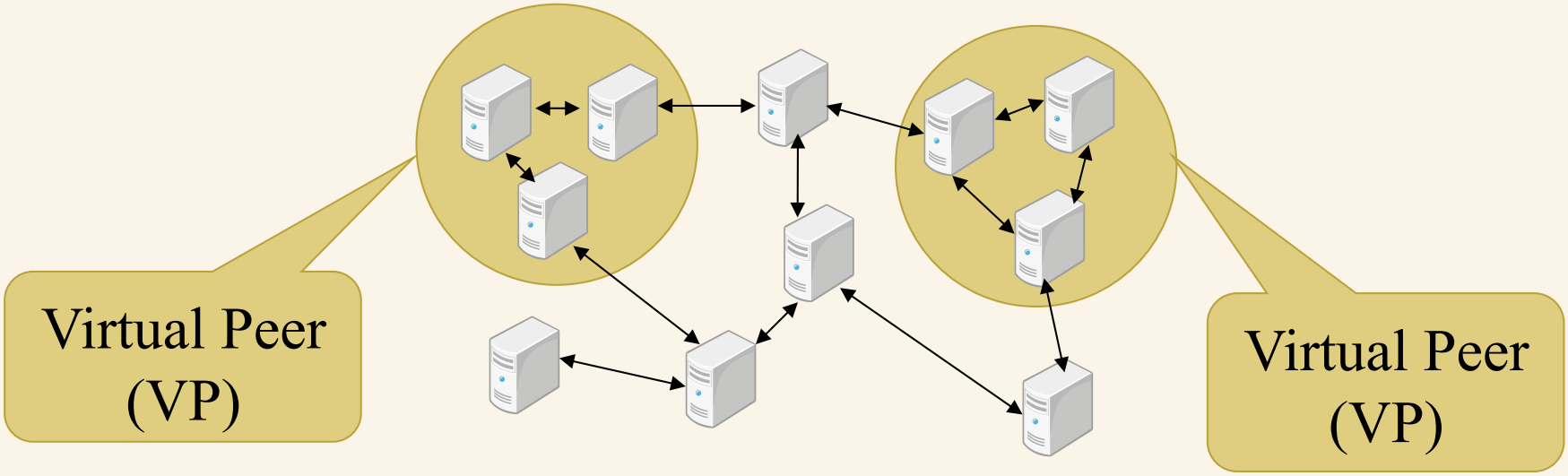
- P2P systems pros and cons
  - pros: scalability, no single point of failure, etc.
  - cons: hard to implement!
    - detect remote peer failure
    - replicate data over multiple peers
    - manage multiple pointers to backup peers
- Implementing these measures is delicate work and troublesome burden for developers

GOAL!

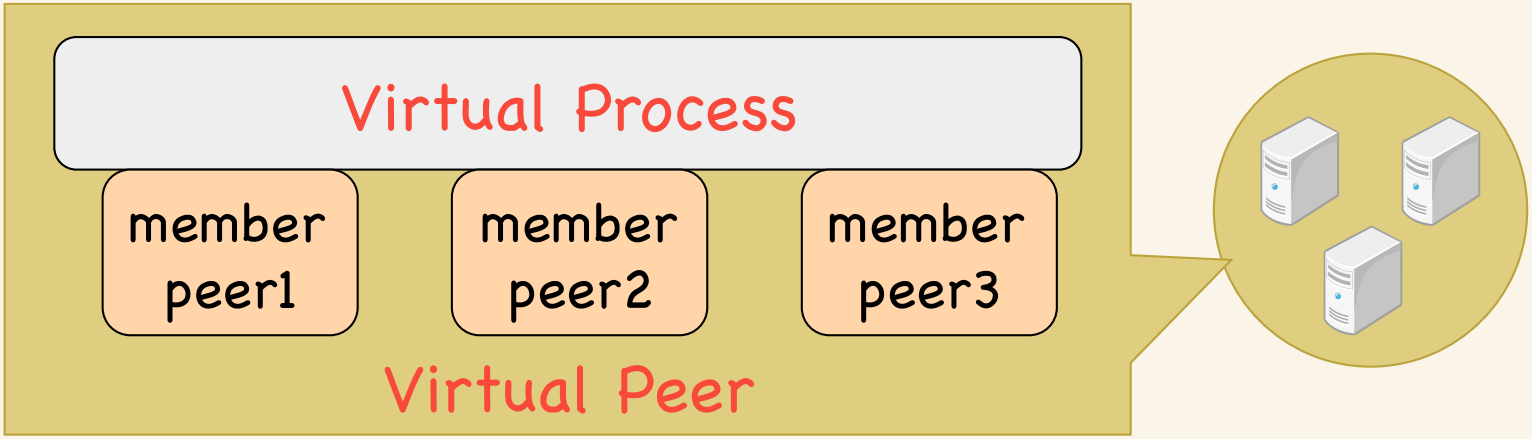
Implement a reliable layer for fault tolerant P2P systems

Our Approach

- Virtual Peer (VP)
  - Group multiple unstable peers to form a stable *virtual peer* (redundant system)



Our Approach (Cont'd)



- A *virtual peer* consists of multiple *member peers*
- A P2P application runs on a virtual peer as a *virtual process*
- Failed member peer is replaced with another (non-failed) one
- A virtual process is fault-tolerant
  - It does not fail even if some part of the member peers fail
  - Application developers do not need to take care of peer failure

Issues to solve

1. How to achieve fault-tolerance of a virtual process?
2. How to ensure identical message sequences?
3. How to handle peer failure?
4. How to communicate with a remote virtual peer?

1. Achieving fault-tolerance of virtual process

- The state of a virtual process must be replicated over multiple member peers
- Each member peer *simultaneously and redundantly executes the same application*, as a *process*
- To maintain the state of each process identical:
  - A process must be a state machine
    - its state must be changed only by external messages
  - Also, each process receives the identical message sequence (aka atomic broadcasting)
- Merit: application programs can be quite simple
  - Just process the received messages in order

2. Ensuring identical message sequences

- To implement atomic broadcast, the Paxos consensus algorithm is used
- Paxos
  - Distributed algorithm to form a consensus between multiple nodes (peers) on an unreliable network
  - Only a dedicated leader peer can propose values
    - The leader is elected by using a leader election algorithm
  - All peers eventually choose an identical value
  - Majority agreement is required
- All the member peers in VP execute Paxos algorithm
  - External messages sent to a VP are processed by the Paxos algorithm to be identically ordered

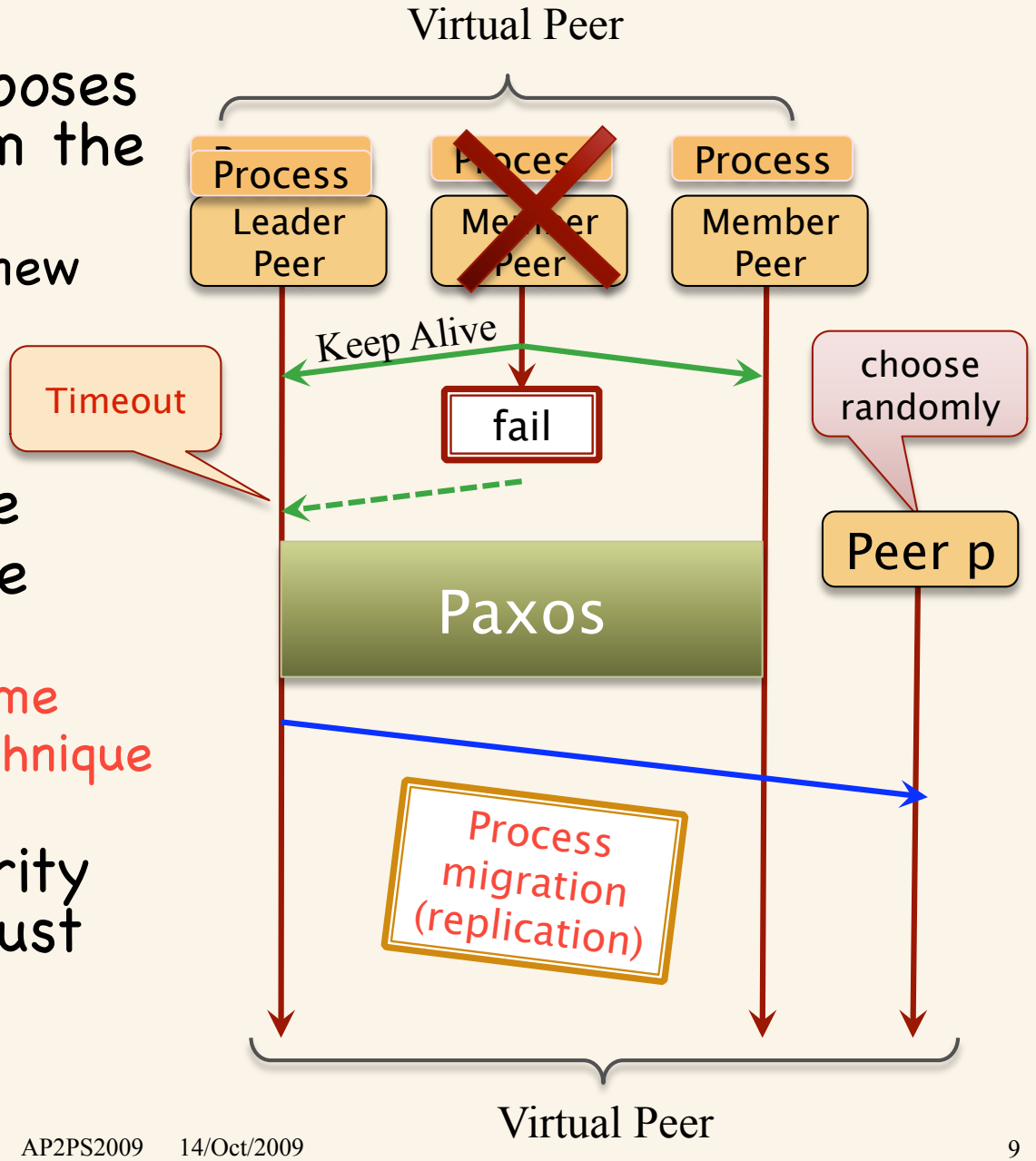
3. Handling peer failure

- Failed member peer must be replaced to keep the number of the peers constant
  - Otherwise the VP eventually will not be functional because majority agreement is required by Paxos

- All the member peers must have a consistent view of membership configuration
- Paxos is also used to update a member configuration without losing consistency

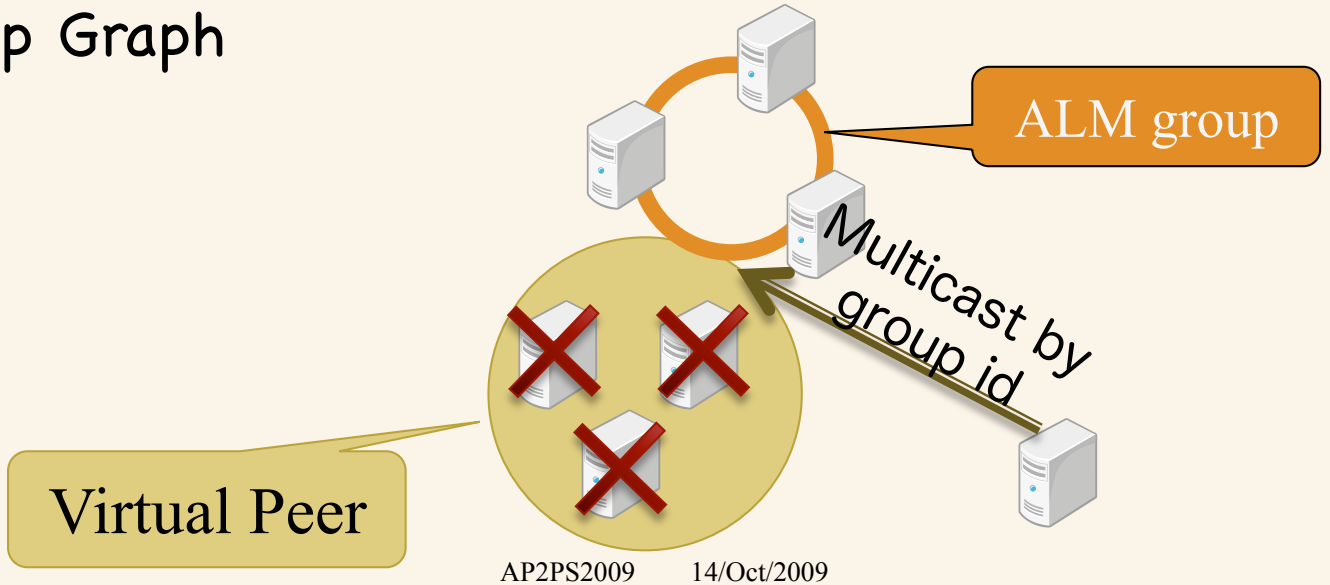
3. Handling peer failure (Cont'd)

- The leader peer chooses another peer p from the P2P network
  - If leader peer fails, new leader is elected
- The leader peer proposes a peer configuration change
- p executes the same process
  - The state must be same
  - Process migration technique is used
- Note that the majority of member peers must be alive during this replacing sequence



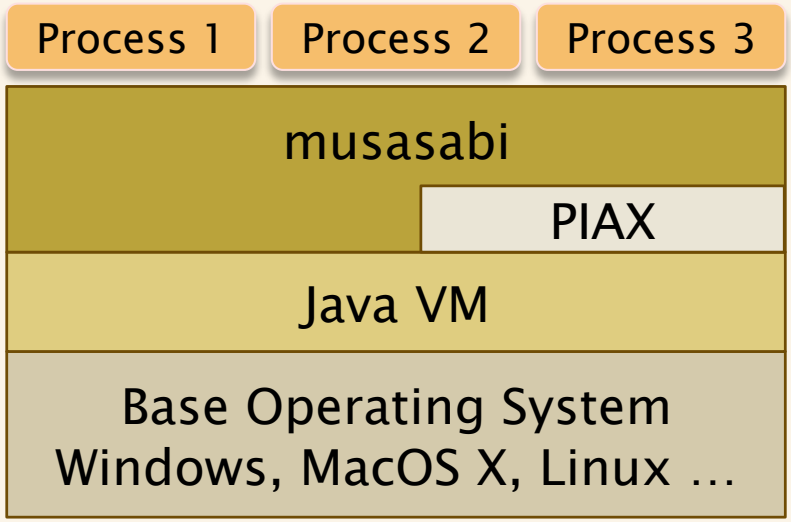
4. Communication with virtual peer

- How to deliver messages to VPs
  - Member peers are not fixed!
- Solution: Use ALM (Application Level Multicast)
  - Each VP has a dedicated ALM group
    - All member peers join in
  - Messages sent to a VP are multicast to the group
  - We have implemented ALM by using range queries on Skip Graph



Our implementation: musasabi

- A platform for implementing P2P services
  - Implemented in Java
- Each peer executes a musasabi instance
- An application program written in Java can be executed on musasabi



Configuration of musasabi

- Java sandbox mechanism is used to protect a local node
- musasabi uses PIAX for P2P networking
  - PIAX provides Skip Graph, ALM (over Skip Graph) etc.
  - http://www.piax.org/en/

Process migration in musasabi

- musasabi supports strong mobility
  - Transfer the program, data and execution context (thread stack and program counter)
  - Not easy in Java (not supported by the standard JVMs)
  - Some implementations use customized JVMs or native libraries (not portable)
    - Not suitable for P2P systems!
- Implementation of strong mobility in musasabi
  - Use Apache Javaflow library
    - Javaflow allows to capture and resume the execution context
    - Captured contexts can be transferred to a remote node!
    - Javaflow uses byte code translation technique and thus works on the standard JVMs

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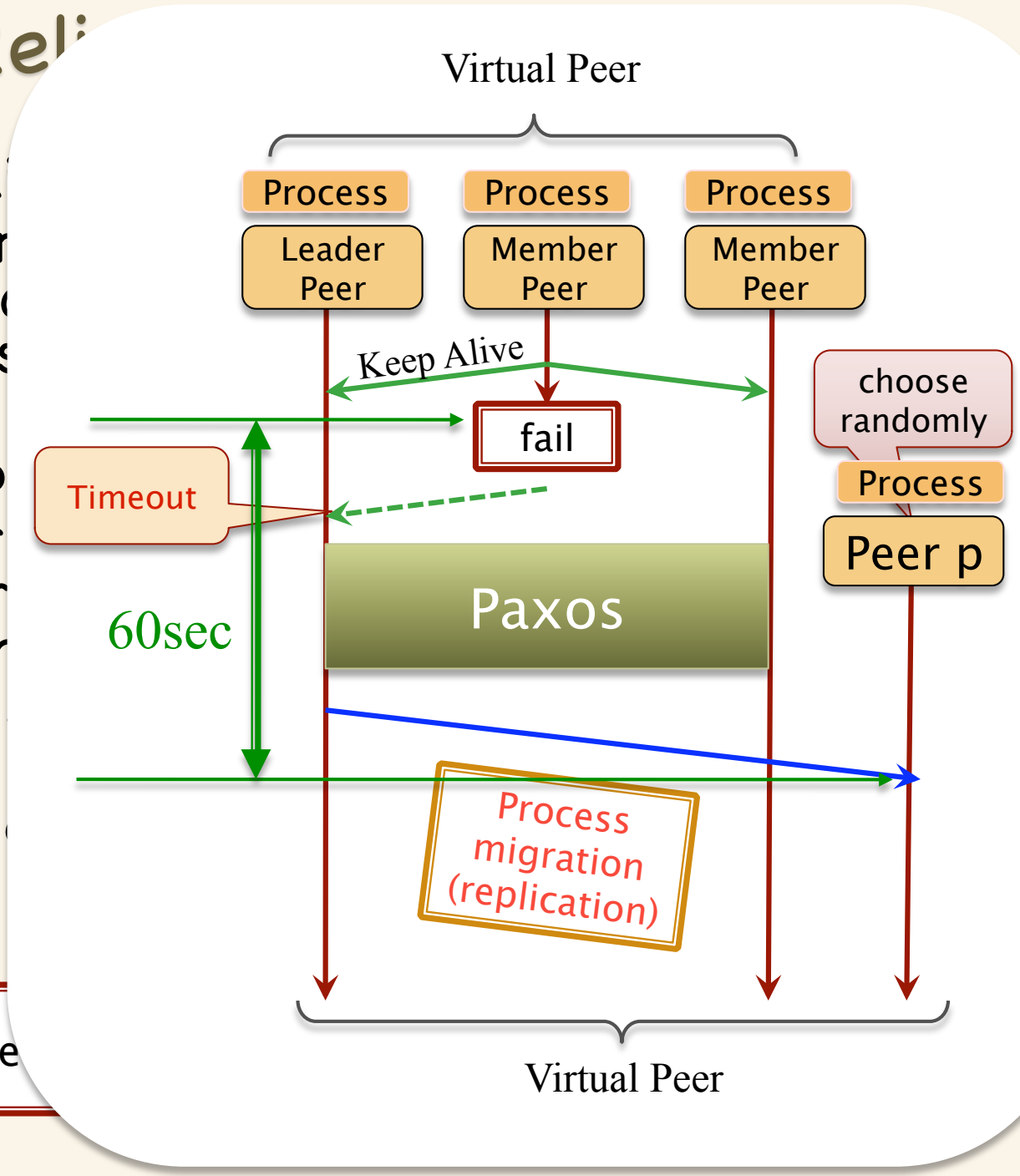
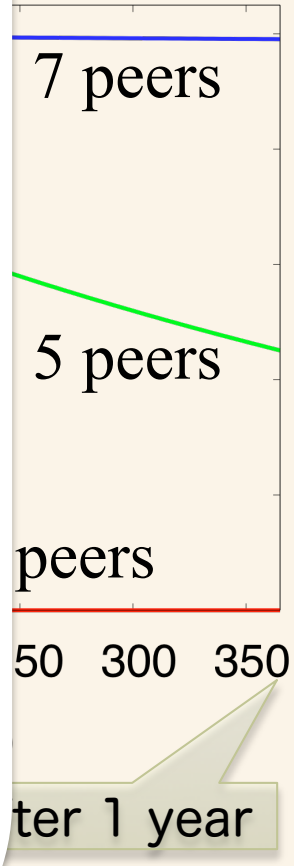
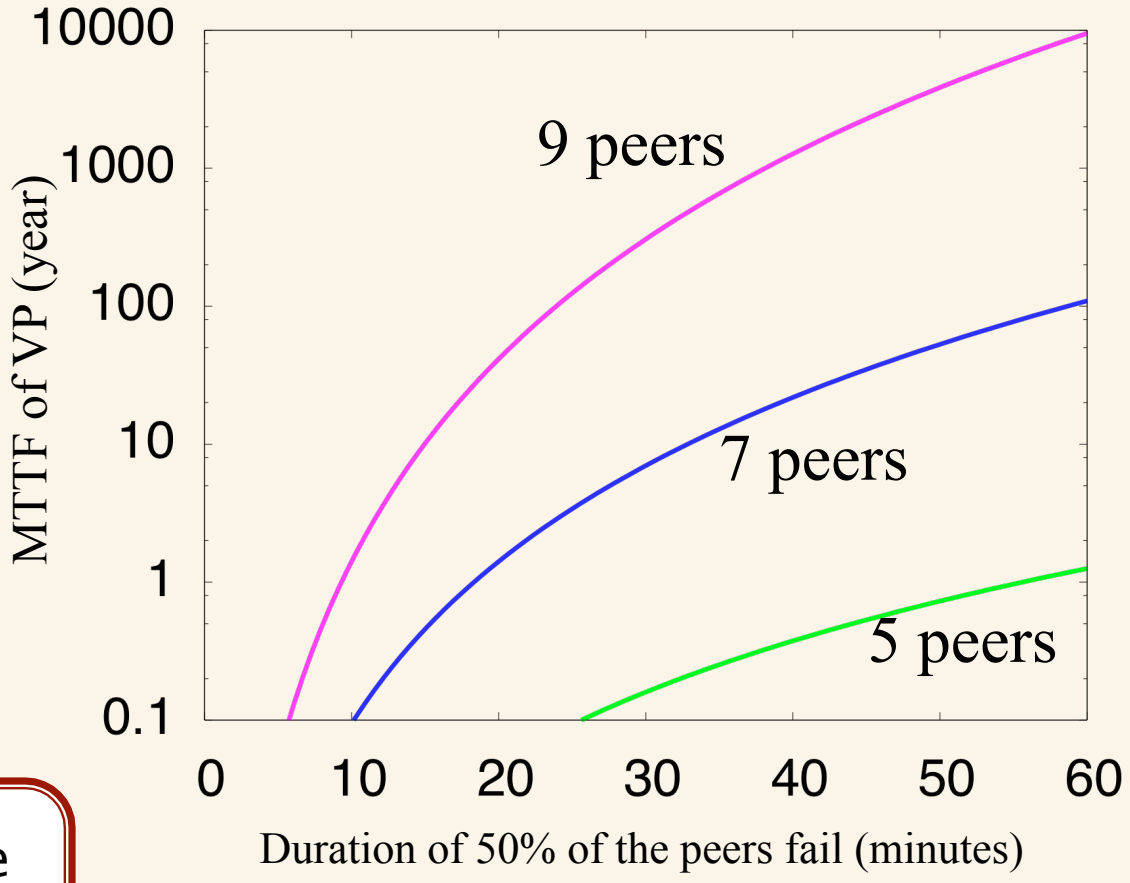




MTTF of virtual peer

Relation between MTTF (Mean Time To Failure) of a VP and # of its member peer is analyzed

- Each peer fails independently
- Intervals of peer failure are exponentially distributed
- Maximum time to replace a failed peer is 60sec
- Peer failure rate is varied (x-axis)



Even in excessive peer failure environment, VP is stable if it has enough member peers

frequently ← peer fails → less frequently

Conclusion and Future work

- We proposed a novel method to construct a stable virtual peer from multiple unstable peers
  - Integrate the Paxos consensus algorithm, process migration technique and ALM
  - An application running on a VP virtually does not fail
  - Application programs can be quite simple
- The method can be used for reducing development costs, and for improving stability, of P2P systems
- Future work
  - Improve the method for choosing *good* member peers
  - Investigate and improve security issues of VPs
  - Evaluate the method on the Internet

Questions?

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