INFORMATION
TECHNOLOGY
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Understanding Self-healing in Service Discovery Systems

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Observations on Self-healing in Distributed Systems

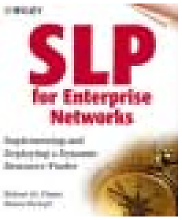
- Recovery strategies are critical for self-healing as failure rate increases.
  - More so than other factors (e.g., architecture, topology, consistency-maintenance mechanisms)
- Recovery strategies can interact in complex and unexpected ways
  - Redundancy (only one is necessary)
  - Complimentaryness (both are necessary)
  - Interference (one strategy prevents another from succeeding)
- When designing self-healing distributed systems based on service discovery protocols, need to consider:
  - The types of failure expected and their likelihood
  - Detailed protocol behaviors (e.g., discovery, update propagation, recovery) and not simply the application-programming interface.

Dynamic discovery protocols in essence…

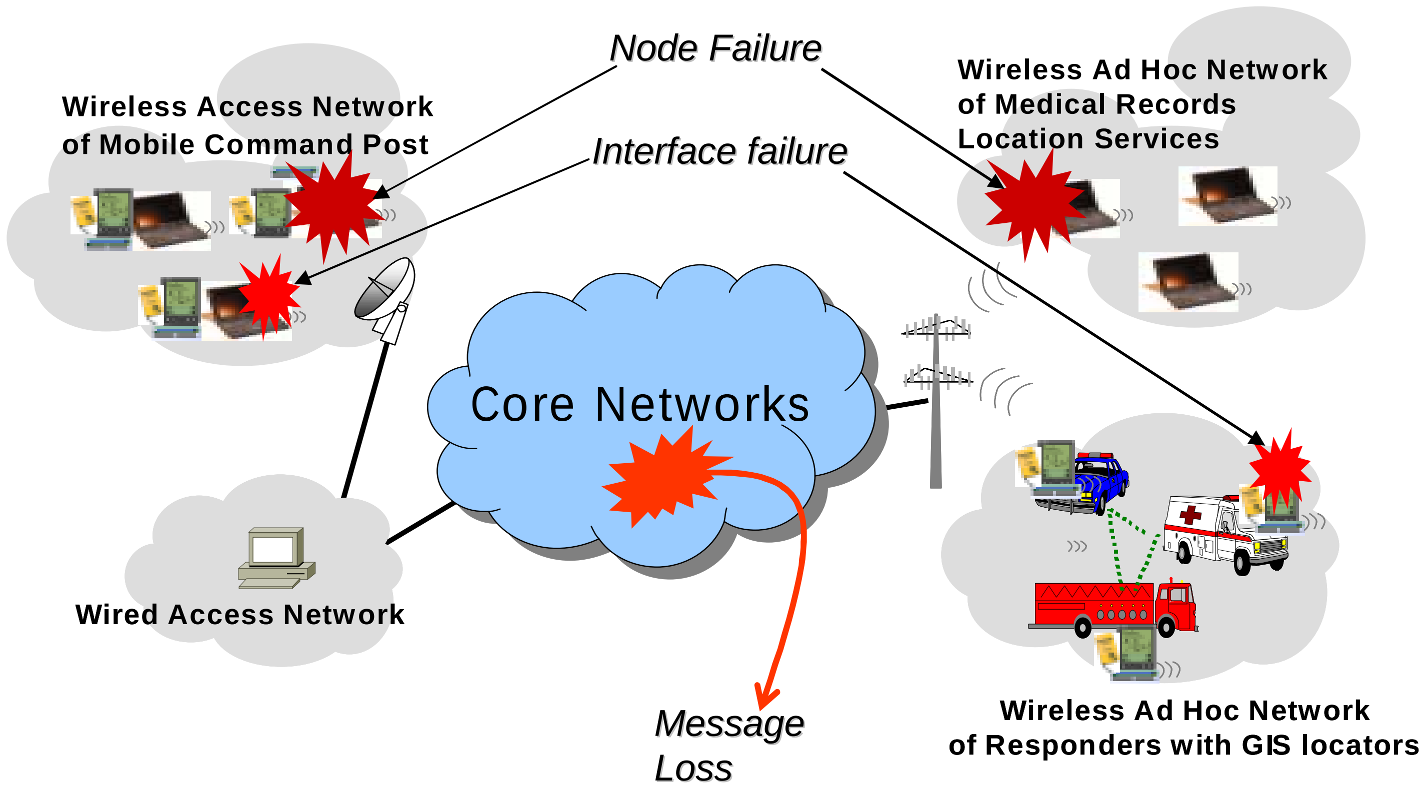
enable ***distributed software components***

(1) to ***discover*** each other without prior arrangement,
(2) to ***express*** opportunities for collaboration,
(3) to ***compose*** themselves into larger collections that cooperate to meet an application need, and
(4) to ***detect and adapt*** to failures.

Some examples:

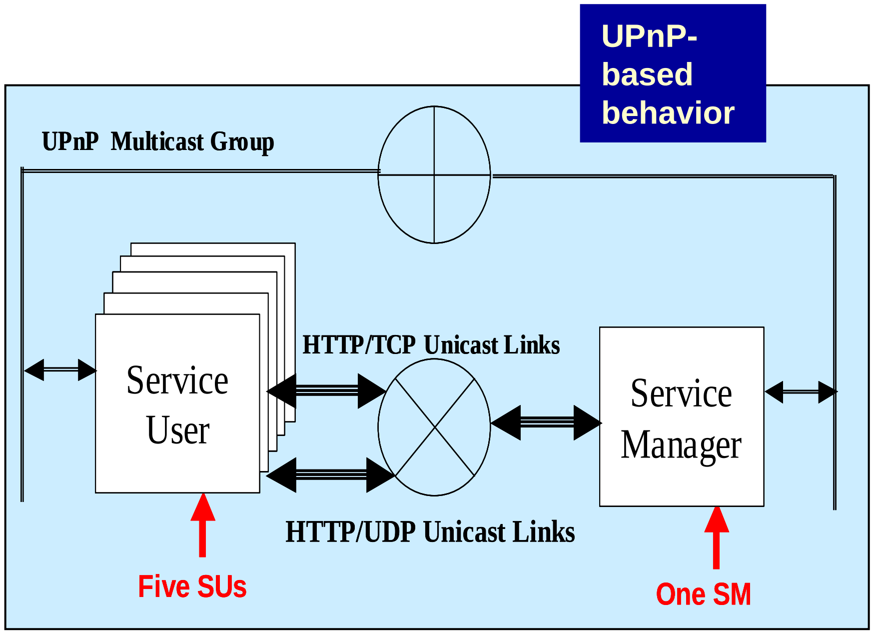
JINI **3-Party Design**	UPnP FORUM **2-Party Design**	 **Adaptive 2/3-Party Design**
The Salutation Consortium **Vertically Integrated 3-Party Design**	HAVi **Network-Dependent 3-Party Design**	Bluetooth™ **Network-Dependent 2-Party Design**

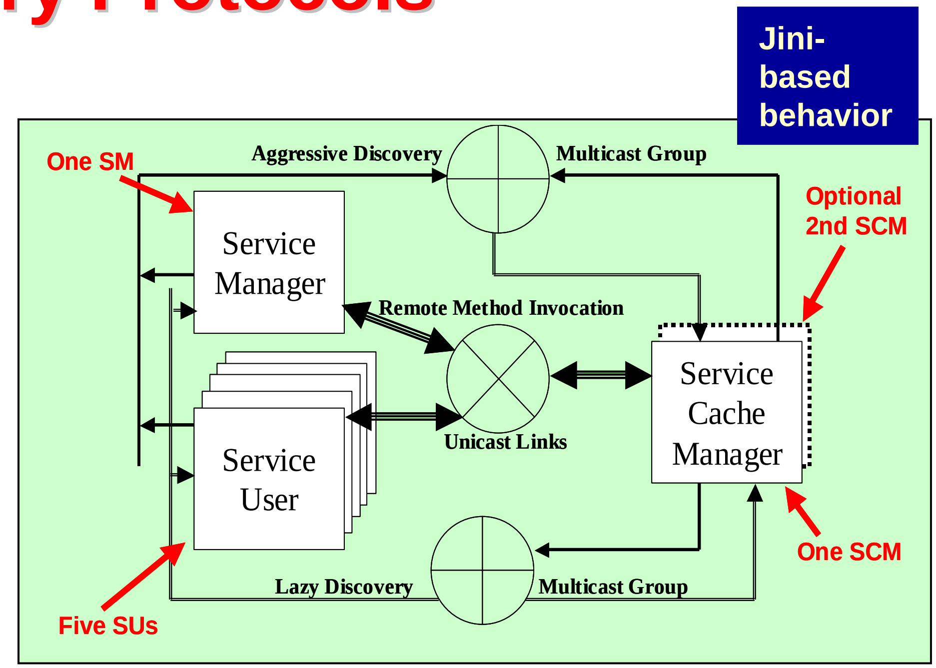
Self-healing in Hostile and Volatile Conditions



- **Service discovery systems must ensure consistency of information about services in failure environments**
- **Contributing factors: recovery strategies, architectures, topologies, and consistency-maintenance mechanisms (polling & notification)**
- ***This study focuses on role of recovery strategies.***

Two Generic Architectures Underlie Six Discovery Protocols



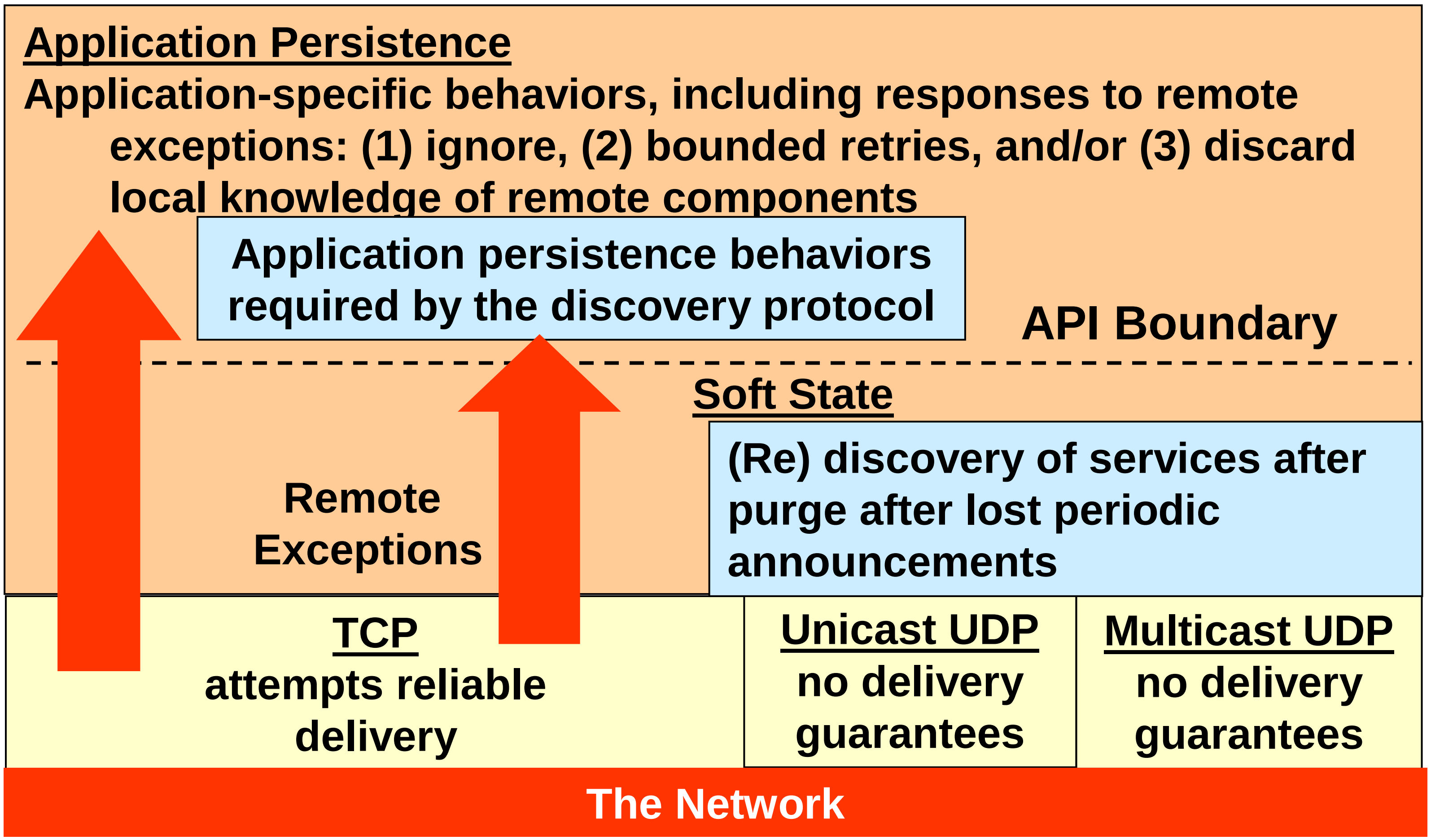


Update Propagation Method

- ***Notification*** – Updates forwarded by Managers immediately after they occur.
  - Service Users request leases with Service Managers to obtain notifications
  - Notifications rely on TCP for robustness, but TCP may fail and issue a remote exception

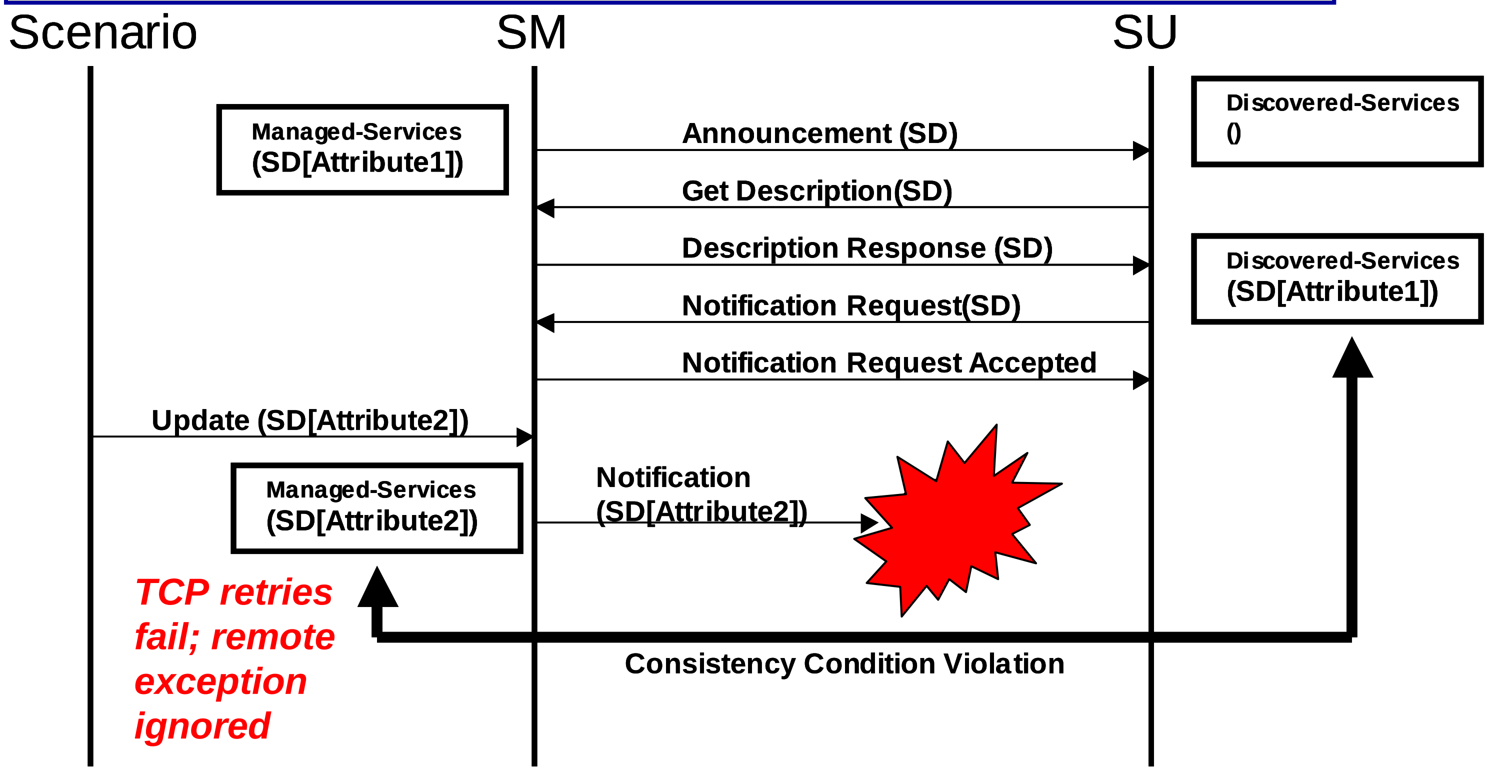
Understanding Contribution of Failure Detection and Recovery Strategies to Update Effectiveness

Types of Strategies:



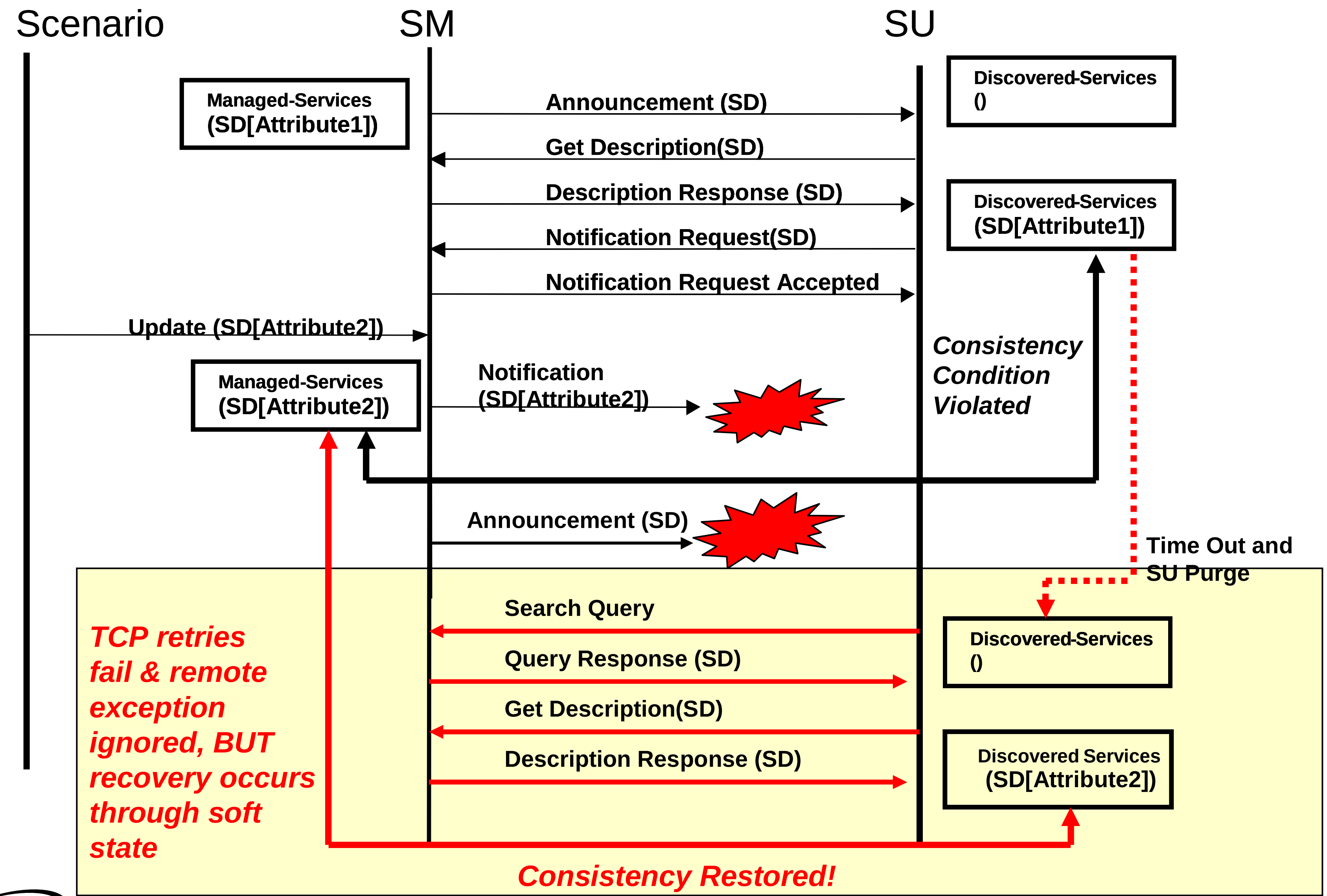
Consistency Maintenance Using Notification

For All **(SM, SU, SD):**
(SM, SD [Attributes1]) *IsElementOf* SU discovered-services
SD [Attributes2] *IsElementOf* SM managed-services
implies **Attributes1 = Attributes2**

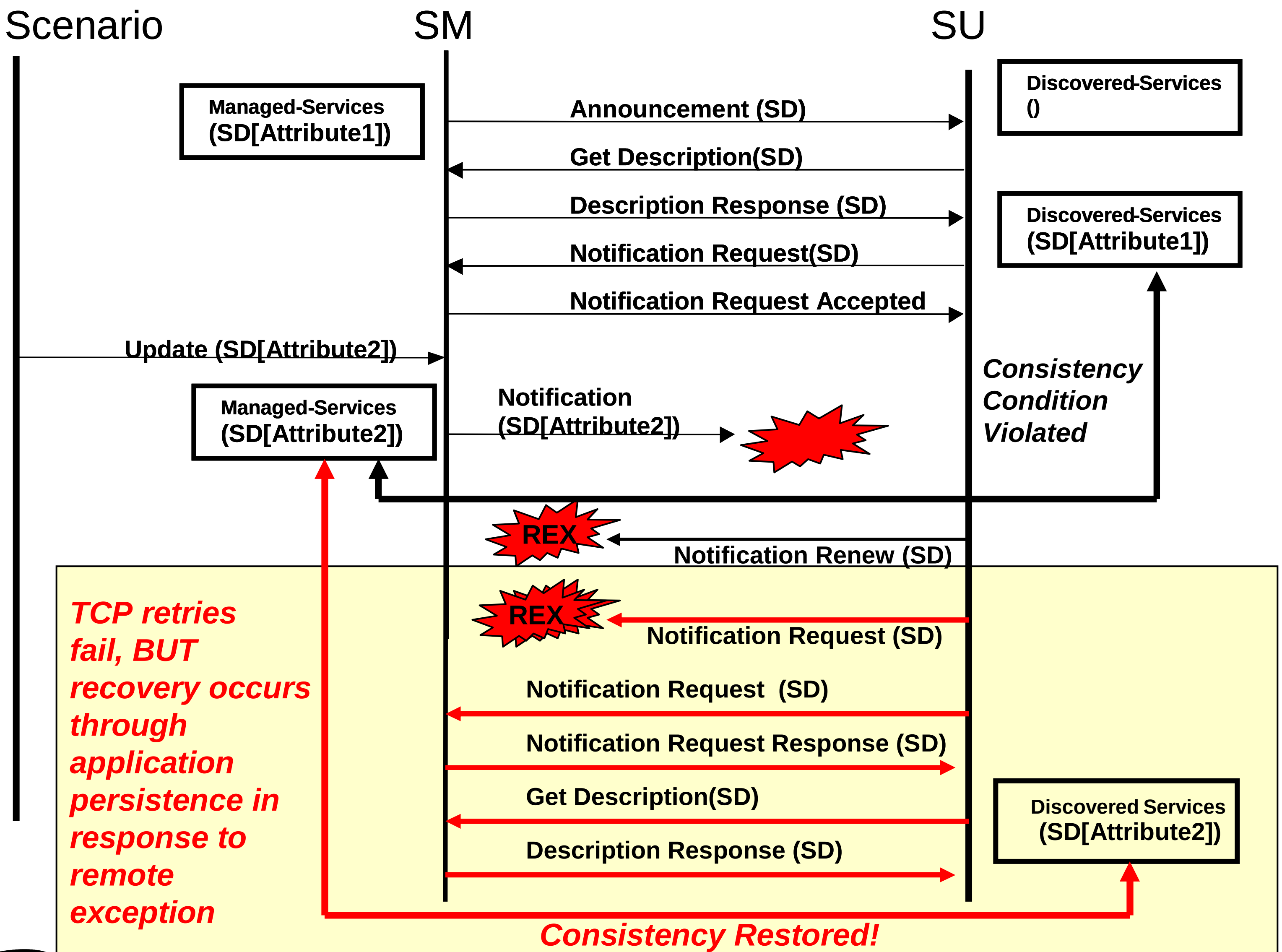


How well does the system restore consistency after failure?

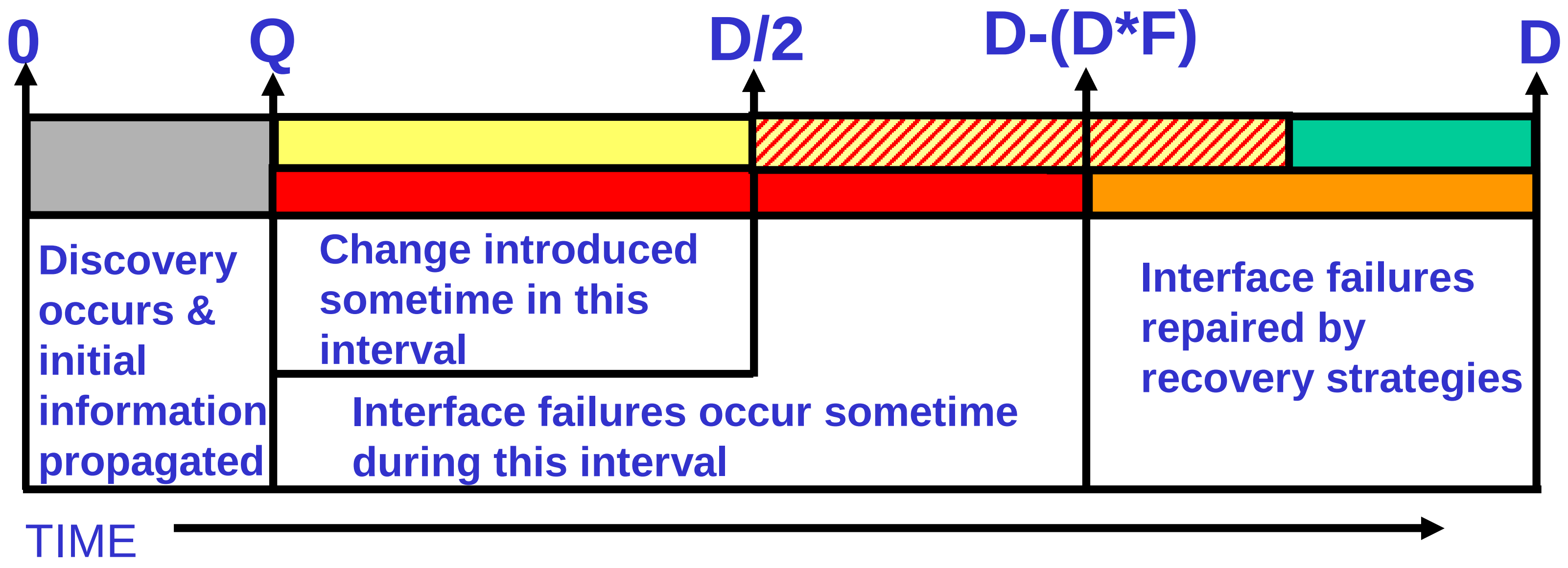
Soft State Recovery of Service After Failed Notification



Application Persistence Recovery of Service After Failed Notification



Interface-Failure Model for Experiment

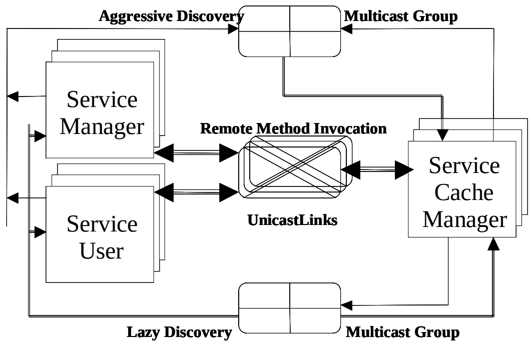


Random Processes

1. Choose a time to introduce the change [uniform(Q, D/2)]
2. For each node, choose a time to introduce an interface failure [uniform(Q, D-(D*F))]
3. When each interface failure occurs, choose the scope of the failure, where each of [Rx, Tx, Both] has an equal probability

Q = end of quiescent period (100 s in our experiment)
D = propagation deadline (5400 s in our experiment)
F = Interface Failure Rate (variable from 0% - 75% in 5% increments in our experiment)

Modeling and Analysis Approach

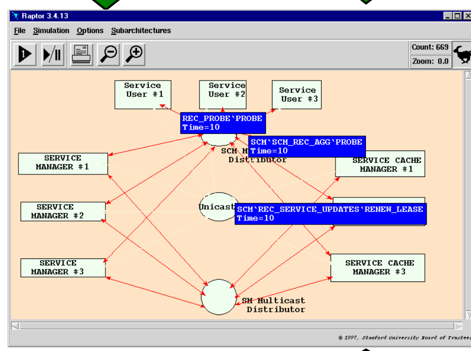


Behavior Model

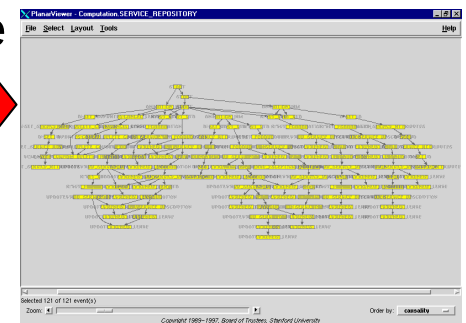
Topology

Scenario

Time	Command	Parameters
5	NodeFail	SM4
5	LinkFail	SCM1 SM4
10	GroupJoin	SM4 GROUP1
10	FindService	SU8 5 1 2 S XYZ ALL
50	AddService	SM4 SCM3 T ATT API GUI 20 30



Execute with Rapide




```
-- ****************************************************
-- ** 3.3  DIRECTED DISCOVERY CLIENT INTERFACE      **
-- ****************************************************
-- This is used by all JINI entities in directed
-- discovery mode.  It is part of the SCM_Discovery
-- Module. Sends Unicast messages to  SCMs on list of
-- SCMS to be discovered until all SCMS are found.
-- Receives updates from SCM DB of discovered SCMs and
-- removes SCMs accordingly
-- NOTE: Failure and recovery behavior are not
-- yet defined and need reviw.
TYPE Directed_Discovery_Client
 (SourceID : IP_Address; InSCMsToDiscover : SCMList; StartOption : DD_Code;
  InRequestInterval : TimeUnit; InMaxNumTries : integer; InPV : ProtocolVersion)
IS INTERFACE
SERVICE DDC_SEND_DIR    : DIRECTED_2_STEP_PROTOCOL;
SERVICE DISC_MODES      : dual SCM_DISCOVERY_MODES;
SERVICE DD_SCM_Update   : DD_SCM_Update;
SERVICE SCM_Update      : SCM_Update;
SERVICE DB_Update       : dual DB_Update;
SERVICE NODE_FAILURES: NODE_FAILURES; -- events for failure and recovery.
ACTION
 IN Send_Requests(),
   BeginDirectedDiscovery();
BEHAVIOR
  action animation_Iam (name: string);
  MySourceID        : VAR IP_Address;
  PV                : VAR ProtocolVersion;
```

Consistency Conditions

For All (SM, SD, SCM):
(SM, SD) IsEleme ntOf SCM registered -services (CC1)
implies SCM IsElementOf SM discovered -SCMs

For All (SM, SD, SCM):
SCM IsEl ementOf SM discovered -SCMs & (CC2)
(SD) IsElementOf SM managed -services
implies (SM, SD) IsElementO f SCM registered -services

For All (SM, SD, SCM):
SCM IsElementOf SM discovered -SCMs & (CC3)
(SM, SD) IsElementOf SCM registered -services &
NOT (SCM IsElementOf SM persistent -list)
implies Intersection (SM GroupsToJoin, SCM GroupsMemberOf)

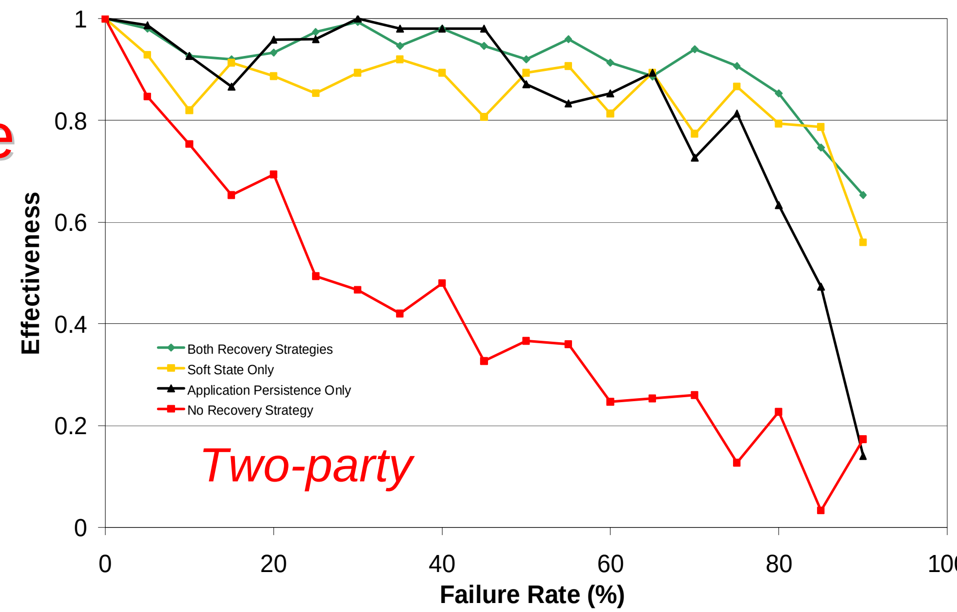
For All (SM, SD, SCM, SU, NR):
(SU, NR) IsElementOf SCM requested -notifications & (CC4)
(SM, SD) IsElement Of SCM registered -services &
Matches((SM, SD), (SU,NR))
implies (SM, SD) IsElementOf SU matched -services

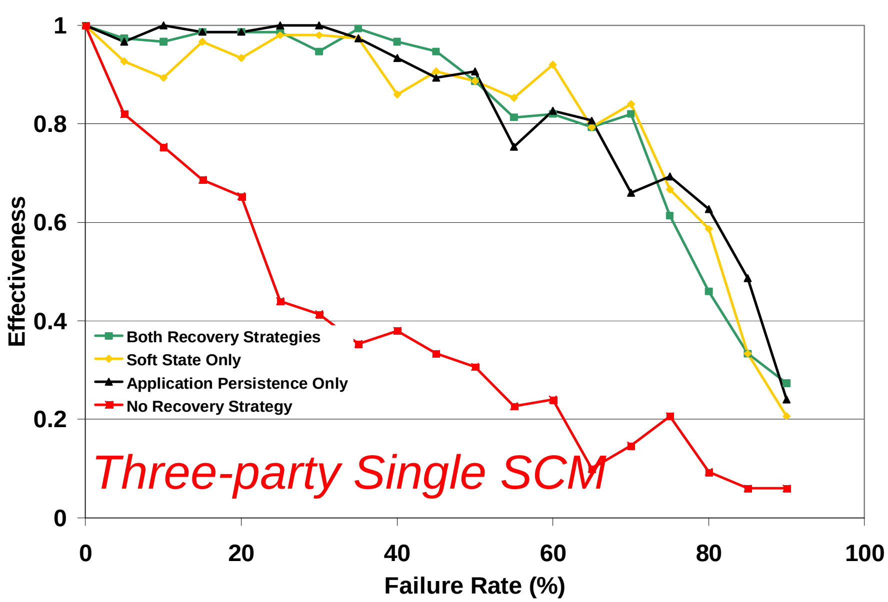
Analyze POSETs

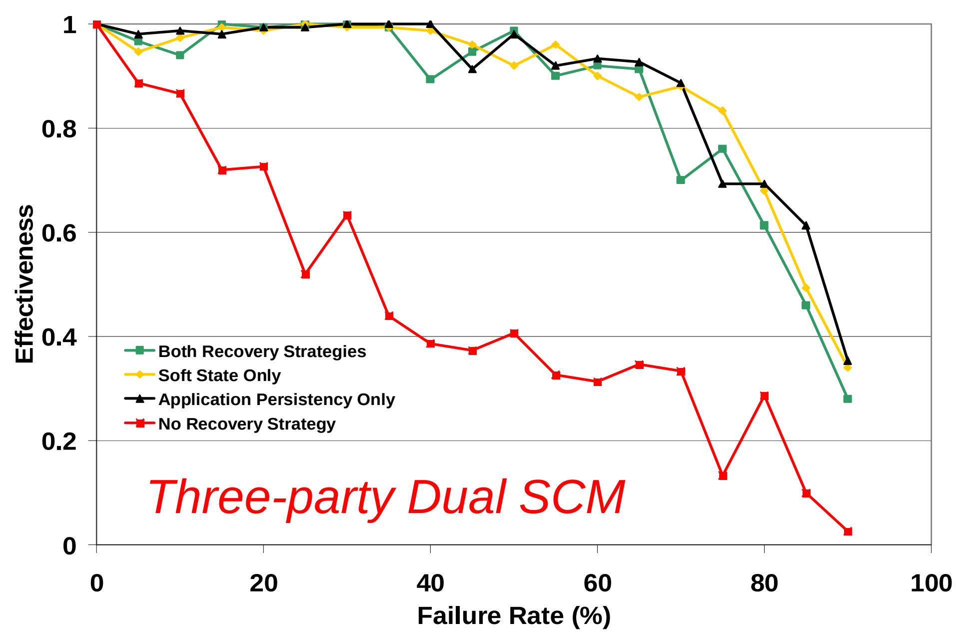
Use metrics to Assess Correctness & Performance

Update Effectiveness in Response to Interface Failure

	Both Recovery Strategies	Soft State Only	Application Persistence Only	No Recovery Strategy
Two-Party Notification	0.915	0.853	0.836	0.431
Three-Party Notification Single SCM	0.819	0.816	0.828	0.383
Three-Party Notification Dual SCM	0.856	0.879	0.887	0.465



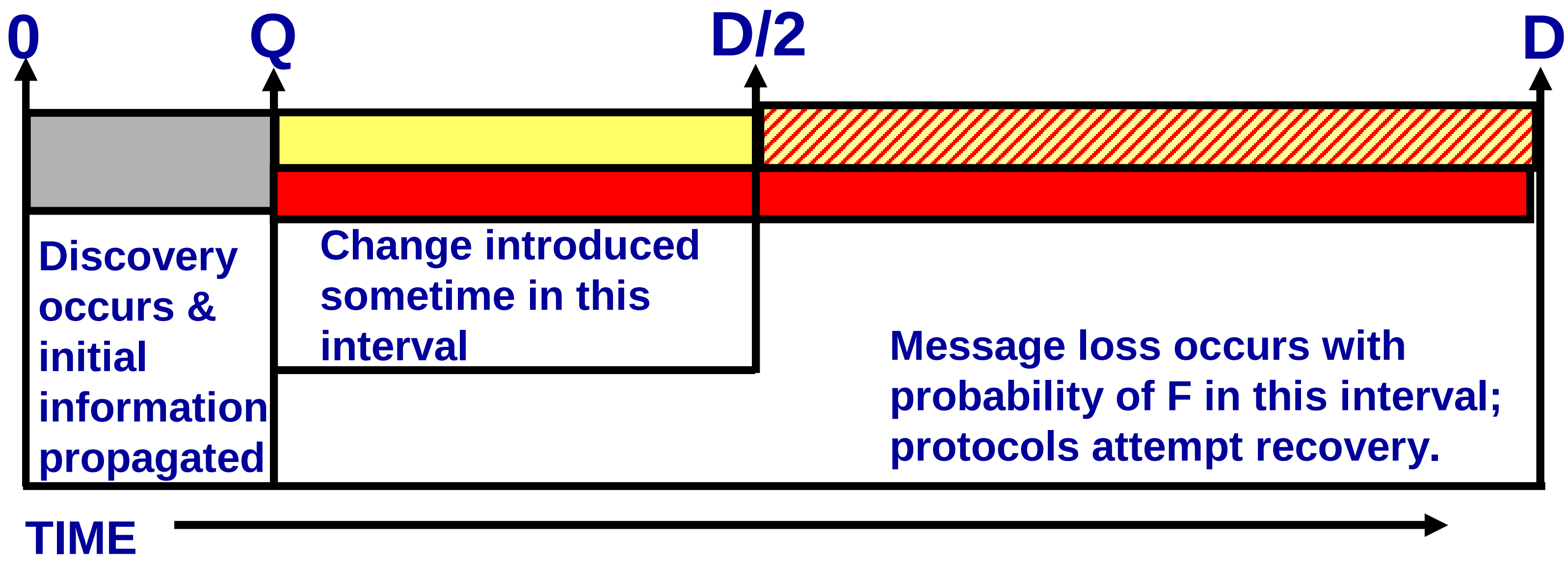




Results

- **Under Conditions of Interface Failure**
  - Performance decreases linearly in absence of recovery strategies
  - Soft State alone :
    - In both architectures, discovery discard decreases time available to recover.
    - In two-party, Soft State recovery alone is insufficient because recovery is not stimulated when failures block Get Description Requests or Notifications, but not announcements.
    - In three-party, Soft State alone approaches performance of both strategies together, because discovery discarded after same period as when both strategies used together.
  - Application Persistence alone:
    - In two-party, Application persistence may be sufficient, but in our experiments it's limited by lease renewal algorithm (residual 2.5% not renewed).
    - In three-party, Application Persistence performs as well as both strategies together because retries continue every 120s.
    - If additional SCMs provided, more paths for recovery and propagation allow Application Persistence to exceed both strategies together.

Message Loss Model for Experiment



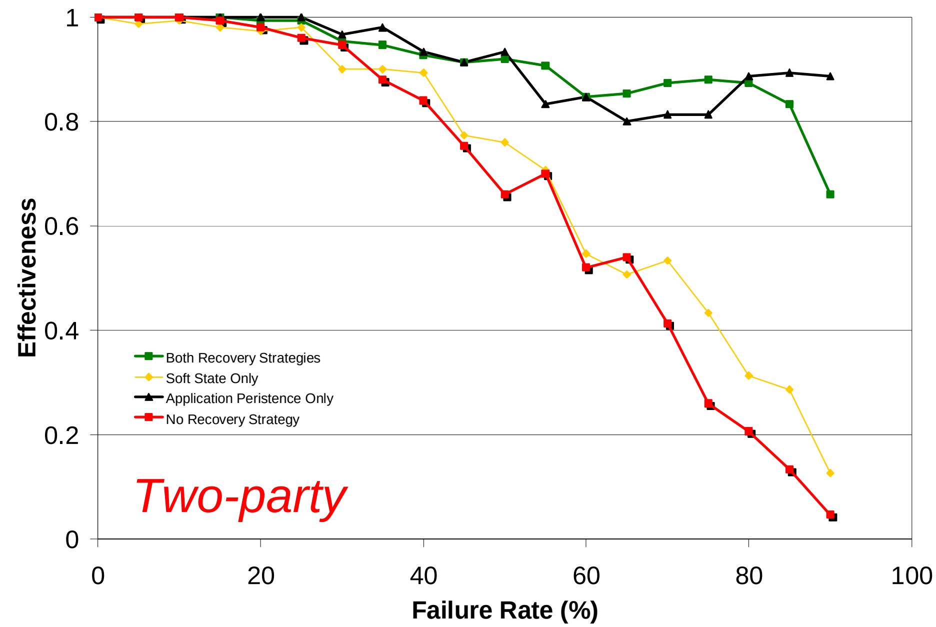
Random Processes

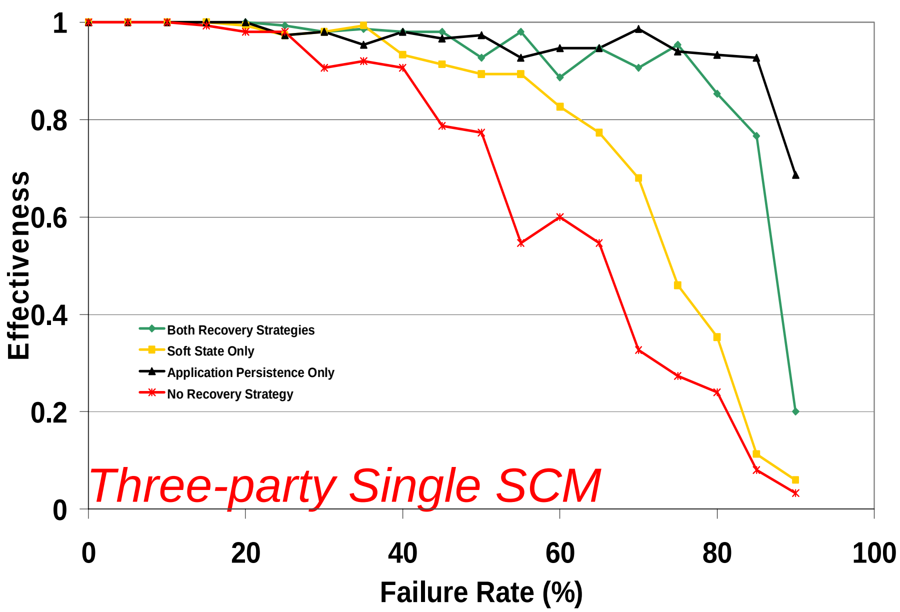
1. **Choose a time to introduce the change [uniform(Q, D/2)]**
2. **For each message transmission, determine if message is lost using F**

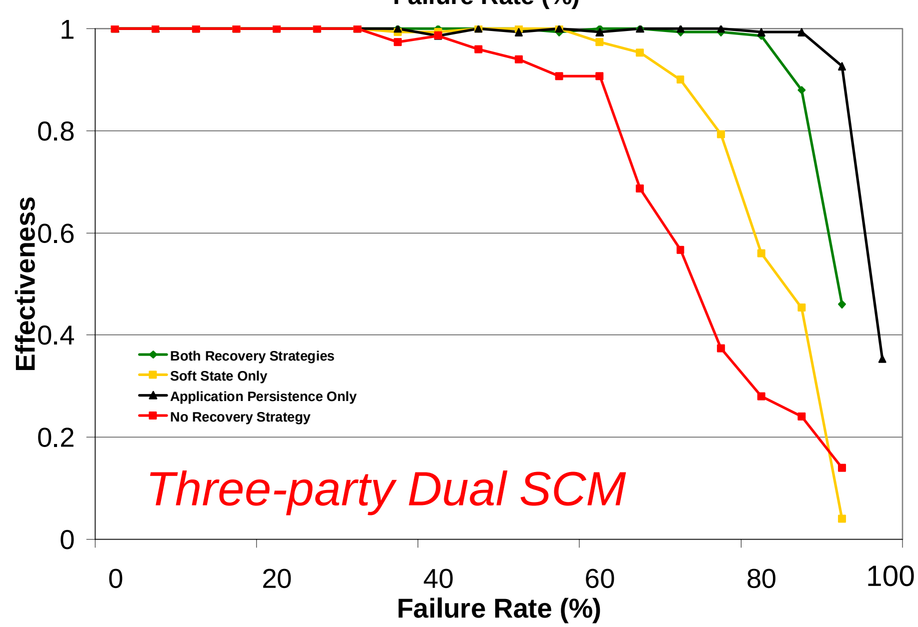
Q = end of quiescent period (100 s in our experiment)
D = propagation deadline (5400 s in our experiment)
F = message loss rate (variable from 0% - 95% in 5% increments in our experiment)

Update Effectiveness in Response to Message Loss

	Both Recovery Strategies	Soft State Only	Application Persistence Only	No Recovery Strategy
Two-Party Notification	0.914	0.715	0.921	0.675
Three-Party Notification Single SCM	0.913	0.781	0.954	0.679
Three-Party Notification Dual SCM	0.964	0.877	0.994	0.787







Results

- **Under Conditions of Message Loss**
  - Again, performance decreases linearly without recovery strategy
  - In three-party architecture, additional SCMs provide more paths for propagation and recovery.
  - Soft State alone:
    - Performance under Soft State alone insufficient because after discovery discard, rediscovery messages continue to be subject to message loss (making it harder to rediscover at high failure rates).
  - In Application Persistence alone
    - Application Persistence better than both strategies together because retries continue every 120s AND additional messages for rediscovery are not used.
- However, if nodes fail and are replaced by new nodes (different experiment), Soft State becomes more important than Application Persistence.

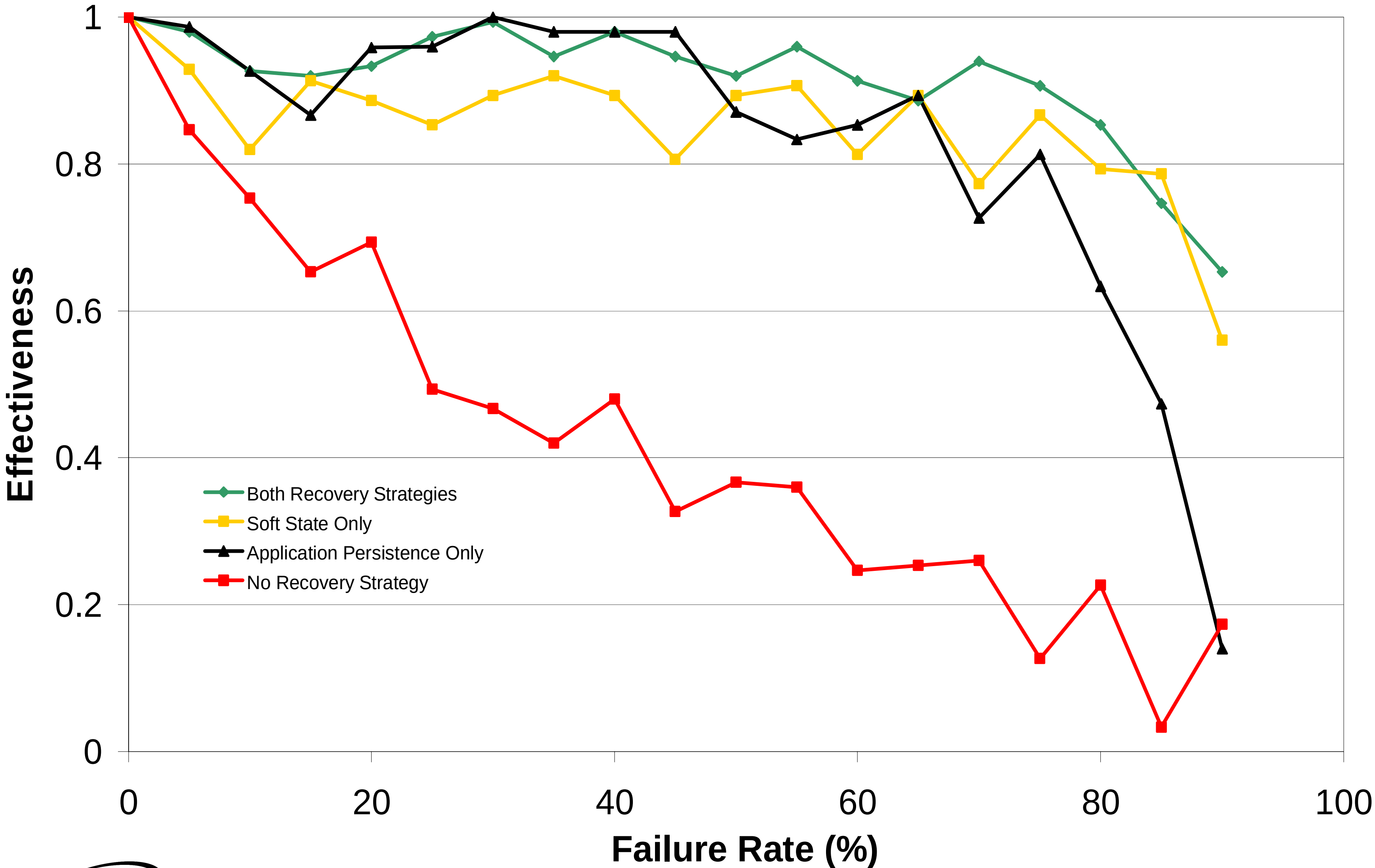
Observations on Self-healing in Distributed Systems

- Recovery strategies are critical for self-healing as failure rate increases.
  - More so than other factors (e.g., architecture, topology, consistency-maintenance mechanisms)
- Recovery strategies can interact in complex and unexpected ways
  - Redundancy (only one is necessary)
  - Complimentaryness (both are necessary)
  - Interference (one strategy prevents another from succeeding)
- When designing self-healing distributed systems based on service discovery protocols, need to consider:
  - The types of failure expected and their likelihood
  - Detailed protocol behaviors (e.g., discovery, update propagation, recovery) and not simply the application-programming interface.

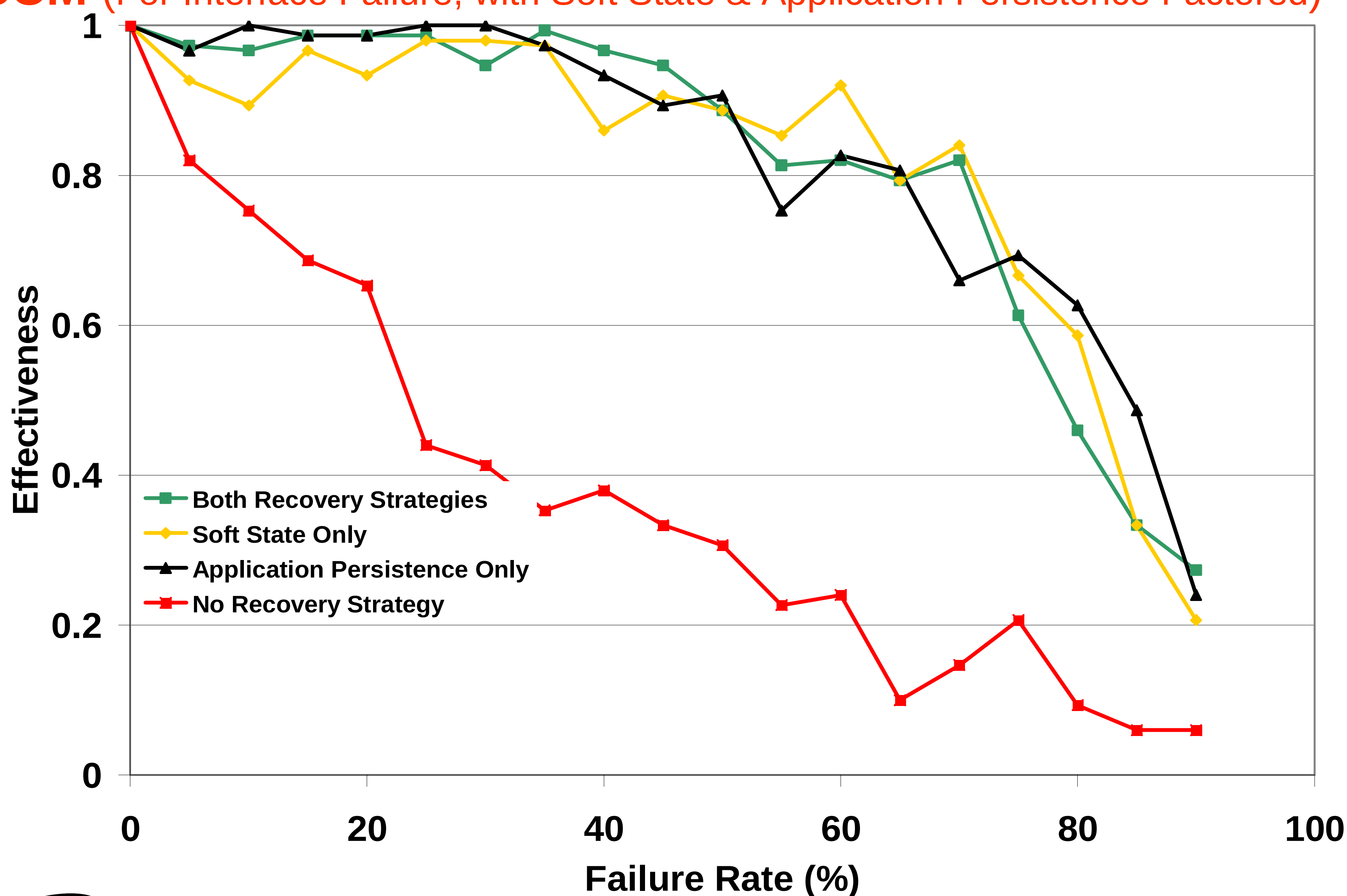
Extra

Update Effectiveness of Two-Party Notification

(For Interface Failure with Soft State & Application Persistence Strategies Factored)

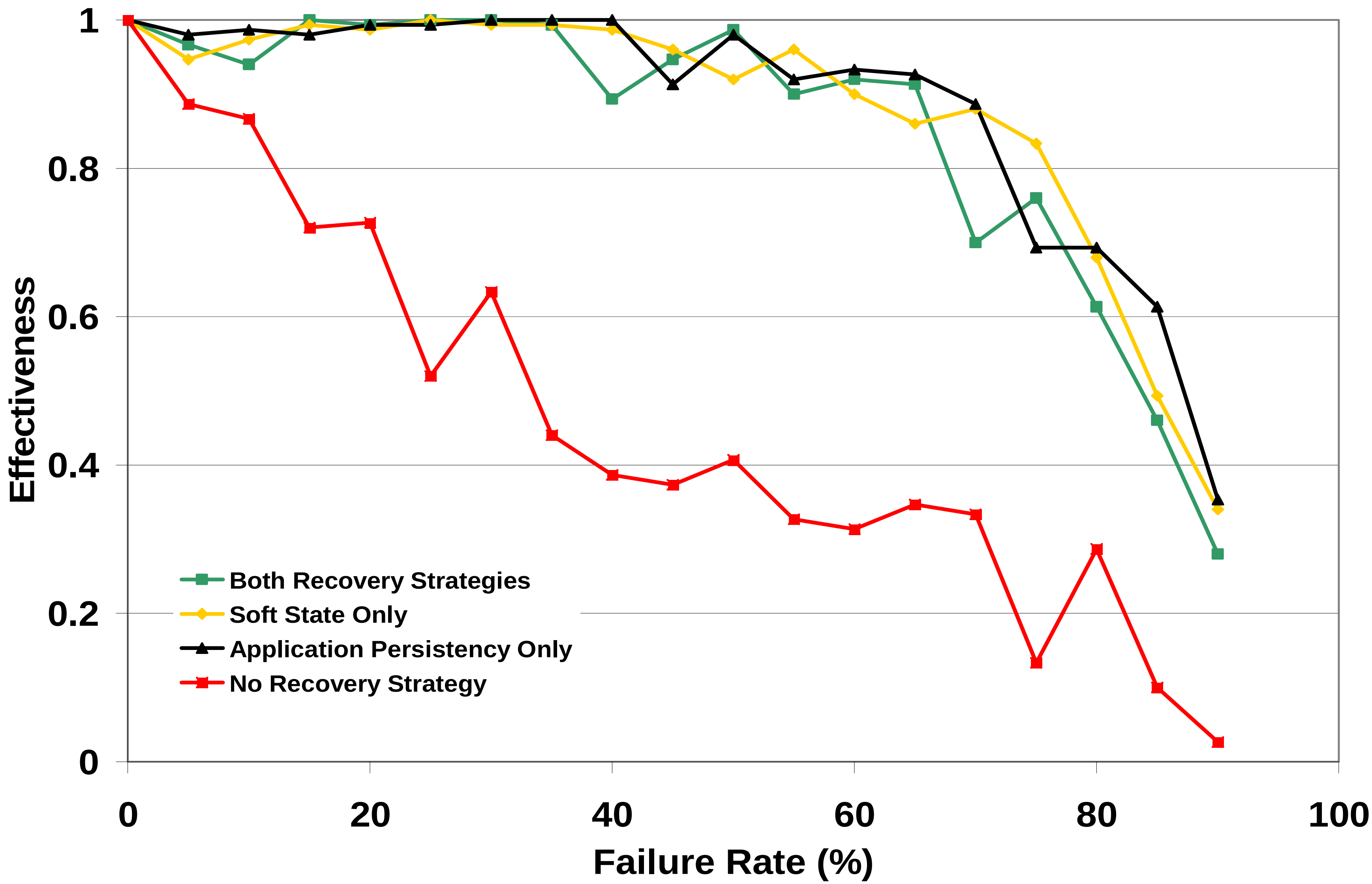


Update Effectiveness of Three-Party Notification, Single SCM (For Interface Failure, with Soft State & Application Persistence Factored)

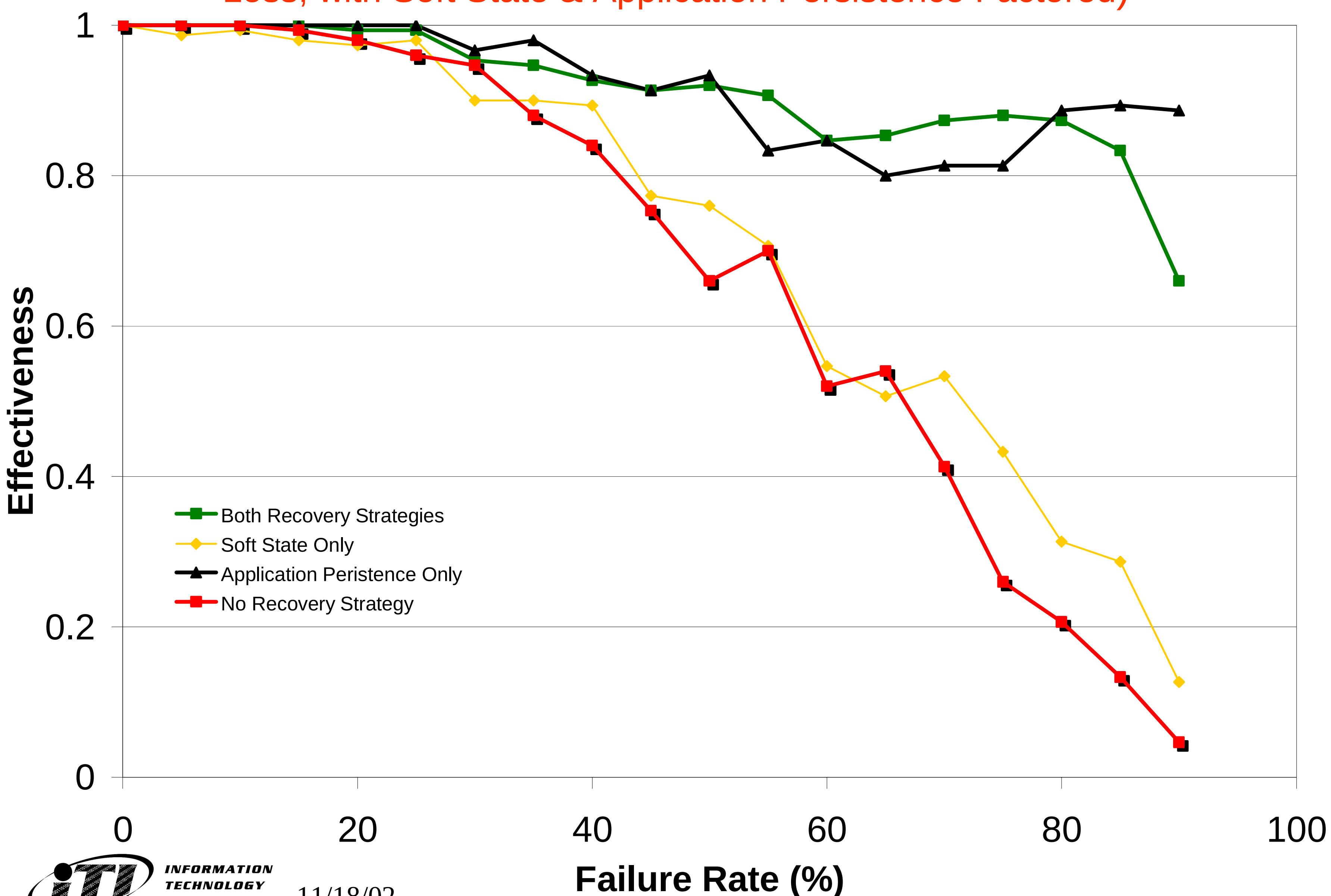


Update Effectiveness of Three-Party Notification, Dual SCM

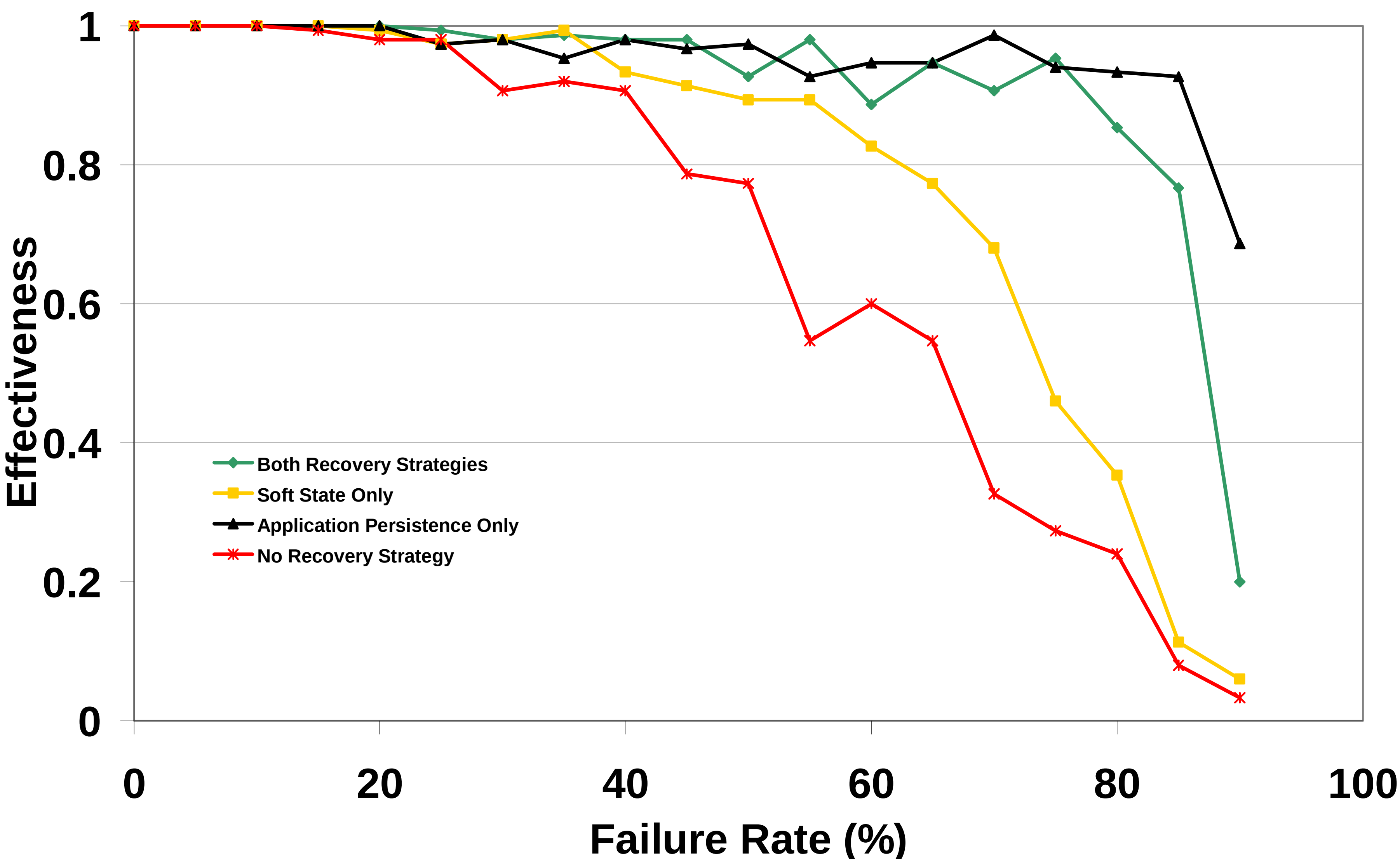
(For Interface Failure, with Soft State & Application Persistence Factored)



Update Effectiveness of Two-Party Notification (For Message Loss, with Soft State & Application Persistence Factored)



Update Effectiveness of Three-Party Notification, Single SCM (For Message Loss, with Soft State & Application Persistence Factored)



Update Effectiveness of Three-Party Notification, Dual SCM

(For Message Loss, with Soft State & Application Persistence Factored)