On Fault Tolerance, Performance, and Reliability for Wireless and Sensor Networks

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Outline

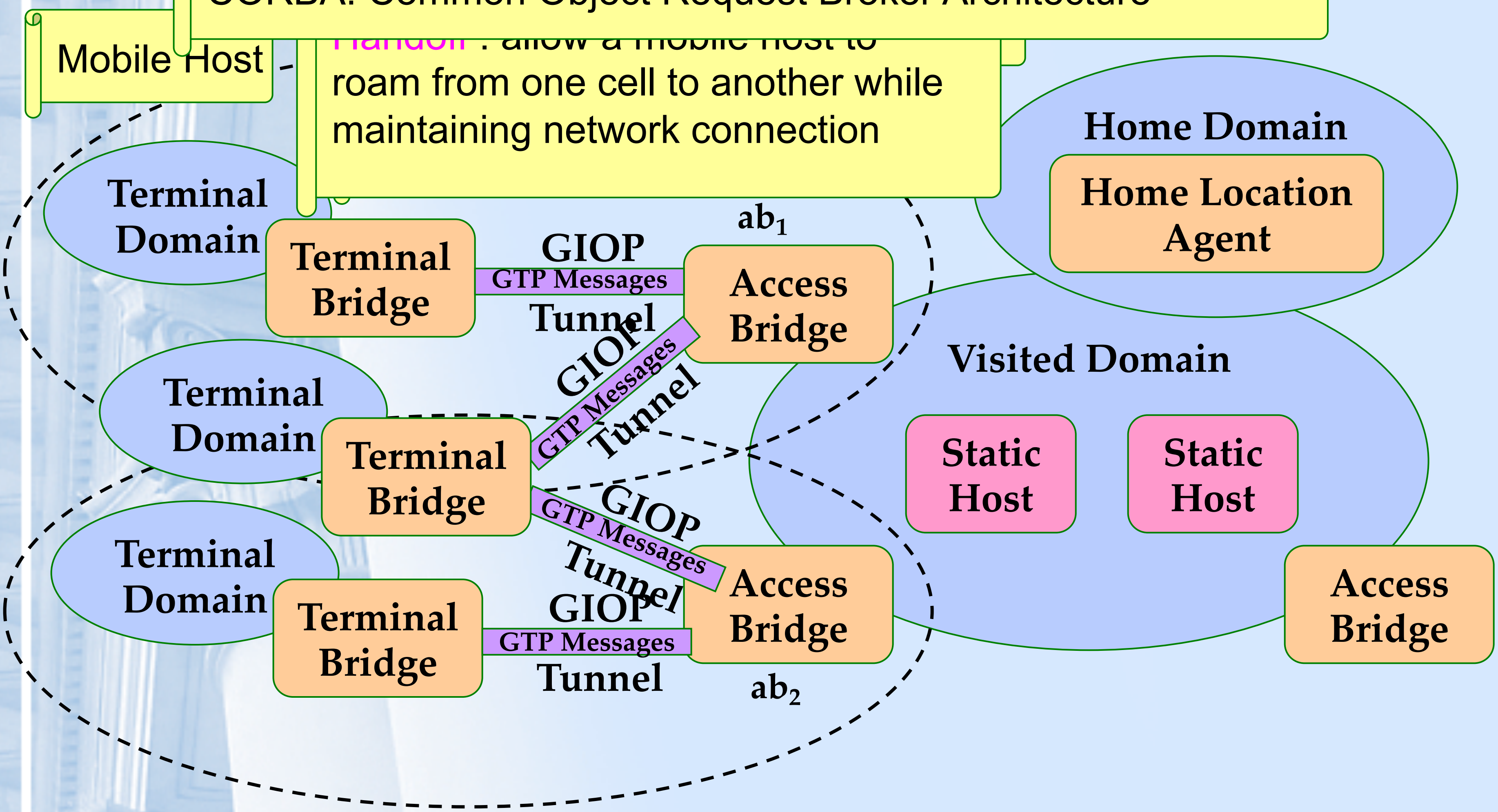
- Introduction and thesis focus
- Wireless Networks
  - Fault tolerance
  - Performance
    - Message sojourn time
    - Program execution time
  - Reliability
- Wireless Sensor Networks
  - Sleeping configuration
    - Coverage with fault tolerance
- Conclusions and future directions

Wireless Network (IEEE 802.11)

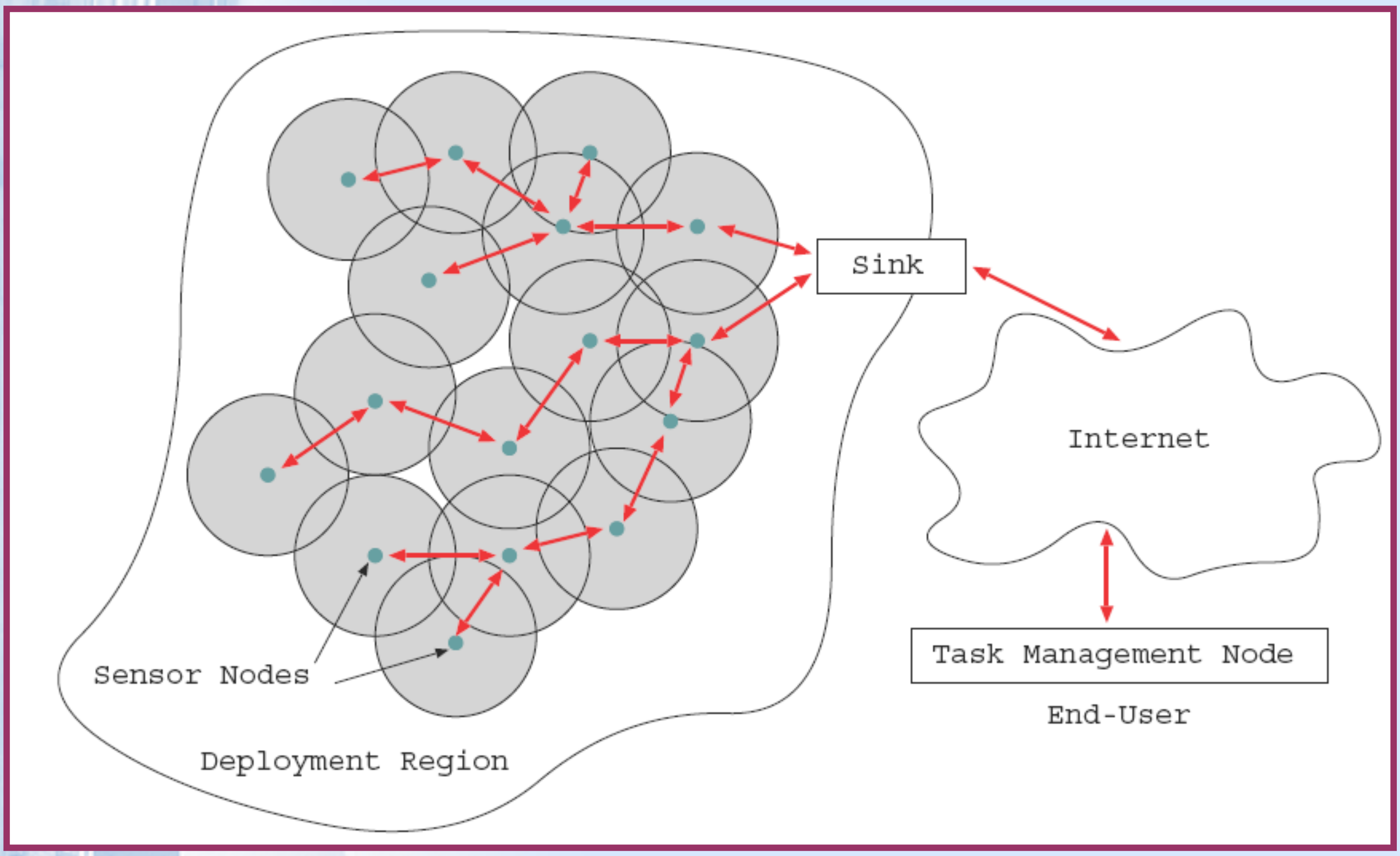
- Wireless Infrastructure Network
  - At least one Access Point (Mobile Support Station) is connected to the wired network infrastructure and a set of wireless terminal devices
  - No communications between wireless terminal devices
- Wireless Ad Hoc Network
  - Composed solely of wireless terminal devices within mutual communication range of each other without intermediary devices
  - Wireless Sensor Network
    - Terminal device with sensing capability

Wireless CORBA Architecture

CORBA: Common Object Request Broker Architecture



Wireless Ad Hoc Sensor Network



Thesis Focus

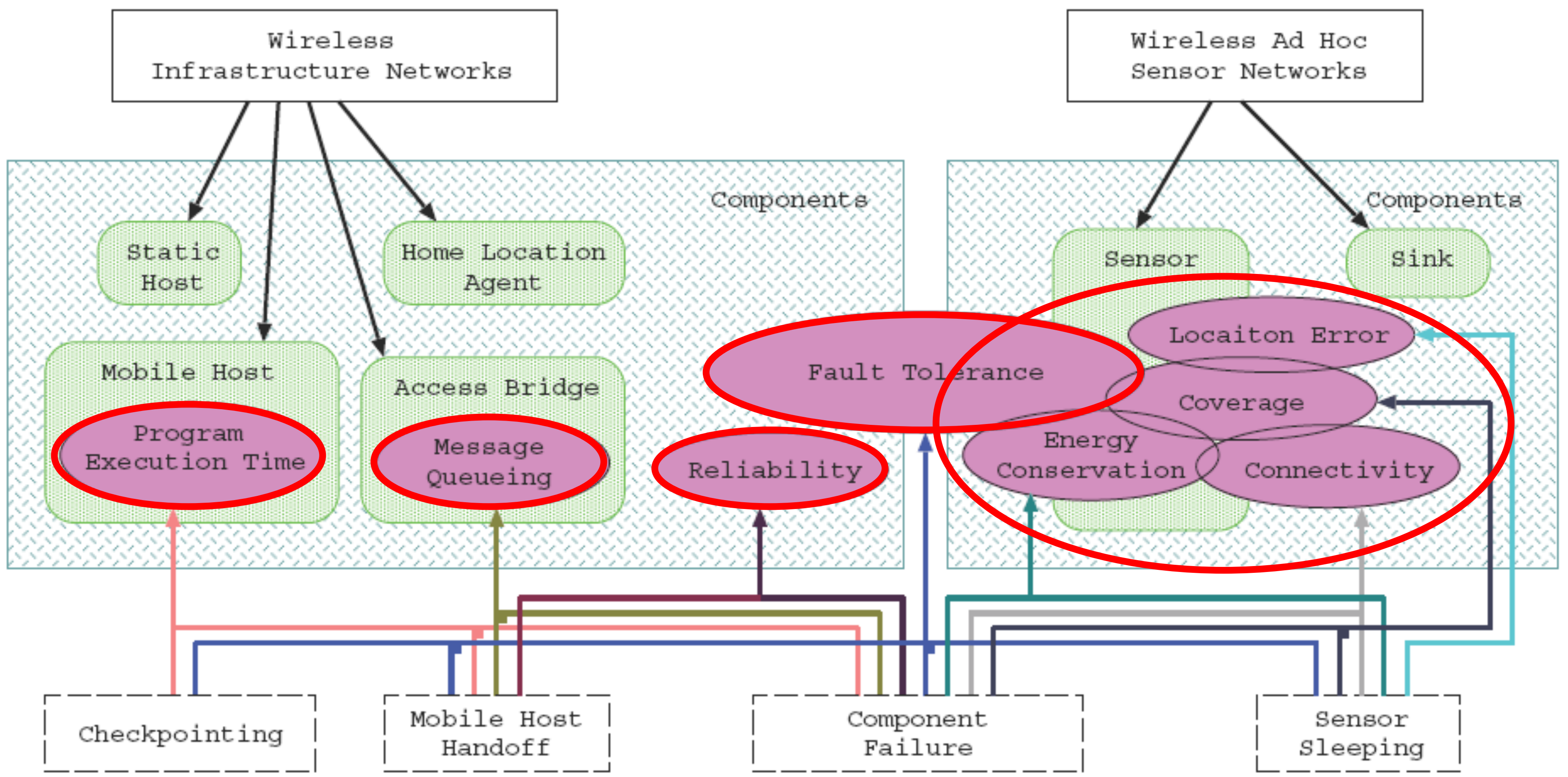
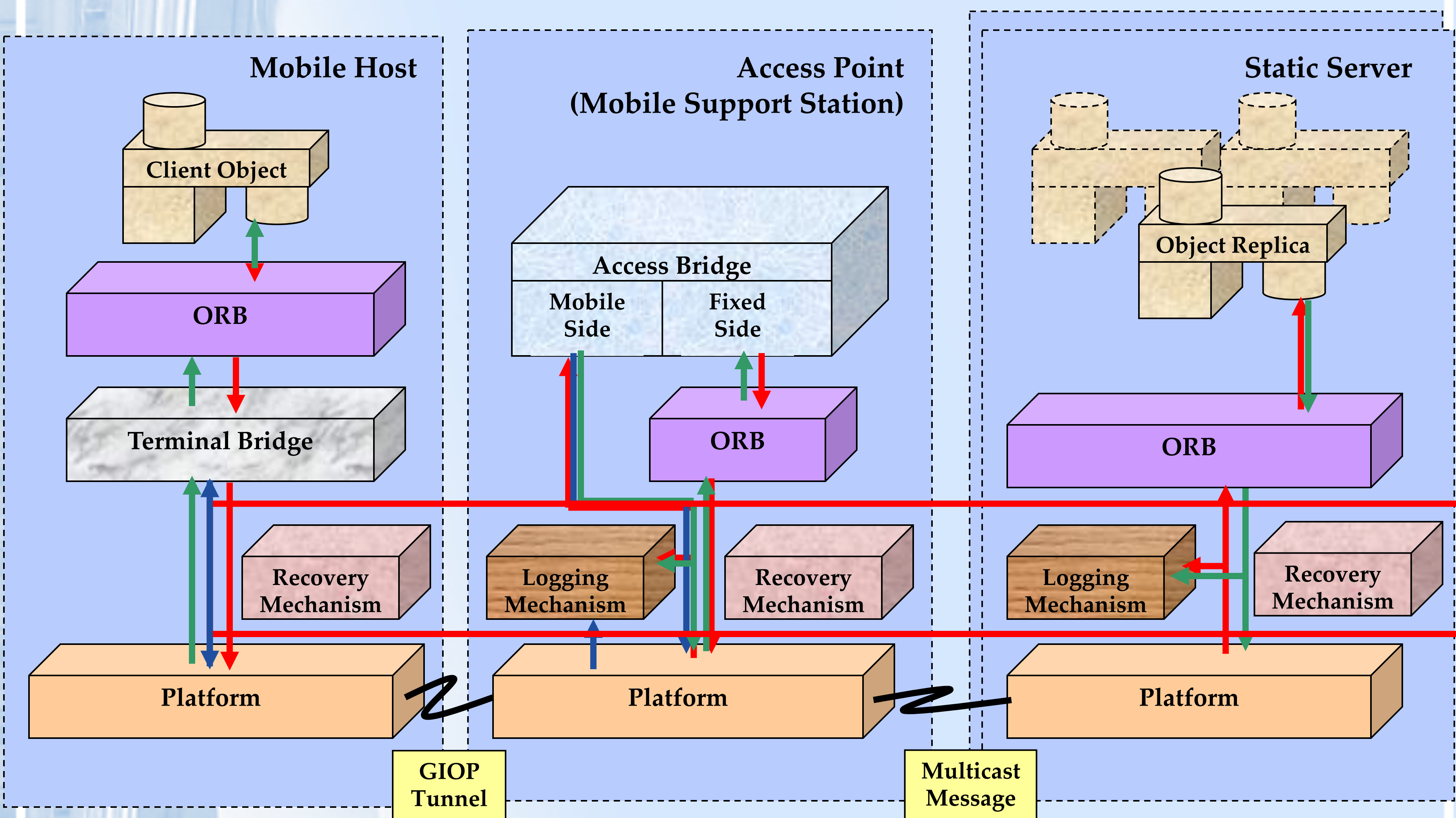


Figure 1.3: Thesis overview.

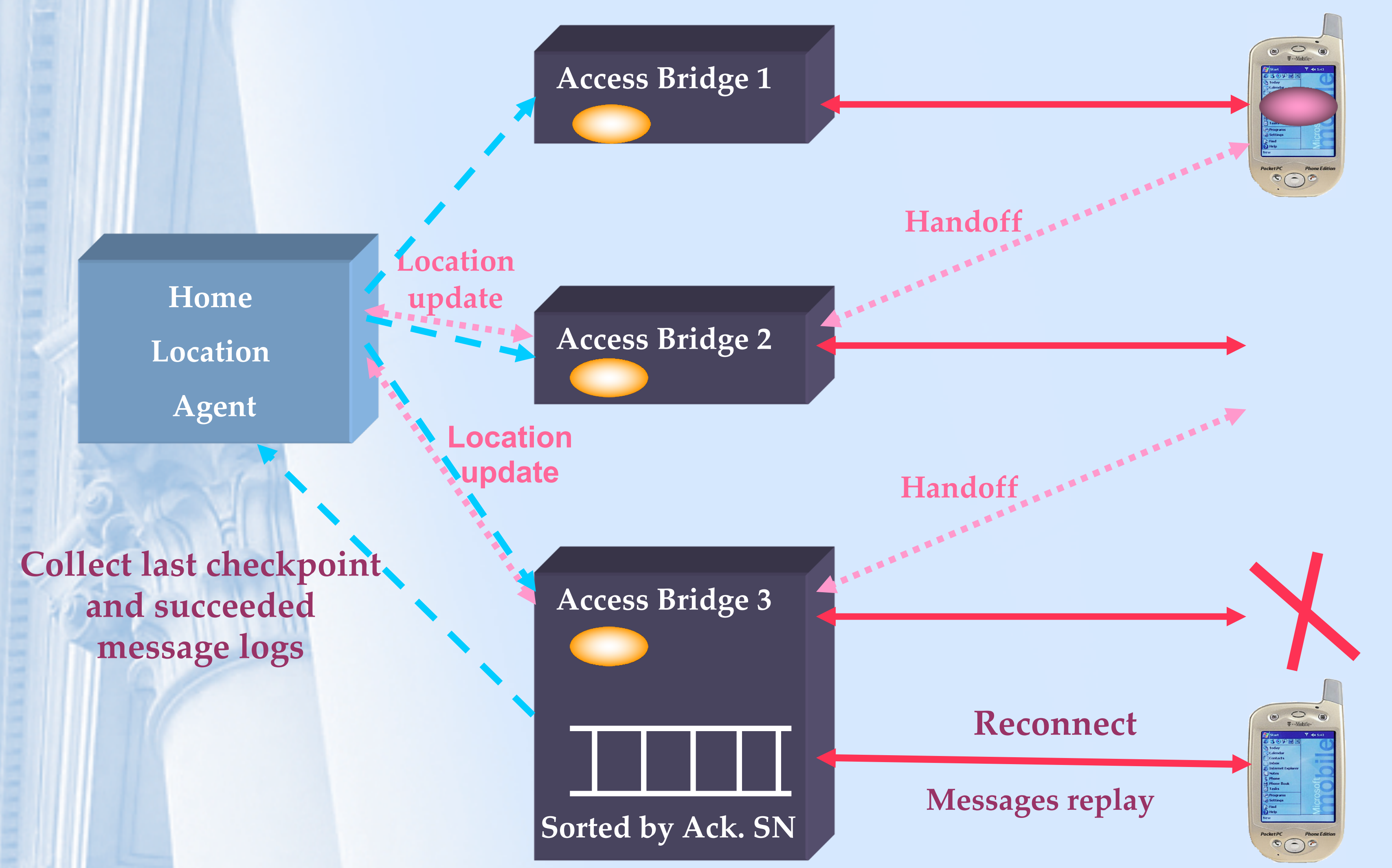
Chapter 3 Message Logging and Recovery in Wireless CORBA

- Motivation
  - Permanent failures
    - Physical damage
  - Transient failures
    - Mobile host
    - Wireless link
    - Environmental conditions
  - Fault-tolerant CORBA
- Objective
  - To construct a fault-tolerant wireless CORBA

Fault-Tolerant Wireless CORBA Architecture



Mobile Host Recovery

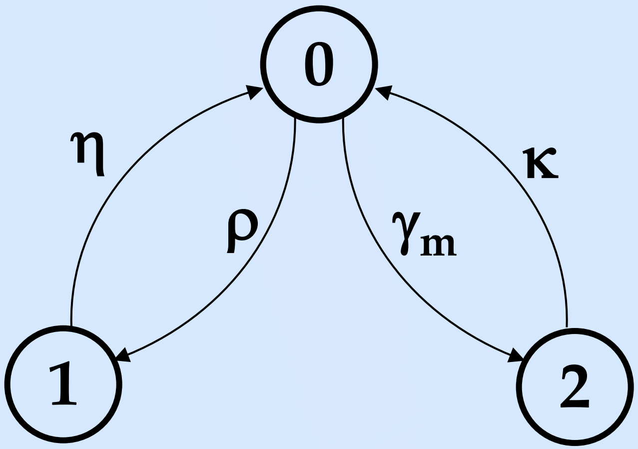


Chapter 4 Message Queueing and Scheduling at Access Bridge

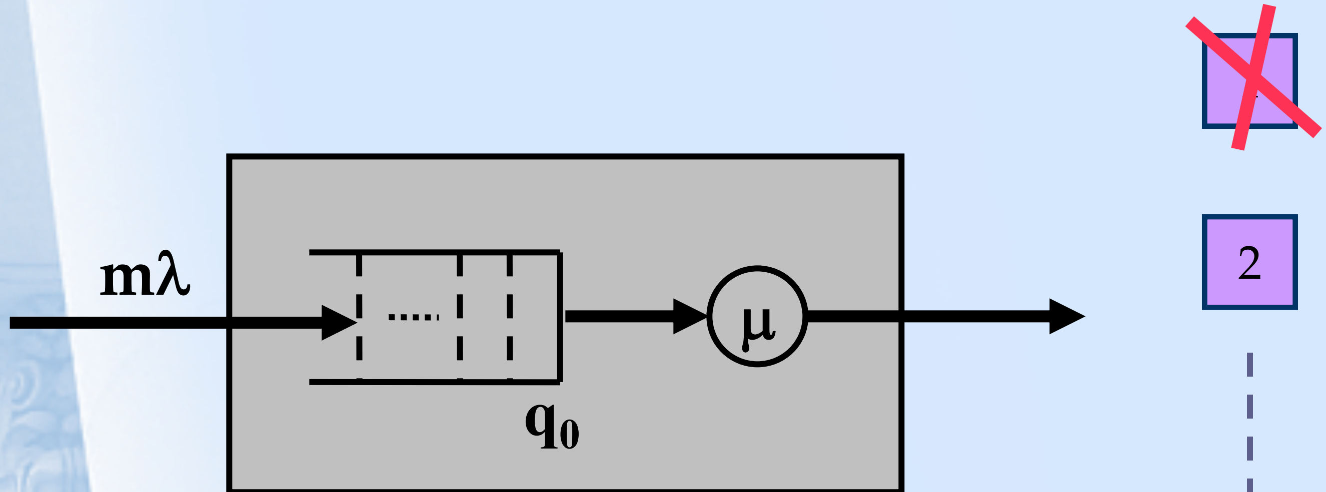
- Motivation
  - Previous work
    - Task response time in the presence of server breakdowns
  - Wireless mobile environments
    - Due to failures and handoffs of mobile hosts, the messages at access bridge cannot be dispatched
- Objective
  - To derive the expected message sojourn time at access bridge in the presence of failures and handoffs of mobile hosts
  - To evaluate different message scheduling strategies

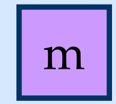
Mobile Host's State Transition

- State 0 : normal
- State 1 : handoff (**H**)
- State 2 : recovery (**U**)
- ρ : handoff rate
- γ_m : failure rate
- η : handoff completion rate
- κ : recovery rate



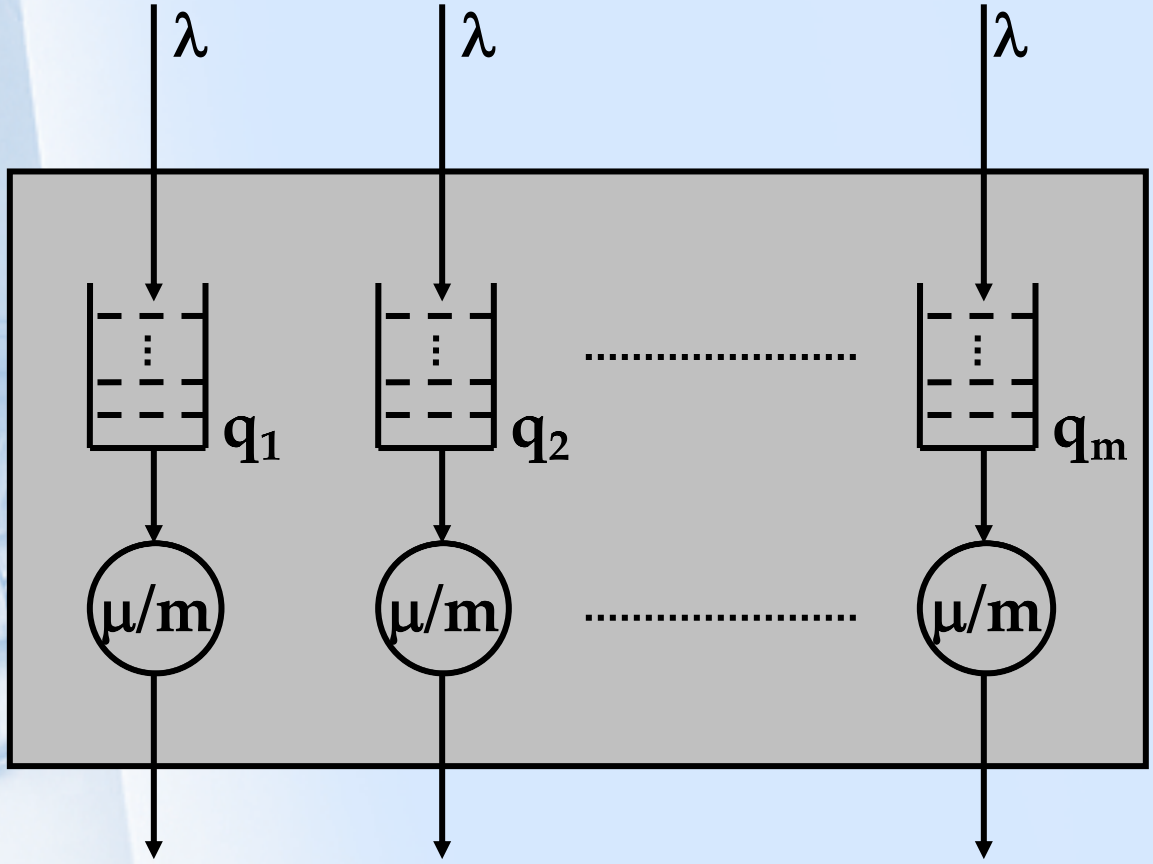
Basic Dispatch Model



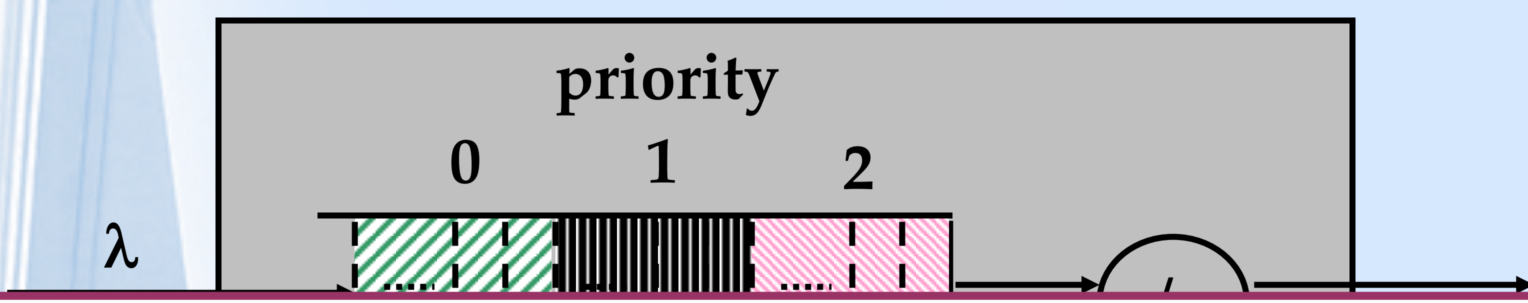


- **λ** : message arrival rate for each mobile host
- **m** : number of mobile hosts
- **μ** : service rate of the dispatch facility

Static Processor-Sharing Dispatch Model



Head-of-the-line Priority Queue



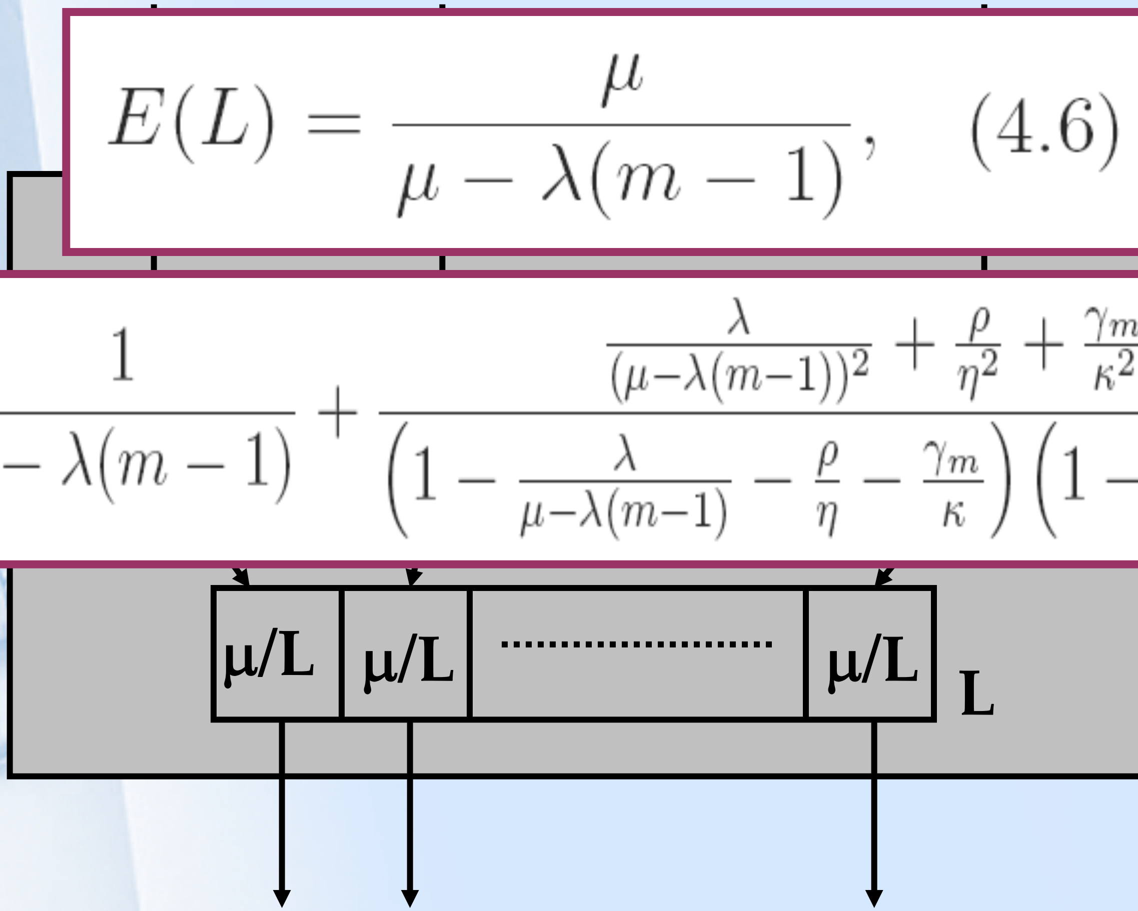
$$E(T_{sps}) = \frac{m}{\mu} + \frac{\frac{m^2\lambda}{\mu^2} + \frac{\rho}{\eta^2} + \frac{\gamma_m}{\kappa^2}}{(1 - \frac{m\lambda}{\mu} - \frac{\rho}{\eta} - \frac{\gamma_m}{\kappa})(1 - \frac{\rho}{\eta} - \frac{\gamma_m}{\kappa})}. \quad (4.3)$$

- λ : message arrival rate
- ρ : handoff rate
- γ_m: mobile host's failure rate
- η : handoff completion rate
- κ : mobile host's recovery rate

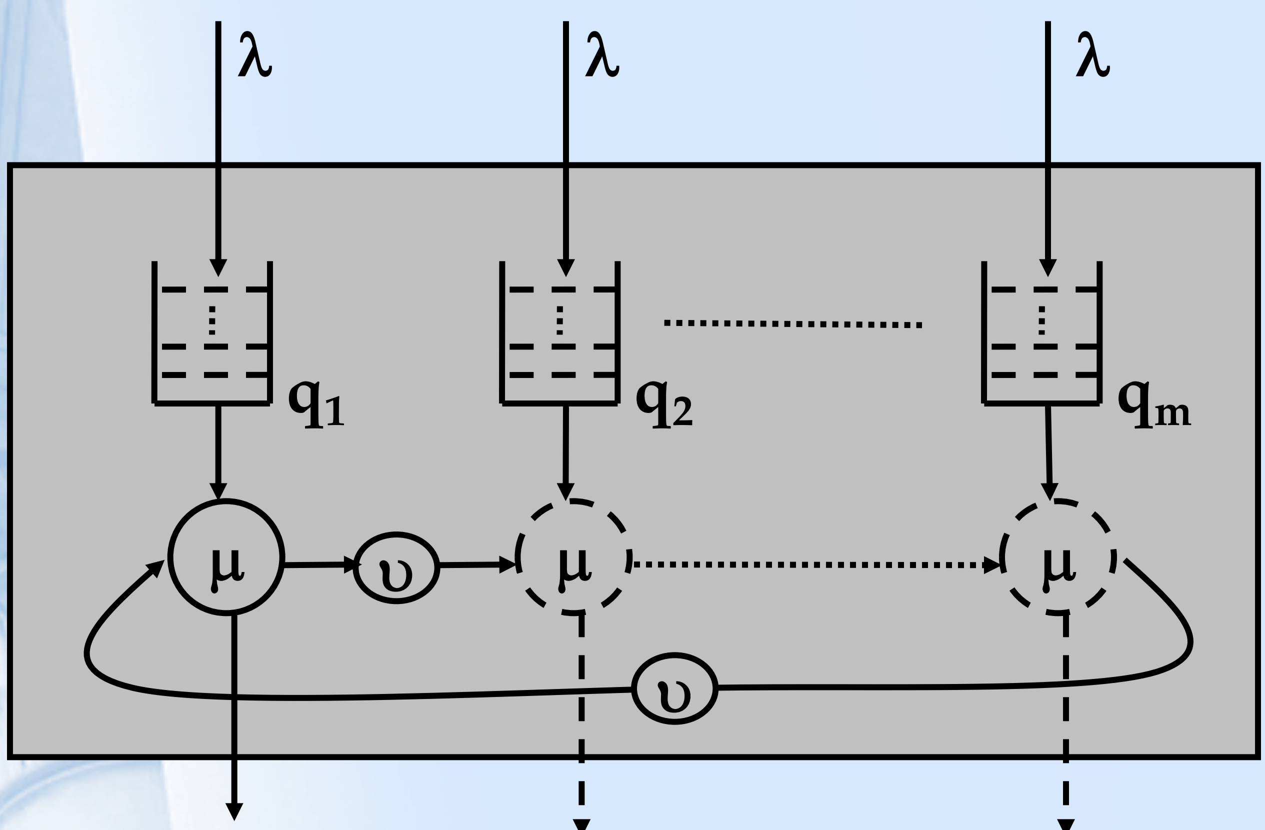
Dynamic Processor-Sharing Dispatch Model

$$E(L) = \frac{\mu}{\mu - \lambda(m-1)}, \qquad (4.6)$$

$$E(T_{dps}) = \frac{1}{\mu - \lambda(m-1)} + \frac{\frac{\lambda}{(\mu-\lambda(m-1))^2} + \frac{\rho}{\eta^2} + \frac{\gamma m}{\kappa^2}}{\left(1 - \frac{\lambda}{\mu-\lambda(m-1)} - \frac{\rho}{\eta} - \frac{\gamma m}{\kappa}\right)\left(1 - \frac{\rho}{\eta} - \frac{\gamma m}{\kappa}\right)} \cdot (4.8)$$

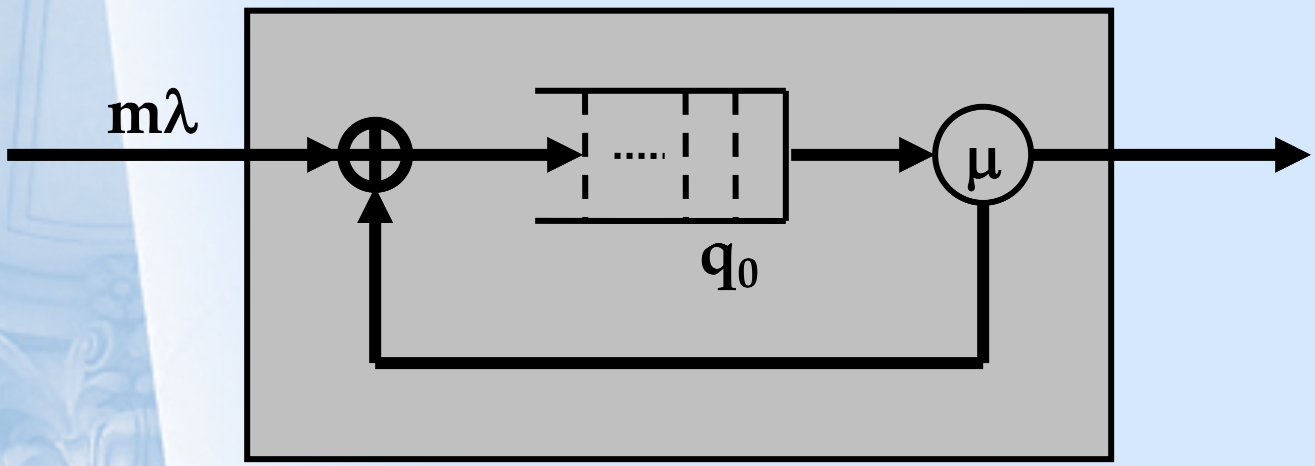


Cyclic Polling Dispatch Model



◆ υ: switchover rate

Feedback Dispatch Model



Simulation and Analytical Results (1)

❖ Number of mobile hosts m

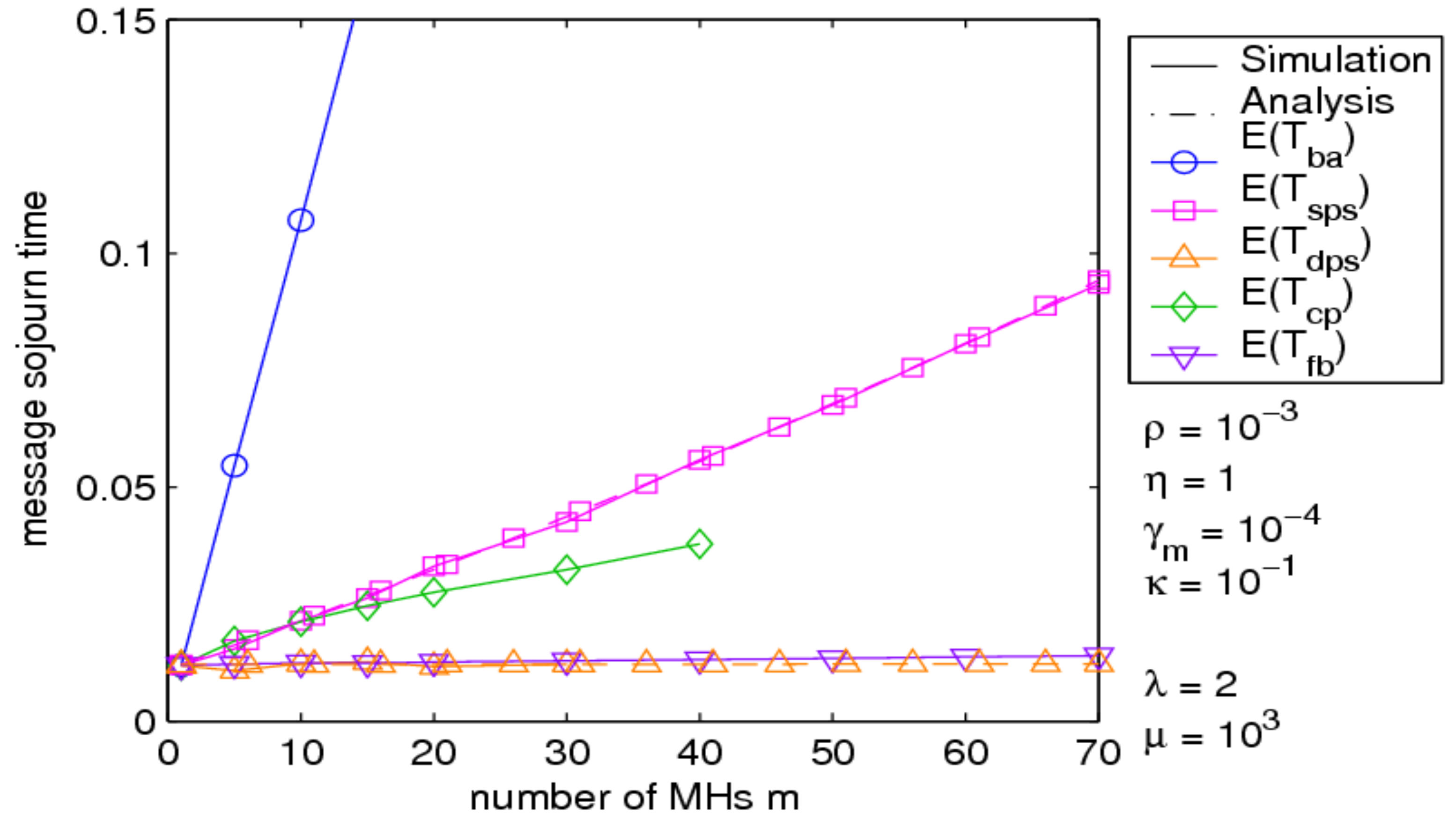


Figure 4.8: Expected message sojourn time vs. number of MHs.

Simulation and Analytical Results (2)

- Mobile host's failure rate γ_m

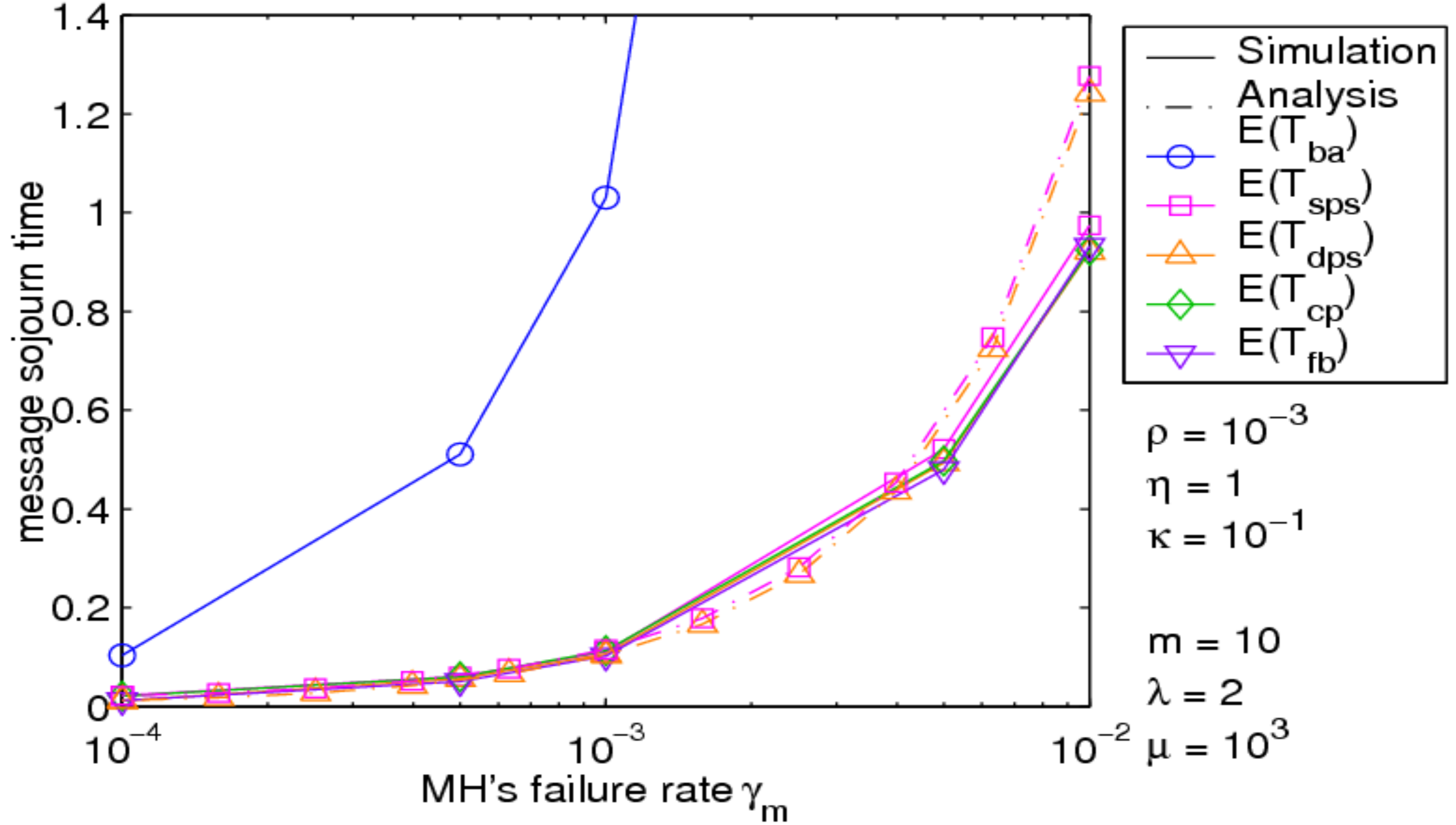


Figure 4.10: Expected message sojourn time vs. MH's failure rate.

Chapter 4 Summary

- Analyze and simulate the message sojourn time at access bridge in the presence of mobile host failures and handoffs
- Observation
  - The basic model and the static processor-sharing model demonstrate the worst performance
  - The dynamic processor-sharing model and the cyclic polling model are favorite to be employed
    - However, the cyclic polling model and the feedback model engage a switchover cost
  - In the basic model and the feedback model, the number of mobile hosts covered by an access bridge should be small

Chapter 5 Program Execution Time at Mobile Host

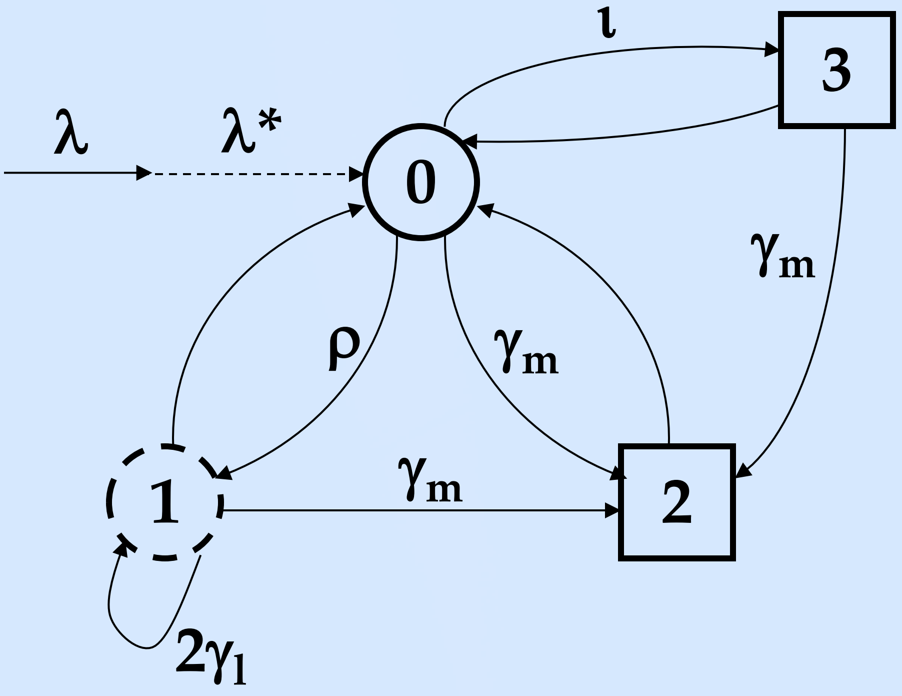
- Motivation
  - Previous work
    - Program execution time with and without checkpointing in the presence of failures on static hosts with given time requirement without failures
  - Wireless mobile environments
    - Underlying message-passing mechanism
      - Network communications
      - Discrete message exchanges
    - Handoff
    - Wireless link failures

Program Termination Condition

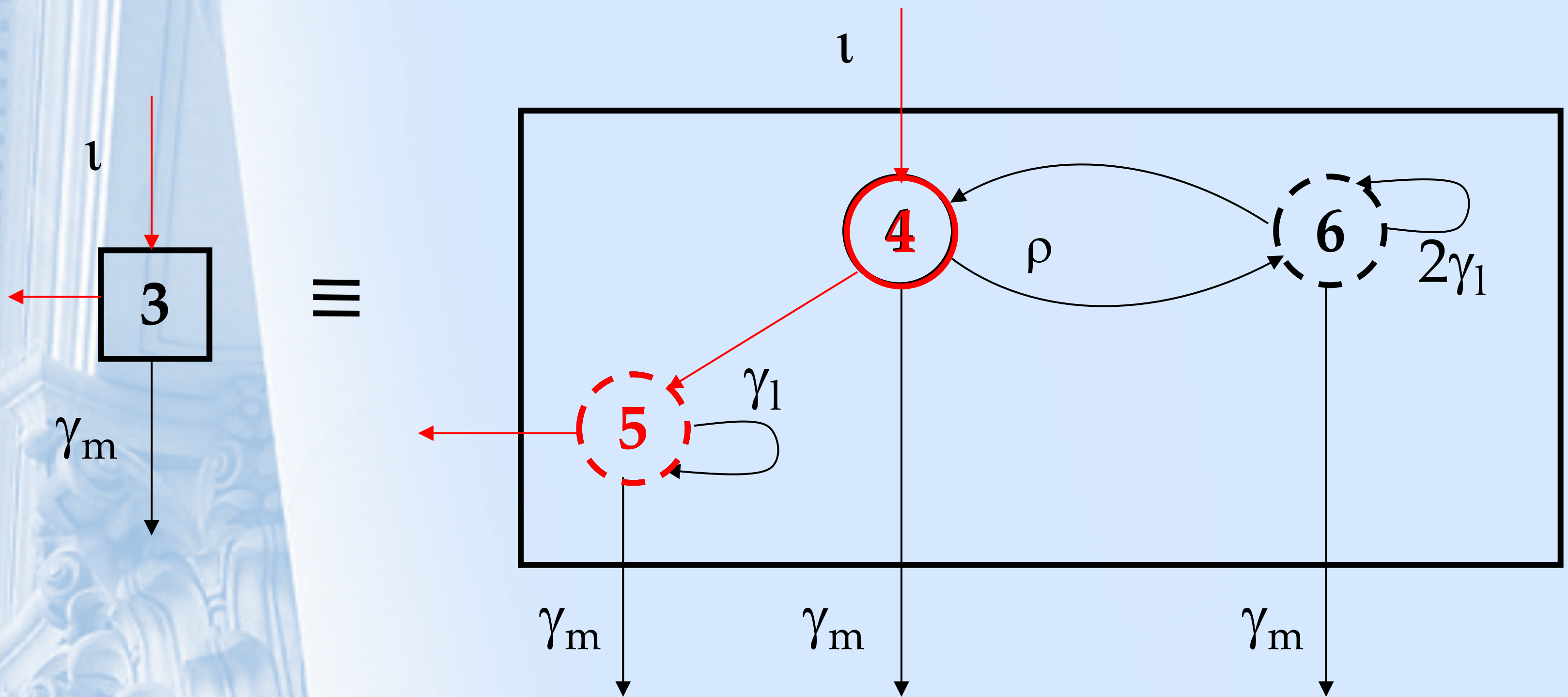
- A program at a mobile host will be successfully terminated if it continuously receives *n* computational messages
- Objective
  - To derive the cumulative distribution function of the program execution time with message number *n* in the presence of failures, handoffs, and checkpointings
  - To evaluate different checkpointing strategies

Assumptions and Mobile Host's State Transition

- State 0 : normal
- State 1 : handoff (**H**)
- State 2 : recovery
- State 3 : checkpointing
- λ : message dispatch rate at access bridge
- λ^* : message arrival rate at mobile host
- ρ : handoff rate
- ι : checkpointing rate
- γ_m : mobile host's failure rate
- γ_l : wireless link's failure rate

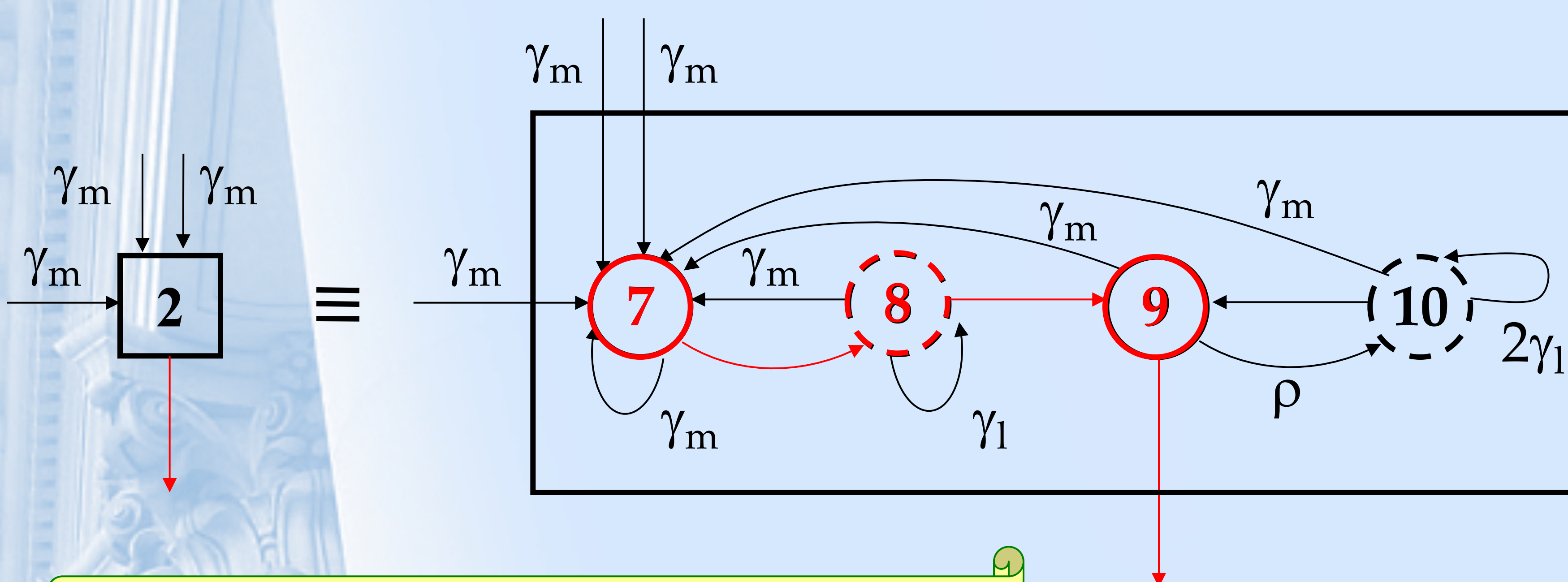


Composite Checkpointing State



- State 4 : take checkpoint (T_1)
- State 5 : save checkpoint (T_2)
- State 6 : handoff (H)

Composite Recovery State



◆State 7 : repair (**R**)

◆State 8 : retrieve checkpoint (T_3)

◆State 9 : reload checkpoint (T_4)

◆State 10 : handoff (**H**)

Deterministic Checkpointing Strategy

- The number of messages in a checkpointing interval is fixed with u
- Checkpointing rate $\iota_{dc} = \lambda / u$

$$E\left[X^{(dc,f,h,l)}(n,u)\right] = \left[\frac{1}{\gamma_m} + E(R')\right]\left[(w-1)\left(\frac{q_1^{-u}}{\phi_C(\gamma_m)} - 1\right) + (q_1^{-u'} - 1)\right]. \quad (5.13)$$

$$E\left[X^{(f,h,l)}(n)\right] = \left[\frac{1}{\gamma_m} + E(R')\right](q_1^{-n} - 1). \quad (5.17)$$

- N
- Checkpointing time **C** = $T_1^{(h,l)} + T_2^{(l)}$
- Recovery time **R'** = $[R + T_3^{(l)} + T_4^{(h,l)}]^{(f)}$

Random Checkpointing Strategy

- Create a checkpoint when I messages have been received since the last checkpoint
  - I: a random variable with a geometric distribution whose parameter is p
- Checkpointing rate $\iota_{rc} = \lambda p$

$$E\left[X^{(rc,f,h,l)}(n,p)\right] = \left[\frac{1}{\gamma_m} + E(R')\right]\left[q_1^{-1} - 1 + \sum_{i=2}^{n} \frac{q_1^{-1} - p\phi_c(\gamma_m) + p - 1}{q_2 + (1-q_2)((1-p)q_1)^{i-1}}\right]. \quad (5.25)$$

Without Failures

❖ Wit

❖ Det

If $u = p^{-1}$, then $p(n-1) \geq w-1$,
which indicates that on average the random checkpointing creates more checkpoints than the deterministic checkpointing.

$$\lim_{\gamma_m,\gamma_l \to 0} E\left[X^{(dc,f,h,l)}(n,u)\right] = [1+\rho E(H)]\left[\frac{n}{\lambda} + (w-1)(E(T_1)+E(T_2))\right], \quad (5.18)$$

❖ Random checkpointing

$$\lim_{\gamma_m,\gamma_l \to 0} E\left[X^{(rc,f,h,l)}(n,p)\right] = [1+\rho E(H)]\left[\frac{n}{\lambda} + p(n-1)(E(T_1)+E(T_2))\right]. \quad (5.28)$$

- w: number of checkpointing intervals
- p: parameter of geometric distribution

Time-based Checkpoint Strategy

- The checkpointing interval is a constant time v
- Checkpointing rate $\iota_{tc} = 1/v$

$$E\left[X^{(tc,f,h,l)}(n,v)\right] = \left[\frac{1}{\gamma_m} + E(R')\right]\left[\frac{1-\phi_C(\gamma_m)\phi_v(q_3)}{G(0,n,v)+\phi_C(\gamma_m)\phi_v(q_3)\sum_{i=1}^{n-1}\frac{(\lambda v)^i}{i!}} - 1\right] + \frac{\phi_C(\gamma_m)\phi_v(q_3)\sum_{i=1}^{n-1}\frac{(\lambda v)^i}{i!}E\left[X^{(tc,f,h,l)}(n-i,v)\right]}{G(0,n,v)+\phi_C(\gamma_m)\phi_v(q_3)\sum_{i=1}^{n-1}\frac{(\lambda v)^i}{i!}}. \qquad (5.35)$$

Average Effectiveness

- Ratio between the expected program execution time without and with failures, handoffs and checkpoints

$$A = \frac{n}{\lambda \cdot E\left[X^{(c,f,h,l)}(n)\right]}. \qquad (5.36)$$

- Checkpointing frequency

$$u^{-1} = p = (v\lambda)^{-1}$$

Comparisons and Discussions (1)

- Message number n

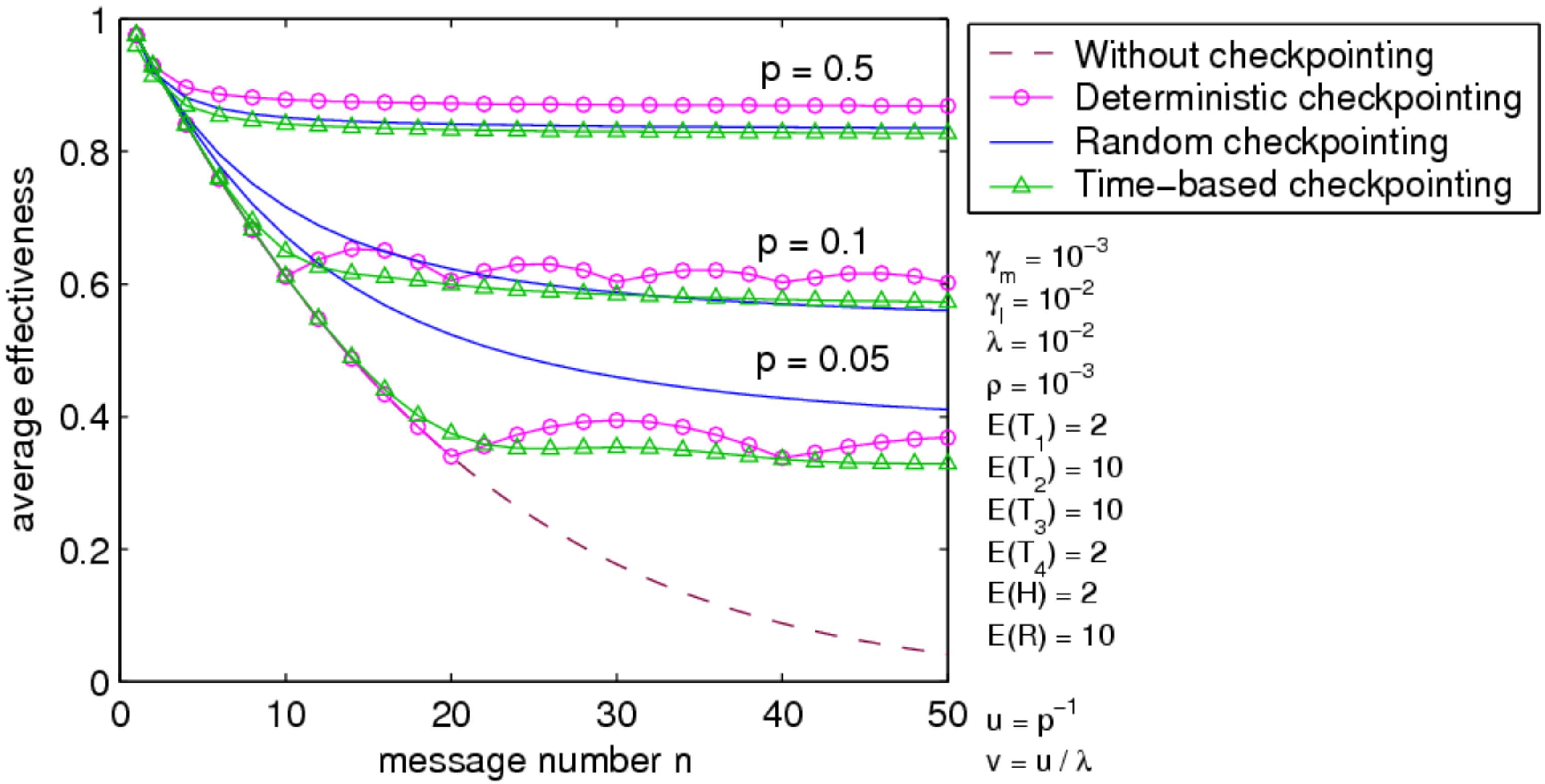


Figure 5.2: Average effectiveness vs. message number.

Comparisons and Discussions (2)

- Message arrival rate

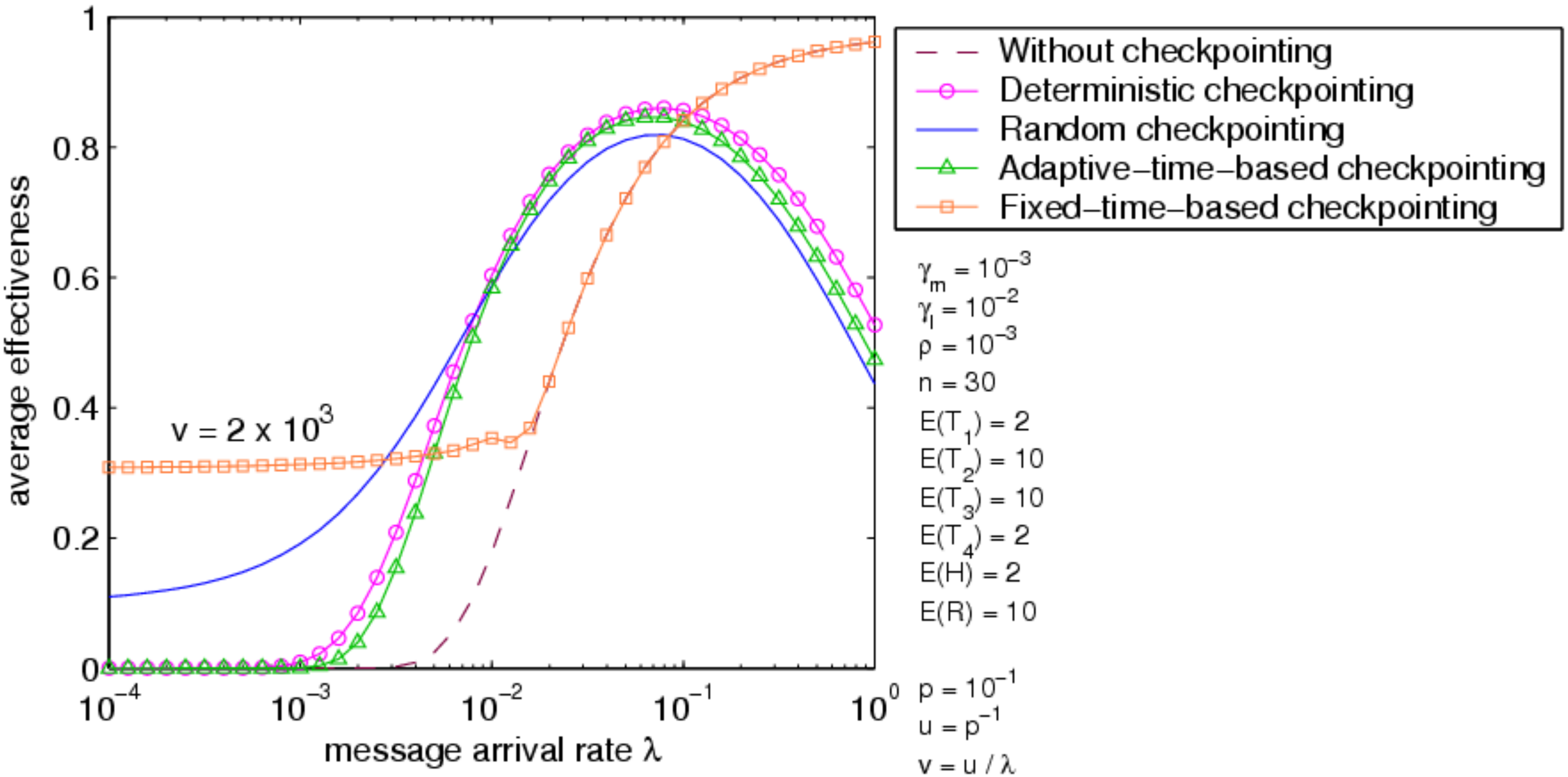


Figure 5.3: Average effectiveness vs. message arrival rate.

Comparisons and Discussions (3)

- Optimal checkpointing frequency

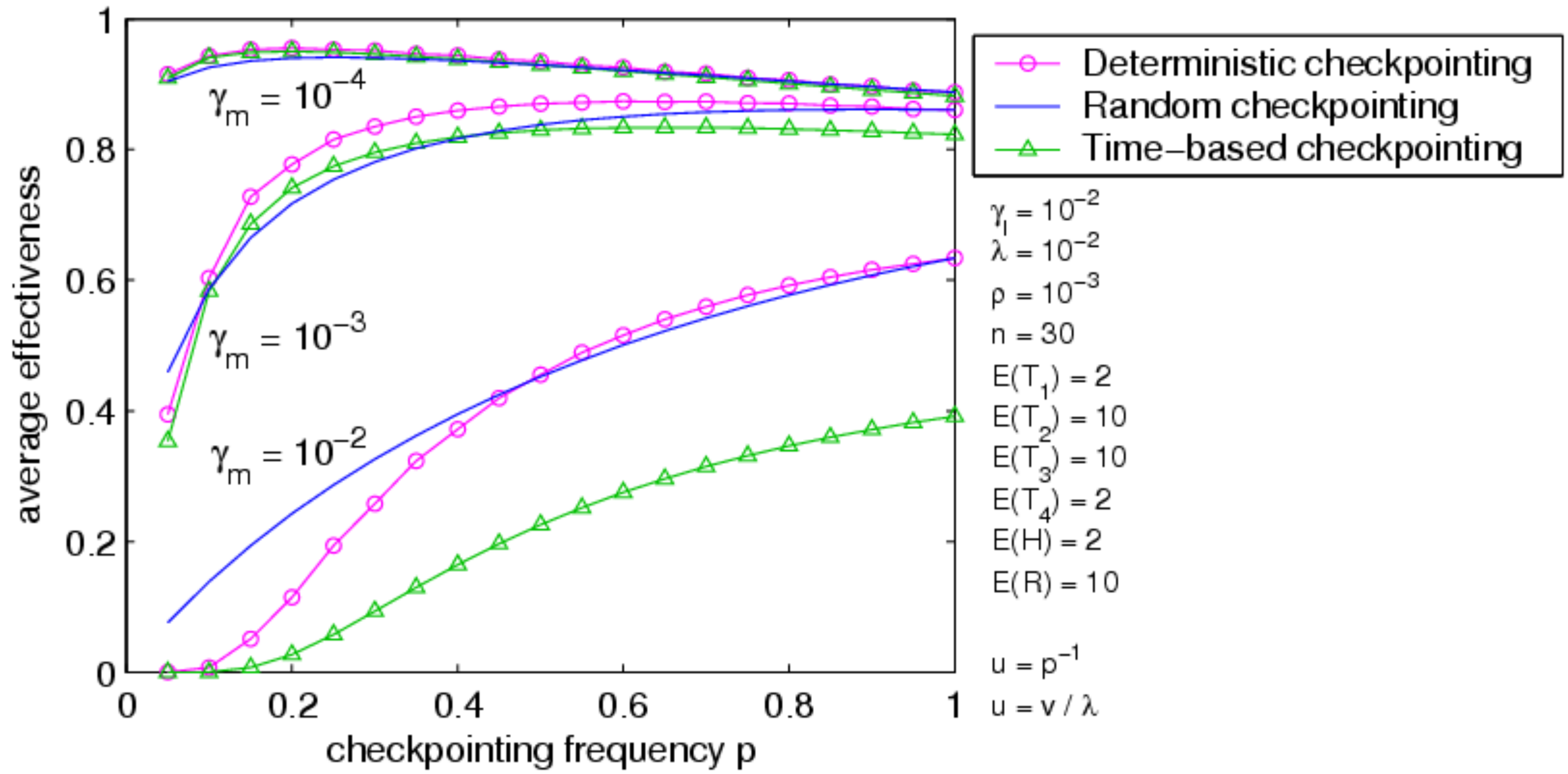


Figure 5.7: Optimal checkpointing frequency.

Chapter 5 Summary

- Derive the Laplace-Stieltjes transform of the cumulative distribution function of the program execution time and its expectation for three checkpointing strategies
- Observation
  - The performance of the random checkpointing approach is more stable against varying parameter conditions
  - Different checkpointing strategies, even including the absence of checkpointing, can be engaged

Chapter 6 Reliability Analysis for Various Communication Schemes

- Motivation
  - Previous work
    - Two-terminal reliability: the probability of successful communication between a source node and a target node
  - Wireless mobile environments
    - Handoff causes the change of number and type of engaged communication components
- Objective
  - To evaluate reliability of wireless networks in the presence of handoff

Expected Instantaneous Reliability (EIR)

- End-to-end expected instantaneous reliability at time t

$$ER(t) = \sum_{x} \pi_x(t) R_x(t), \quad (6.1)$$

  - $\pi_x(t)$: the probability of the system in state x at time t
  - $R_x(t)$: the reliability of the system in state x at time t

Assumptions

- There will always be a reliable path in the wired network
- The wireless link failure is negligible
- All the four components, access bridge, mobile host, static host, and home location agent, of wireless CORBA are failure-prone and will fail independently
  - Constant failure rates: γ_a, γ_m, γ_s, and γ_h

Four Communication Schemes

- Static Host to Static Host (SS)
  - Traditional communication scheme

$$ER_{ss}(t) = [R_{sh}(t)]^2$$

- Mobile Host to Static Host (MS)
  - 2 system states
- Static Host to Mobile Host (SM)
  - 5 system states
- Mobile Host to Mobile Host (MM)
  - 11 system states

The MS Scheme (Mobile Host – Static Host)

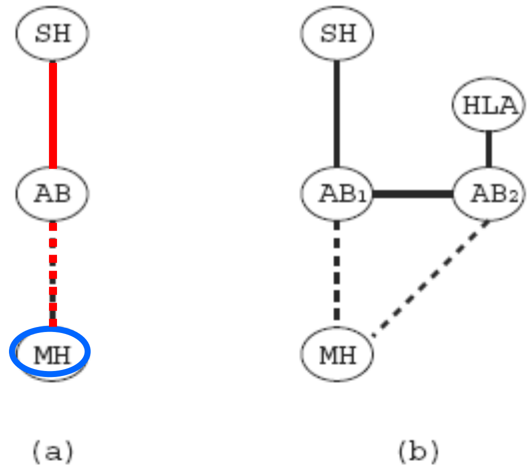


Figure 6.1: System states in the MS scheme:
(a) normal communication; (b) handoff procedure.

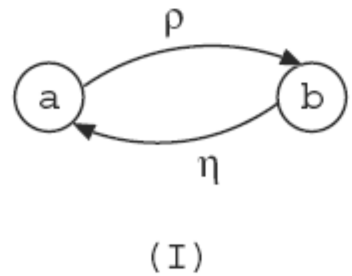


Figure 6.2: Markov model for the MS scheme.

EIR of the MS Scheme

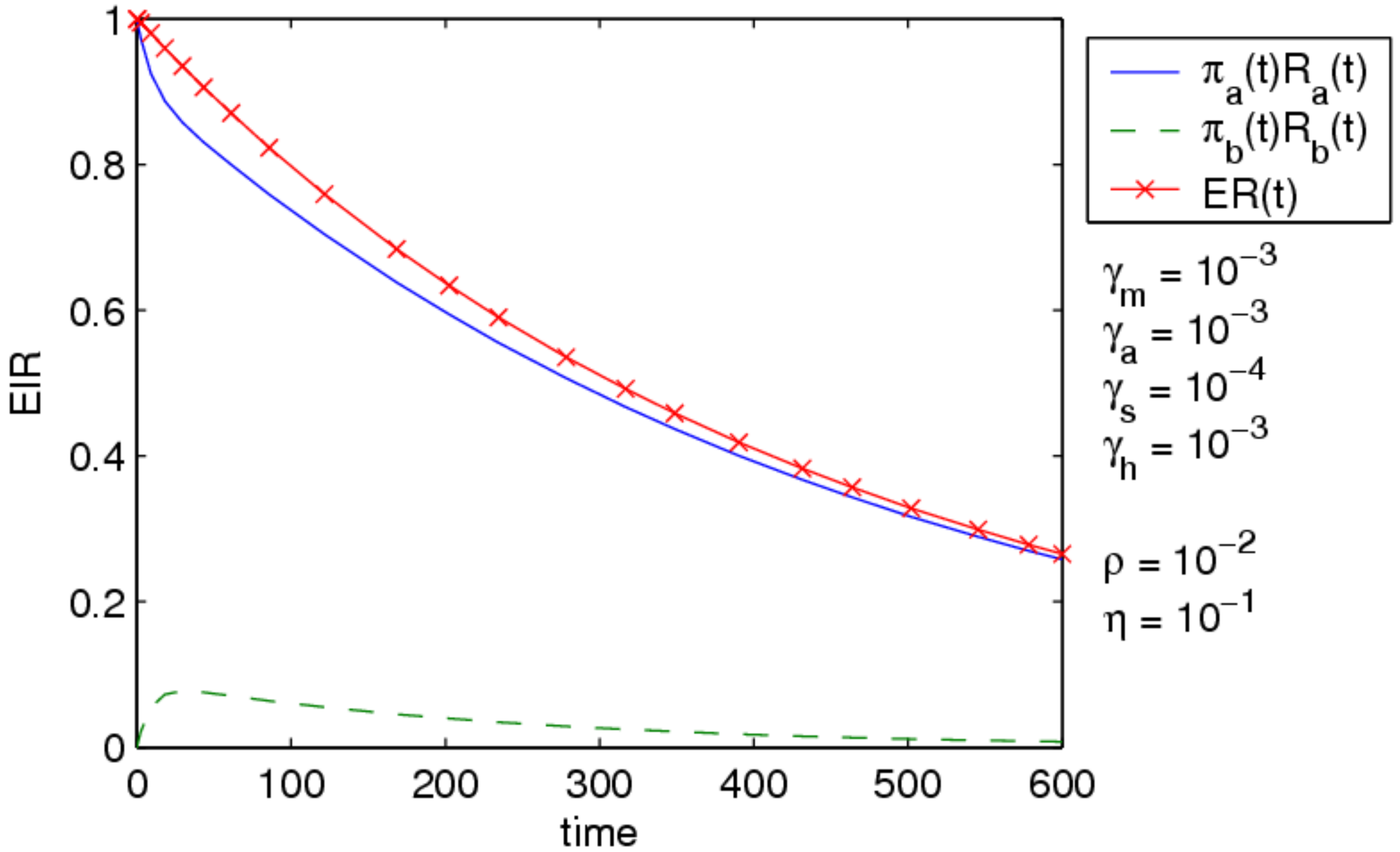


Figure 6.3: EIR of the MS scheme.

MTTF (Mean Time To Failure) of the MS Scheme

$$ER_{ms}(t) = \pi_a(t)e^{-(\gamma_m+\gamma_a+\gamma_s)t} + \pi_b(t)e^{-(\gamma_m+2\gamma_a+\gamma_s+\gamma_h)t}, \quad (6.6)$$

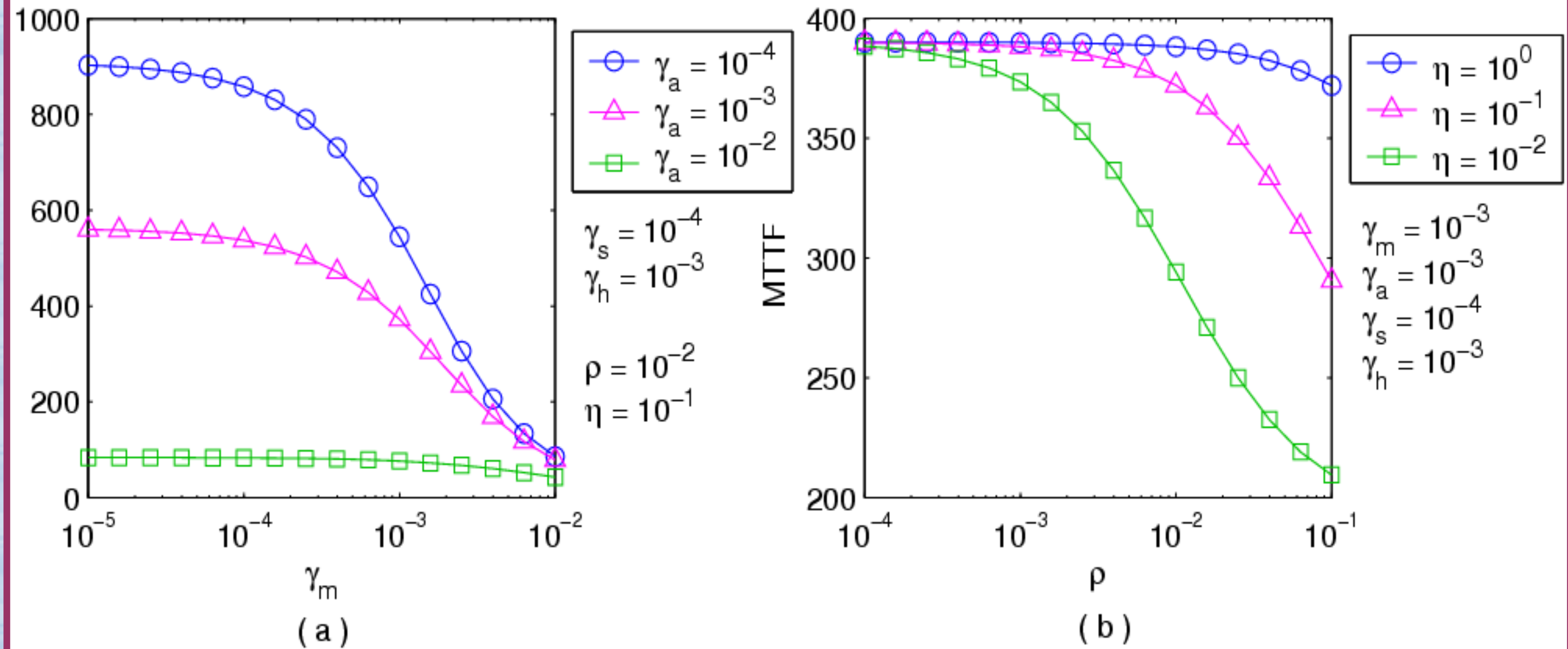
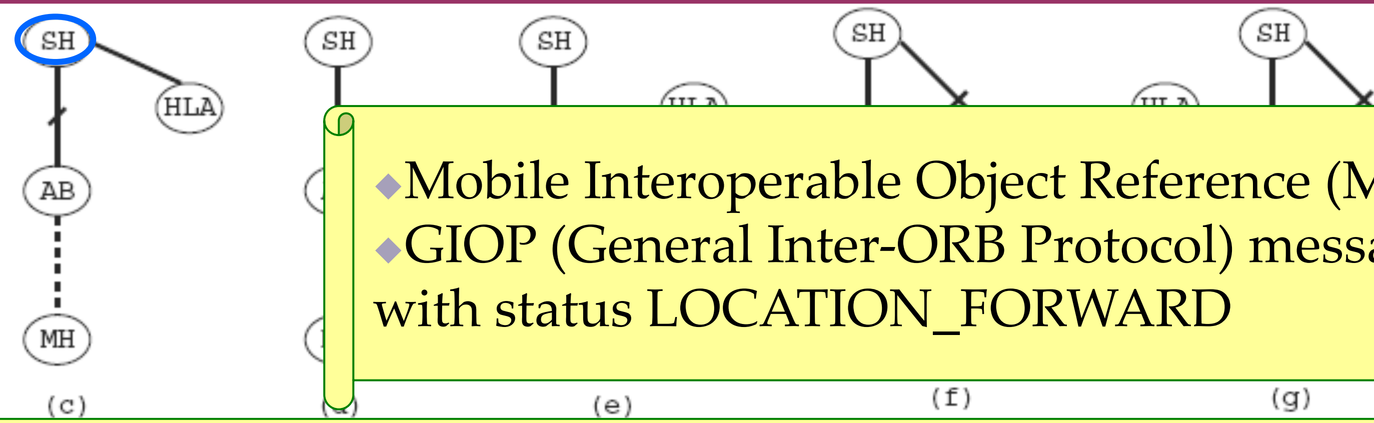


Figure 6.4: End-to-end MTTF of the MS scheme: (a) failure parameters γ_m and γ_a; (b) service parameters ρ and η.

The SM Scheme (Static Host – Mobile Host)



- Mobile Interoperable Object Reference (MIOR)
- GIOP (General Inter-ORB Protocol) message with status LOCATION_FORWARD

Three options for location-forwarding after a handoff:

③ **LF_AB**: the address of the mobile host's access bridge to which it moves

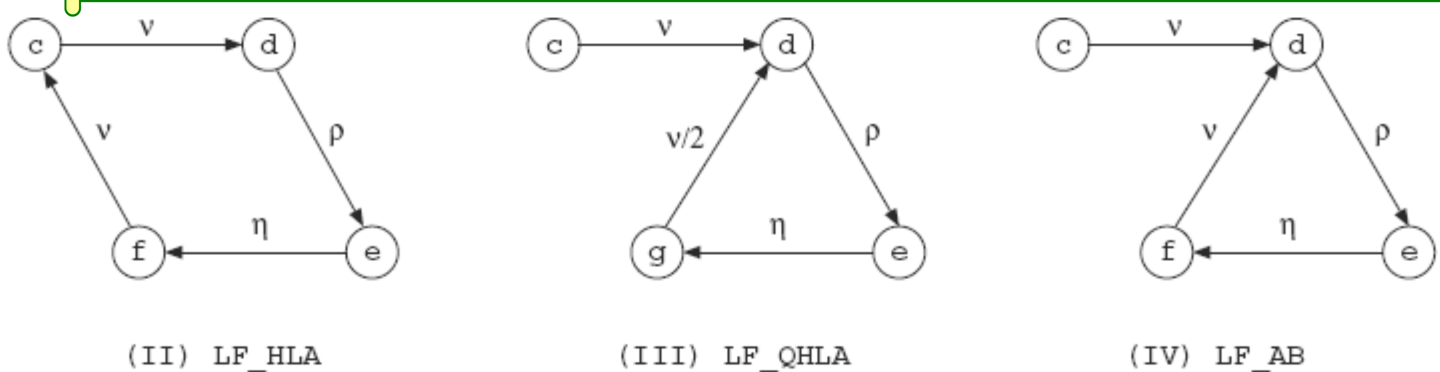


Figure 6.6: Markov models for the SM scheme.

EIR of the SM Scheme (LF_QHLA)

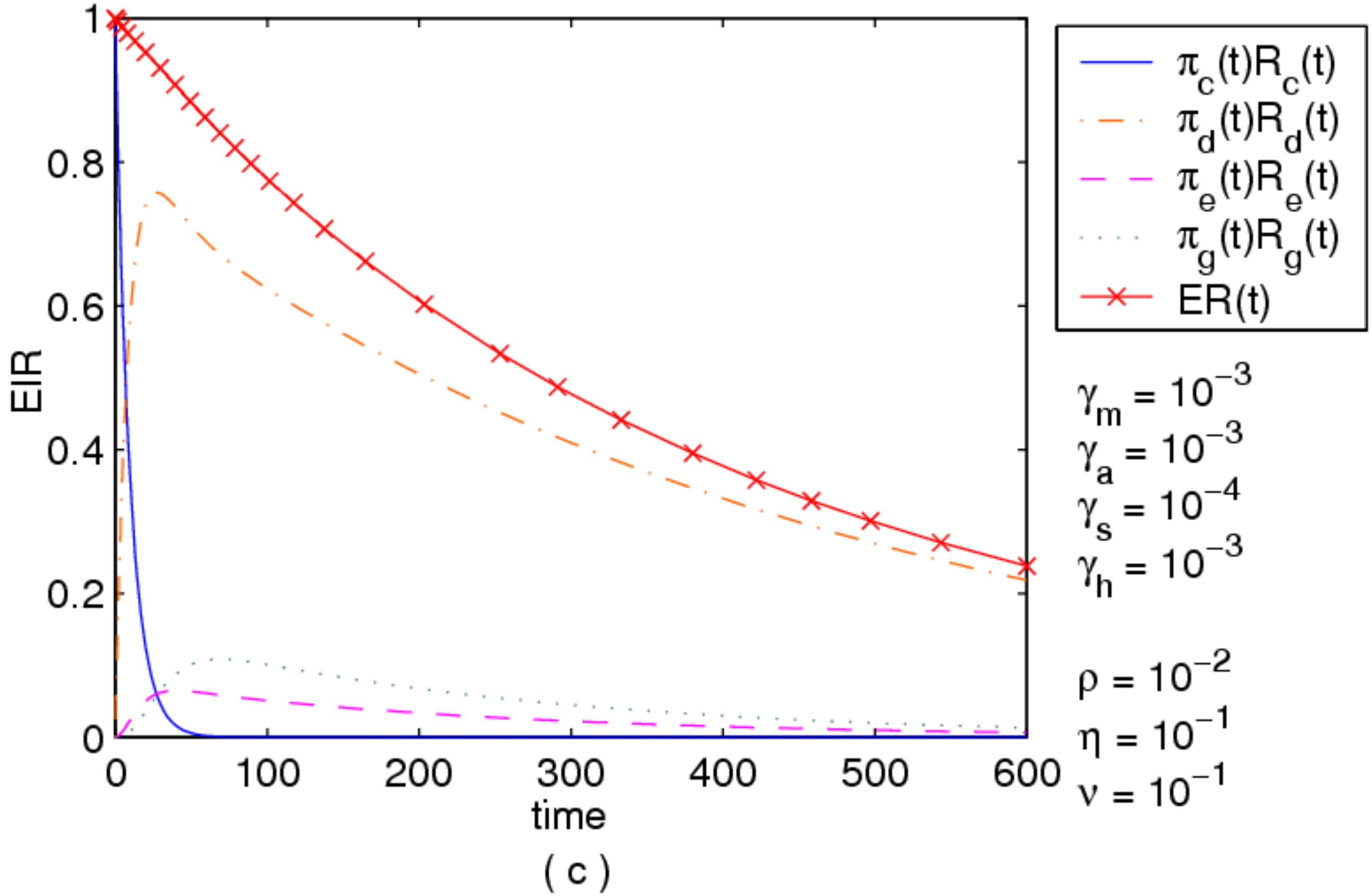


Figure 6.7: State probabilities and EIR of the SM scheme

EIR with Location-Forwarding Strategies

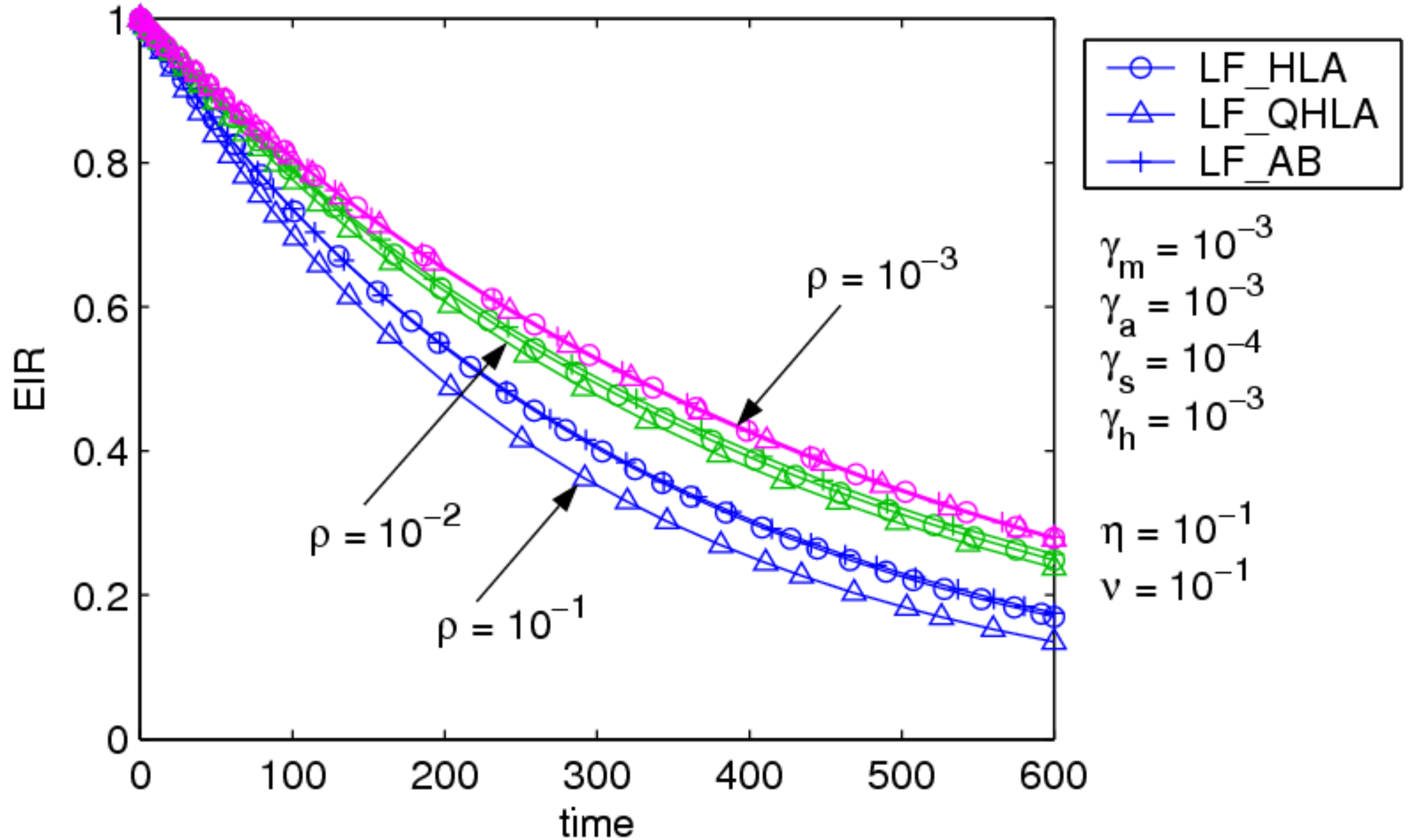


Figure 6.8: EIR with location-forwarding strategies in the SM scheme.

Time-Dependent Reliability Importance

- Measure the contribution of component-reliability to the system expected instantaneous reliability

$$I_{R_i}(t) = \frac{\partial ER(t)}{\partial R_i(t)} = \sum_x \pi_x(t) \cdot n_i(x)[R_i(t)]^{n_i(x)-1} \cdot \prod_c [R_c(t)]^{n_c(x)}, \quad c \neq i, \ (6.7)$$

Reliability Importance of the SM Scheme

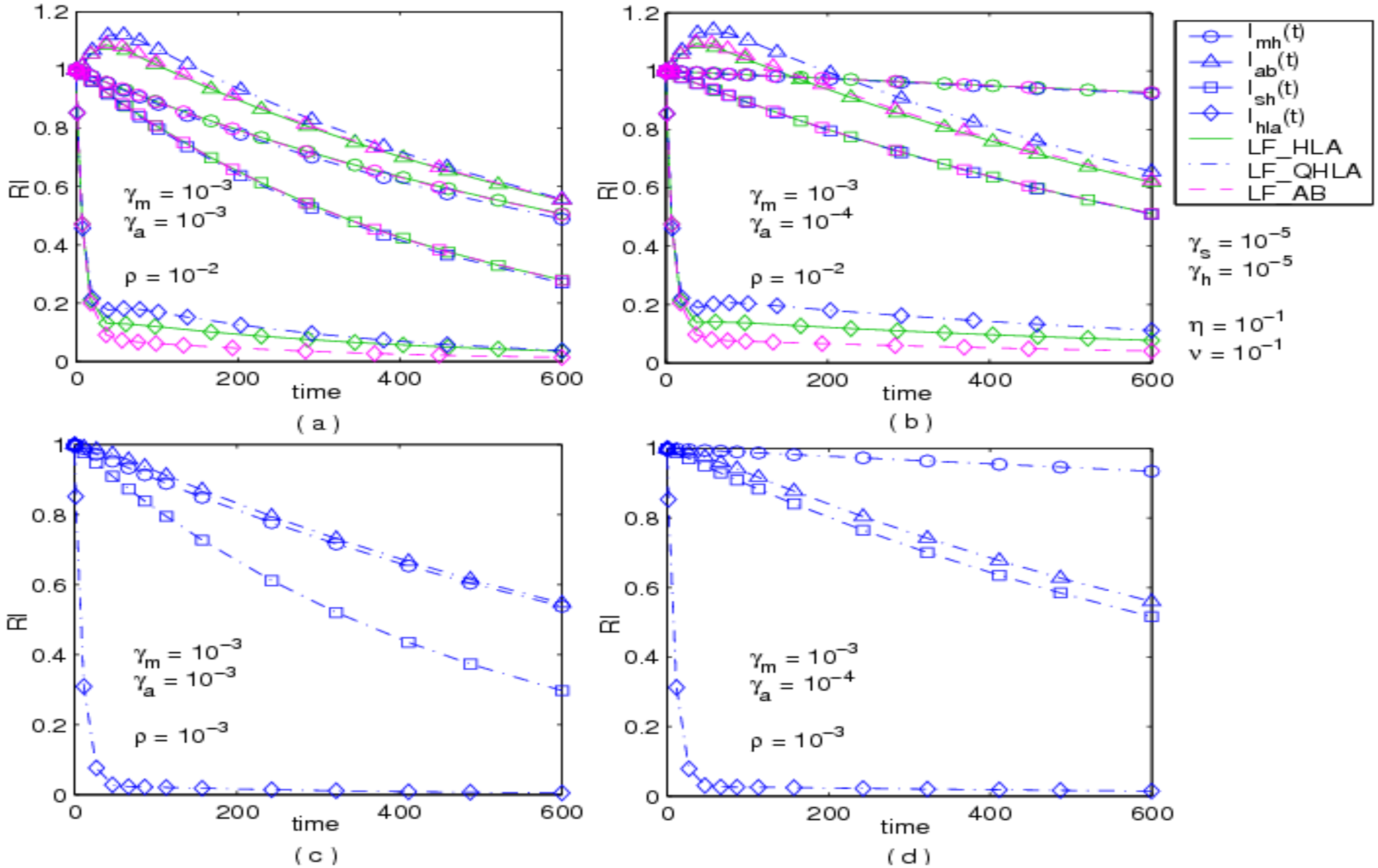
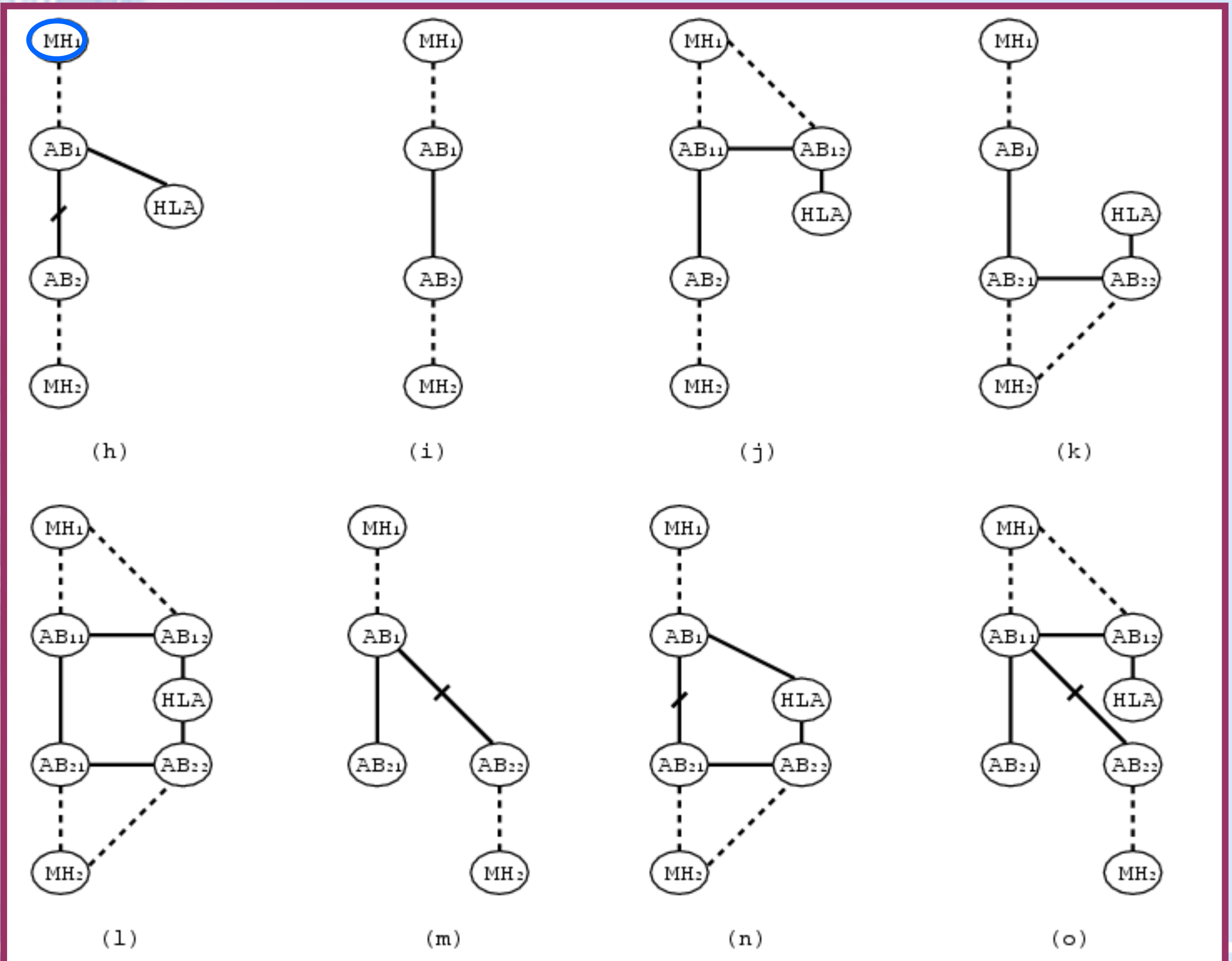


Figure 6.11: RI of the SM scheme: (a) same failure rate and high handoff rate; (b) different failure rates and high handoff rate; (c) same failure rate and low handoff rate; (d) different failure rates and low handoff rate.

The MM Scheme (Mobile Host – Mobile Host)



The MM Scheme (Mobile Host – Mobile Host)

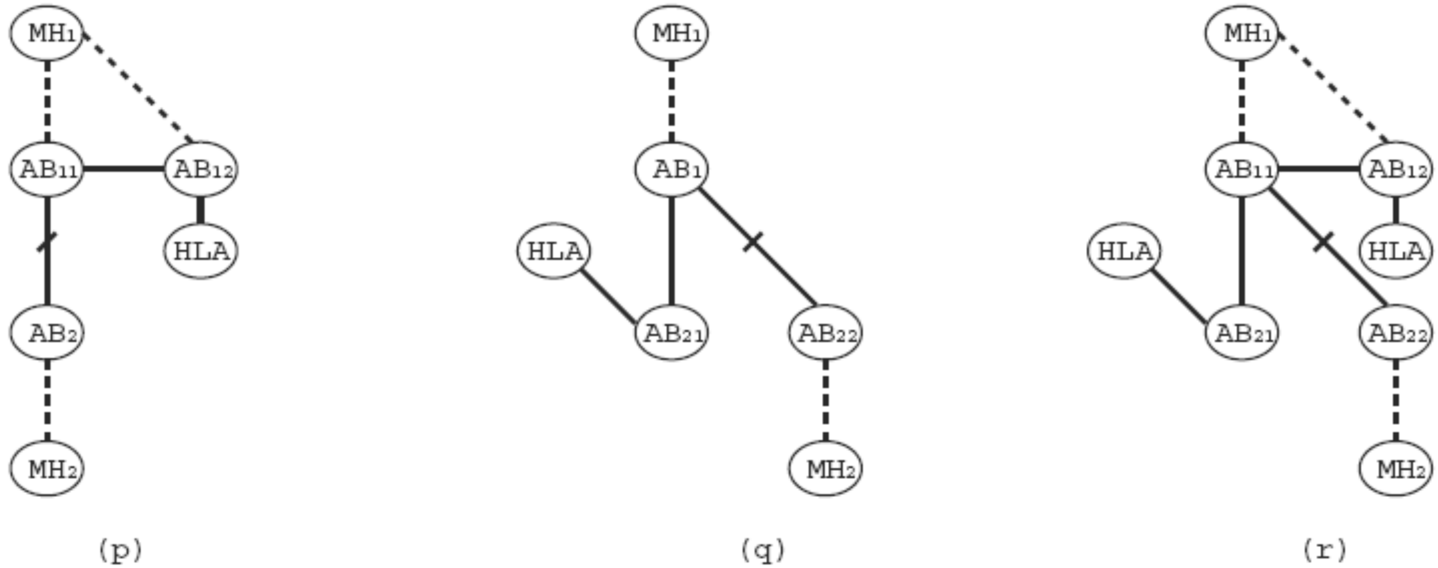


Figure 6.12: System states in the MM scheme: (h) location-querying; (i) normal communication; (j) MH_1 in handoff; (k) MH_2 in handoff; (l) both MH_1 and MH_2 in handoff; (m and q) location-forwarding; (n) location-querying and MH_2 in handoff; (o and r) location-forwarding and MH_1 in handoff; and (p) location-querying and MH_1 in handoff.

Markov Models for the MM Scheme

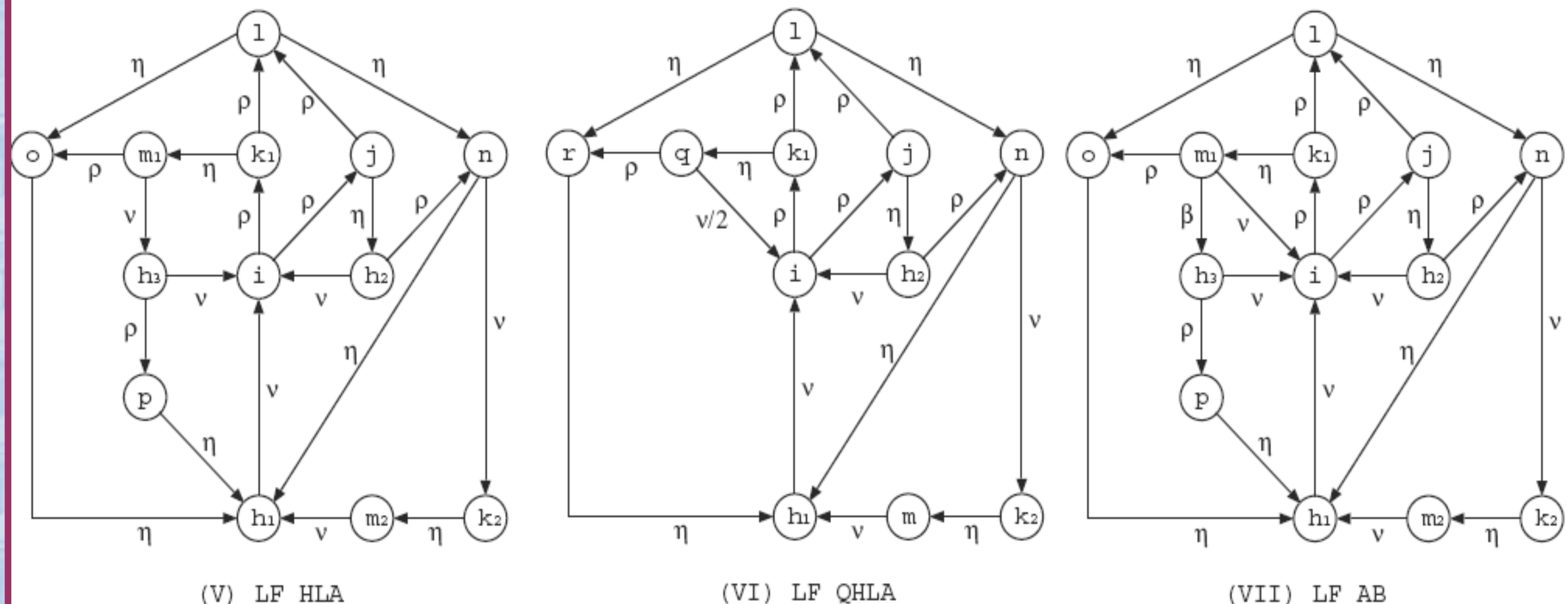


Figure 6.13: Markov models for the MM scheme.

Chapter 6 Summary

- Measure the end-to-end reliability of wireless networks in the presence of mobile host handoff
- Observation
  - Handoff and location-forwarding procedures should be completed as soon as possible
  - The reliability importance of different components should be determined with specific failure and service parameters
  - The number of engaged components during a communication state is more critical than the number of system states

Chapter 7 Sensibility-Based Sleeping Configuration in Sensor Networks

- Motivation
  - Maintaining coverage
    - Every point in the region of interest should be sensed within given parameters
  - Extending system lifetime
    - The energy source is usually battery power
    - Battery recharging or replacement is undesirable or impossible due to the unattended nature of sensors and hostile sensing environments
  - Fault tolerance
    - Sensors may fail or be blocked due to physical damage or environmental interference
    - Produce some void areas which do not satisfy the coverage requirement
  - Scalability
    - High density of deployed nodes
    - Each sensor must configure its own operational mode adaptively based on local information, not on global information

Objective: Coverage Configuration

- Coverage configuration is a promising way to extend network lifetime by alternately activating only a subset of sensors and scheduling others to sleep according to some heuristic schemes while providing sufficient coverage and tolerating sensor failures in a geographic region

Boolean Sensing Model (BSM)

- Each sensor has a certain sensing range sr
  - Within this sensing range, the occurrence of an event could be detected by the sensor alone

$$\exists N_i \in \Omega,\ d(N_i, y) < sr_i. \quad (7.2)$$

- **N_i** : sensor i
- **y** : a measuring point
- **Ω** : deployed sensors in a deployment region Φ
- **$d(N_i,y)$** : distance between N_i and y
- **sr_i** : sensing radius of sensor N_i

Collaborative Sensing Model (CSM)

- Capture the fact that signals emitted by a target of interest decay over the distance of propagation
- Exploit the collaboration between adjacent sensors
- Point Sensibility $s(N_i, p)$: the sensibility of a sensor N_i for an event occurring at an arbitrary measuring point p

$$s(N_i, y) = \frac{\alpha}{[d(N_i, y)]^\beta}, \quad (7.3)$$

- α : energy emitted by events occurring at point p
- β : decaying factor of the sensing signal

Field Sensibility

❖ Collective-Sensor Field Sensibility (CSFS)

$$S_c(y) = \sum_{i \,:\, s(N_i,\, y) \,\geq\, \epsilon_n} s(N_i, y), \quad (7.4)$$

◆ ε_n : signal threshold

❖ Neighboring-Sensor Field Sensibility (NSFS)

$$S_n^i(y) = s(N_i, y) + \sum_{j \,:\, N_j \,\in\, N(i) \,\wedge\, s(N_j,\, y) \,\geq\, \epsilon_n} s(N_j, y). \quad (7.5)$$

◆ **N(i)** : one-hop communication neighbor set of sensor N_i

◆ ε_s : required sensibility threshold

Relations between the BSM and the CSM

- Ensured-sensibility radius

$$sr_i^e = \left(\frac{\alpha}{\epsilon_s}\right)^{\frac{1}{\beta}}. \qquad (7.6)$$

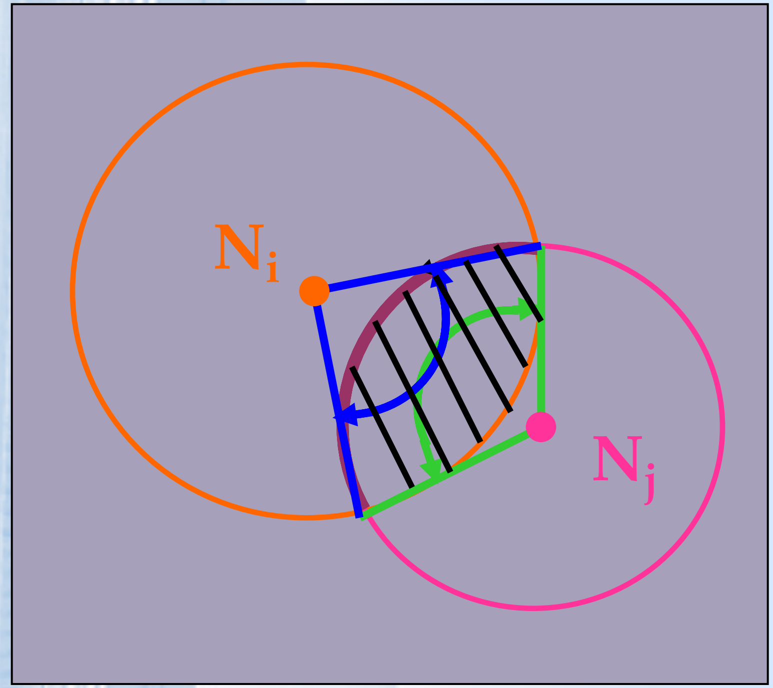
- Collaborative-sensibility radius

$$sr_i^c = \left(\frac{\alpha}{\epsilon_n}\right)^{\frac{1}{\beta}}. \qquad (7.7)$$

- ε_s : required sensibility threshold
- ε_n : signal threshold
- α : energy emitted by events occurring at point p
- β : decaying factor of the sensing signal

Sleeping Candidate Condition for the BSM with Arc-Coverage

- Each sensor N_i knows its location (x_i, y_i), sensing radius sr_i, communication radius cr



Sponsored Sensing Region (SSR)

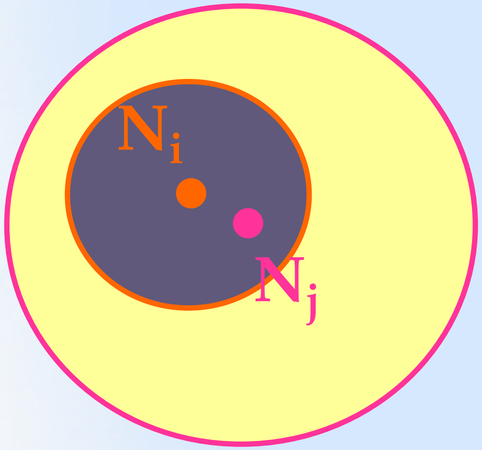
Sponsored Sensing Arc (SSA) τ_{ij}

Sponsored Sensing Angle (SSG) θ_{ij}

Covered Sensing Angle (CSG) ϖ_{ij}

Complete-Coverage Sponsor (CCS)

- $d(N_i, N_j) \le sr_j - sr_i$



SSG θ_{ij} is not defined
CSG ϖ_{ij} =2π

Complete-Coverage Sponsor (CCS) of N_i | **CCS(i)**

Degree of Complete Coverage (DCC) ζ_i = |CCS(i)|

Minimum Partial Arc-Coverage (MPAC)

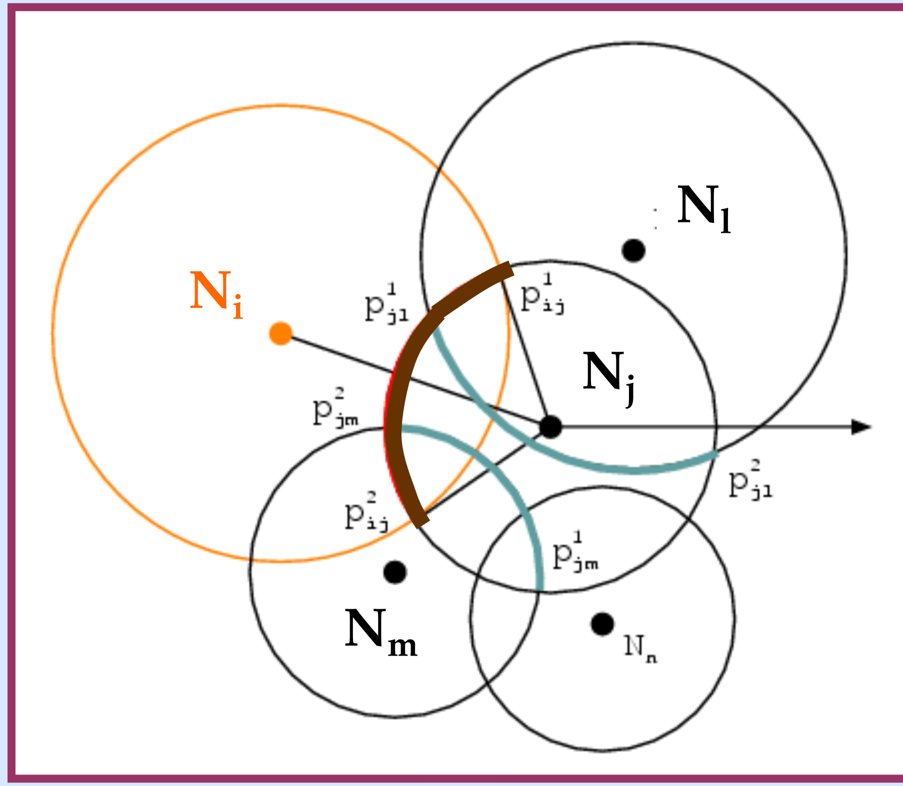
- The minimum partial arc-coverage (MPAC) sponsored by sensor N_j to sensor N_i, denoted as ξ_{ij},
  - on SSA τ_{ij} find a point y that is covered by the minimum number of sensors
  - the number of N_i's non-CCSs covering the point y

- SSA: Sponsored Sensing Arc
- CCS: Complete-Coverage Sponsor

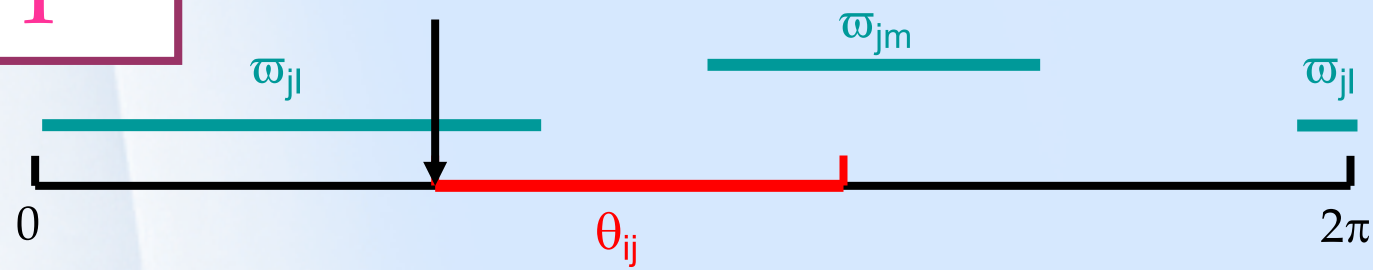
Derivation of MPAC ξ_{ij}

Sponsored Sensing Angle (SSG) θ_{ij}

Covered Sensing Angle (CSG) ϖ_{ij}



$\xi_{ij} = 1$



MPAC and DCC Based *k*-Coverage Sleeping Candidate Condition

- k-coverage
  - "A region is k-covered" means every point inside this region is covered by at least k sensors.
- Theorem 4
  - A sensor N_i is a sleeping candidate while preserving *k*-coverage under the constraint of one-hop neighbors, iff $\zeta_i \geq k$ or $\forall N_j \in N(i) - CCS(i), \xi_{ij} > k - \zeta_i$.

- ζ_i : Degree of Complete Coverage (DCC)
- ξ_{ij} : Minimum Partial Arc-Coverage (MPAC)
- N(i) : one-hop communication neighbors
- CCS(i): Complete-Coverage Sponsor

Sleeping Candidate Condition for the BSM with Voronoi Diagram

- Theorem 5
  - A sensor N_i is on the boundary of coverage iff its Voronoi cell is not completely covered by its sensing disk.

A sensor N_i is said to be on the boundary of coverage if there exists a point y on its sensing perimeter such that y is not coverd by its one-hop working neighbors N(i).

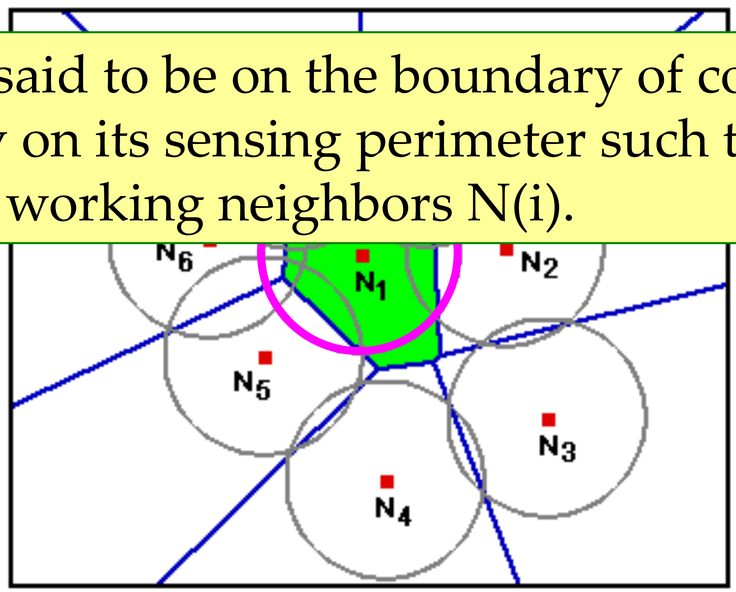


Figure 7.6: Example of coverage boundary: N_1.

Theorem 6

- A sensor N_i is a sleeping candidate iff
  - It is not on the coverage boundary
  - When constructing another Voronoi diagram without N_i, all the Voronoi vertices of its one-hop working neighbors in N_i's sensing disk are still covered.

Example of Sleeping-Eligible Sensor: N_1

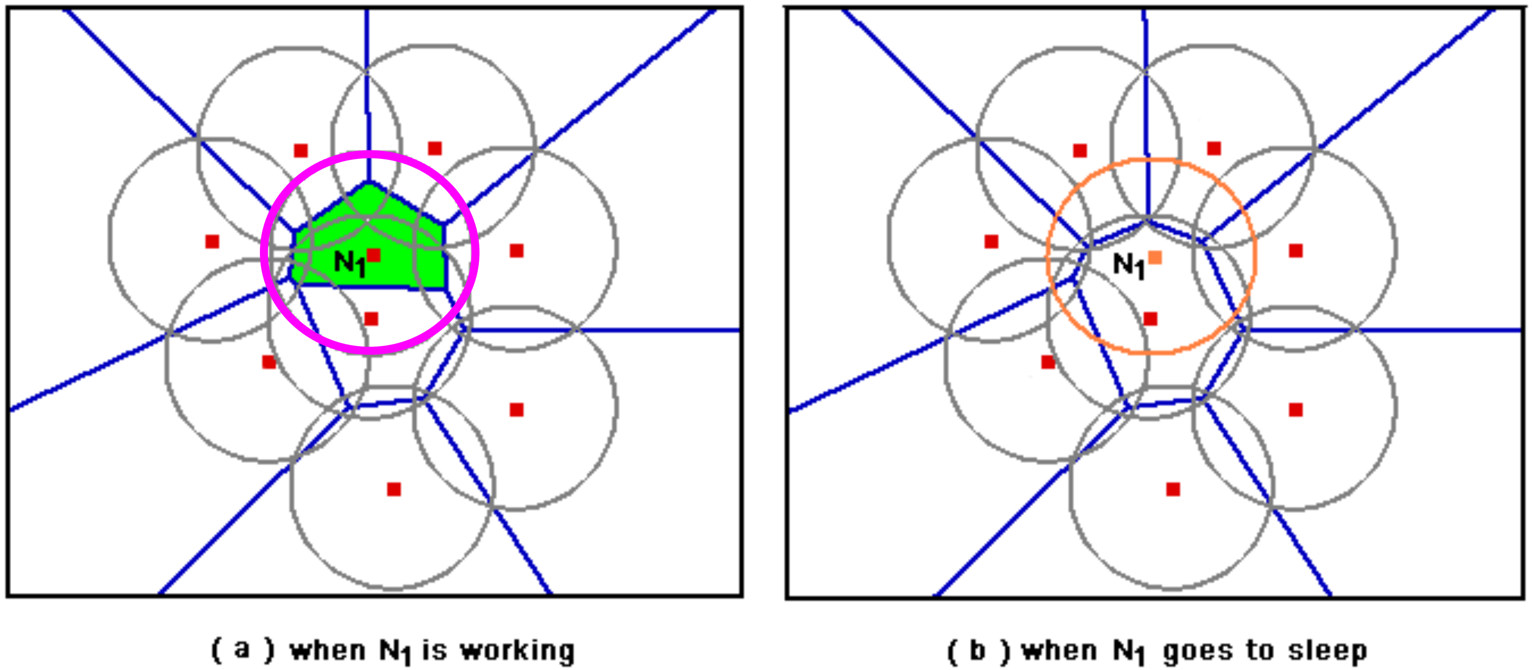


Figure 7.7: Example of sleeping-eligible sensor: N_1.

Sleeping Candidate Condition for the CSM

- With the NSFS, if the Voronoi cells of all a sensor’s one-hop neighbors are still covered without this sensor, then it is a sleeping candidate.

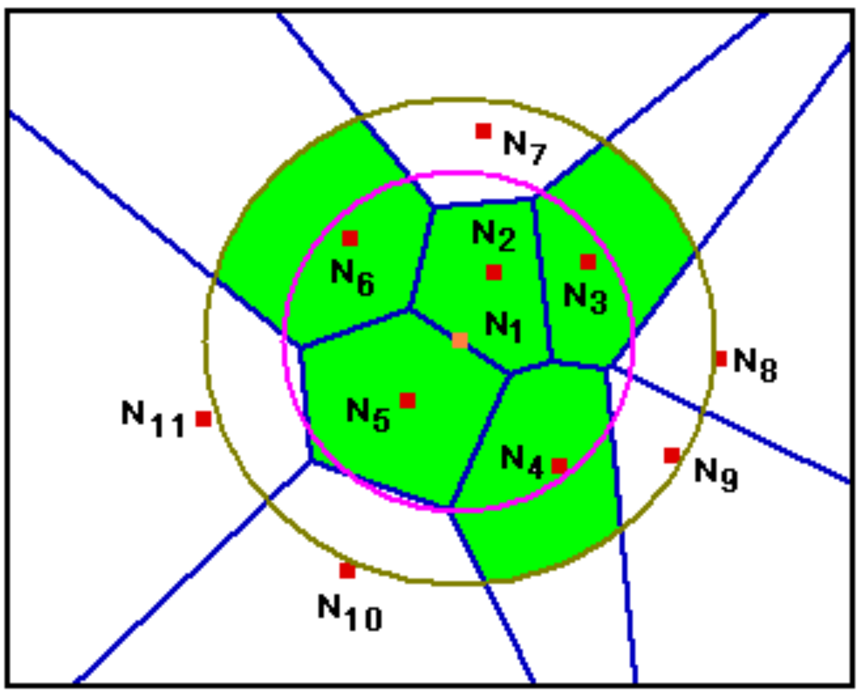


Figure 7.9: Scan region for sensor N_1.

- CSM: Collaborative Sensing Model
- NSFS: Neighboring-Sensor Field Sensibility
- sr_i^c: collaborative-sensibility radius

Location Error

- Assume that a sensor's obtained location is uniformly distributed in a circle located at its accurate position with radius ε_d
- normalized deviation of location ε
  - the ratio of the maximum location deviation ε_d to a sensor's sensing radius
- normalized distance d
  - the ratio of the distance between a point and a sensor to the sensor's sensing radius

Coverage Relationship with Location Error

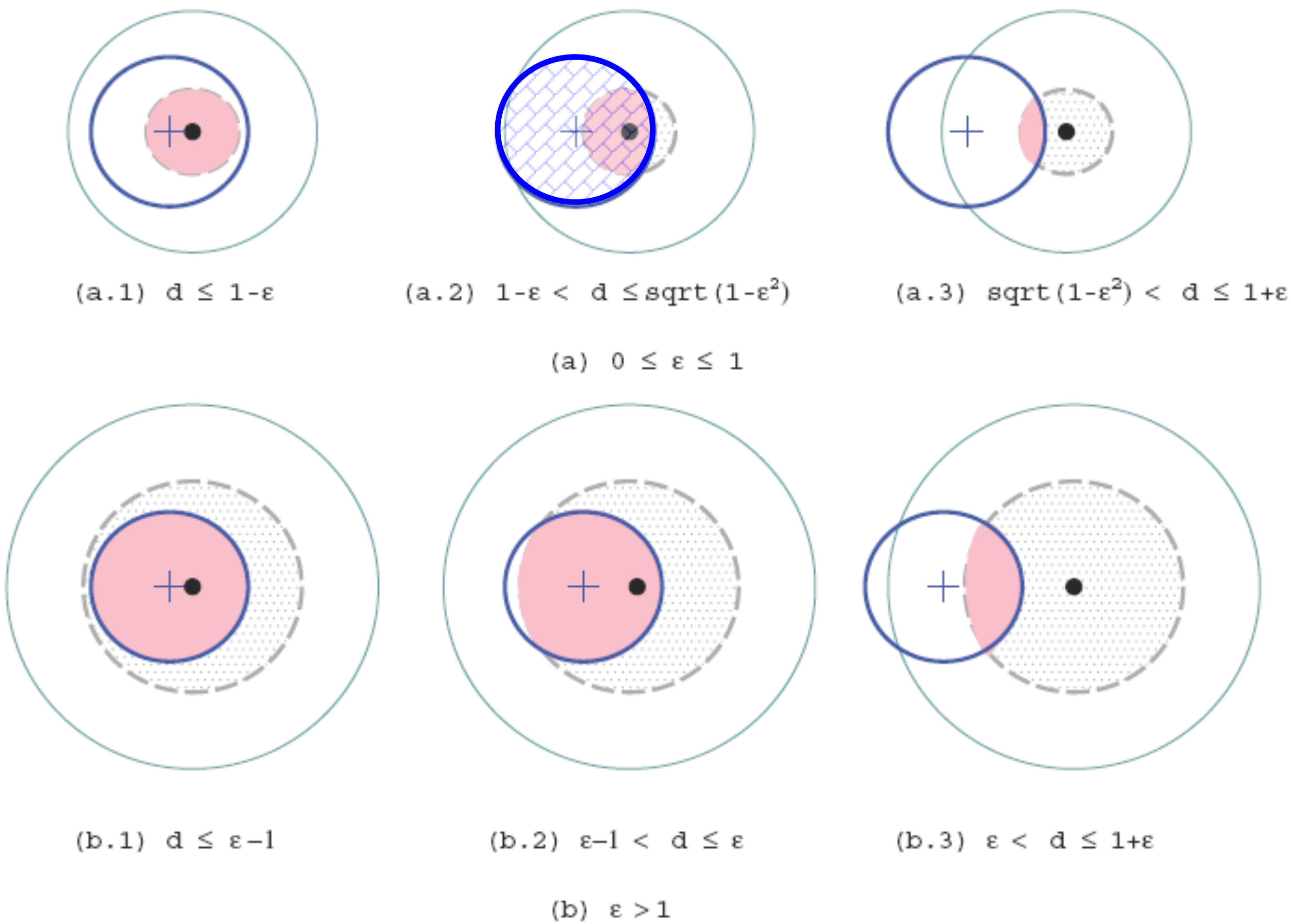


Figure 7.10: The coverage relationship between a point and a sensor with location error.

Probability of Coverage with Location Error

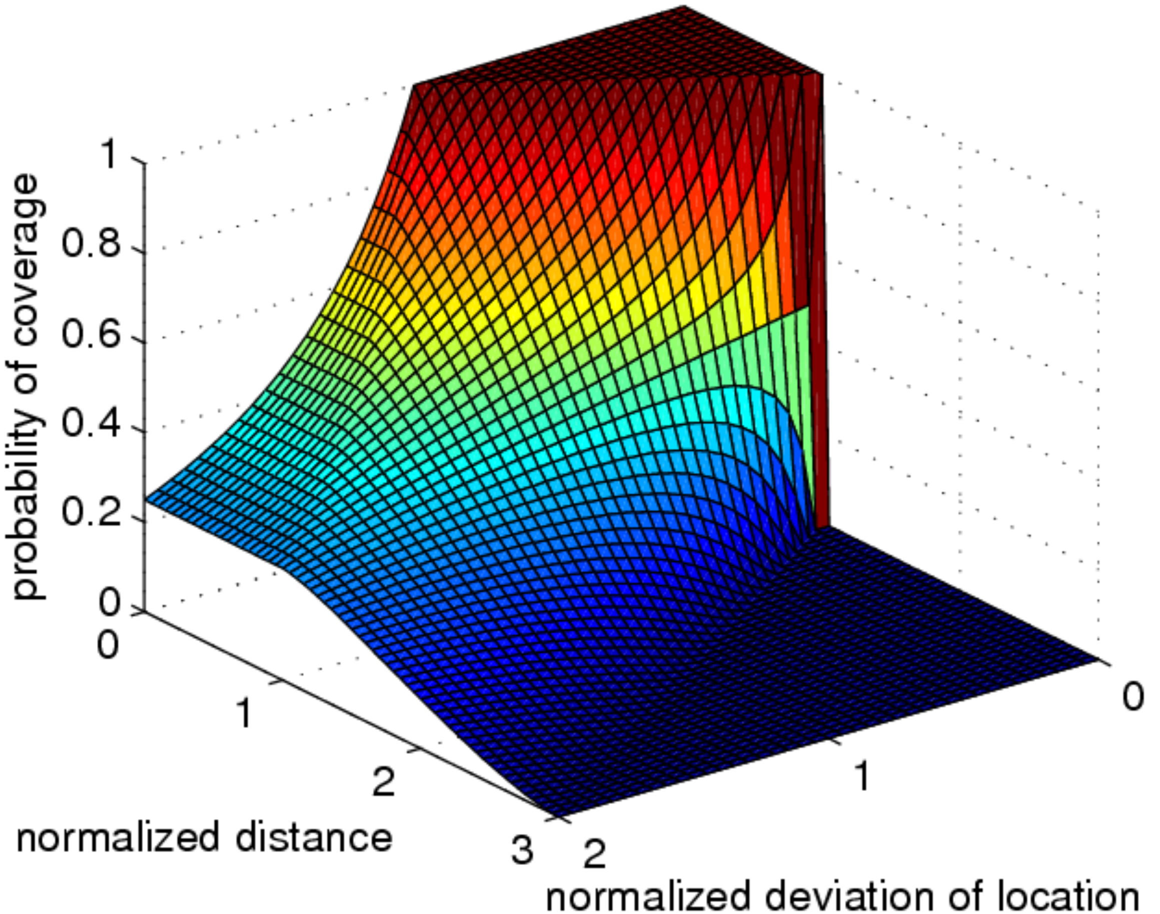


Figure 7.11: Probability of coverage with location error.

Sensibility-Based Sleeping Configuration Protocol (SSCP)

- Round-based
  - Divide the time into rounds
  - Approximately synchronized
  - In each round, every live sensor is given a chance to be sleeping eligible
- Adaptive sleeping
  - Let each node calculate its sleeping time locally and adaptively

Performance Evaluation with ns-2

- Boolean sensing model
  - **SS**: Sponsored Sector
    - Proposed by Tian *et. al.* of Univ. of Ottawa, 2002
    - Consider only the nodes inside the sensing radius of the evaluated node
  - **CCP**: Coverage Configuration Protocol
    - Proposed by Wang *et. al.* of UCLA, 2003
    - Evaluate the coverage of intersection points among sensing perimeters
  - **SscpAc**: the sleeping candidate condition with arc-coverage in the round-robin SSCP
  - **SscpAcA**: the sleeping candidate condition with arc-coverage in the adaptive SSCP
  - **SscpVo**: the sleeping candidate condition with Voronoi diagram in the round-robin SSCP
- Collaborative sensing model
  - **SscpCo**: the sleeping candidate condition for the CSM in the round-robin SSCP
  - **Central**: a centralized algorithm with global coordination

Performance Evaluation (1)

- Communication radius cr

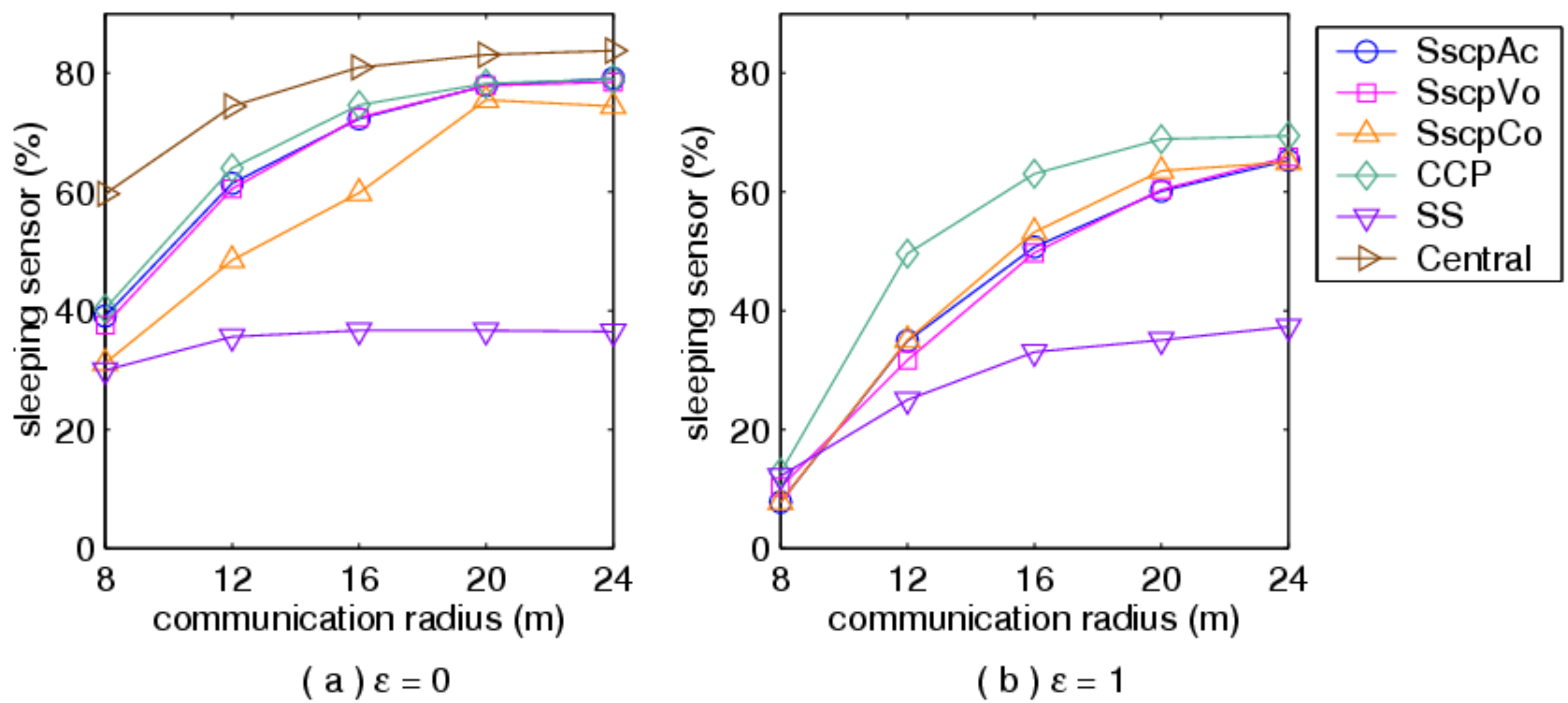


Figure 7.14: Percentage of sleeping sensors vs. communication radius *cr*.

Performance Evaluation (2)

- Number of working vs. deployed sensors

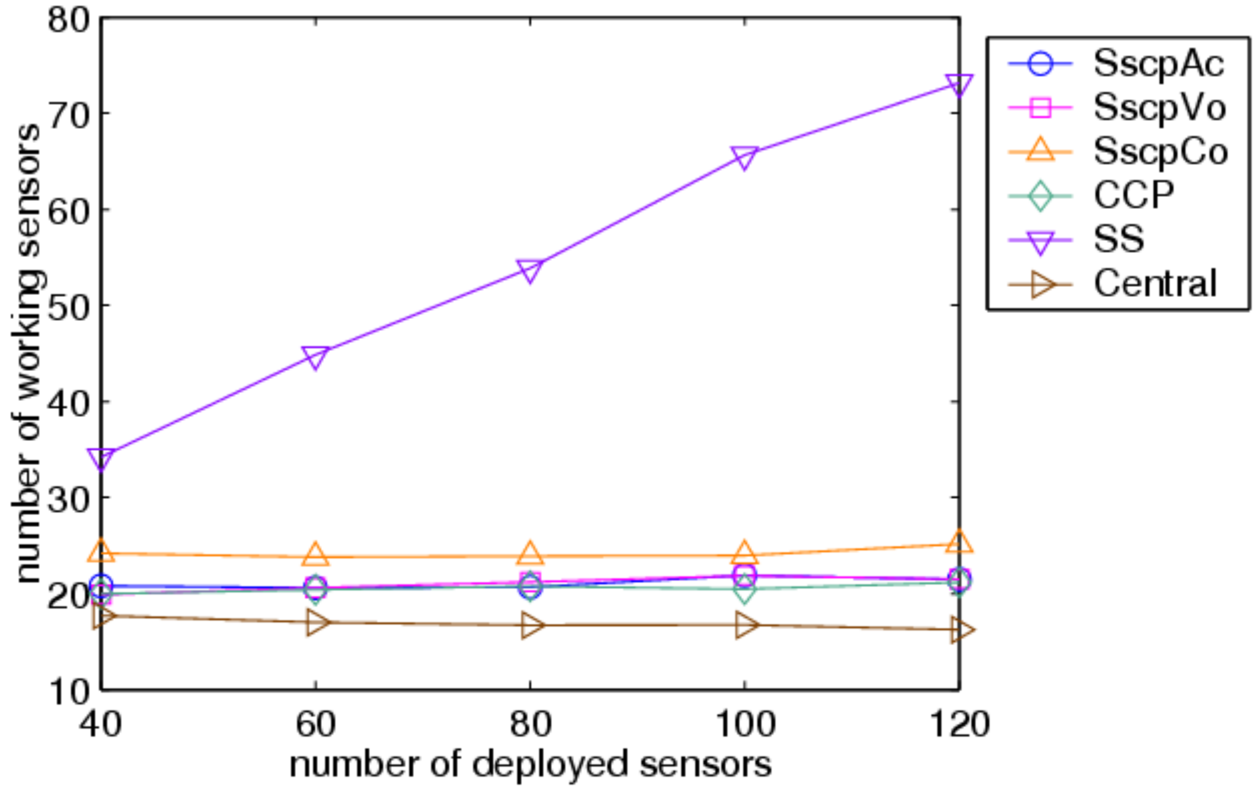


Figure 7.15: Number of working vs. deployed sensors.

Performance Evaluation (3)

❖ Field sensibility distribution

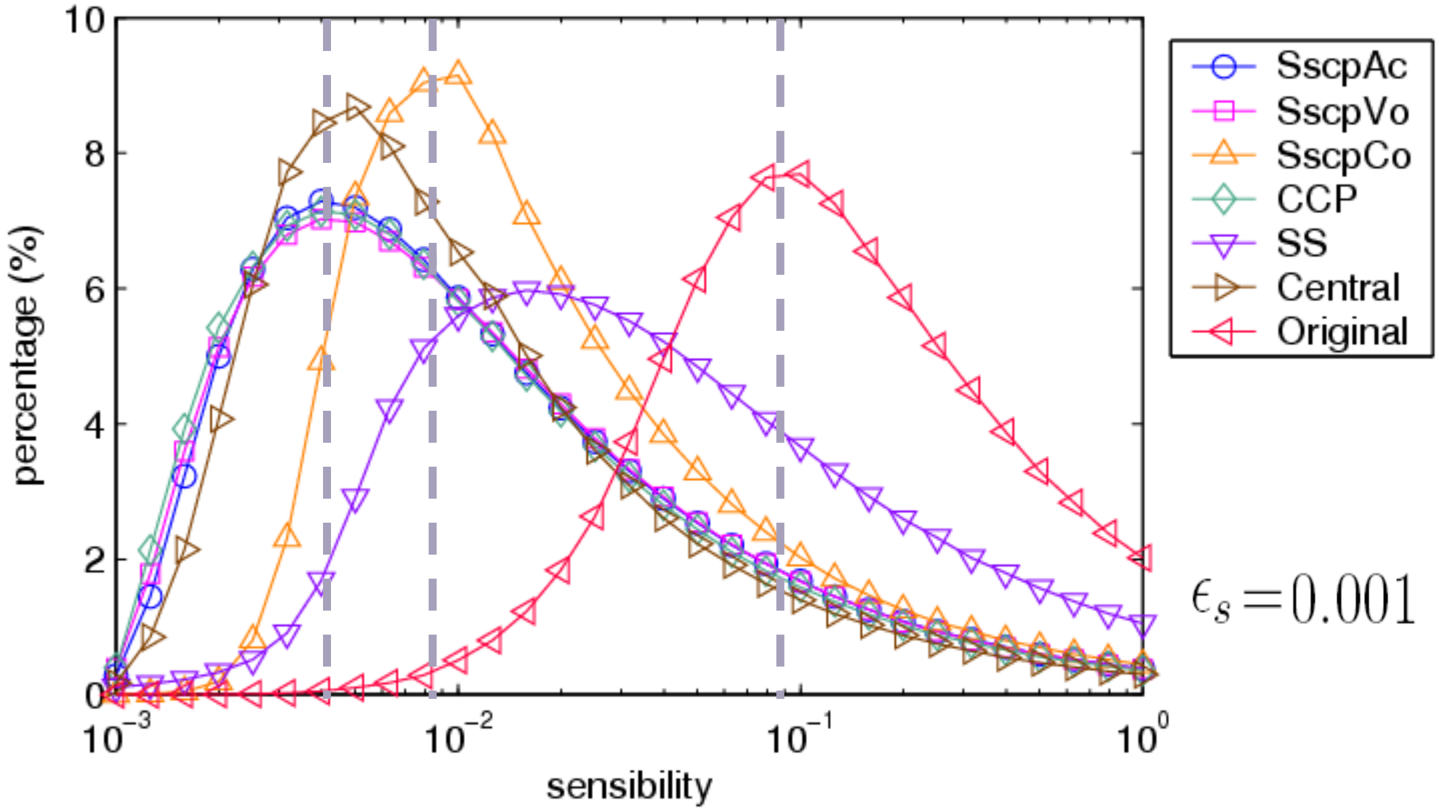


Figure 7.18: Field sensibility distribution.

Performance Evaluation (4)

- Loss of area coverage

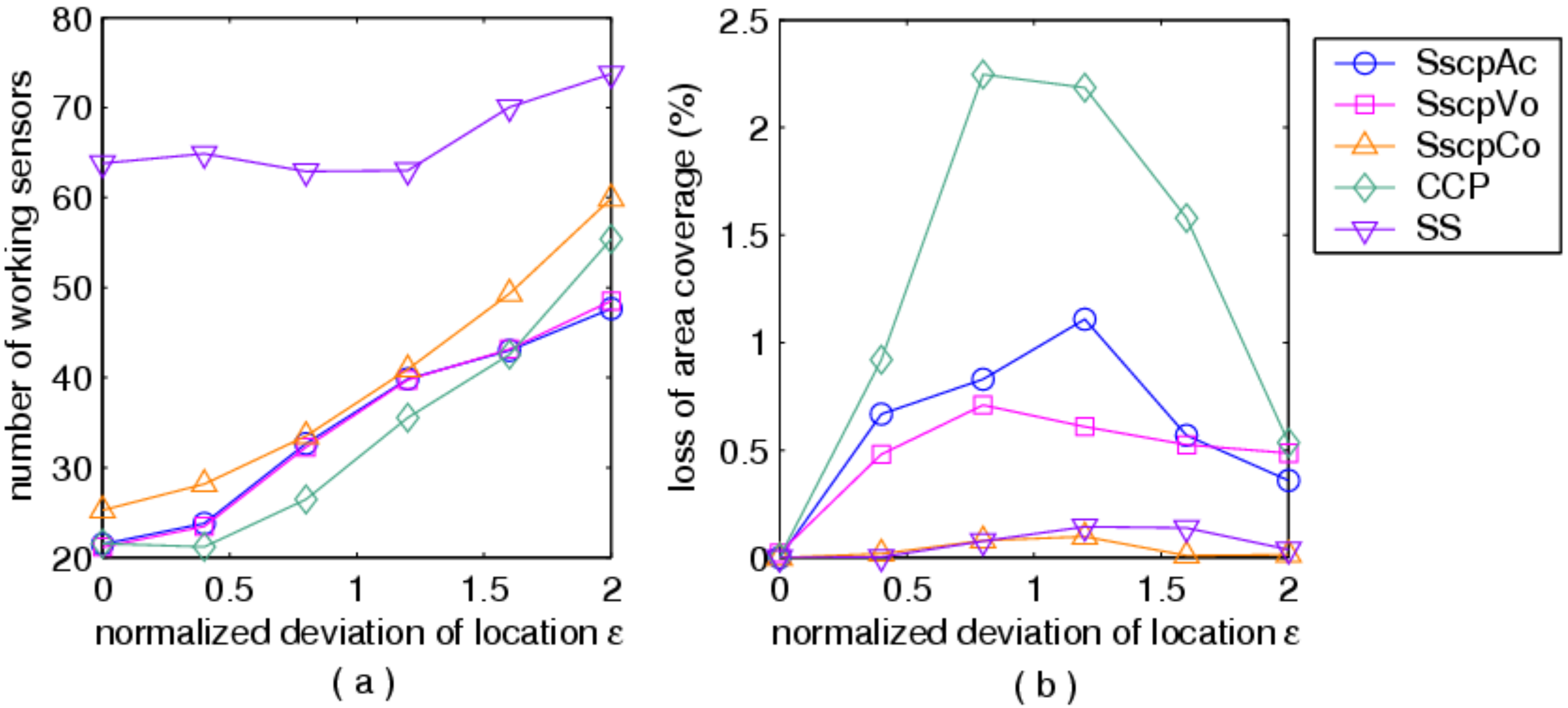
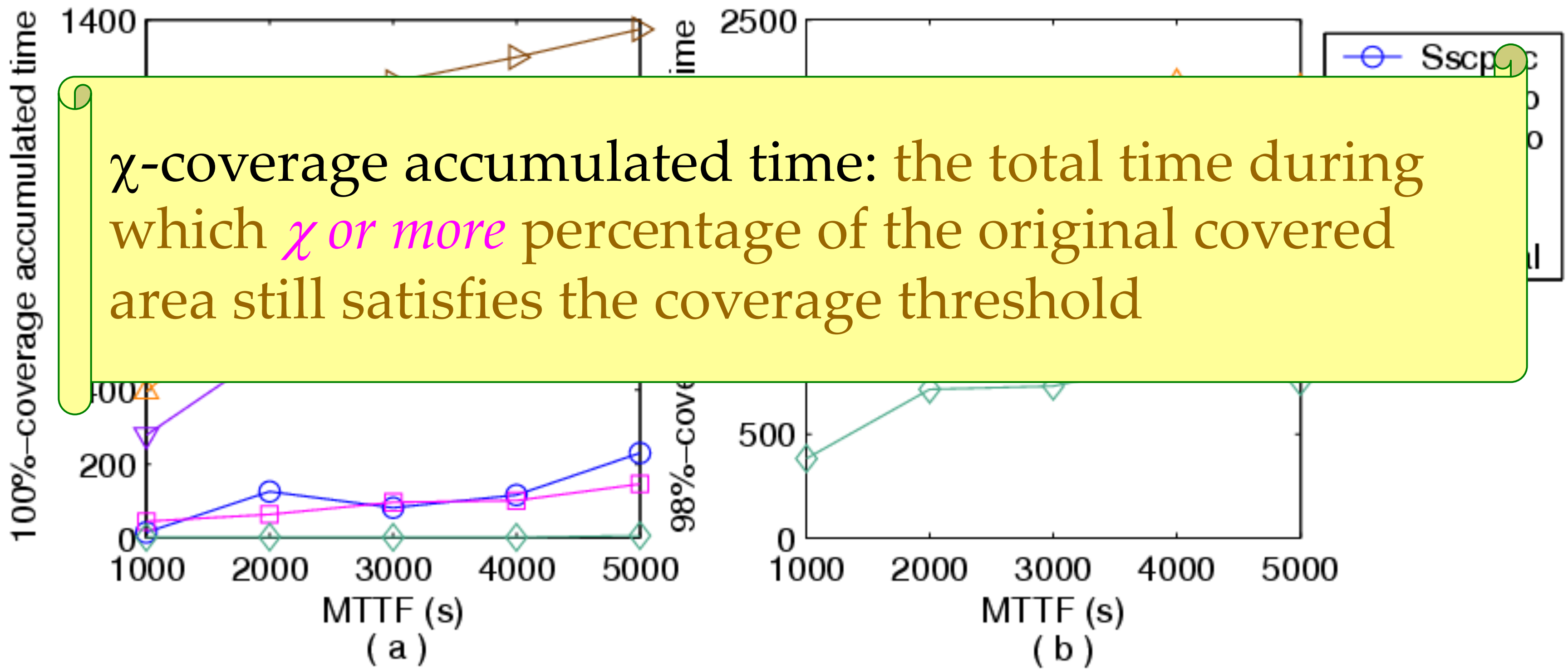


Figure 7.21: Deviation of location.

Performance Evaluation (5)

❖ Sensitivity to sensor failures



χ-coverage accumulated time: the total time during which *χ or more* percentage of the original covered area still satisfies the coverage threshold

Figure 7.22: χ-coverage accumulated time vs. MTTF when $\epsilon = 1$.

Performance Evaluation (6)

❖ Sensitivity to sensor failures with fault tolerance

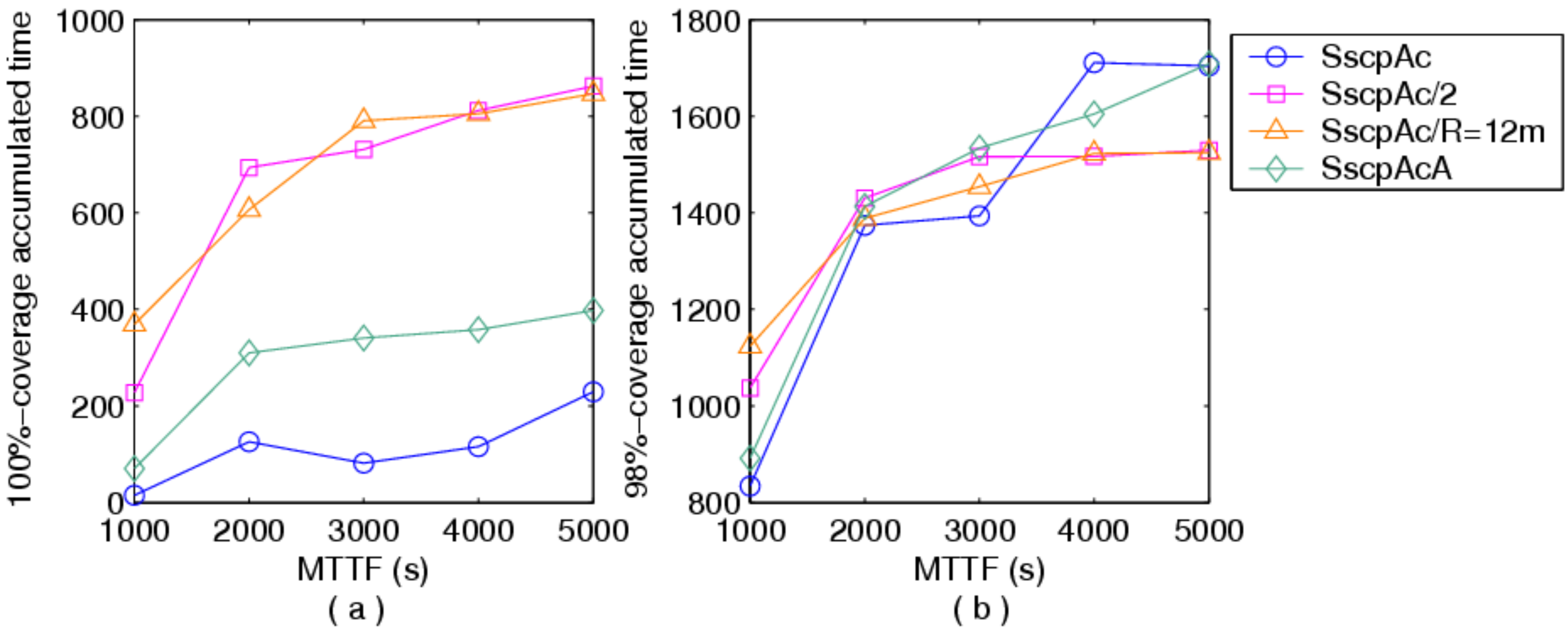


Figure 7.23: χ-coverage accumulated time vs. MTTF with FT approaches when $\epsilon = 1$.

Chapter 7 Summary

- Exploit problems of energy conservation and fault tolerance while maintaining desired coverage and network connectivity with location error in wireless sensor networks
  - Investigate two sensing models: BSM and CSM
  - Develop two distributed and localized sleeping configuration protocols (SSCPs): round-based and adaptive sleeping
- Suggest three effective approaches to build dependable wireless sensor networks
  - increasing the required degree of coverage or reducing the communication radius during sleeping configuration
  - configuring sensor sleeping adaptively
  - utilizing the cooperation between neighboring sensors

Conclusions and Future Directions

- Build a fault tolerance architecture for wireless CORBA (Chapter 3)
  - Construct various and hybrid message logging protocols
- Study the expected message sojourn time at access bridge (Chapter 4)
  - Derive analytical results for the left three models
  - Generalize the exponentially distributed message inter-arrival time and service time
- Analyze the program execution time at mobile host (Chapter 5)
  - Exploit the effect of wireless bandwidth and mobile host disconnection on program execution time

Conclusions and Future Directions (cont'd)

- Evaluate reliability for various communication schemes (Chapter 6)
  - Develop end-to-end reliability evaluation for wireless sensor networks
- Propose sleeping candidate conditions to conserve sensor energy while preserving redundancy to tolerate sensor failures and location error (Chapter 7)
  - Relax the assumption of known location information and no packet loss
  - Find a reliable path to report event to end-user
  - Integrate sleeping configuration protocol with routing protocol

Q & A

Thank You