



Performance and Security Tradeoff

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Bertinoro, June 26, 2010

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- ▶ what does the performance security tradeoff mean?
- ▶ we need to measure performance
- ▶ we need to measure security
- ▶ what are the costs of performance?
- ▶ what are the costs of security?
- ▶ can we trade one against the other?

performance

classical metrics

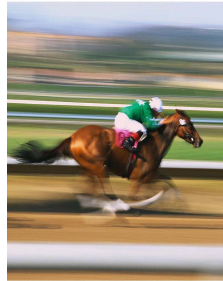
- ▶ throughput
- ▶ response time, completion time

evaluation tools

- ▶ CTMC
- ▶ queueing model
- ▶ GSPN, SRN, PEPA

measures

- ▶ accumulated reward
- ▶ expected reward
- ▶ moments of reward
- ▶ time to absorption



Quantification

- ▶ performance can be measured, quantified
- ▶ cost of performance can be quantified
- ▶ can we measure security?
- ▶ can we determine the cost of security?
- ▶ ultimately cost in terms of performance

It cost British Columbians almost \$15 million a day to ensure a peaceful Olympics.



Members of the Vancouver 2010 Olympic Games Integrated Security Unit

April 2007

- ▶ Forrester Research survey of 28 companies
- ▶ Security Breaches Cost \$90 To \$305 Per Lost Record
- ▶ 25% respondents do not know how to quantify loss



Google

Gmail now can be set to encrypt communications between a browser and Google's servers by default, an option that makes the e-mail service harder to snoop on but also potentially slower.

Google mail

Your computer has to do extra work to decrypt all that data, and encrypted data doesn't travel across the Internet as efficiently as unencrypted data, that's why we leave the choice up to you.

IBM Security Solutions

Manage Risk. Reduce Costs. Enable Innovation.

IBM Virtualisation

Virtualisation Security Solutions from IBM Internet Security SystemsTM
Manage the risks of virtualisations and realise the cost savings.

IBM security

IBM cloud computing security

IBM offers end-to-end solutions that enable you to take a business-driven and holistic approach to securing your cloud computing environment. IBM's capabilities empower you to dynamically monitor and quantify security risks, enabling you to better:

- ▶ understand threats and vulnerabilities in terms of business impact,
- ▶ respond to security events with security controls that optimize business results,
- ▶ prioritize and balance your security investments.

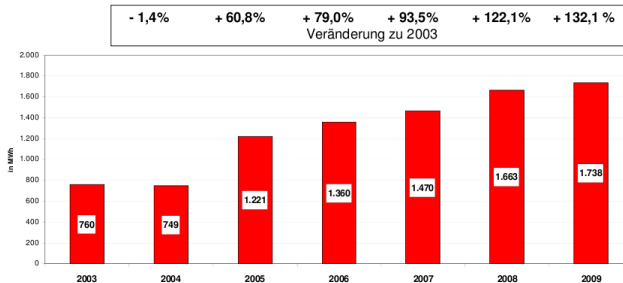
IBM Security Solutions for Data Centers

Your company can build a secure, dynamic information infrastructure that helps you accelerate innovation while reducing cost and complexity of security.

energy costs

IT costs

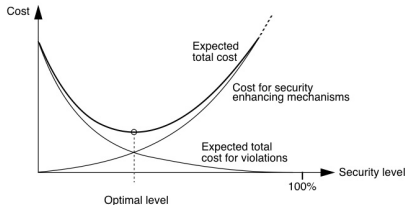
- ▶ total energy costs of FUB 10 M Euro
- ▶ electricity 50%
- ▶ power consumption of FUB's central IT services
- ▶ how much redundancy, security is necessary?



security concerns are not new

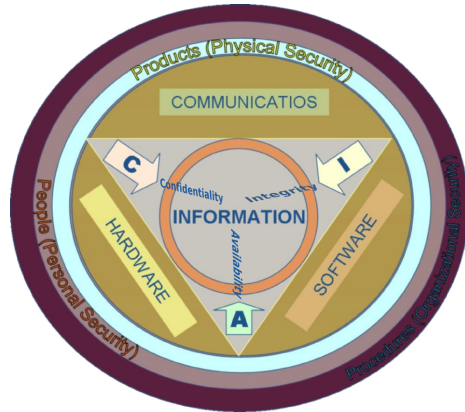
Problems

- ▶ cost of security incident unknown
- ▶ incidents may not be detected
- ▶ information security aims to get close to theoretical max. without knowing the cost.
- ▶ security risks may have very low probability. Don't invest close to potential damage to prevent, but detect.



Source: A Structured Approach to Computer Security, T. Olovsson (1992)

- ▶ Confidentiality
(information is not passed to unauthorised parties, defense)
- ▶ Integrity
(information is not modified by unauthorised parties, banking)
- ▶ Availability
(information is at disposition, telephone)
- ▶ (non-repudiation)
sender and receiver are authentic



security versus dependability

analogies

- ▶ error, fault, failure in dependability
- ▶ vulnerability, security fault (Trojan horse), security failure
- ▶ failures can be modelled as random processes

differences

- ▶ accidental problems in dependability
- ▶ intentional problems in security
- ▶ attacker accumulates reward
- ▶ redundancy is helpful in dependability, detrimental for security

references

- ▶ Littlewood, Brocklehurst, Fenton, Mellor, Page, Wright (1993)
- ▶ Littlewood, Strigini (2004), Nicol, Sanders, Trivedi (2004)

survey of security quantification

- ▶ Verendel 2009: survey of 90 papers between 1981 and 2008.
- ▶ includes hardly model-based analysis
- ▶ it is unclear whether the methods applied are appropriate
- ▶ quantitative analysis needs large numbers of results
- ▶ solid, empirical data is necessary, hence

survey of security quantification

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- ▶ includes hardly model-based analysis
- ▶ it is unclear whether the methods applied are appropriate
- ▶ quantitative analysis needs large numbers of results
- ▶ solid, empirical data is necessary, hence
- ▶ Quantified Security is a Weak Hypothesis

prevention

protect data and communication to avoid security breaches

diagnosis/detection

identify whether and when a security incident has happened

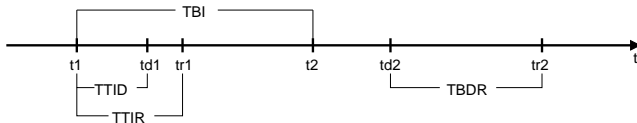
response

stop attack from causing further damage

recovery

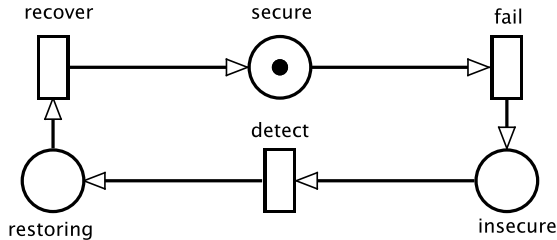
recover from security breach, rekey, use backup data

metrics for security in analogy with dependability metrics



- ▶ TBI: Time Between Incidents
- ▶ TTID: Time To Incident Discovery
- ▶ TTIR: Time To Incident Recovery
- ▶ TBDR: Time Between Detection and Recovery

simple Markovian security model



parameterise using

- ▶ inverse of MTBSI as rate of the *fail* transition
- ▶ inverse of MTTID as rate of the *detect* transition
- ▶ inverse of MTBDR as rate of the *recover* transition.

The states relate to prevention, diagnosis, recovery.

Open question: how do we know the rates?

Performance Cost of Encryption

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performance cost of encryption

experiments

- ▶ experimental study, no model
- ▶ investigation of different algorithms for symmetric and asymmetric encryption
- ▶ investigation of different implementations
- ▶ encryption of 1,137 byte plaintext file
- ▶ keylength: DES 56bit, DESede (Triple DES) 112, Skipjack 80, 128 all others
- ▶ results for symmetric and asymmetric algorithms include key generation, algorithm initialization and message encryption times

C. Lamprecht, A. van Moorsel, P. Tomlinson, and N. Thomas. Investigating the efficiency of cryptographic algorithms in online transactions. *International Journal of Simulation: Systems, Science & Technology*, 7(2):63–75, 2006.

- ▶ encryption times range between 85ms and 180ms
- ▶ triple DES (DESede) hardly slower than DES

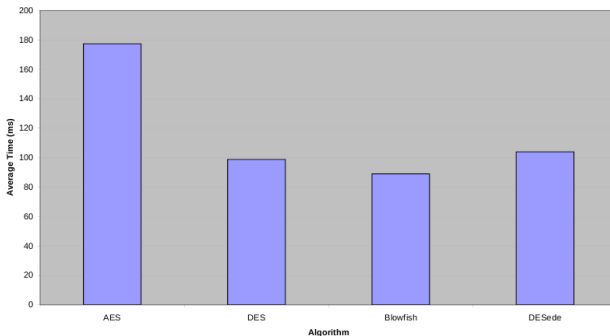


Figure 1: Average time to encrypt a 1137B file using JCE distributions

- ▶ encryption times range between 15ms and 50ms
- ▶ AES = Rijndael hardly slower than DES
- ▶ triple DES (DESEde) slightly slower than DES

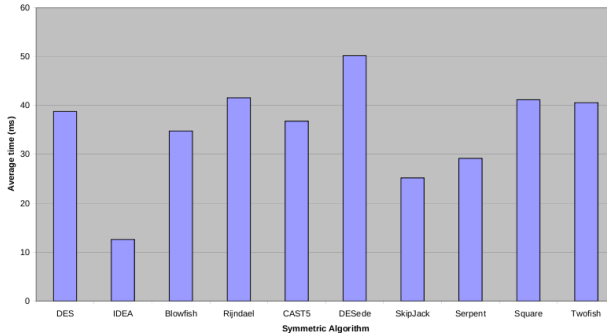


Figure 2: Average time to encrypt a 1137B file using Cryptix distributions

performance versus security

- ▶ IDEA and Cryptix implementation seem to be best
- ▶ security measured in key length \Rightarrow DES and Skypjack less secure
- ▶ security and cost do not correlate
- ▶ implementation matters

public key cryptography

- ▶ encrypt with destinations public key
- ▶ receiver decrypts with private key
- ▶ avoids problem of secure key transmission
- ▶ security increases with key length
- ▶ current security standard RSA-1024
- ▶ measurement of key generation and encryption time

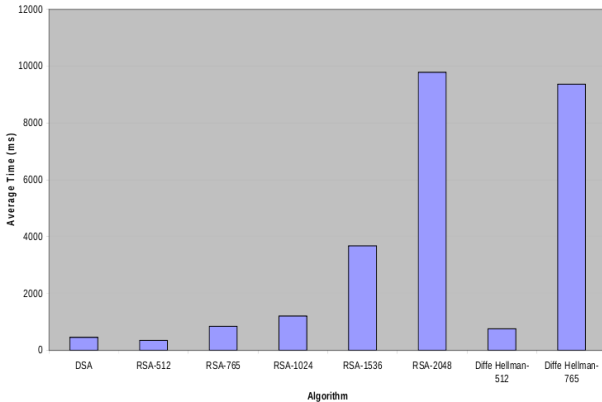


Figure 4: Average time for key generation and encryption using public key algorithms

- ▶ DSA only provides non-repudiation, no data confidentiality
- ▶ Diffie-Hellman 1024 is omitted for clarity

Cost of different algorithms to produce a message digest

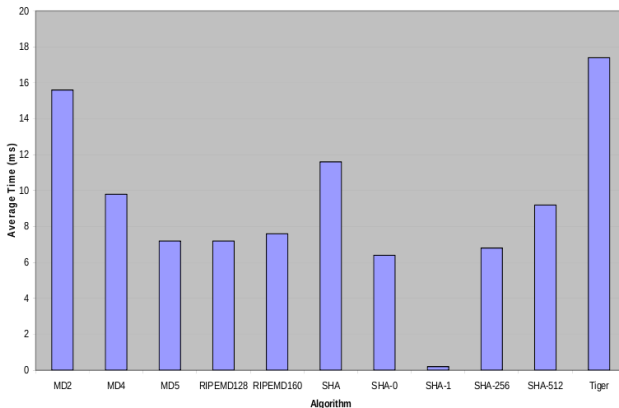


Figure 5: Average time to generate a message digest

summary encryption cost

symmetric encryption

IDEA is fastest

asymmetric encryption

best were:

RSA-1024 for public key encryption

SHA-256 for hashing (producing a digest)

performance security tradeoff

There is no indication that the recommendations provide a good tradeoff

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performance of authentication algorithm

- ▶ key distribution for secure access to resources
- ▶ key distribution for secure communication
- ▶ stochastic process algebra model for the Needham-Schroeder protocol (Kerberos) from [Zhao&Thomas09]

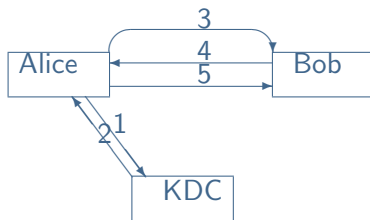
questions

1. how many clients can a given KDC configuration support?
2. how much service capacity must we provide at a KDC to satisfy a given number of clients?
3. how long can a key be used before it is insecure?

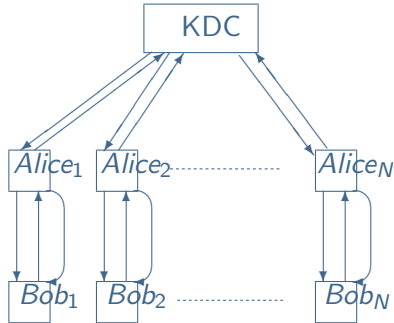
Y. Zhao and N. Thomas, Efficient solutions of a PEPA model of a key distribution centre, Performance Evaluation, 67(2010), pp. 740–756

2. Performance-Evaluation of a Key-Distribution Centre (Zhao, Thomas)

1. Alice \rightarrow KDC : A, B, N_1
2. KDC \rightarrow Alice :
 $\{K_S, A, B, N_1, \{K_S, ID_A\}_{K_B}\}_{K_A}$
3. Alice \rightarrow Bob : $\{K_S, ID_A\}_{K_B}$
4. Bob \rightarrow Alice : $\{N_2\}_{K_S}$
5. Alice \rightarrow Bob : $\{f(N_2)\}_{K_S}$



- ▶ N_1 and N_2 are nonces (random items of data).
- ▶ ID_A is a unique identifier for Alice.
- ▶ $f(N)$ is a predefined function applied to the nonce N .
- ▶ Alice and KDC share a key K_A
- ▶ Bob and KDC share a key K_B



does it scale

modelling N pairs of Alice and Bob

For $N = 1$

$$KDC \stackrel{def}{=} (request, \top).(response, r_p).KDC$$

$$Alice \stackrel{def}{=} (request, r_q).(response, \top).Alice'$$

$$Alice' \stackrel{def}{=} (sendBob, r_B).(sendAlice, \top).(confirm, r_c).Alice''$$

$$Alice'' \stackrel{def}{=} (usekey, r_u).Alice$$

$$Bob \stackrel{def}{=} (sendBob, \top).(sendAlice, r_A).(confirm, \top).Bob'$$

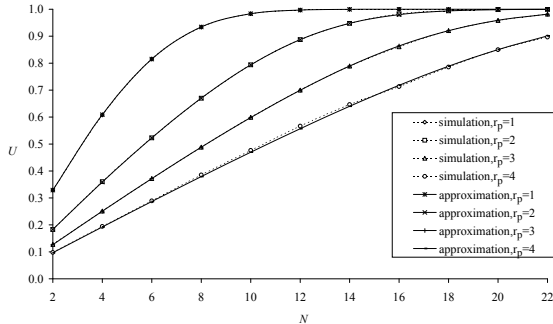
$$Bob' \stackrel{def}{=} (usekey, \top).Bob$$

$$System \stackrel{def}{=} KDC \bowtie_{\mathcal{L}} Alice \bowtie_{\mathcal{K}} Bob$$

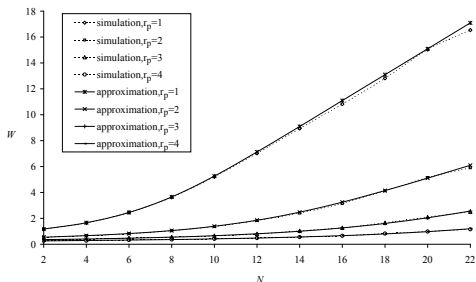
where, $\mathcal{L} = \{request, response\}$,
 $\mathcal{K} = \{sendBob, sendAlice, confirm, usekey\}$.

server utilisation of key distribution centre

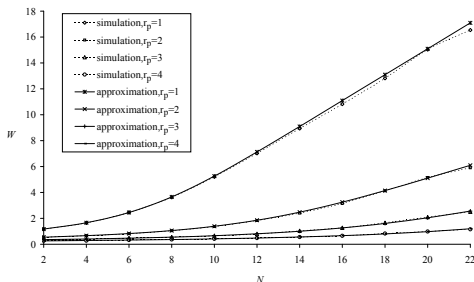
a number of simplifications and approximations lead to results.



average utilisation versus the number of client pairs. $r_u = 1.1$,
 $r_A = r_B = r_c = r_q = 1$.

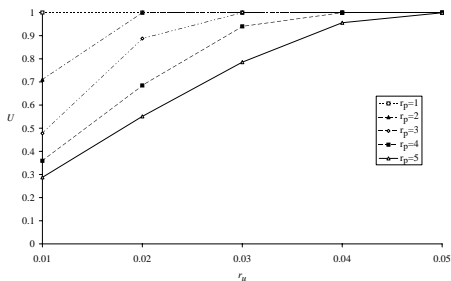


average response time versus the number of client pairs. $r_u = 1.1$,
 $r_A = r_B = r_c = r_q = 1$.



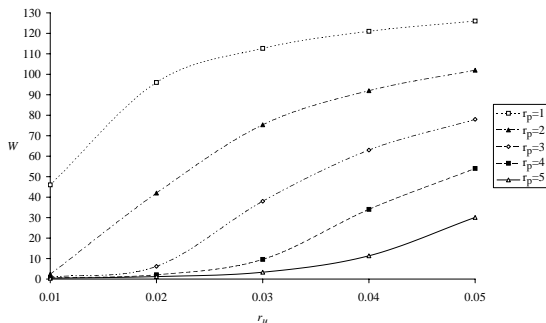
average response time versus the number of client pairs. $r_u = 1.1$,
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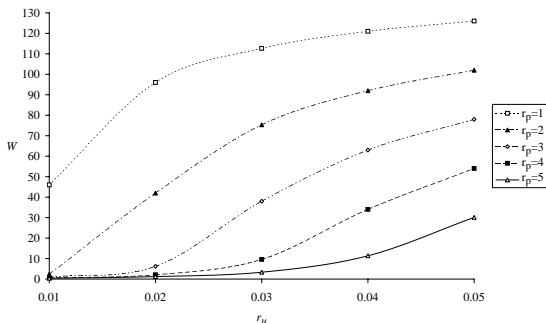
average utilisation varied against the rate of session key use, r_u .

$$r_q = r_A = r_B = r_c = 1, N = 150.$$



average response time varied against the rate of session key use, r_u .

$$r_q = r_A = r_B = r_c = 1, N = 150.$$



average response time varied against the rate of session key use, r_u .

$$r_q = r_A = r_B = r_c = 1, N = 150.$$

3. how long can a key be used before it is insecure?

Summary

- ▶ utilisation, response time of KDC increase with number of clients
- ▶ shorter use of session key increases security
- ▶ shorter use of session key increases utilisation and response time of KDC

but

- ▶ parameters do not translate to a system
- ▶ tradeoff between performance and security is not formulated

Models for Software-System Security

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security of intrusion tolerant system

- ▶ abstract model for system security
- ▶ purpose is to describe and quantify security
- ▶ compromise of confidentiality
- ▶ compromise of data integrity
- ▶ denial of service attacks
- ▶ description of security state
- ▶ stochastic process with levels of security

B. B. Madan, K. Goseva-Popstojanova, K. Vaidyanathan and K. S. Trivedi. A Method for Modeling and Quantifying the Security Attributes of Intrusion Tolerant Systems, Performance Evaluation (2004), 56, pp. 167–186.

states of the model

good state

preserved through

- ▶ authentication, access control, encryption
- ▶ firewalls, proxy servers
- ▶ strong configuration management, upgrades for known vulnerabilities

vulnerable state

reached through

- ▶ penetration
- ▶ exploration phases of an attack.

active attack state

- ▶ potential damage

several degraded states

- ▶ masking through redundancy, backups (MC)
- ▶ restauration/reconfiguration possible (graceful degradation, GD) to handle DoS
- ▶ fail-secure to preserve confidentiality, integrity (FS)

several failed states

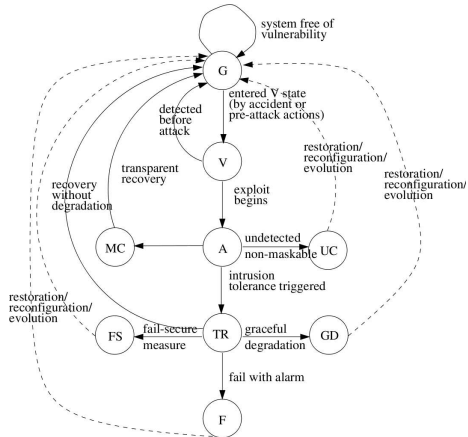
- ▶ intrusion detection fails (undetected compromised state, UC) (false negative)
- ▶ fail with alarm (F) (true positive)

design and implementation of intrusion tolerant system

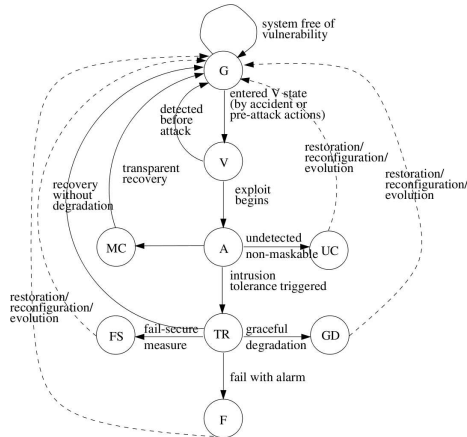
- ▶ error detection
- ▶ damage assessment
- ▶ error recovery, updates (redundancy)
- ▶ fault treatment

recovery states

- ▶ graceful degradation prevents denial-of-service attack
- ▶ stop system to protect confidentiality or data integrity

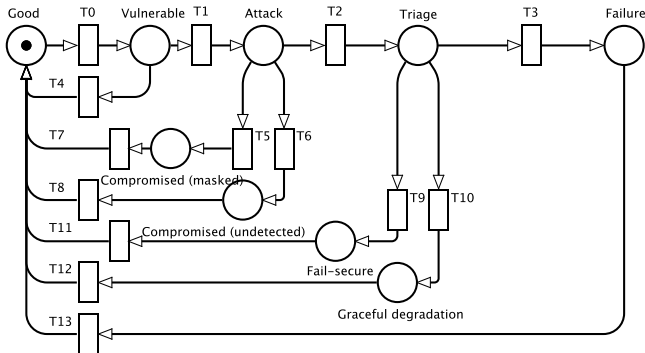


state-transition model



possible outcome of analysis

where should I invest, depending on attack model?



- ▶ unavailable in states FS, F, UC, $A = 1 - \pi_{FS} - \pi_F - \pi_{UC}$
- ▶ for DoS, $A_{DoS} = 1 - (\pi_F + \pi_{UC})$
- ▶ for MTTSF states UC, GD, FS, F are absorbing states, compute time to absorption in a DTMC.

considered measures

- ▶ availability
- ▶ mean time to security failure (MTTSF)

parameters

- ▶ mean sojourn times
 $h_g = 1/2, h_V = 1/3, h_A = 1/4, h_{MC} = 1/4, h_{UC} = 1/2, h_{TR} = 1/6.$
- ▶ p_a probability of successful attack from vulnerable state

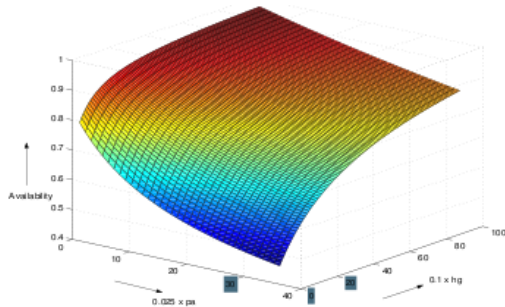


Figure 6. Availability as a function of p_a and h_G

insights

- ▶ higher probability of successful attack from vulnerable state p_a reduces availability
- ▶ longer mean time in the good state h_G increases availability

results: mean time to security failure

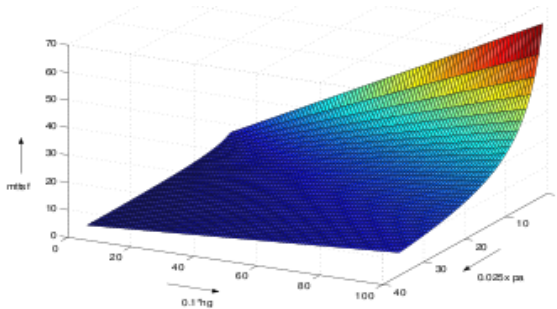


Figure 5. MTTSF as a function of p_a and h_G

insights

- ▶ MTTSF increases with longer mean time in the good state h_G
- ▶ MTTSF decreases with higher probability of successful attack from vulnerable state p_a .

modelling an intrusion tolerant system

- ▶ flexibel model that can represent different types of attacks
- ▶ quantification of security (considering DoS, confidentiality, integrity attacks)
- ▶ inspired by performability analysis
- ▶ doubtful parameter choices (planned improvements using SITAR)
- ▶ no notion of performance (planned improvements)
- ▶ no security cost
- ▶ no tradeoff

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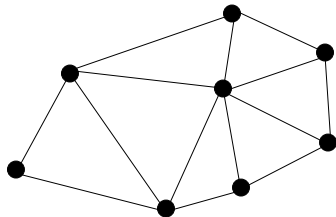
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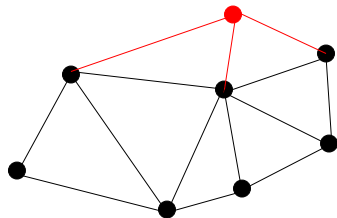
Modelling Performance Security Tradeoff

Conclusions

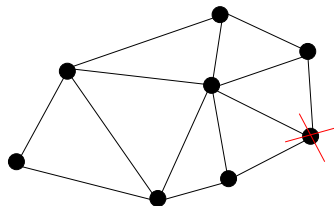
- ▶ group communication in mobile ad hoc network using group key
- ▶ intrusion detection system (IDS) checks for compromised nodes



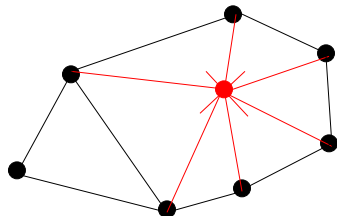
- ▶ group communication in mobile ad hoc network using group key
- ▶ intrusion detection system (IDS) checks for compromised nodes
- ▶ IDS may not detect (false negative)



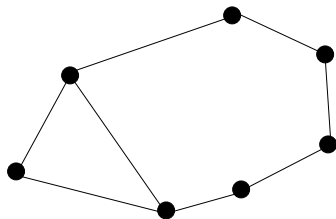
- ▶ group communication in mobile ad hoc network using group key
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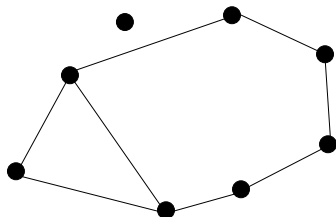
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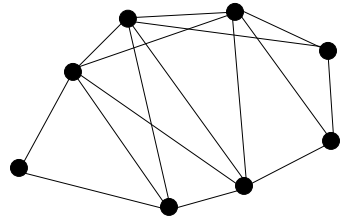


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- ▶ IDS may erroneously detect (false positive)
- ▶ IDS may correctly detect and remove
- ▶ node is excluded



security of MANETs

- ▶ group communication in mobile ad hoc network using group key
- ▶ intrusion detection system (IDS) checks for compromised nodes
- ▶ IDS may erroneously detect (false positive)
- ▶ IDS may correctly detect and remove node is excluded
- ▶ new node arrives and is included
- ▶ key change is necessary to maintain secure communication



Performance analysis of dynamic group communication systems with intrusion detection integrated with batch rekeying in mobile ad hoc networks. J.-H. Cho, I.-R. Chen, and P.-G. Feng. AINAW '08: Proceedings of the 22nd International Conference on Advanced Information Networking and Applications – Workshops, pp. 644–649, Washington, DC, USA, 2008.

intrusion detection

- ▶ voting-based intrusion detection
- ▶ byzantine failure, more than $1/3$ of nodes compromised

rekeying frequency

- ▶ rekeying increases security
- ▶ rekeying increases load (cost)
- ▶ batch rekeying after n membership changes

intrusion detection

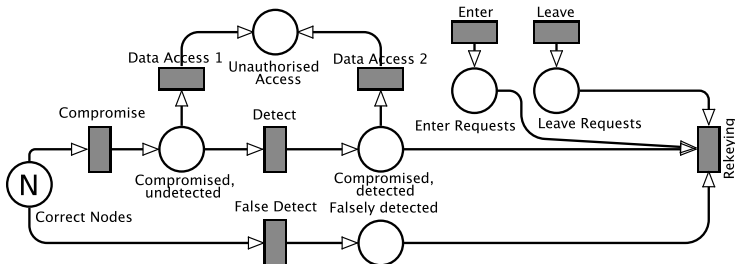
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rekeying frequency

- ▶ rekeying increases security
- ▶ rekeying increases load (cost)
- ▶ batch rekeying after n membership changes

optimisation problem

how often to change key for optimal performance and security?



parameters

- ▶ k_1 rekey limit on (trusted) join and leave requests
- ▶ k_2 rekey limit on detected and falsely detected compromised nodes

performance measure

average response time R of transmitted message

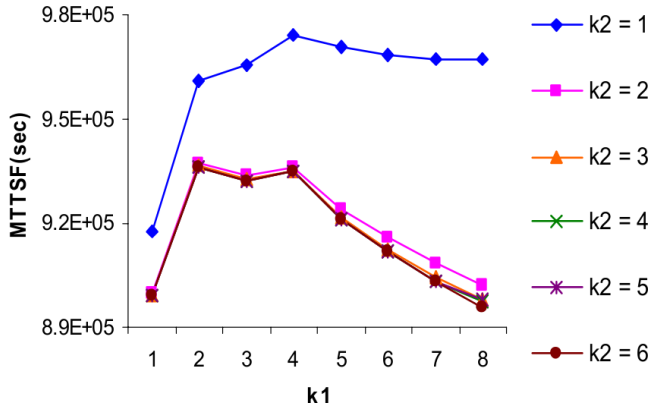
security measure

MTTSF (attacker takes over or system becomes unavailable, more than $1/3$ compromised nodes)

computation method

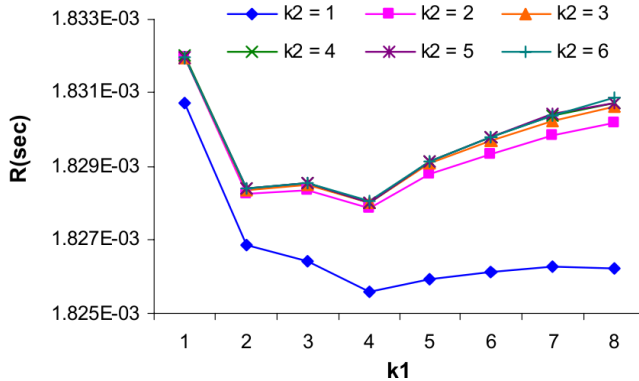
- ▶ analysis of SPN
- ▶ MTTA method (mean time to absorption)

mean time to security failure



parameters

- ▶ k_1 rekey limit on (trusted) join and leave requests
- ▶ k_2 rekey limit on detected and falsely detected compromised nodes



vary rekeying thresholds

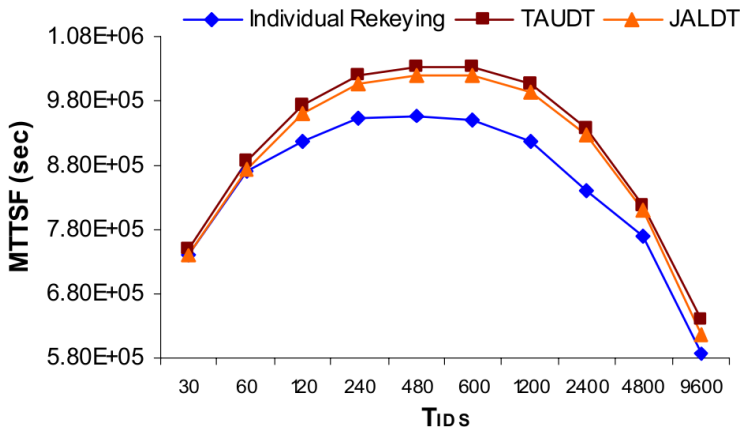
- ▶ rekeying limit at 4 join/leave requests seems optimal
- ▶ for higher detected/falsely detected limit 2 join/leave requests might be better
- ▶ either consider less join/leave requests, or less detected/falsely detected nodes?

rekeying strategies

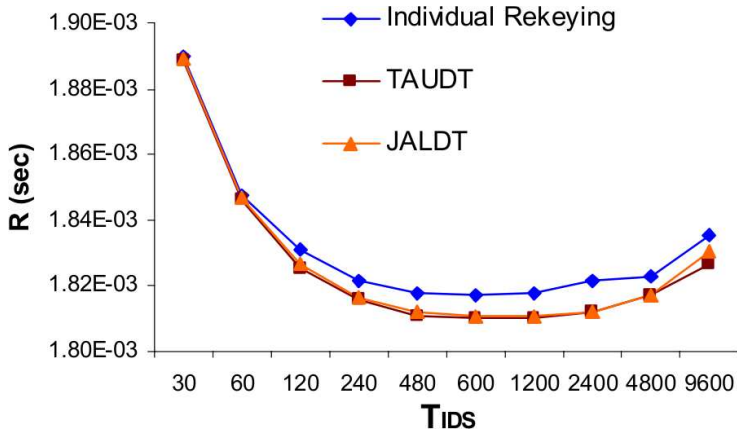
- ▶ individual rekeying (after each join, leave, evict event)
- ▶ threshold-based rekeying
 - ▶ TAUDT, k_1 , k_2 as above
 - ▶ JALDT, k_1 = limit on join requests, k_2 = limit in leave requests and evicted nodes.

parameters

- ▶ investigate optimal IDS interval (firing time)
- ▶ set TAUDT: $(k_1, k_2) = (4, 1)$, JALDT: $(k_1, k_2) = (5, 2)$ (enabling condition)



- ▶ $T_{IDS} = 480$ optimises MTTSF for individual rekeying
- ▶ $T_{IDS} = 600$ optimises MTTSF for threshold-based rekeying



- $T_{IDS} = 600$ optimises response time for all rekeying strategies

results

- ▶ security and performance of wireless group communication system
- ▶ security is measured in terms of MTTSF
- ▶ performance is measured in terms of response time
- ▶ intrusion detection threshold and
- ▶ intrusion detection interval are chosen as to optimise those measures

Security of the email system

Introduction

Performance Cost of Encryption

Performance Evaluation of a Key Distribution Centre

Modelling and Quantifying Intrusion Tolerant Systems

Security of MANETs

Security of the email system

Modelling Performance Security Tradeoff

Conclusions

considered system

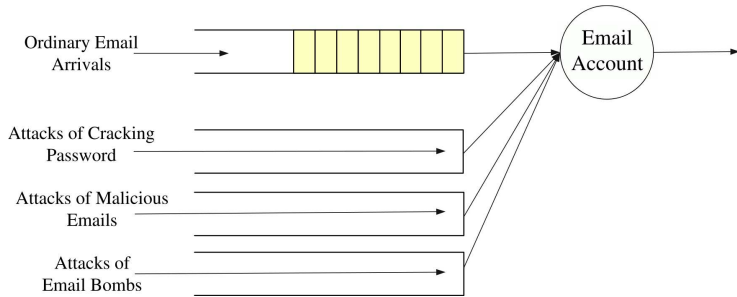
- ▶ email system considered a queue
- ▶ Inbox, filtering mechanisms, user,?

attack types

- ▶ gather information (malicious access to mailbox, click on link in malicious email)
- ▶ denial of service (email bombs flood the mail system)

Y. Wang, C. Lin, and Q.-L. Li. Performance Analysis of the Email System under Three Types of Attacks. Performance Evaluation, 67(6), (June 2010)

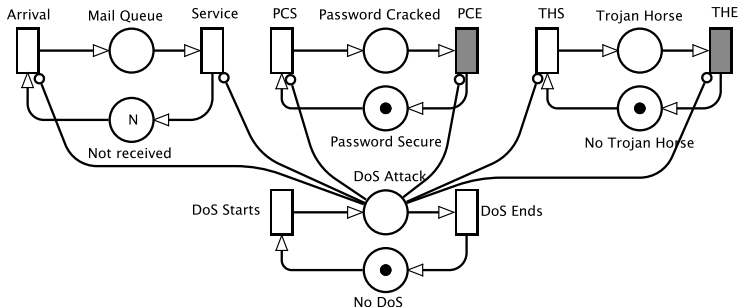
multiple queues



parameters

each queue is described by arrival and service time distribution/rate

- ▶ emails, M/M/1/N: λ, μ
- ▶ Cracking password, M/PH/1/1: α_c and (γ_c, S_c)
- ▶ Malicious email, M/PH/1/1: α_m and (γ_m, S_m)
- ▶ Email bombs, M/M/1/1: α_b, β_b



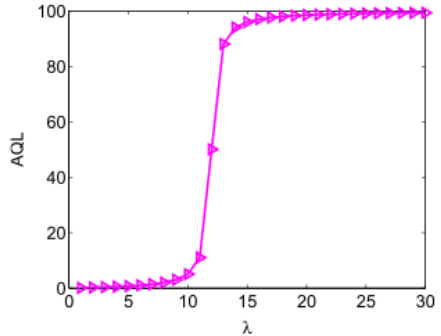
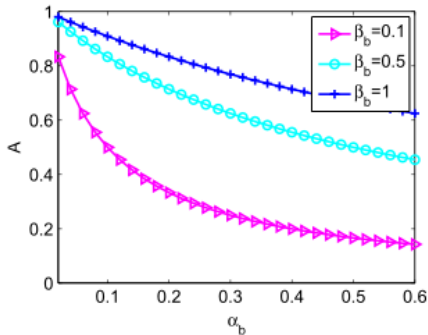
performance measure

- queue length
- system availability

security measure

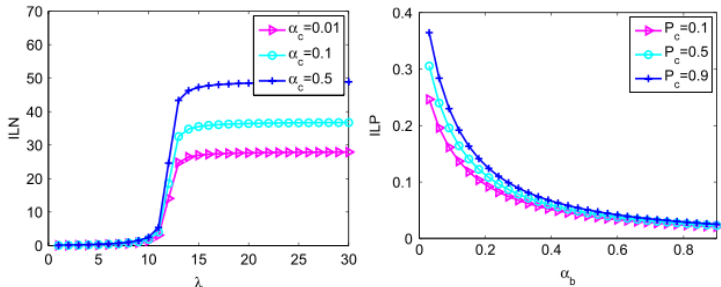
- (availability)
- information leakage probability

performance measures



availability and queue length

- availability versus arrival rate of email bombs for different damage duration
- average queue length versus email arrival rate



information leakage

- ▶ information leakage versus email arrival rate for different arrival rates of cracking attacks
- ▶ information leakage probability versus email bomb arrival rate for different probabilities of obtaining information after cracking the password.

security of email

- ▶ malicious emails are known security concern
- ▶ formalisation as finite queueing models doubtful
- ▶ provided performance as well as security measures
- ▶ availability, queue length, information leakage

Modelling Performance Security Tradeoff

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Modelling Performance Security Tradeoff

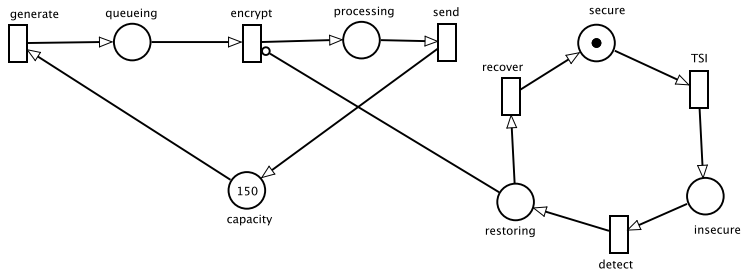
Conclusions

objective

- ▶ separate performance and security models
- ▶ combined measures with optima (cf. performability)
- ▶ example: encryption of messages (recall Lamprecht et al.)
- ▶ assumption: longer keys \rightarrow more secure, longer encryption time

model specification

- ▶ performance model (queue)
- ▶ security model (CTMC, ...)



parameters

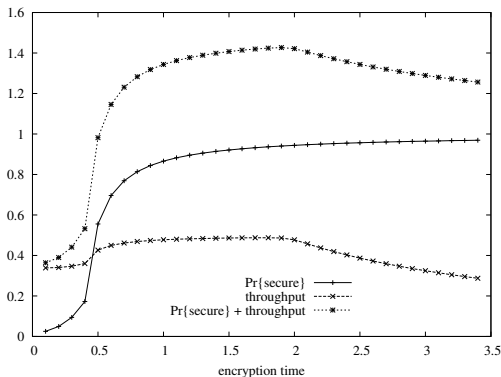
Parameter Name	Value/Delay
generate	2.0
send	0.1
N	150
encrypt	0.1, . . . , 3.4 by 0.1
TSI	12.5, 25, 50, 100, . . . , 15100 by 500
detect	120
recover	360

measures

combine performance and security

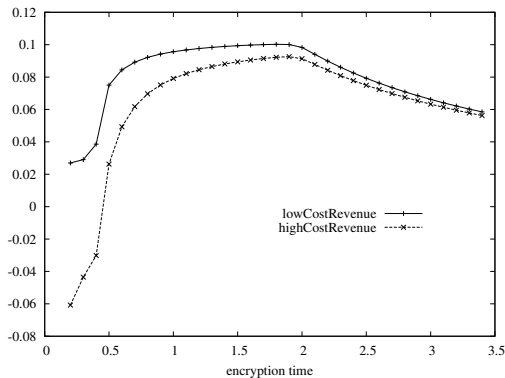
- ▶ pure performance measure (throughput)
- ▶ pure security measure (prob. secure state)
- ▶ combined measures involving costs

Throughput(<i>send</i>)	$10 \cdot \Pr \{ \#processing > 0 \}$
$\Pr \{ secure \}$	$E [\#secure] = \Pr \{ \#secure > 0 \}$
CPSM	$\text{Throughput}(\text{send}) + \Pr \{ secure \}$
Gain	$2 \cdot E [\#processing \text{ IF } \#secure = 1]$
Loss	$-E [\#processing \text{ IF } \#insecure = 1]$
lowCostRevenue	$2 \cdot E [\#processing \text{ IF } \#secure = 1] -$ $E [\#processing \text{ IF } \#insecure = 1]$
highCostRevenue	$E [\#processing] \cdot (2 \cdot E [\#secure] -$ $5 \cdot E [\#insecure])$



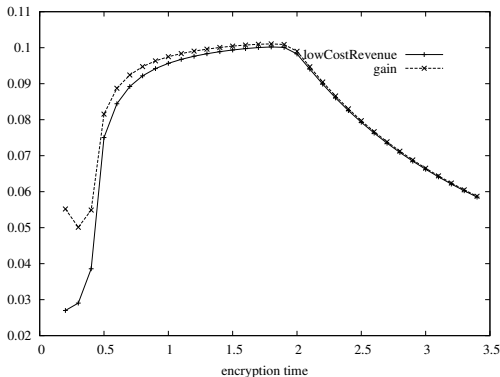
results

- ▶ $\text{Pr}(\text{secure})$ and throughput both *high better metrics* (Raj Jain)
- ▶ sum is HB as well



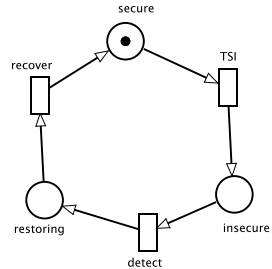
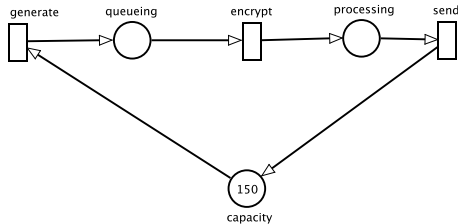
penalties

- ▶ higher penalty \Rightarrow lower benefit
- ▶ optimum key length is the same



encryption cost

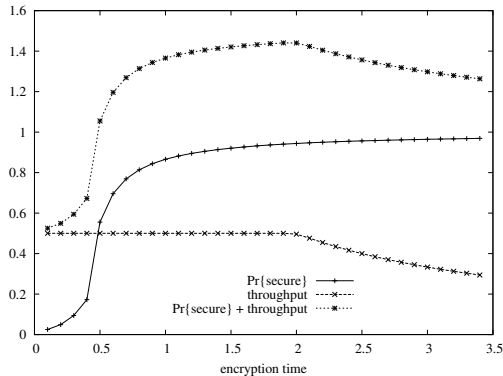
- $\text{cost} = \text{revenue} - \text{gain}$
- cost negligible for long keys
- cost of security failure



separation of performance and security model

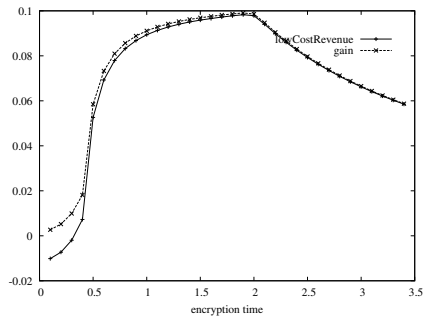
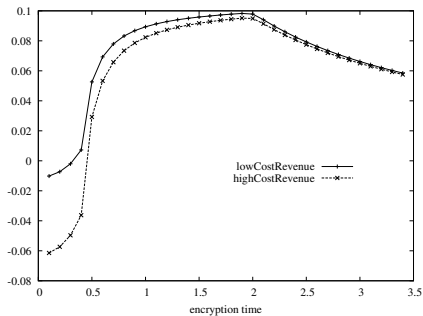
- ▶ what happens if we keep the submodels completely separate?
- ▶ monotonous performance and security measures?

simplified model throughput



combined performance and security measure

- ▶ limiting arrival process more pronounced
- ▶ throughput unaffected

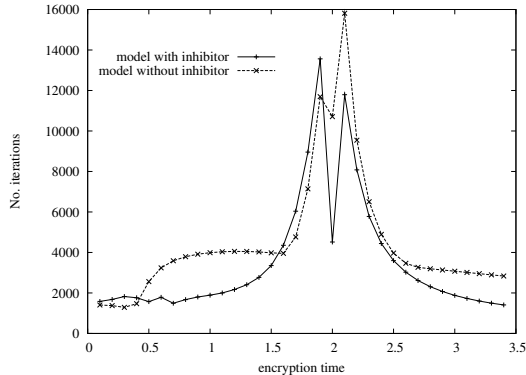


lessons learnt

- ▶ assumptions made: TSI and encryption time are correlated
- ▶ processing discontinues/continues in case of recovery, what about the measures?
- ▶ do we gain information beyond the assumptions made initially?

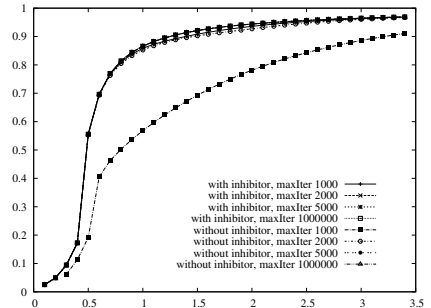
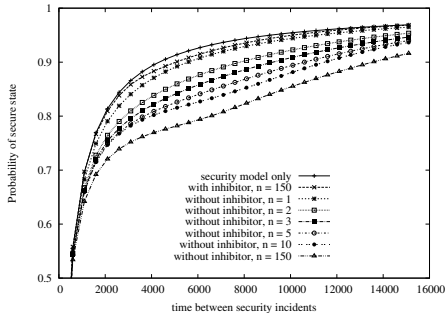
parameters

- ▶ we find optimal parameter settings!!
- ▶ how about realistic parameter values?



remember performability

- ▶ many iterations needed
- ▶ poor accuracy



- ▶ solution sensitive to queue length
- ▶ solution sensitive to no. of iterations

conclusions

quantify security

- ▶ model-based analysis of performance and security is a new field although the issue has been around for long
- ▶ we still have no metric for security, but
- ▶ frequent change of key, or ticket increases security
- ▶ longer keys for encryption increase security
- ▶ performance can be measured using throughput and response time
- ▶ tradeoff can be formulated

security statement

- ▶ cryptographic algorithms are known to be secure
- ▶ security problems are dependability problems (overflow, implementation, failures, etc.)

model results

- ▶ do we find out something about the system, or about the model?
- ▶ setting up a good model is very difficult.

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