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Markovian Modeling and Security Measure Analysis for Networks under Flooding DoS Attacks

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Flooding DoS Attacks

- Flooding DoS attacks aim at obstructing regular service provisioning.
- Malicious attackers send large number of requests.
- Requests of legitimate users cannot be efficiently handled as designated.
- Aim: Give a Markov model for DoS attacks, incorporate 'Random Dropping Strategy' and compute security measures using special techniques for Quasi-Birth-Death processes.

Model assumptions (1)

- One server with N connection channels
- Basic model: Requests arrive according to Poisson processes with different rates λ_0 (regular requests) and λ_1 (attack requests), service times are exponentially distributed with rates β_0 (regular requests) and β_1 (attack requests), usually $\beta_1 << \beta_0$.
- Basic model yields two-dimensional Markov chain.

Model assumptions (2)

- Consider randomly changing environment: arrival rates and service completion rates are not constant but depend on some environmental state $v \in \{1, \ldots, m\}$.
- Switching rates σ_{vw} for change of environmental state.
- Together: Three-dimensional Markov chain, $X_t = (R_t, A_t, E_t)$.
- State space $\mathcal{S} = \{(i, j, v) \in \mathbb{N}^3 : \ i + j \leq N, \ v \in \{1, \ldots, m\}\}$.

Random dropping strategy

- Define threshold $t(N)$, use random dropping for $i + j > t(N)$.
- Use dropping rate $\delta(i + j) = d \cdot (i + j - t(N))$ for $i + j > t(N)$ with some 'dropping constant' d.
- The request to be dropped is chosen randomly.
- Result: specified dropping rates $\delta_0(i, j) = \frac{i}{i+j}\delta(i + j)$ (regular requests) and $\delta_1(i, j) = \frac{j}{i+j}\delta(i + j)$ (attack requests).

Markov chain model – Transitions

from	to	rate	condition
(i,j,v)	$(i+1,j,v)$	$\lambda_0(v)$	$i+j \leq N$
(i,j,v)	$(i,j+1,v)$	$\lambda_1(v)$	$i+j \leq N$
(i,j,v)	$(i-1,j,v)$	$\beta_0(v) \cdot i$	$i > 0,\ i+j \leq t(N)$
(i,j,v)	$(i,j-1,v)$	$\beta_1(v) \cdot j$	$j > 0,\ i+j \leq t(N)$
(i,j,v)	$(i-1,j,v)$	$\beta_0(v) \cdot i + d \cdot \frac{i+j-t(N)}{i+j} \cdot i$	$i > 0,\ i+j > t(N)$
(i,j,v)	$(i,j-1,v)$	$\beta_1(v) \cdot j + d \cdot \frac{i+j-t(N)}{i+j} \cdot j$	$j > 0,\ i+j > t(N)$
(i,j,v)	(i,j,w)	σ_{vw}	

QBD model

- Define *level* ℓ: $\mathcal{S}^{(\ell)} = \{(i,j,v) \in \mathcal{S} : \ i+j=\ell\}$, $\left|\mathcal{S}^{(\ell)}\right| = (\ell+1)\cdot m$.
- Transitions change the level at most by 1, resulting in Quasi-Birth-Death-Process (QBD).
- By appropriate ordering of states the generator is a block tridiagonal matrix:

$$Q = \begin{pmatrix} \tilde{Q}_{00} & \tilde{Q}_{01} & & & \\ \tilde{Q}_{10} & \tilde{Q}_{11} & \tilde{Q}_{12} & & \\ \ddots & \ddots & \ddots & \ddots & \\ & \tilde{Q}_{N-1,N-2} & \tilde{Q}_{N-1,N-1} & \tilde{Q}_{N-1,N} & \\ & & \tilde{Q}_{N,N-1} & \tilde{Q}_{NN} & \end{pmatrix}$$

Solution method – algorithm

Matrix analytic method for computing stationary distribution $\pi = (\tilde{\pi}_0\ \tilde{\pi}_1\ \ldots\ \tilde{\pi}_N)$:

- Compute $R_{N-1} = -\tilde{Q}_{N-1,N}\tilde{Q}_{NN}^{-1}$.
- For $\ell = N-1, N-2, \ldots, 1$: Iterate
  $R_{\ell-1} = -\tilde{Q}_{\ell-1,\ell}\left(\tilde{Q}_{\ell\ell} + R_\ell \tilde{Q}_{\ell+1,\ell}\right)^{-1}$.
- Obtain a solution $\tilde{\pi}_0 \neq 0$ from $\tilde{\pi}_0\left(\tilde{Q}_{00} + R_0\tilde{Q}_{10}\right) = 0$.
- For $\ell = 0, 1, \ldots, N-1$: Iterate $\tilde{\pi}_{\ell+1} = \tilde{\pi}_\ell R_\ell$.
- Normalize $\tilde{\pi}$.

Considered security measures (1)

- Stationary probability for i channels working on regular requests, j channels working on attack requests: $\pi(i,j) = \sum_{v=1}^{m} \pi(i,j,v)$.
- Ratio of channels occupied by regular requests to total number of channels:

$$p_r = \frac{1}{N} \sum_{\substack{i,j \\ i+j \leq N}} i \cdot \pi(i,j).$$

- Ratio of channels occupied by attack requests to total number of channels:

$$p_a = \frac{1}{N} \sum_{\substack{i,j \\ i+j \leq N}} j \cdot \pi(i,j).$$

Considered security measures (2)

- Probability of loss, that is rejection of regular request

$$p_{loss} = \sum_{i+j=N} \pi(i,j).$$

- Probablitiy for dropping regular requests rather than serving them successfully

$$p_{drop} = \frac{\sum \pi(i,j) \frac{i}{i+j} \delta(i+j)}{\sum \pi(i,j) \left(\beta_0 i + \frac{i}{i+j} \delta(i+j) \right)}.$$

- Probability for successfully serving an incoming regular request

$$p_{succ} = (1 - p_{loss})(1 - p_{drop}).$$

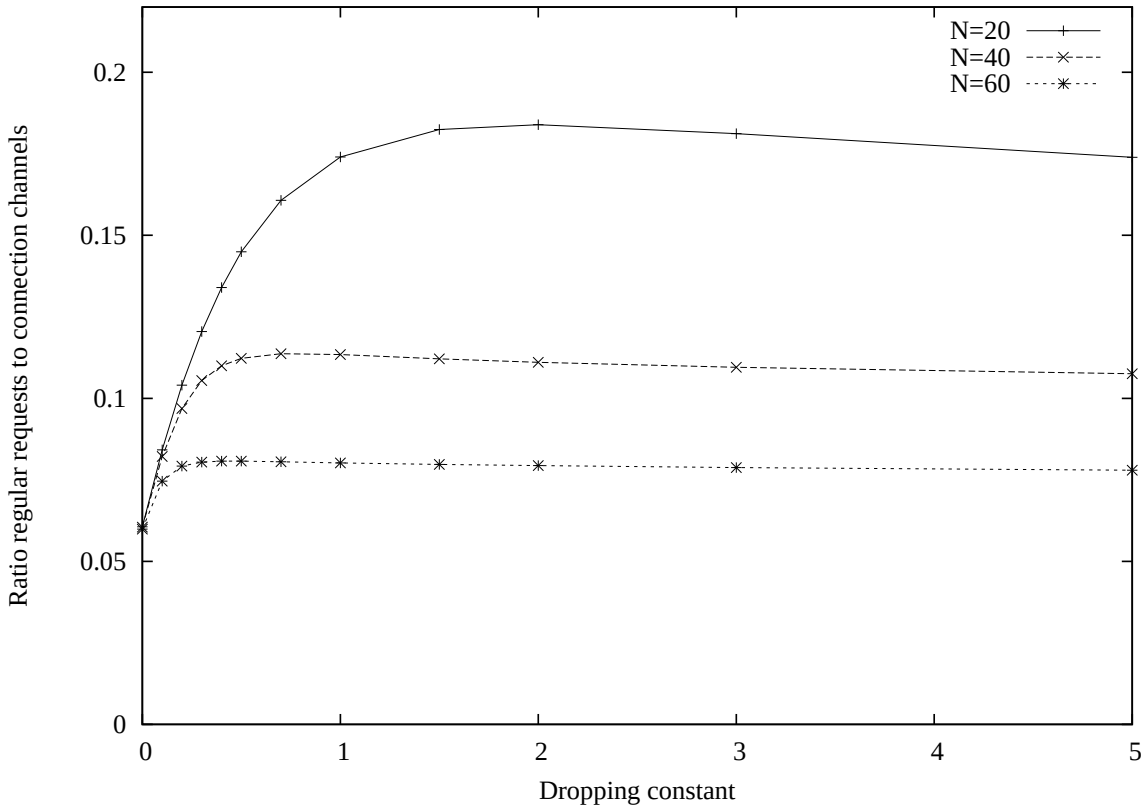
Parameter setting

- $m = 3$ environment states with switching rates

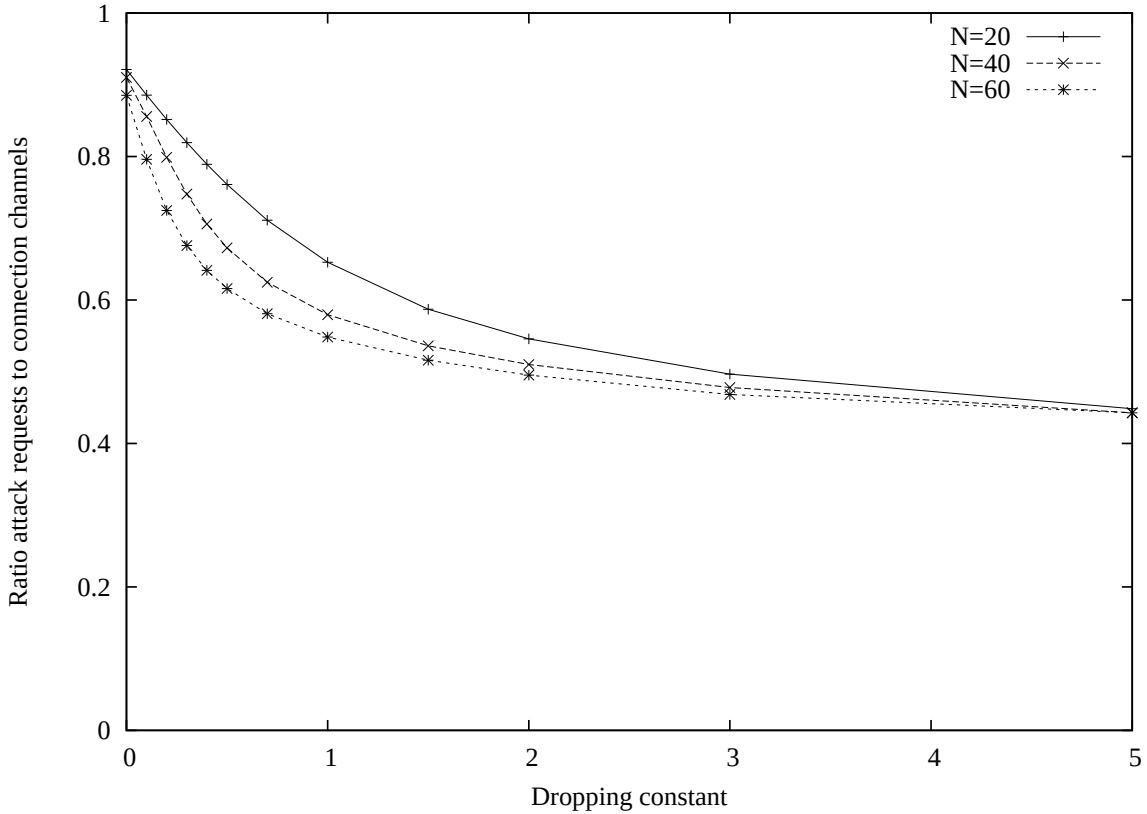
$v \mid w$	1	2	3
1		0.2	0.1
2	0.4		0.1
3	0.6	0.2	

- $\lambda_0(1) = \lambda_0(2) = 5$, $\lambda_0(3) = 25$.
- $\lambda_1(1) = \lambda_1(3) = 6$, $\lambda_1(2) = 60$.
- $\beta_0(v) = 2$, $\beta_1(v) = 0.1$.
- $t(N) = \frac{N}{2}$.
- Variate dropping rate d between 0 (no dropping) and 5 for $N = 20, 40, 60$.

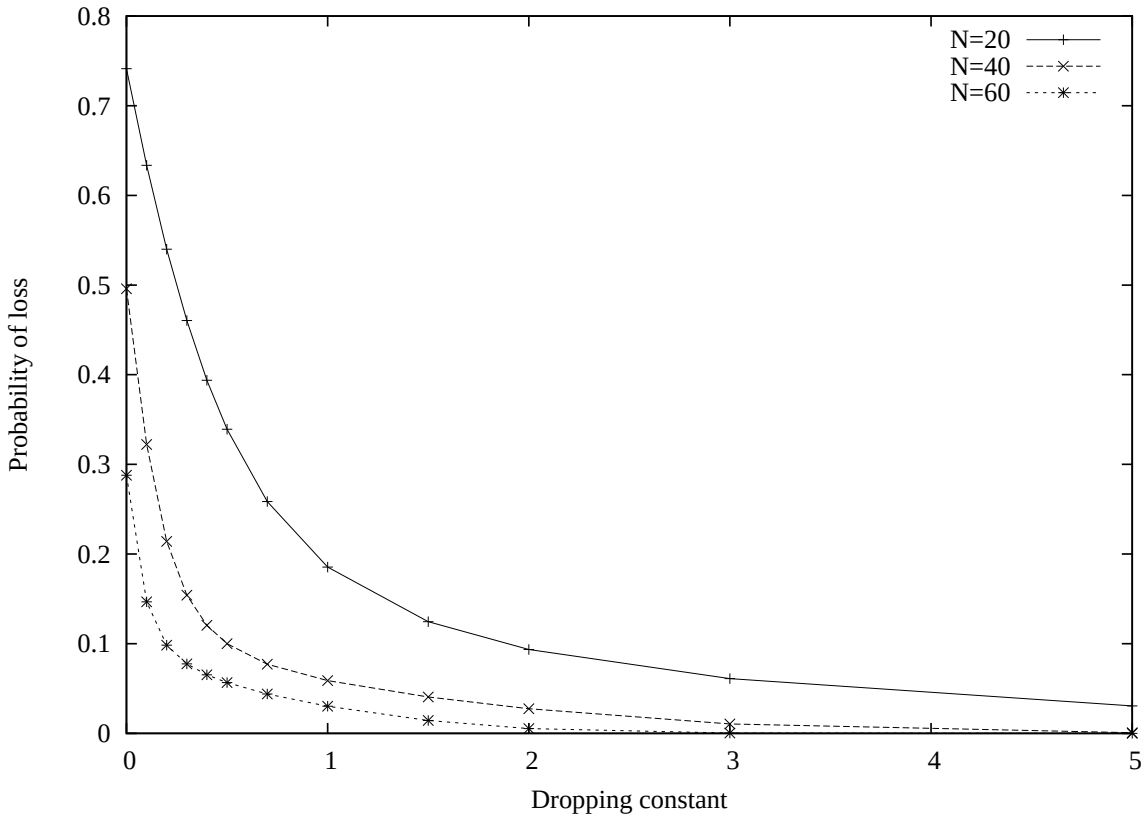
Numerical results (1)



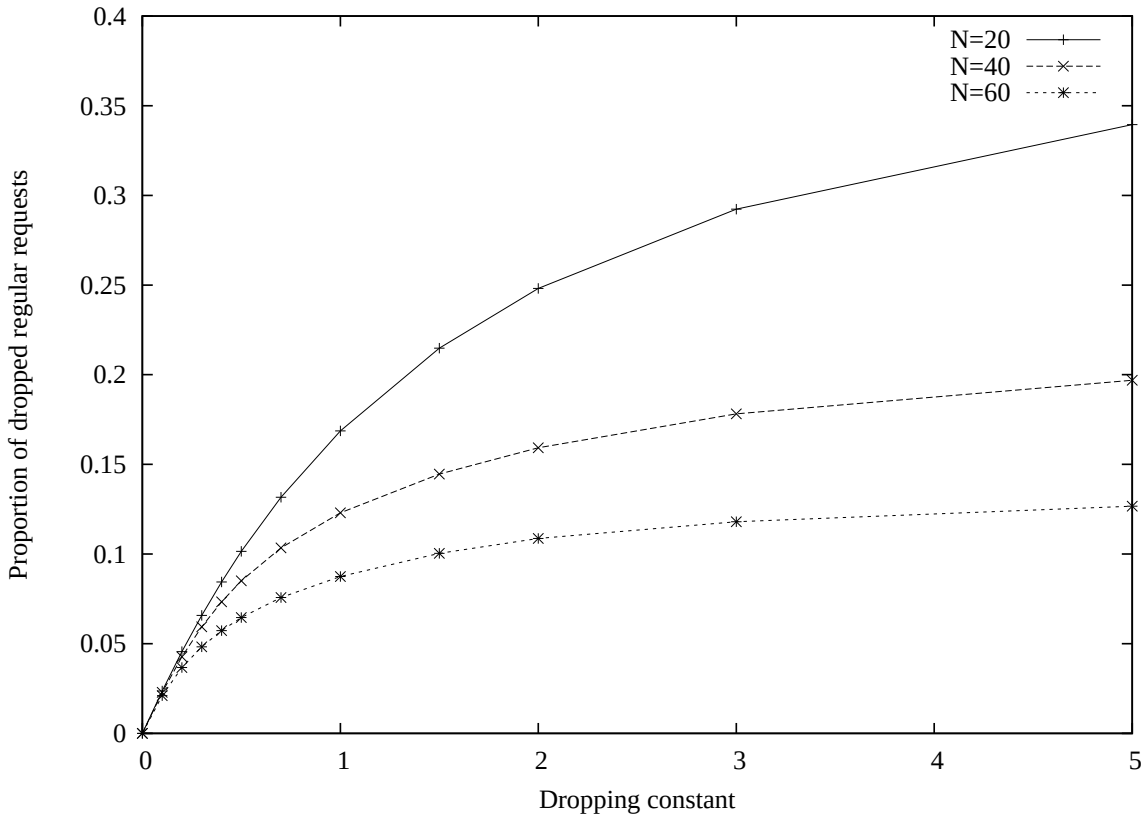
Numerical results (2)



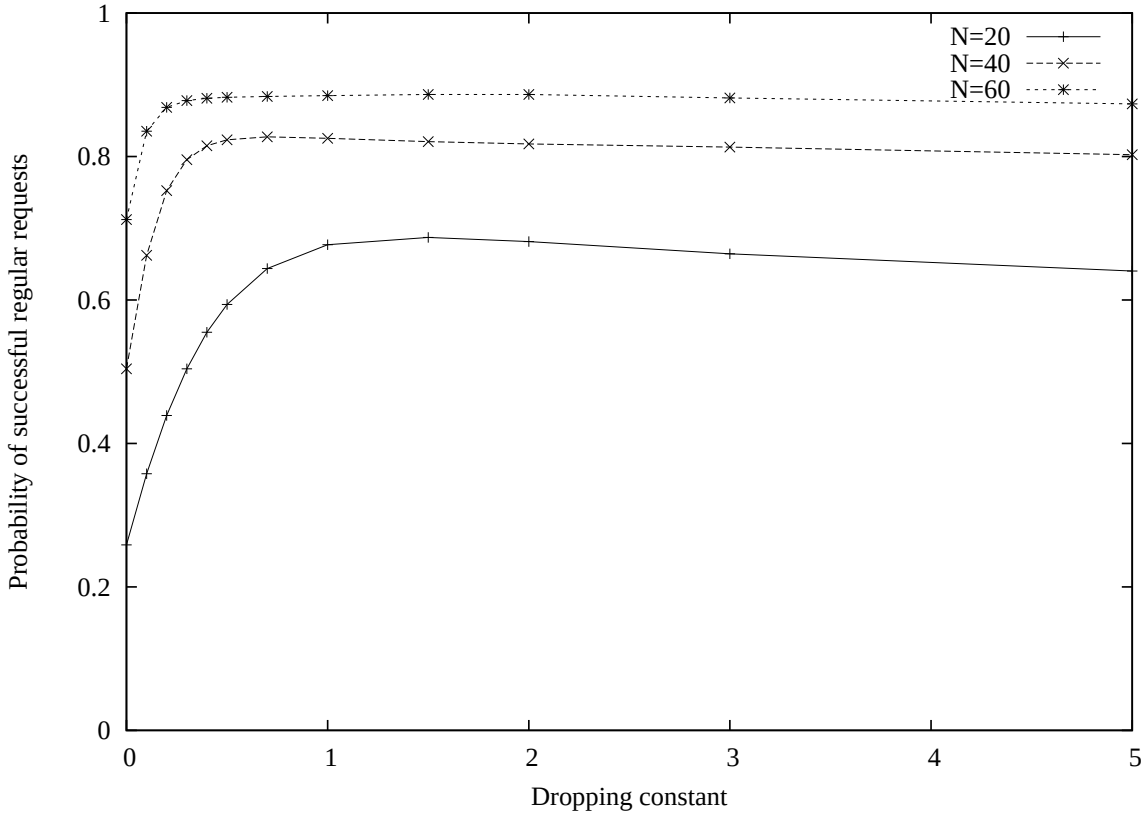
Numerical results (3)



Numerical results (4)



Numerical results (5)



Conclusions

- We have modelled flooding DoS-Attacks in a Markov chain including a random environment.
- We have analyzed them by efficient matrix analytic methods.
- Incorporation of random dropping improves the service significantly.

Future work

- Analysis of transient behaviour.
- Memory-efficient direct computation of stationary security measures.
- Consideration of BMAPs for arrivals instead of mere Markov modulated Poisson processes.
- Consideration of other service times distributions, approximation by PH-distributions.