Optimizing Age of Information with Attacks

Josu Doncel
University of the Basque Country, UPV/EHU.

Joint work with M. Assaad (L2S, CentraleSupelec)

NETGCOOP 2024. Lille, France.
October 9, 2024

Outline

Outline

Introduction

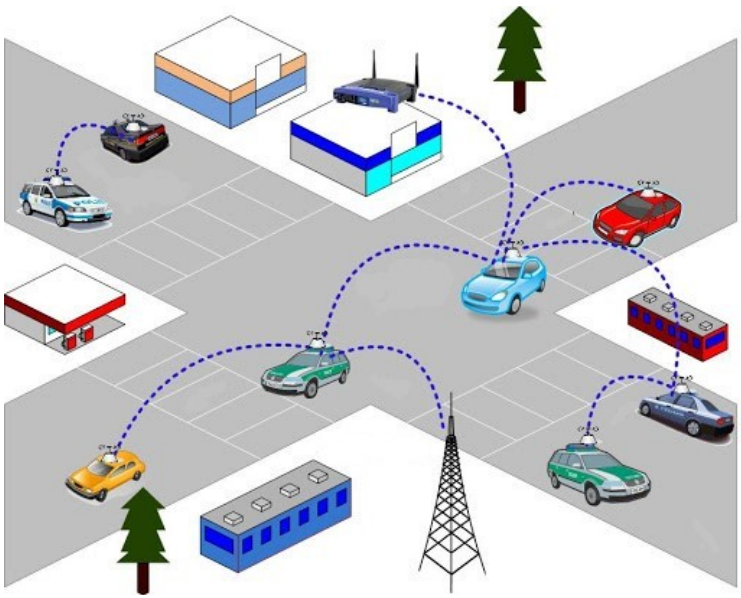
In a system that is observed remotely (by a monitor)

Timely information is crucial

Introduction

In a system that is observed remotely (by a monitor)

Timely information is crucial



Other examples in industry

Age of Information

Generated packets (updates): information + timestamp

Age of Information

Generated packets (updates): information + timestamp

Definition: Age of Information (AoI)

The time elapsed since the generation time of the last arrived packet at the destination.

Large AoI $\Rightarrow$ obsolete information

Age of Information

Generated packets (updates): information + timestamp

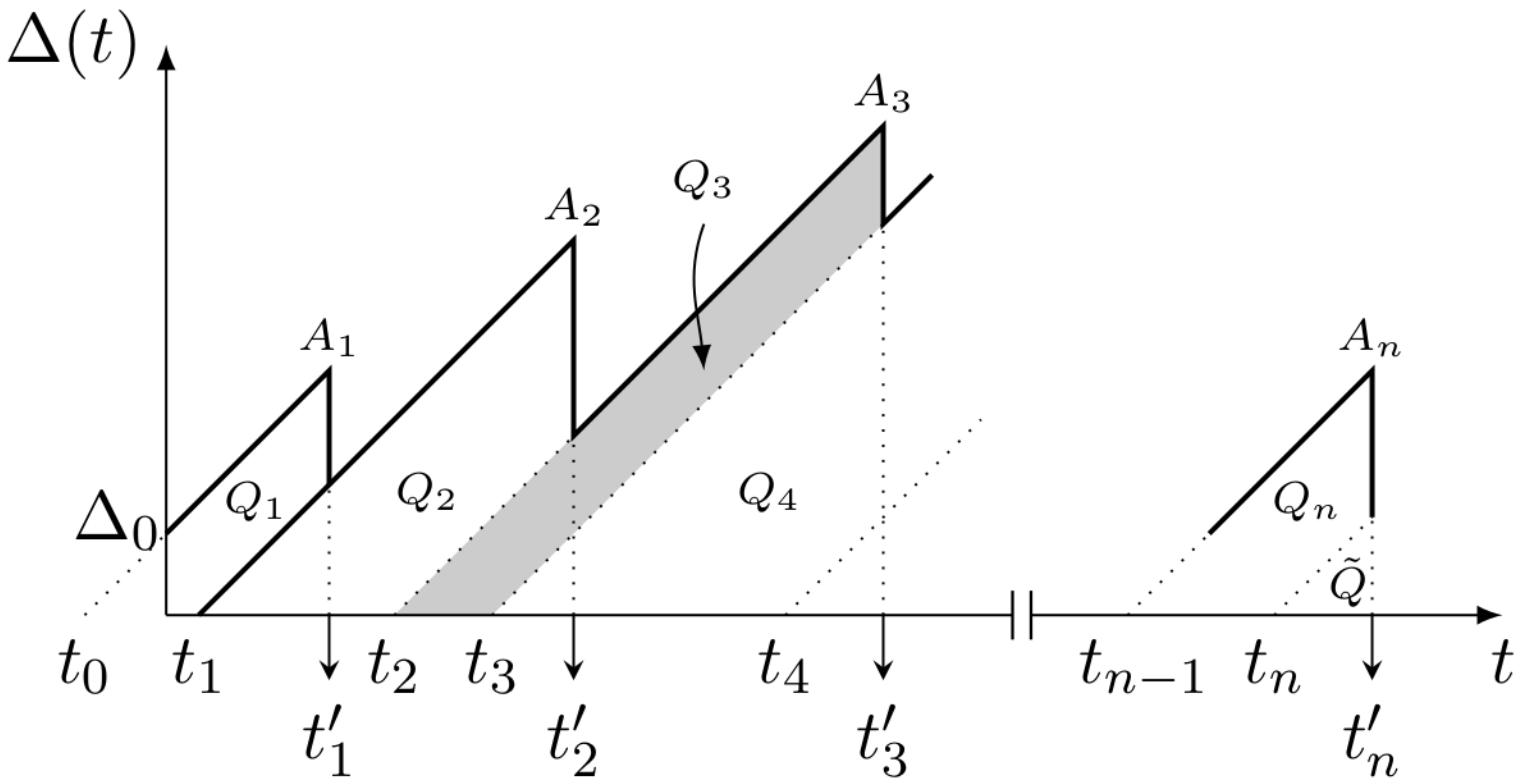
Definition: Age of Information (AoI)

The time elapsed since the generation time of the last arrived packet at the destination.

Large AoI $\Rightarrow$ obsolete information
Small AoI $\Rightarrow$ timely (or recent) information!

Example

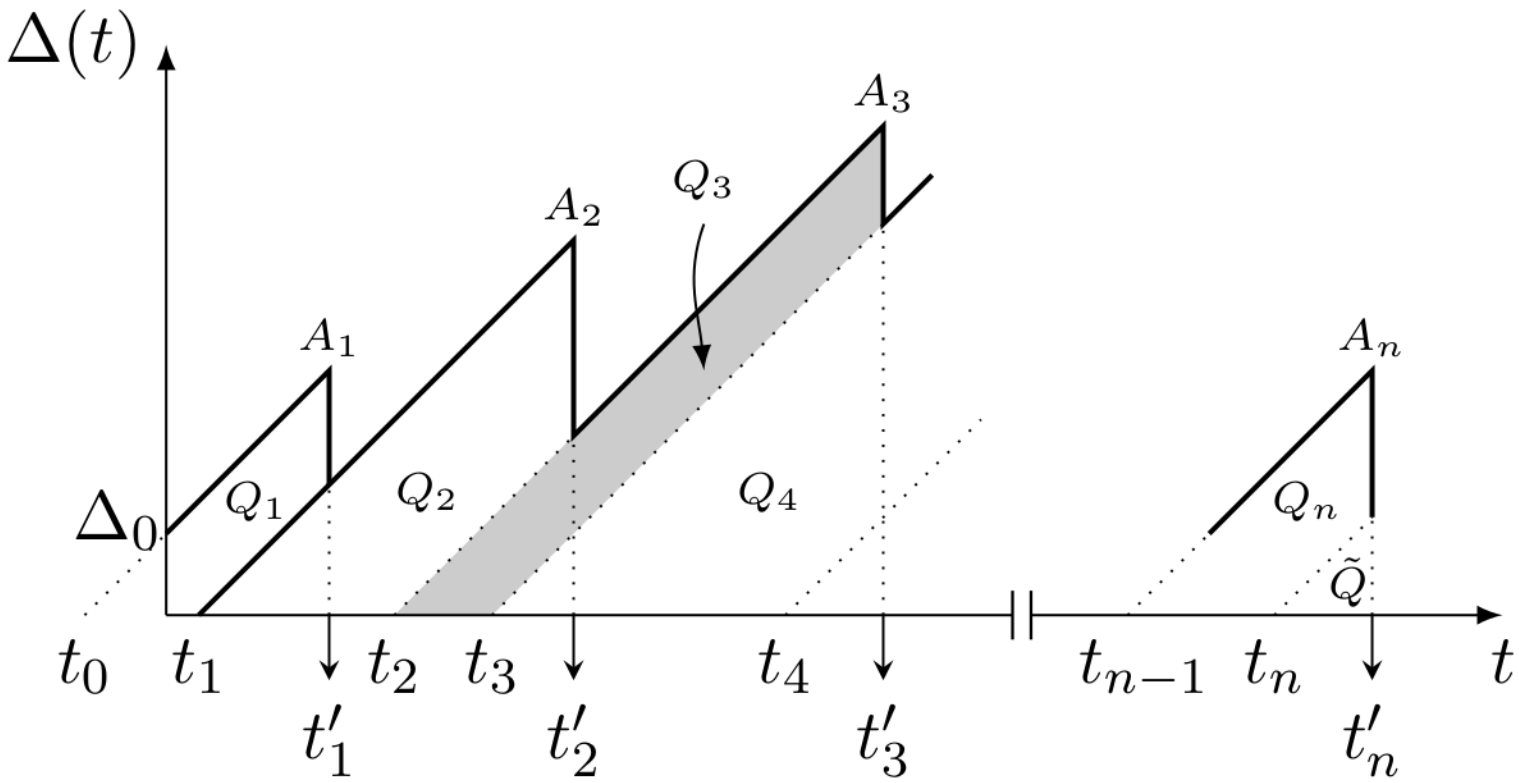
t_i : generation time of packet i
t'_i : delivery time of packet i to the monitor



Average AoI calculation:

Example

t_i : generation time of packet i
t'_i : delivery time of packet i to the monitor



Average AoI calculation: not possible in a general setting

Age of Information

Average AoI calculation: not possible in a general setting

For particular queueing models (of the transmission channel)

Known expressions for M/M/1, M/M/1/1, M/M/1/2, M/M/2...

Age of Information

Average AoI calculation: not possible in a general setting

For particular queueing models (of the transmission channel)

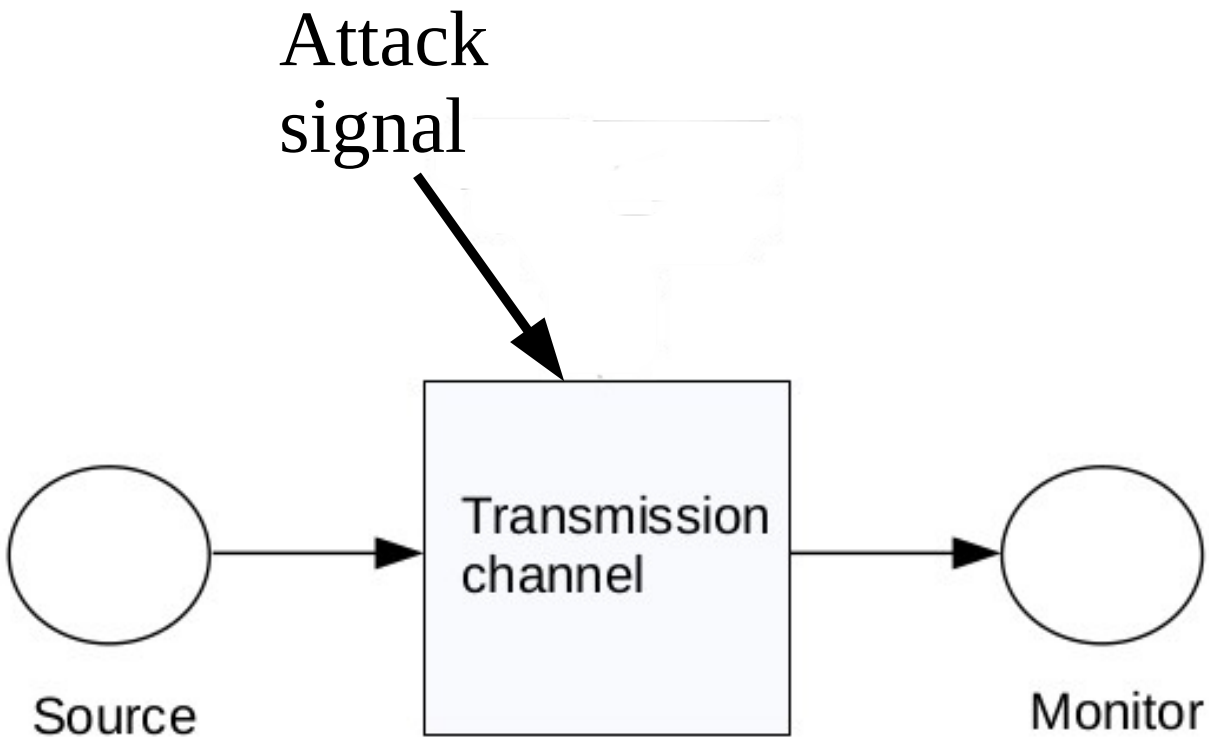
Known expressions for M/M/1, M/M/1/1, M/M/1/2, M/M/2...

Current challenges

- Analytical expression of interesting queueing models
- Optimization problems with derived expressions

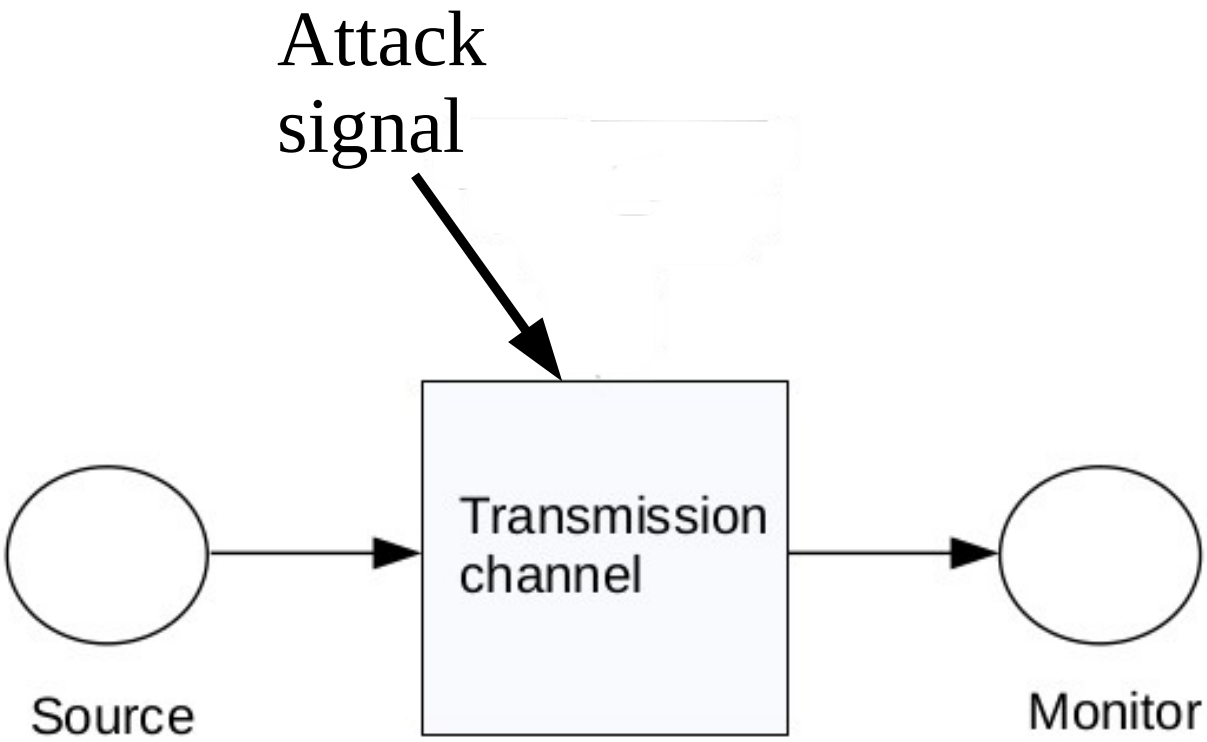
Our work

Our work



Attack signal $\Rightarrow$ empty system

Our work

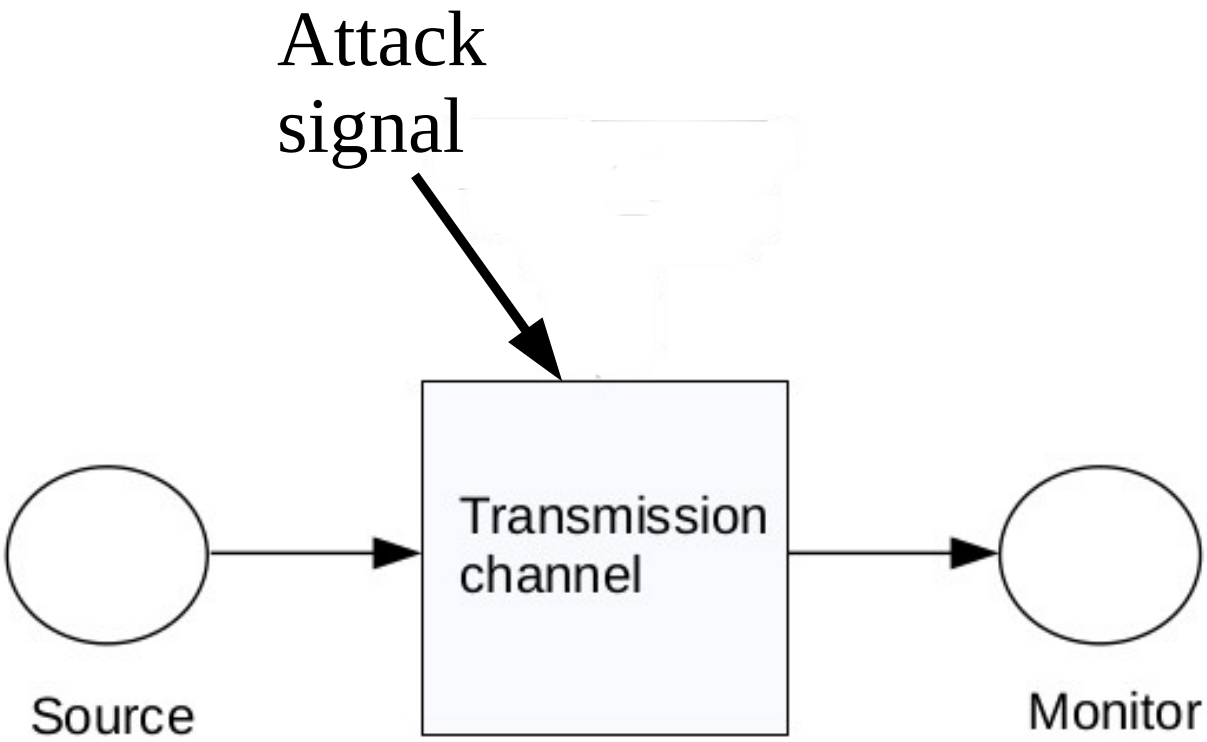


Attack signal $\Rightarrow$ empty system

Questions:

Do attacks minimize AoI?

Our work



Attack signal $\Rightarrow$ empty system

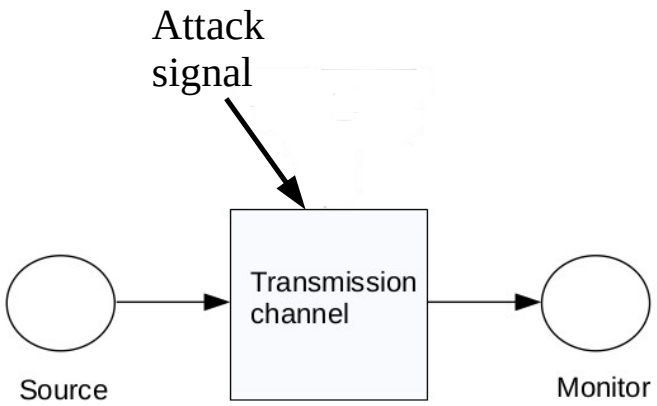
Questions:

Do attacks minimize AoI?
Why and under which conditions?

Outline

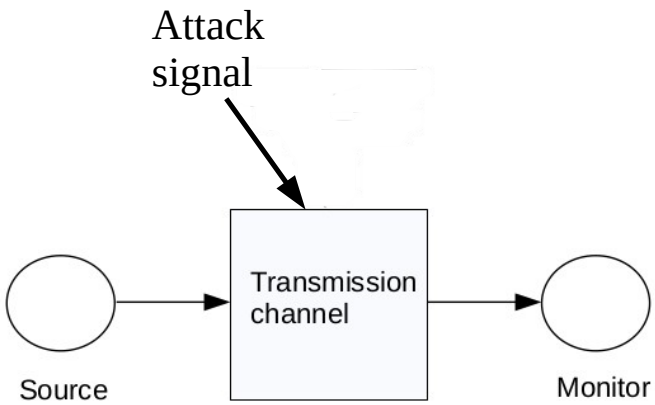
Model Description

Generation time of updates: Poisson with rate λ
Service time in the queues: exponential with rate μ
Attacks signal: Poisson with rate α



Model Description

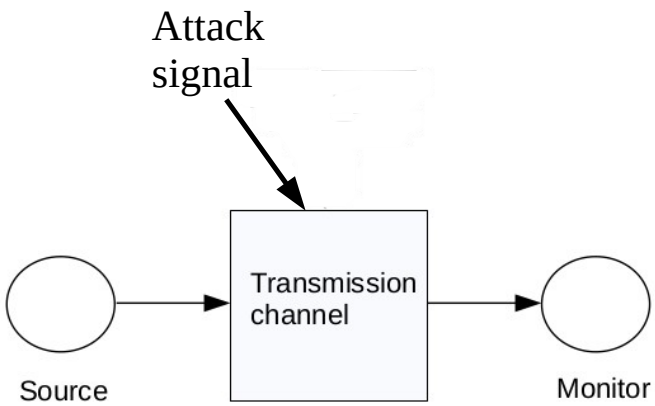
Generation time of updates: Poisson with rate λ
Service time in the queues: exponential with rate μ
Attacks signal: Poisson with rate α



$\Delta(\alpha)$: Average AoI as a function of α

Model Description

Generation time of updates: Poisson with rate λ
Service time in the queues: exponential with rate μ
Attacks signal: Poisson with rate α

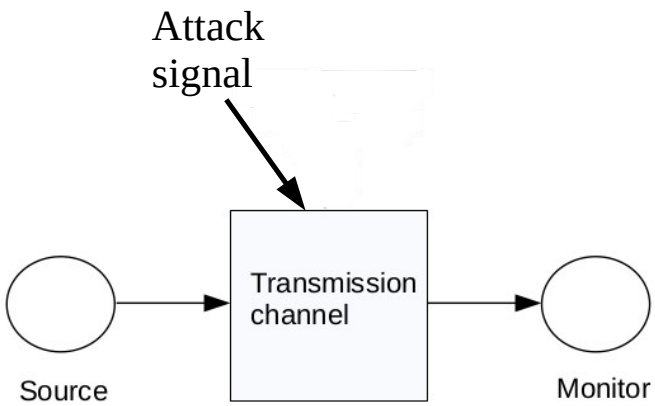


$\Delta(\alpha)$: Average AoI as a function of α

$$\mathcal{R} = \frac{\lim_{\alpha \to 0+} \Delta(\alpha)}{\min_{\alpha} \Delta(\alpha)}$$

Model Description

Generation time of updates: Poisson with rate λ
Service time in the queues: exponential with rate μ
Attacks signal: Poisson with rate α



$\Delta(\alpha)$: Average AoI as a function of α

$$\mathcal{R} = \frac{\lim_{\alpha \to 0+} \Delta(\alpha)}{\min_{\alpha} \Delta(\alpha)}$$

$\mathcal{R} > 1 \Rightarrow$ Attacks minimize AoI

Considered Models

	M/M/1/1 Queue	Tandem M/M/1/1 Queues
Non-preemtive		
Preemtive		

Outline

Non-preemptive M/M/1/1 Queue

Proposition

$$\Delta(\alpha) = \frac{1}{\lambda} + \frac{1}{\mu} + \frac{\lambda}{(\mu+\alpha)(\lambda+\mu+\alpha)} + \frac{\alpha}{\lambda\mu}.$$

Non-preemptive M/M/1/1 Queue

Proposition

$$\Delta(\alpha) = \frac{1}{\lambda} + \frac{1}{\mu} + \frac{\lambda}{(\mu+\alpha)(\lambda+\mu+\alpha)} + \frac{\alpha}{\lambda\mu}.$$

Lemma

$\Delta(\alpha)$ is convex

Non-preemptive M/M/1/1 Queue

Proposition

$$\Delta(\alpha) = \frac{1}{\lambda} + \frac{1}{\mu} + \frac{\lambda}{(\mu+\alpha)(\lambda+\mu+\alpha)} + \frac{\alpha}{\lambda\mu}.$$

Lemma

$\Delta(\alpha)$ is convex

Lemma

$\Delta(\alpha)$ is decreasing at $\alpha = 0$ if and only if $\lambda/\mu > 1{,}2469$

Non-preemptive M/M/1/1 Queue

Proposition

$$\Delta(\alpha) = \frac{1}{\lambda} + \frac{1}{\mu} + \frac{\lambda}{(\mu+\alpha)(\lambda+\mu+\alpha)} + \frac{\alpha}{\lambda\mu}.$$

Lemma

$\Delta(\alpha)$ is convex

Lemma

$\Delta(\alpha)$ is decreasing at $\alpha = 0$ if and only if $\lambda/\mu > 1{,}2469$

Proposition

$\mathcal{R} > 1$ if and only if $\lambda/\mu > 1{,}2469$

Considered Models

	M/M/1/1 Queue	Tandem M/M/1/1 Queues
Non-Preemtive	$\mathcal{R} > 1$	
Preemtive		

Conclusions

- Non-preemptive M/M/1/1 Queue: attacks might reduce AoI

Preemptive M/M/1/1 Queue

Proposition

$$\Delta(\alpha) = \frac{1}{\lambda}\left(1 + \frac{\lambda + \alpha}{\mu}\right)$$

Preemptive M/M/1/1 Queue

Proposition

$$\Delta(\alpha) = \frac{1}{\lambda}\left(1 + \frac{\lambda + \alpha}{\mu}\right)$$

Lemma

$\Delta(\alpha)$ is increasing with α

Preemptive M/M/1/1 Queue

Proposition

$$\Delta(\alpha) = \frac{1}{\lambda}\left(1 + \frac{\lambda + \alpha}{\mu}\right)$$

Lemma

$\Delta(\alpha)$ is increasing with α

	M/M/1/1 Queue	Tandem M/M/1/1 Queues
Non-Preemtive	$\mathcal{R} > 1$	
Preemtive	$\mathcal{R} = 1$	

Conclusions

- Non-preemptive M/M/1/1 Queue: attacks might reduce AoI
- Preemptive M/M/1/1 Queue: attacks DO NOT reduce AoI

Preemptive M/M/1/1 Tandem Queues

n: number of preemptive M/M/1/1 queues in tandem
Service times in queue i: Exp(μ_i)

Preemptive M/M/1/1 Tandem Queues

n: number of preemptive M/M/1/1 queues in tandem
Service times in queue i: Exp(μ_i)

Proposition

$$\Delta(\alpha) = \sum_{i=0}^{n} \frac{1}{\mu_i} \prod_{j=0}^{i-1} \left(1 + \frac{\alpha}{\mu_j}\right),$$

where $\mu_0 = \lambda$.

Preemptive M/M/1/1 Tandem Queues

n: number of preemptive M/M/1/1 queues in tandem
Service times in queue i: Exp(μ_i)

Proposition

$$\Delta(\alpha) = \sum_{i=0}^{n} \frac{1}{\mu_i} \prod_{j=0}^{i-1} \left(1 + \frac{\alpha}{\mu_j}\right),$$

where $\mu_0 = \lambda$.

Lemma

$\Delta(\alpha)$ is increasing with α

Preemptive M/M/1/1 Tandem Queues

n: number of preemptive M/M/1/1 queues in tandem
Service times in queue i: Exp(μ_i)

Proposition

$$\Delta(\alpha) = \sum_{i=0}^{n} \frac{1}{\mu_i} \prod_{j=0}^{i-1} \left(1 + \frac{\alpha}{\mu_j}\right),$$

where $\mu_0 = \lambda$.

Lemma

$\Delta(\alpha)$ is increasing with α

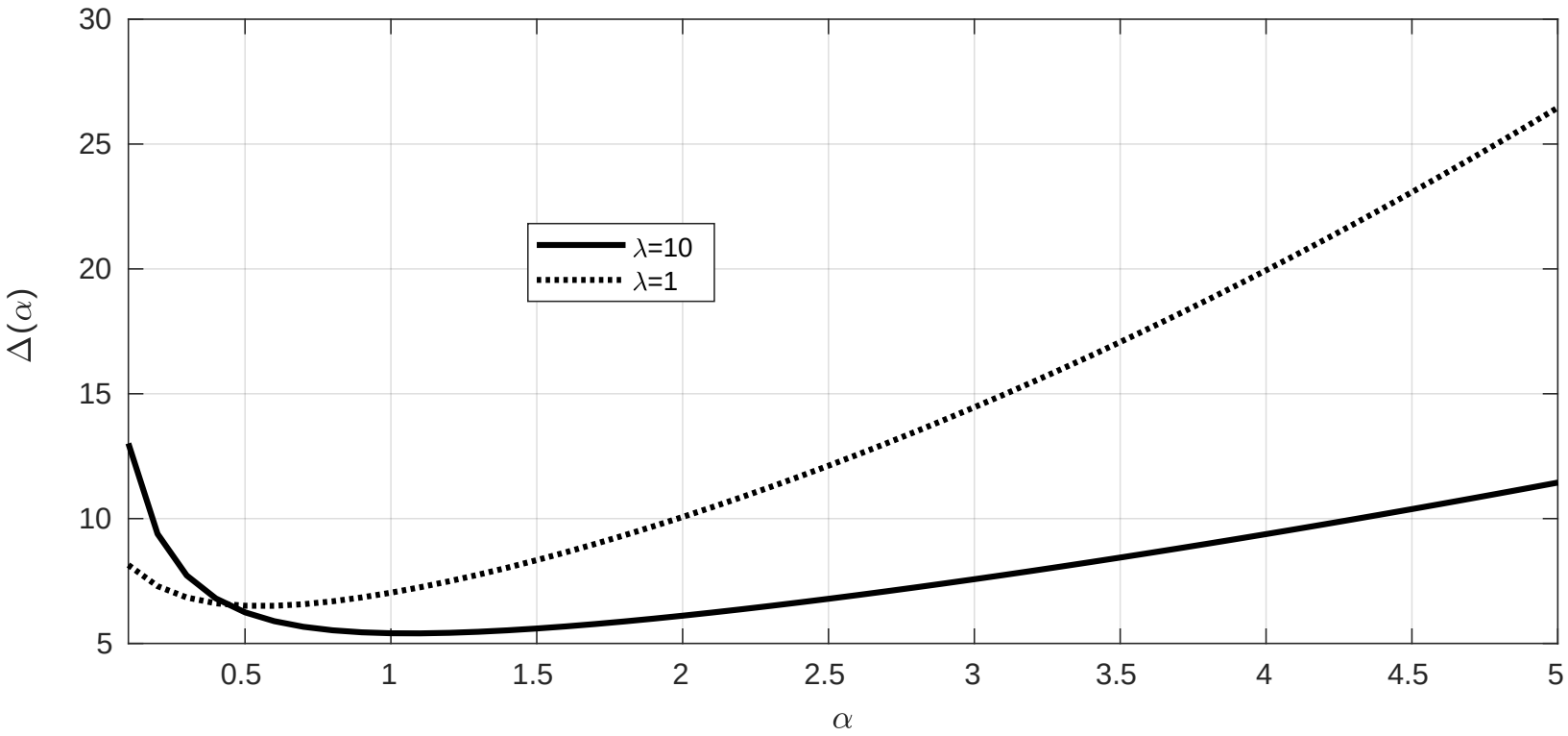
	M/M/1/1 Queue	Tandem M/M/1/1 Queues
Non-Preemtive	$\mathcal{R} > 1$	
Preemtive	$\mathcal{R} = 1$	$\mathcal{R} = 1$

Conclusion

- Preemptive M/M/1/1 Tandem Queues DO NOT reduce AoI

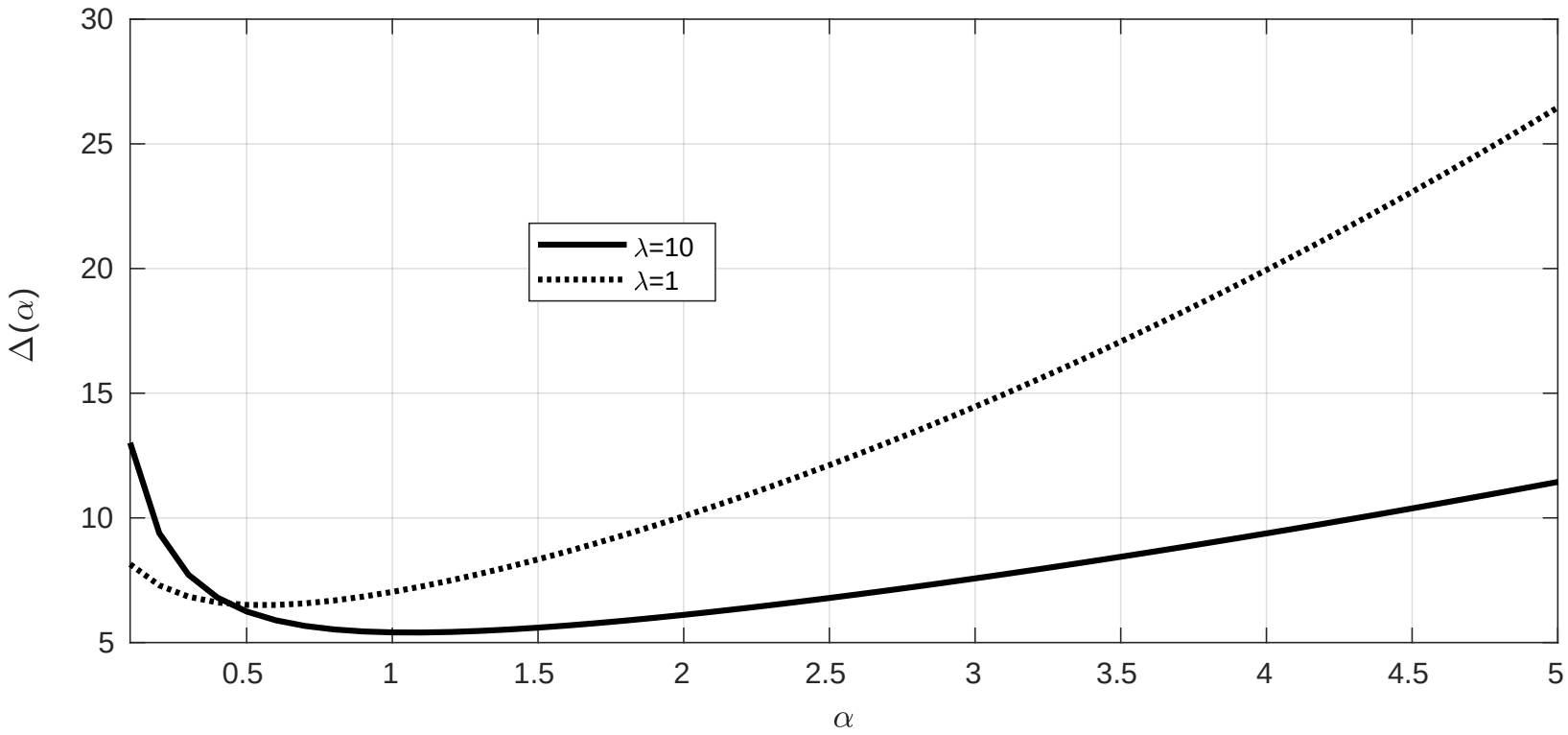
Two Non-preemptive M/M/1/1 Queues in Tandem

$\mu_1 = \mu_2 = 1$



Two Non-preemptive M/M/1/1 Queues in Tandem

$\mu_1 = \mu_2 = 1$



$\mathcal{R} = 1$ for $\lambda = 1$ and $\lambda = 10$

Two Non-preemptive M/M/1/1 Queues in Tandem

	M/M/1/1 Queue	Tandem M/M/1/1 Queues
Non-Preemtive	$\mathcal{R} > 1$	$\mathcal{R} > 1$
Preemtive	$\mathcal{R} = 1$	$\mathcal{R} = 1$

Conclusion

- Non-preemptive M/M/1/1 Tandem Queues might reduce *AoI* (numerical)

Outline

Conclusions

	M/M/1/1 Queue	Tandem M/M/1/1 Queues
Non-Preemtive	$\mathcal{R} > 1$	$\mathcal{R} > 1$
Preemtive	$\mathcal{R} = 1$	$\mathcal{R} = 1$

Conclusion

- Non-preemptive M/M/1/1 Queue: attacks might reduce AoI
- Preemptive M/M/1/1 Queue: attacks DO NOT reduce AoI
- Preemptive M/M/1/1 Tandem Queues DO NOT reduce *AoI*
- Non-preemptive M/M/1/1 Tandem Queues might reduce *AoI* (numerical)

Conclusions

	M/M/1/1 Queue	Tandem M/M/1/1 Queues
Non-Preemtive	$\mathcal{R} > 1$	$\mathcal{R} > 1$
Preemtive	$\mathcal{R} = 1$	$\mathcal{R} = 1$

Conclusion

- Non-preemptive M/M/1/1 Queue: attacks might reduce AoI
- Preemptive M/M/1/1 Queue: attacks DO NOT reduce AoI
- Preemptive M/M/1/1 Tandem Queues DO NOT reduce *AoI*
- Non-preemptive M/M/1/1 Tandem Queues might reduce *AoI* (numerical)

Non-preemptive: attacks might lead to AoI reduction
Preemptive: AoI cannot be reduced

Future Work

Other queueing systems:

- M/M/1 queue
- M/M/1/K queue (preemptive and non-preemptive)
- ...

Variations of attacks: only some packets are discarded (not all)

Bibliography

1. Kaul, S., M. Gruteser, V. Rai, and J. Kenney. "Minimizing age of information in vehicular networks". In 8th Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks (SECON). 350-358. 2011.
2. Kaul, S. K., R. D. Yates, and M. Gruteser. "Status updates through queues". In 46th Annual Conference on Information Sciences and Systems (CISS). 1-6. 2012.
3. R. D. Yates, Y. Sun, D. R. Brown, S. K. Kaul, E. Modiano, and S. Ulukus. Age of information: An introduction and survey. IEEE Journal on Selected Areas in Communications, 39(5):1183-1210. 2021.

That's all folks

THANKS FOR YOUR ATTENTION

QUESTIONS?