NetSys 2023, International Conference on Networked Systems 2023
4-7 September 2023 – Potsdam, Germany

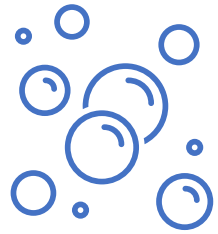
Part II: Domain Specific Applications

Jorge Torres Gómez
TU Berlin

Nikolaos Pappas
Linköping University

Vehicular Networks

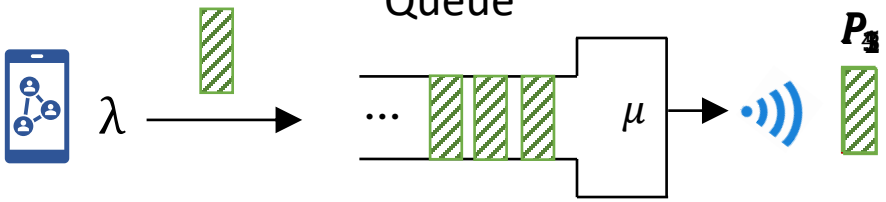
Satellite Networks

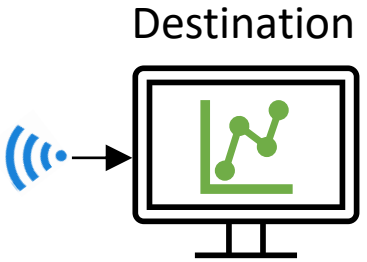


Molecular Communications

[1] N. Pappas, M. A. Abd-Elmagid, B. Zhou, W. Saad, and H. S. Dhillon, *Age of Information: Foundations and Applications*. Cambridge University Press, 2023.

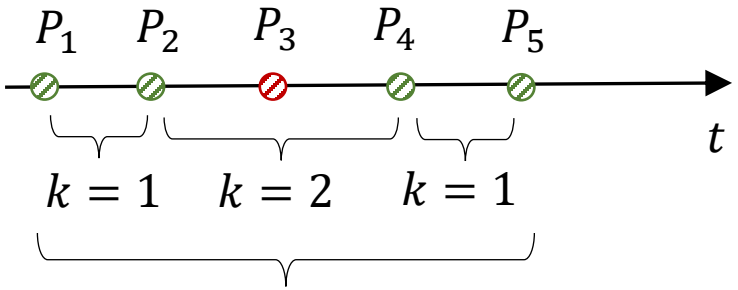
Erasure channels



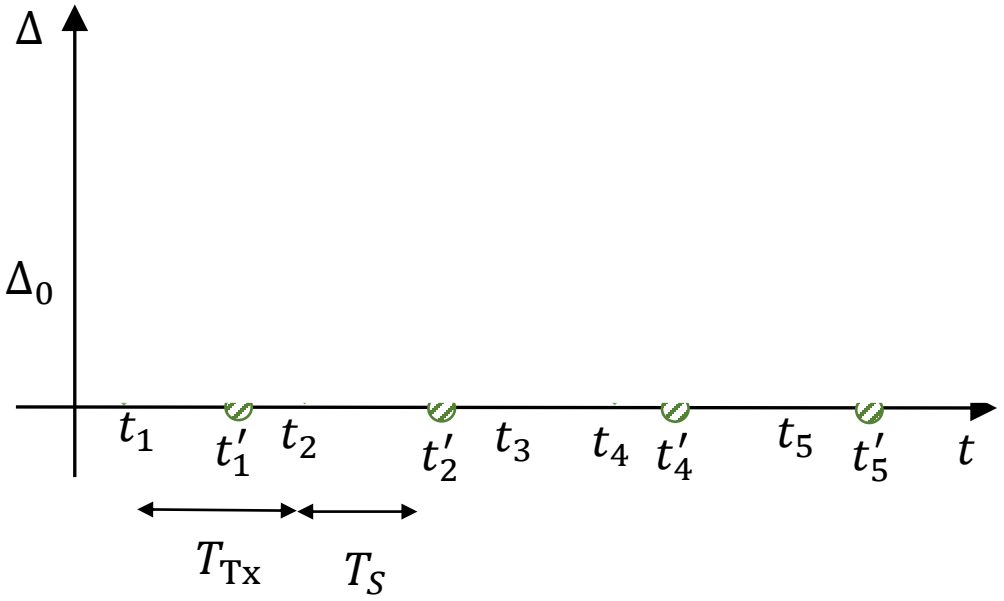


$$\mathbb{E}[T_{\mathrm{S}}] = \frac{1}{\mu - \lambda}$$

$$\mathbb{E}[T_{\mathrm{Tx}}] = \mathbb{E}[k]\frac{1}{\lambda} = \frac{1}{1-p_e}\frac{1}{\lambda}$$



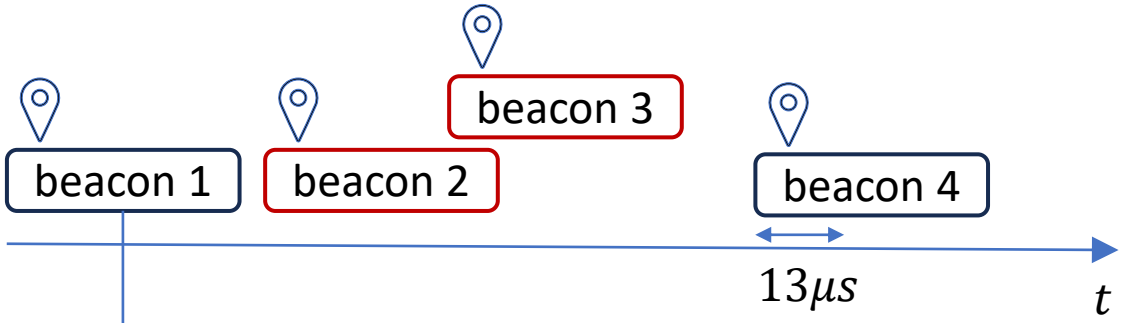
The random variable k follows a negative binomial distribution



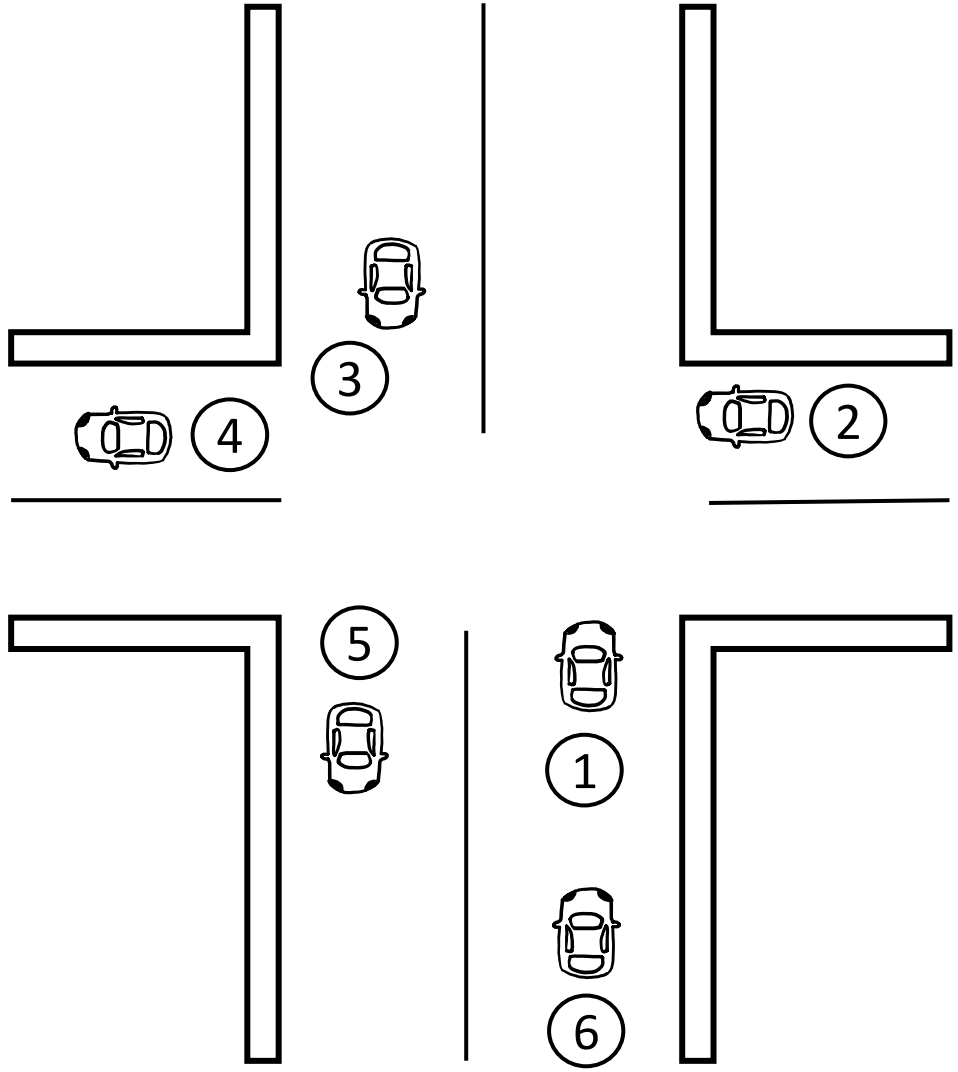
$$\Delta^{(p)} = \frac{1}{N(T)}\sum_{i=1}^{N(t)} A_i = \mathbb{E}[T_{\mathrm{Tx}}] + \mathbb{E}[T_{\mathrm{S}}]$$

[1] K. Chen and L. Huang, "Age-of-information in the presence of error," 2016 IEEE International Symposium on Information Theory (ISIT), Barcelona, Spain, 2016, pp. 2579-2583, doi: 10.1109/ISIT.2016.7541765.

Vehicular Networks (VANETS)

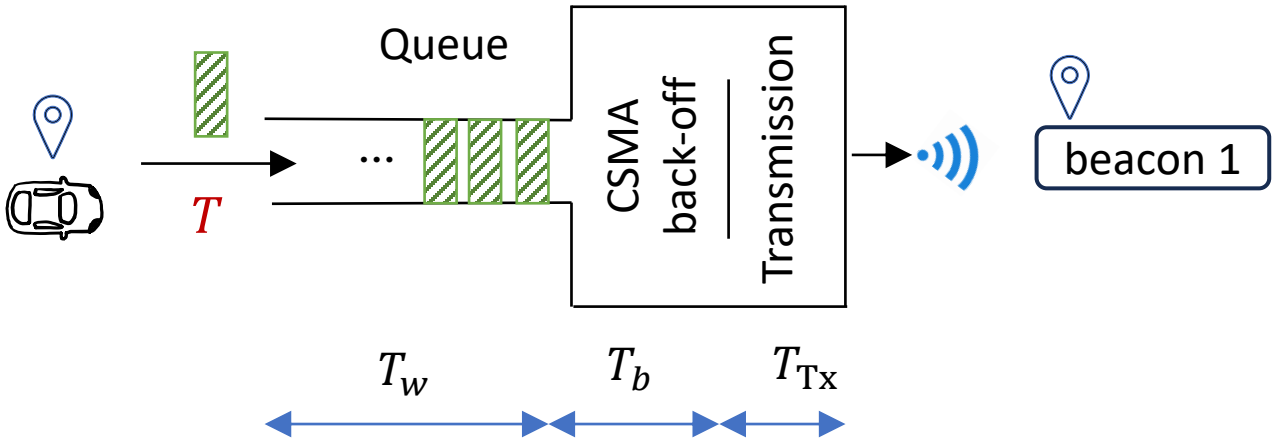


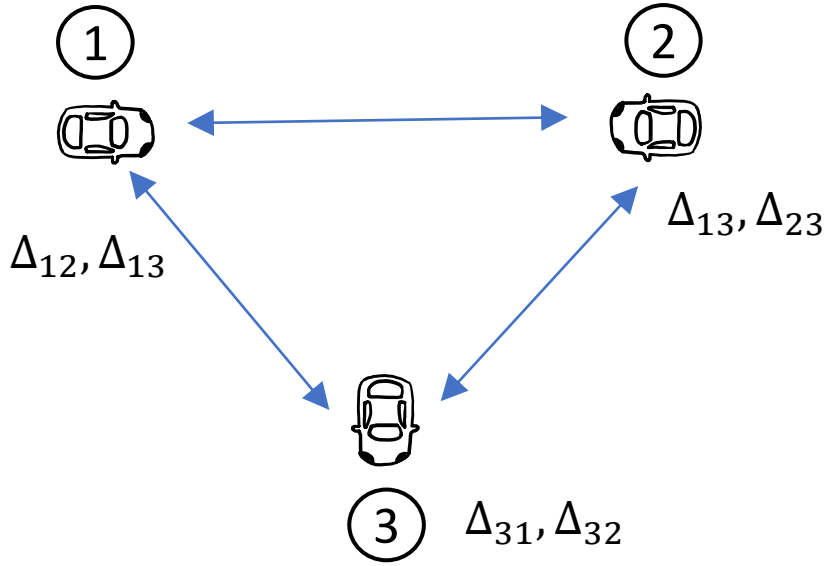
- Position of the vehicle
- Speed of the vehicle
- Direction of the vehicle

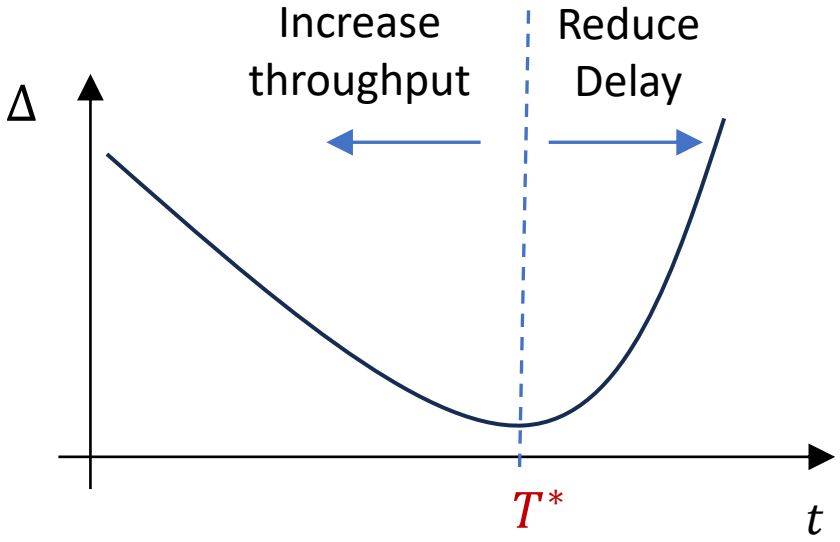


[1] S. Kaul, M. Gruteser, V. Rai and J. Kenney, "Minimizing age of information in vehicular networks," 2011 8th Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks, Salt Lake City, UT, USA, 2011, pp. 350-358, doi: 10.1109/SAHCN.2011.5984917.

Vehicular Networks (VANETS)







System Age

$$\Delta = \frac{1}{N(N-1)} \sum_{u,v} \Delta_{u,v}$$

[1] S. Kaul, M. Gruteser, V. Rai and J. Kenney, "Minimizing age of information in vehicular networks," 2011 8th Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks, Salt Lake City, UT, USA, 2011, pp. 350-358, doi: 10.1109/SAHCN.2011.5984917.

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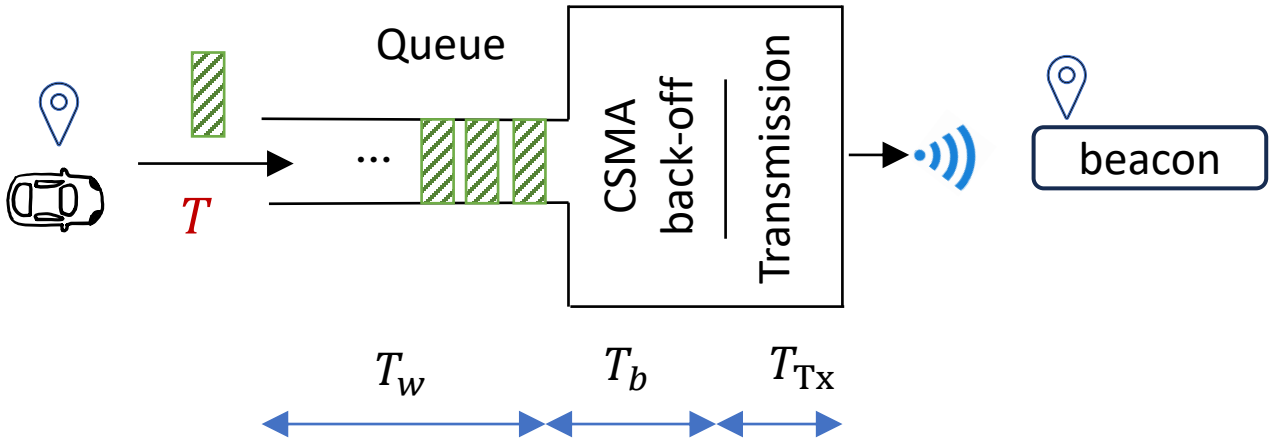

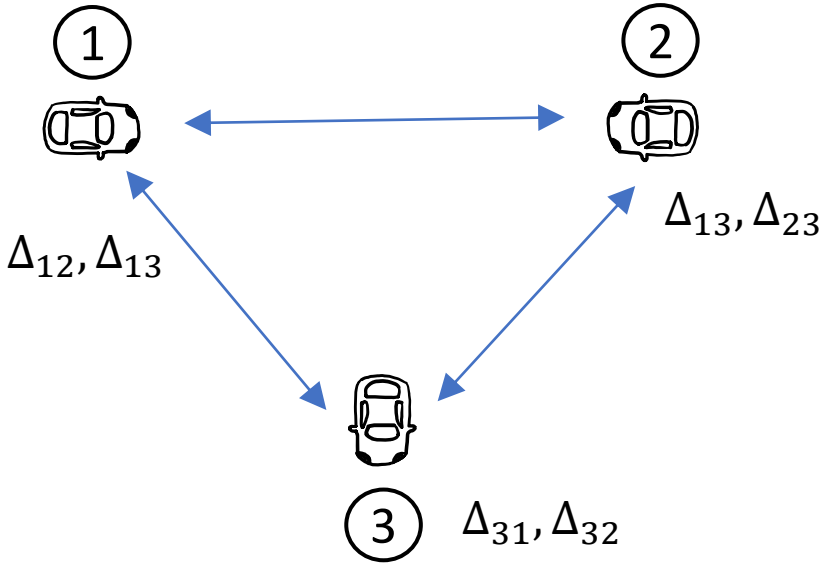

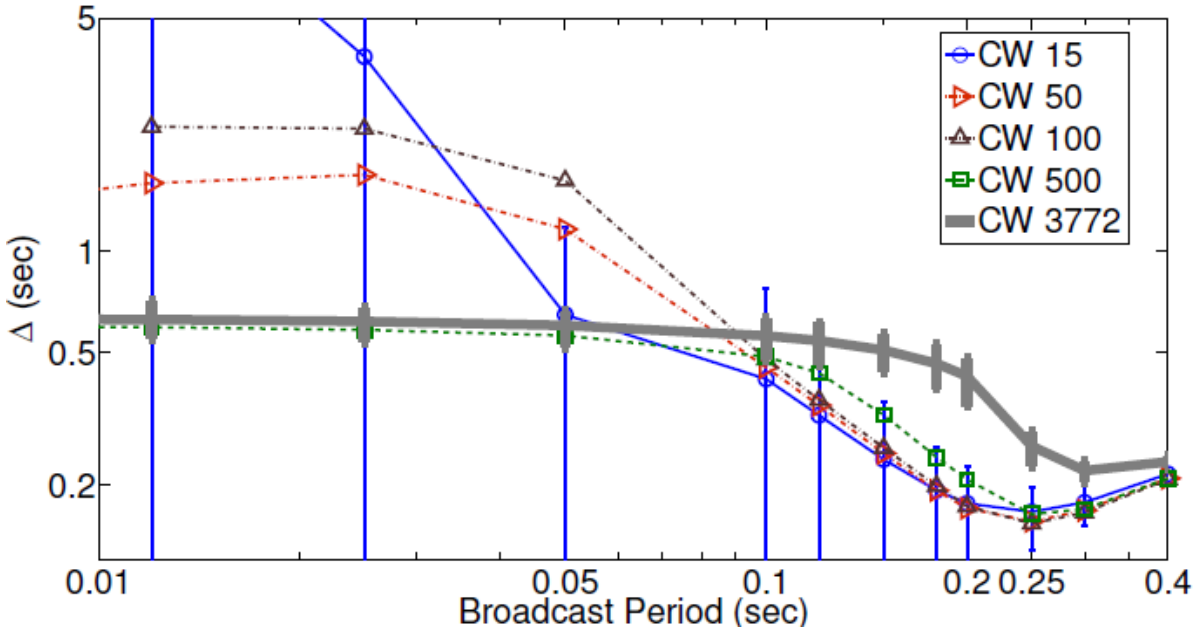

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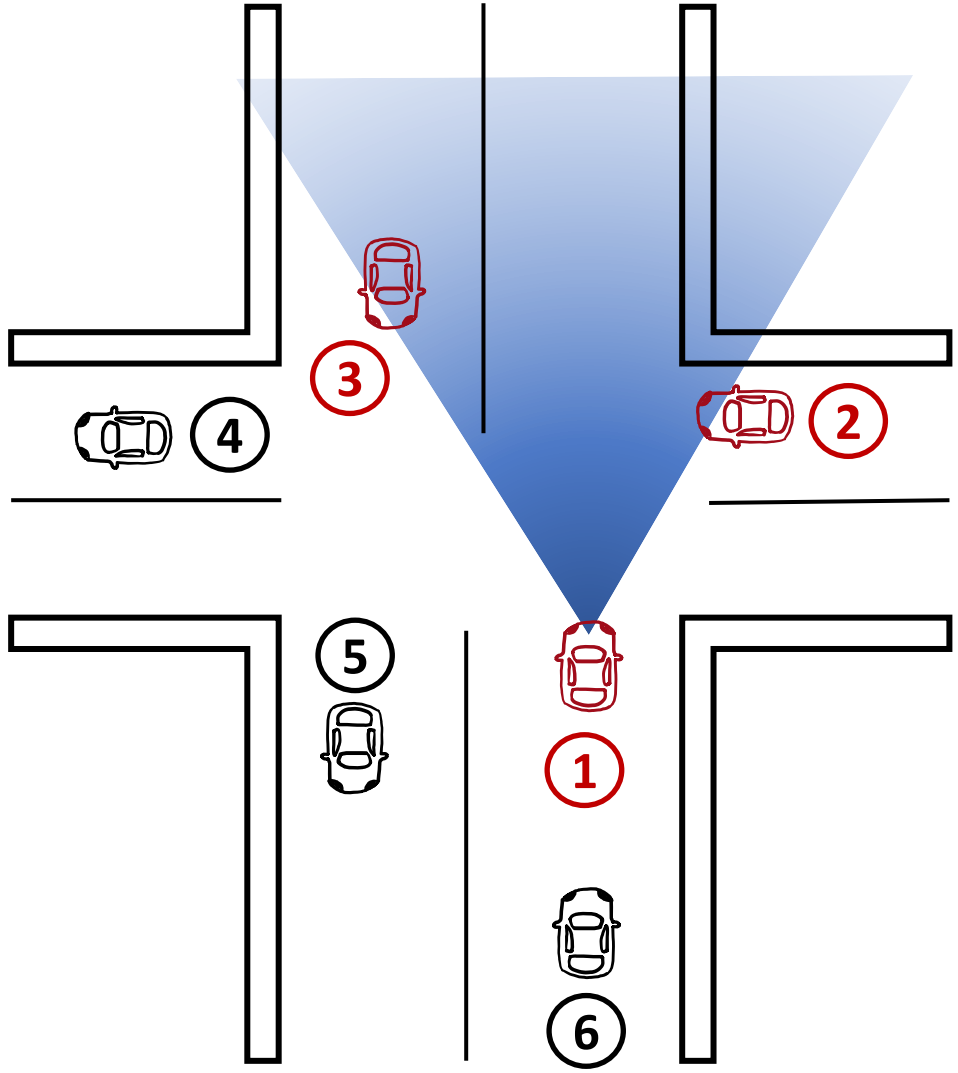
Vehicular Networks at Interceptions

System Age

$$\Delta = \frac{1}{N(N-1)} \sum_{u,v} \boldsymbol{\omega_{u,v}} \, \Delta_{u,v}$$



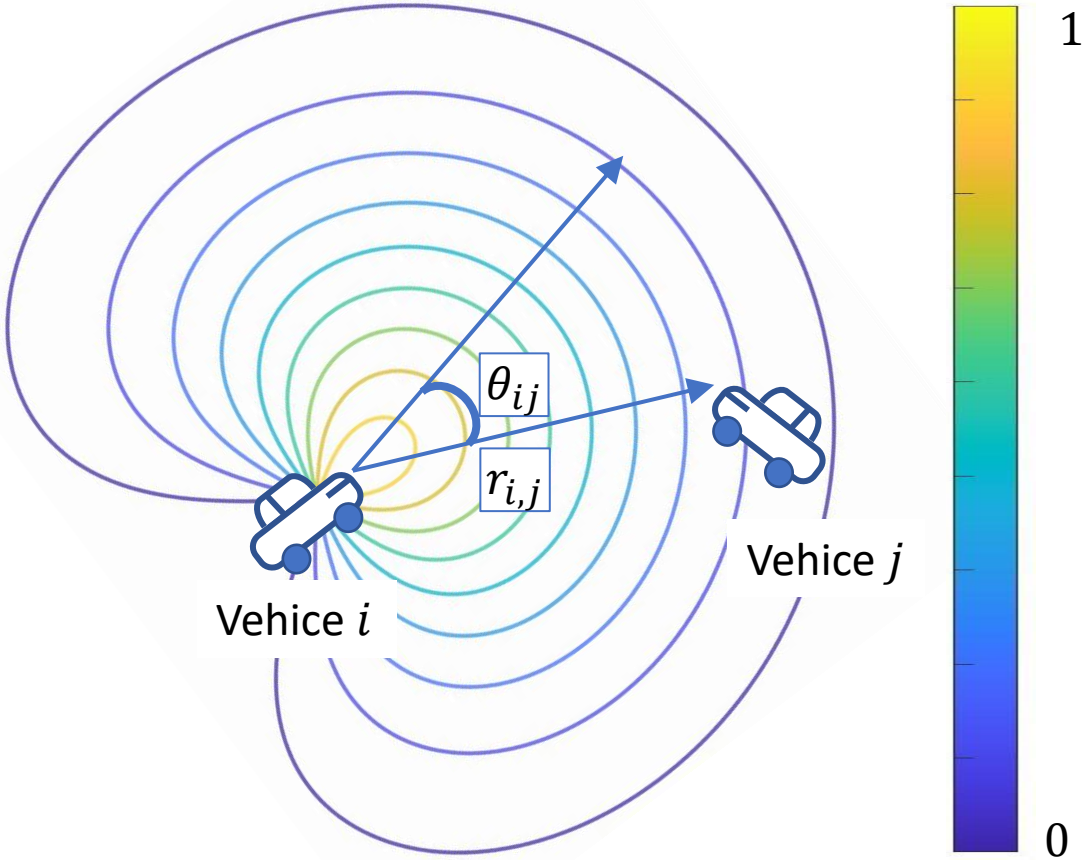
[1] Julian Heinovski, Jorge Torres Gómez and Falko Dressler, "Focusing on Information Context for ITS using a Spatial Age of Information Model," Elsevier Computer Communications, vol. 209, pp. 203–216, September 2023.

Vehicular Networks at Interceptions

System Age

$$\Delta = \frac{1}{N(N-1)} \sum_{u,v} \boldsymbol{\omega_{u,v}} \, \Delta_{u,v} \qquad (1)$$

$$\boldsymbol{\omega_{u,v}} = \frac{1}{2}\left(1 + \cos\left(\alpha\theta_{u,v}\right)\right) e^{-\beta \| d_{u,v} \|} \qquad (2)$$



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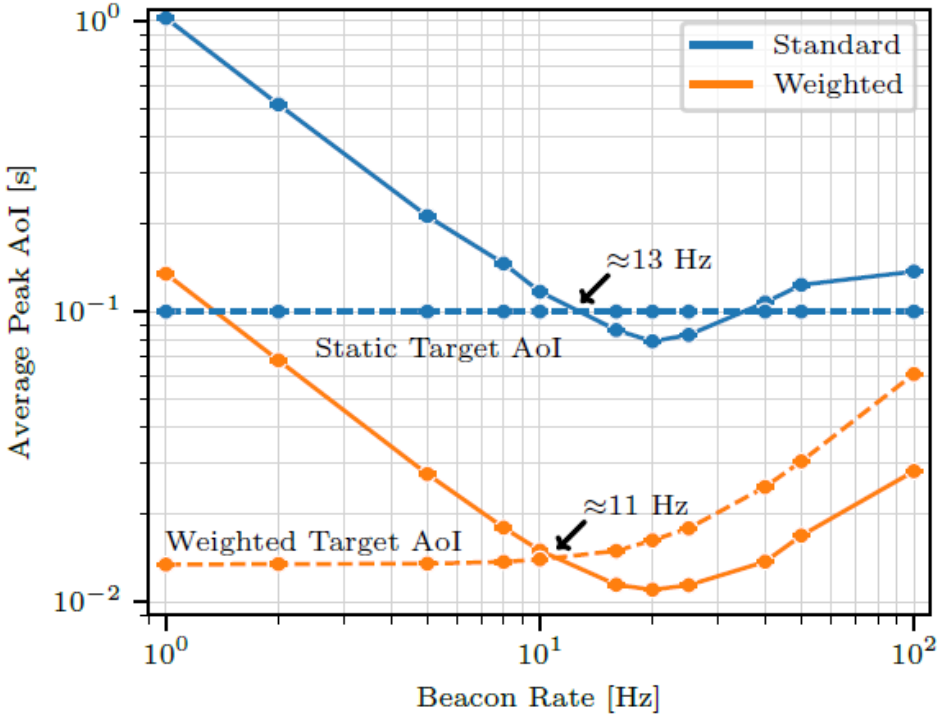

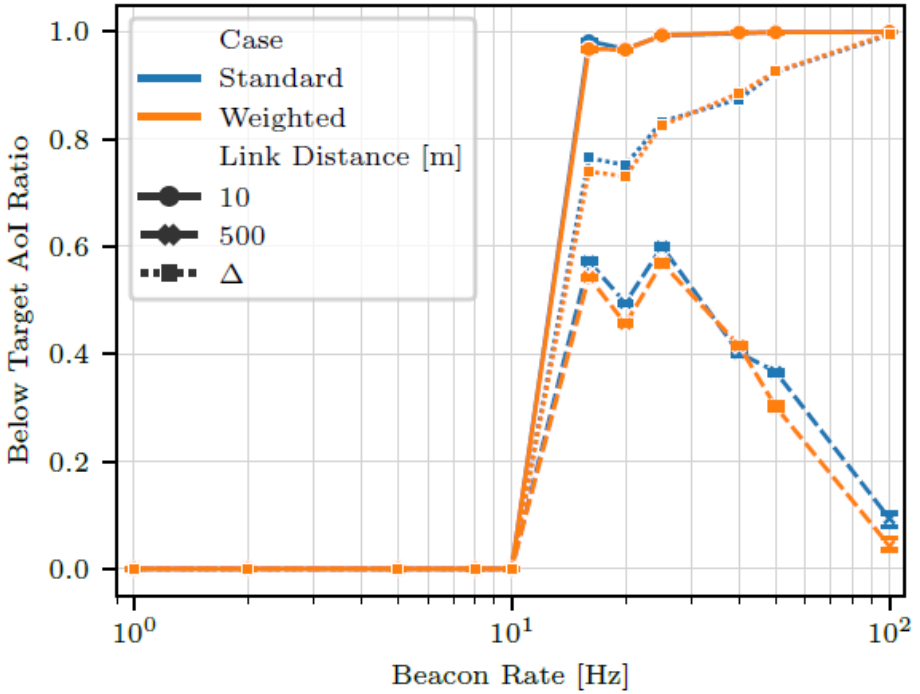

[1] Julian Heinovski, Jorge Torres Gómez and Falko Dressler, "Focusing on Information Context for ITS using a Spatial A
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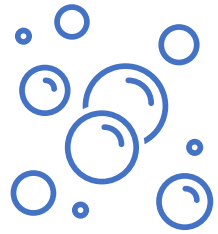
Part II: Domain Specific Applications

Vehicular Networks

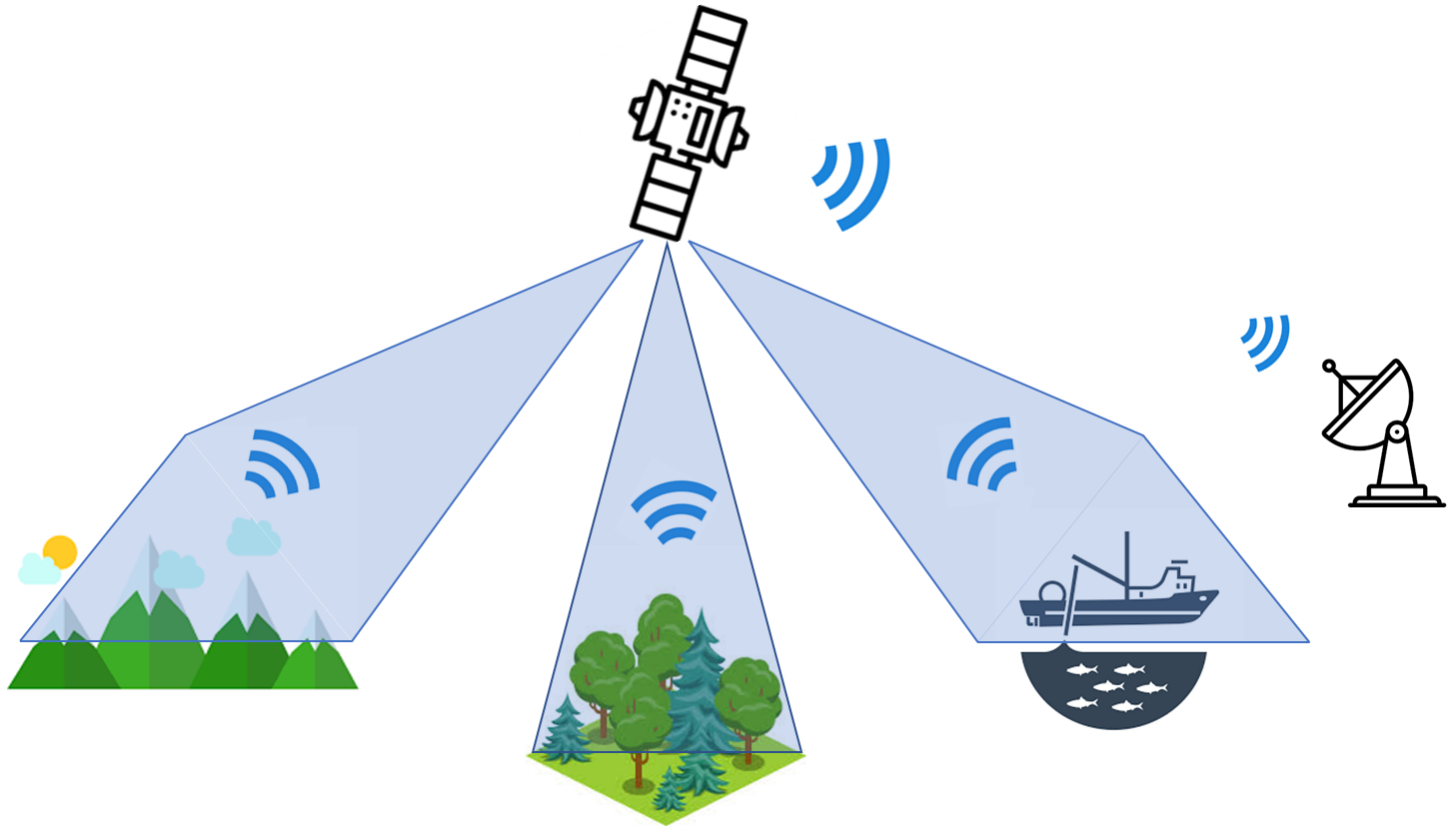
Satellite Networks

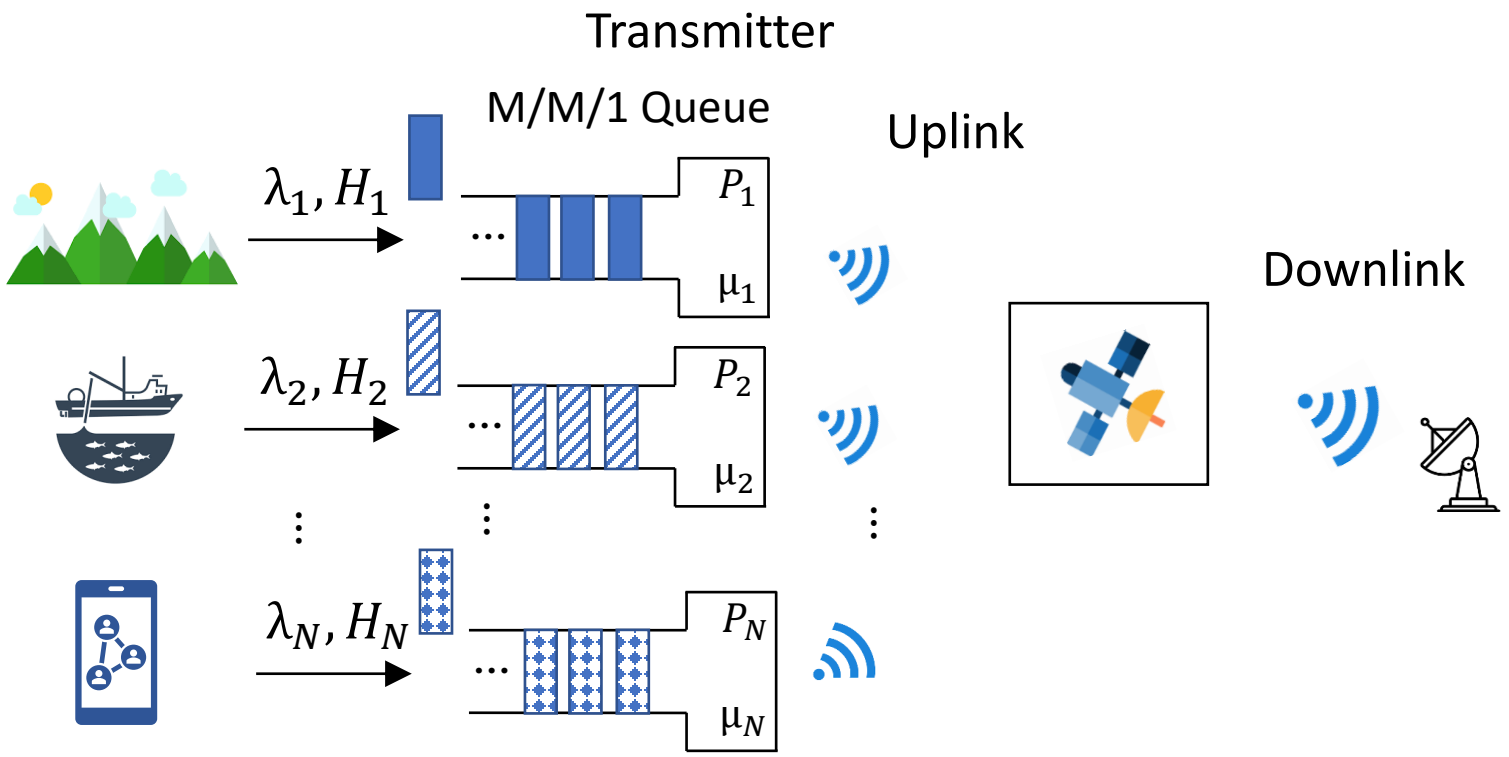


Molecular Communications

Satellite Networks

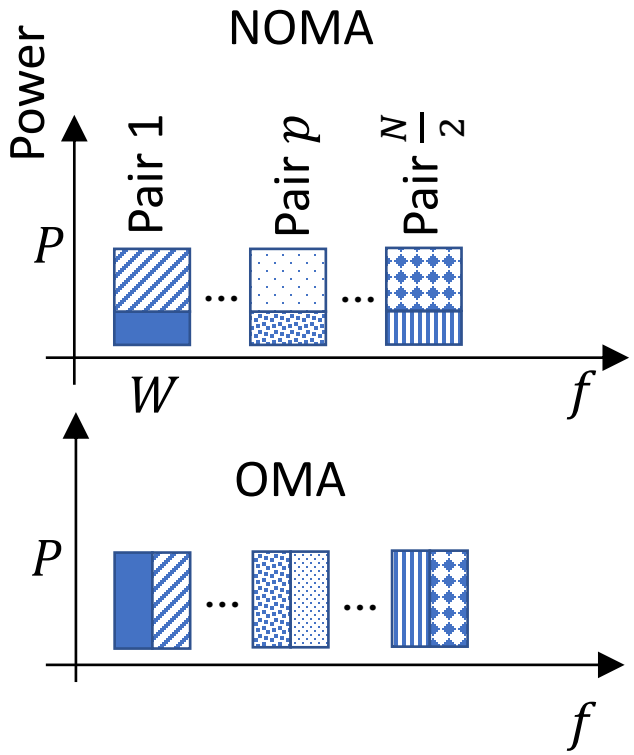
- Cover the limited areas of terrestrial networks
  - 80% land, 90% ocean.
- NOMA users' advantage due to spectrum efficiency
  - Satellite and users power restriction
  - User allocation
  - QoS: node rate





λ: rate of transmissions

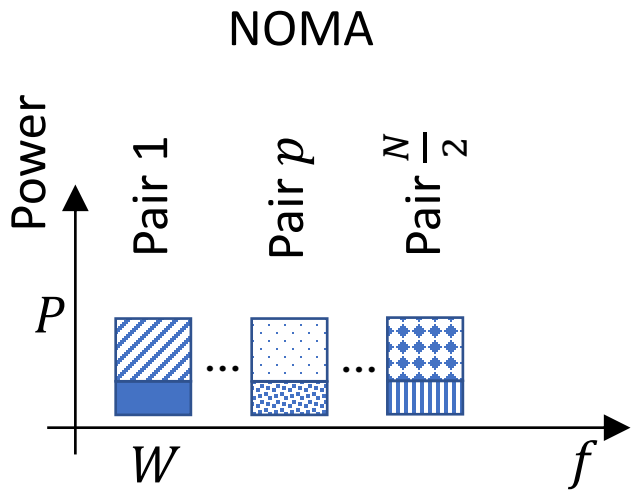
H: Source Entropy

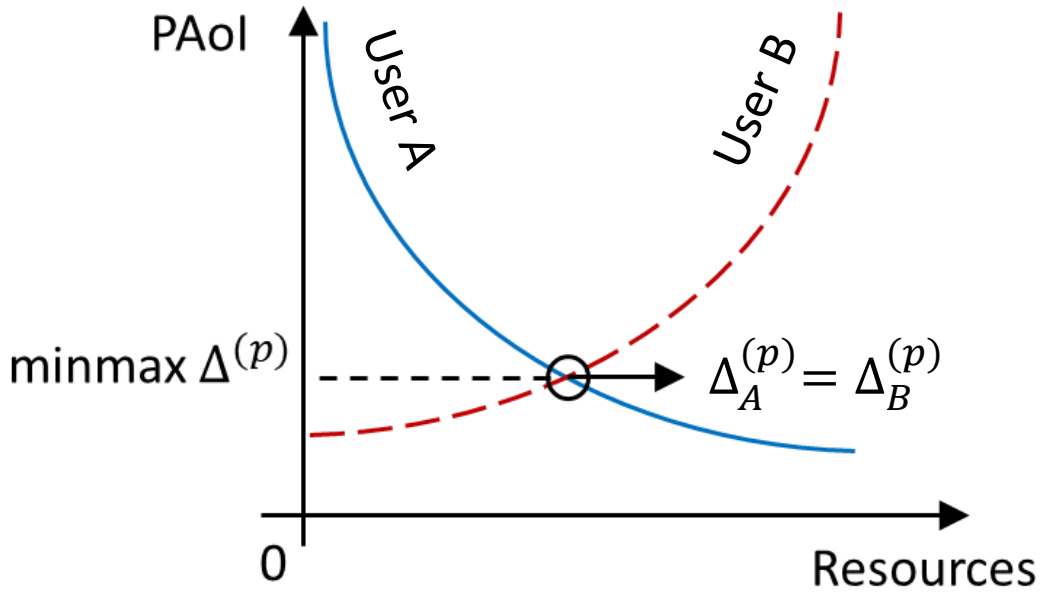


Problems:

- Resource allocation per frequency band.
- User pairing.

[1] Jorge Torres Gómez, Maximo Morales-Céspedes, Musbah Shaat, Ana I. Pérez Neira and Ana García Armada, "Power and Bandwidth Allocation based on Age of Information metrics in Satellite Uplink Channels," Proceedings of 21st IEEE Mediterranean Electrotechnical Conference (MELECON 2022)





Fairness

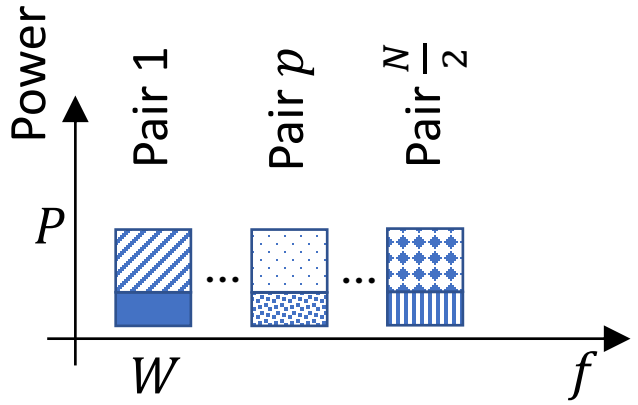
PAoI: $\Delta_k^{(p)}$

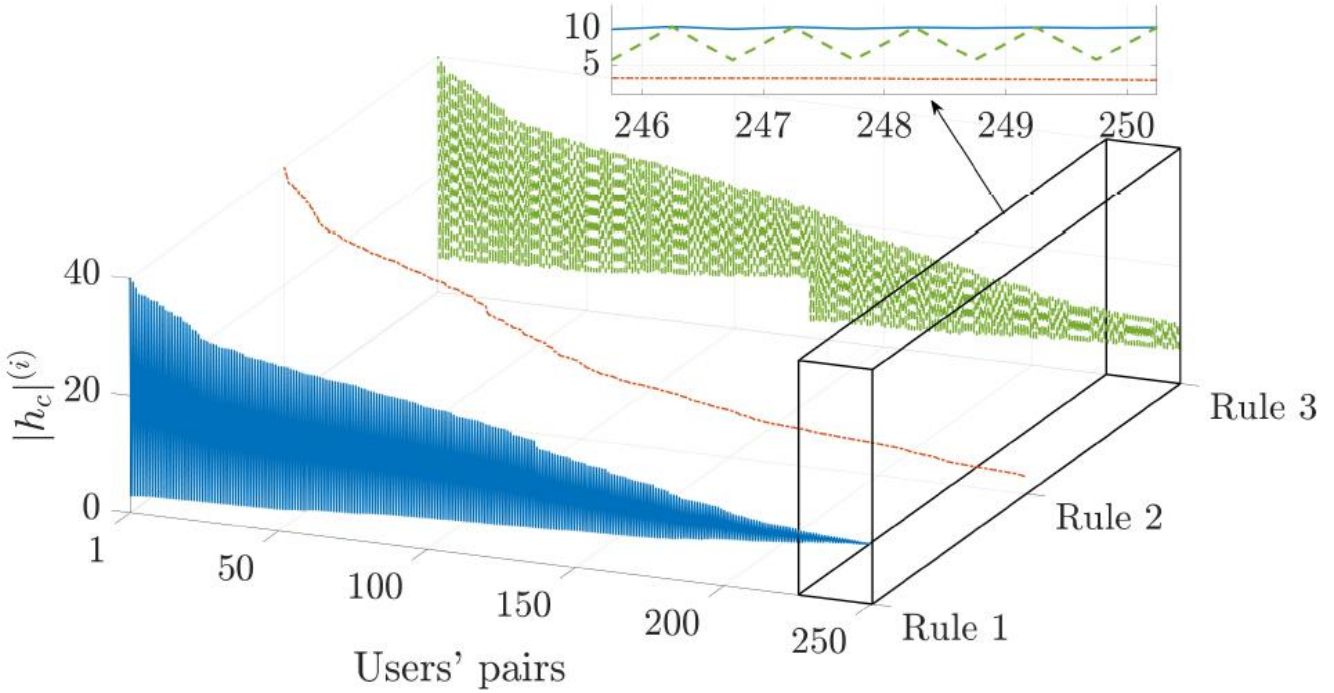
$$\min_{\lambda_k, P_k, \mu_k} \max \frac{H_k}{R_k} \left(\frac{1}{(1-\mathrm{SER})\lambda_k} + \frac{1}{\mu_k - \lambda_k} + T_d \right)$$

$$\text{s.t.:} \quad P_k \leq P, \lambda_k \leq \mu_k, \mu_k \leq \frac{W}{2},$$

[1] Jorge Torres Gómez, Maximo Morales-Céspedes, Musbah Shaat, Ana I. Pérez Neira and Ana García Armada, "Power and Bandwidth Allocation based on Age of Information metrics in Satellite Uplink Channels," Proceedings of 21st IEEE Mediterranean Electrotechnical Conference (MELECON 2022)

NOMA





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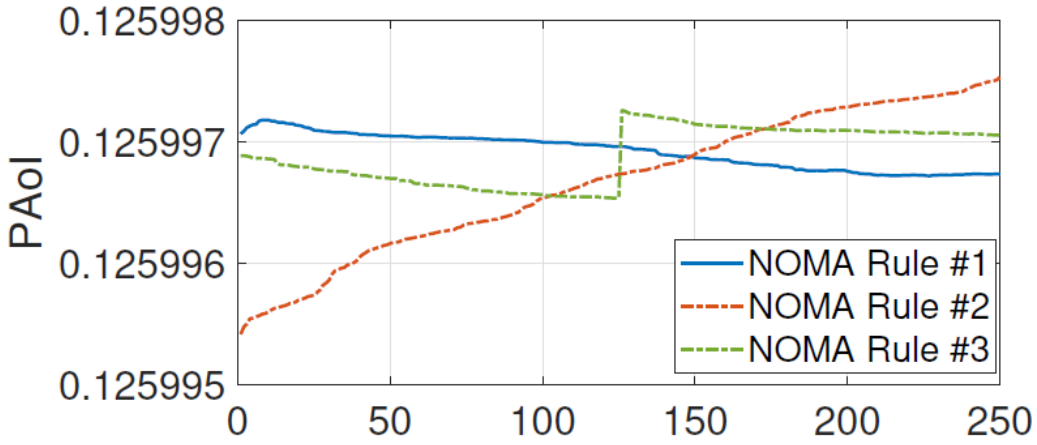

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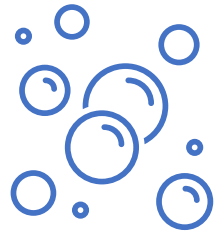
Part II: Domain Specific Applications

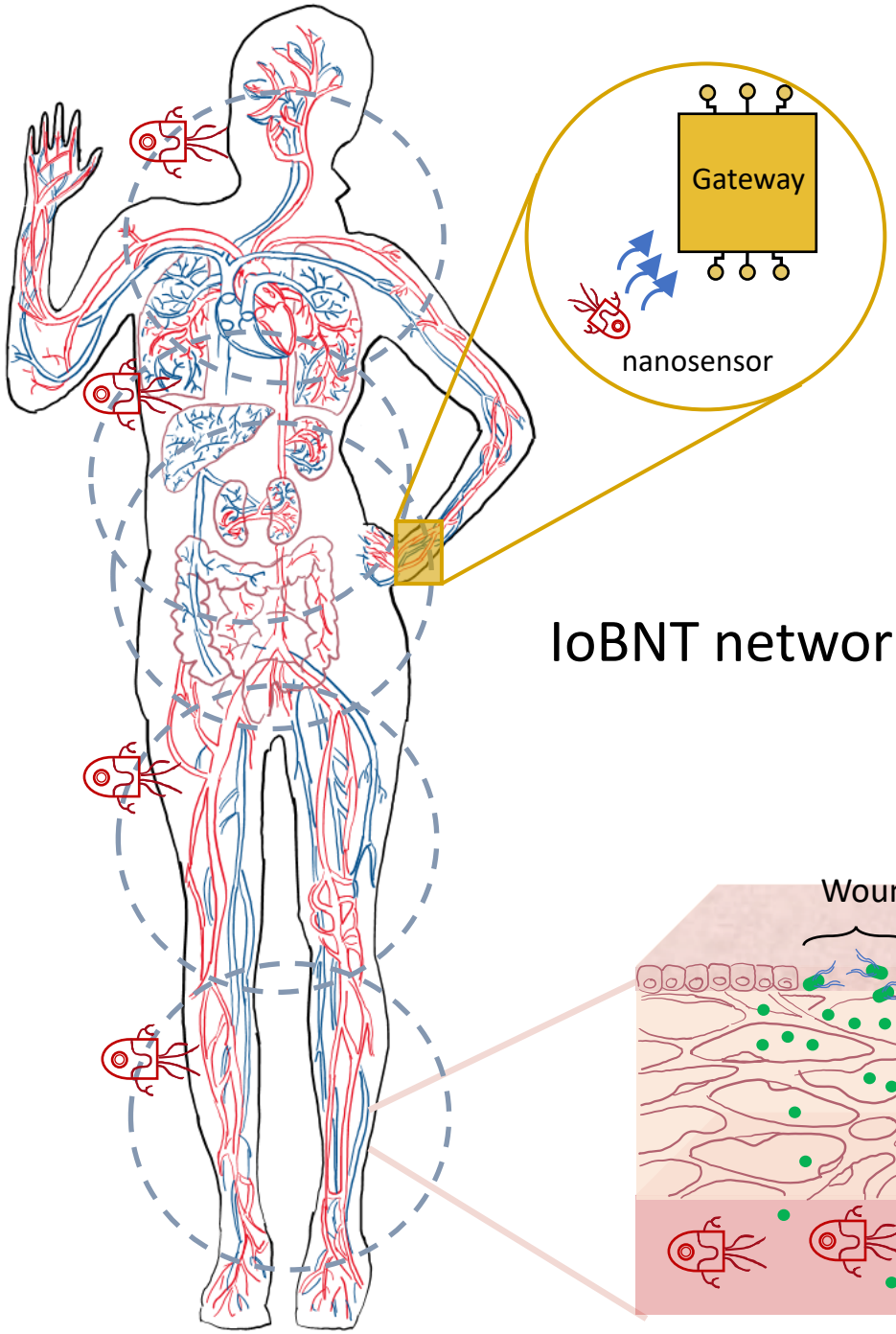
Vehicular Networks

Satellite Networks

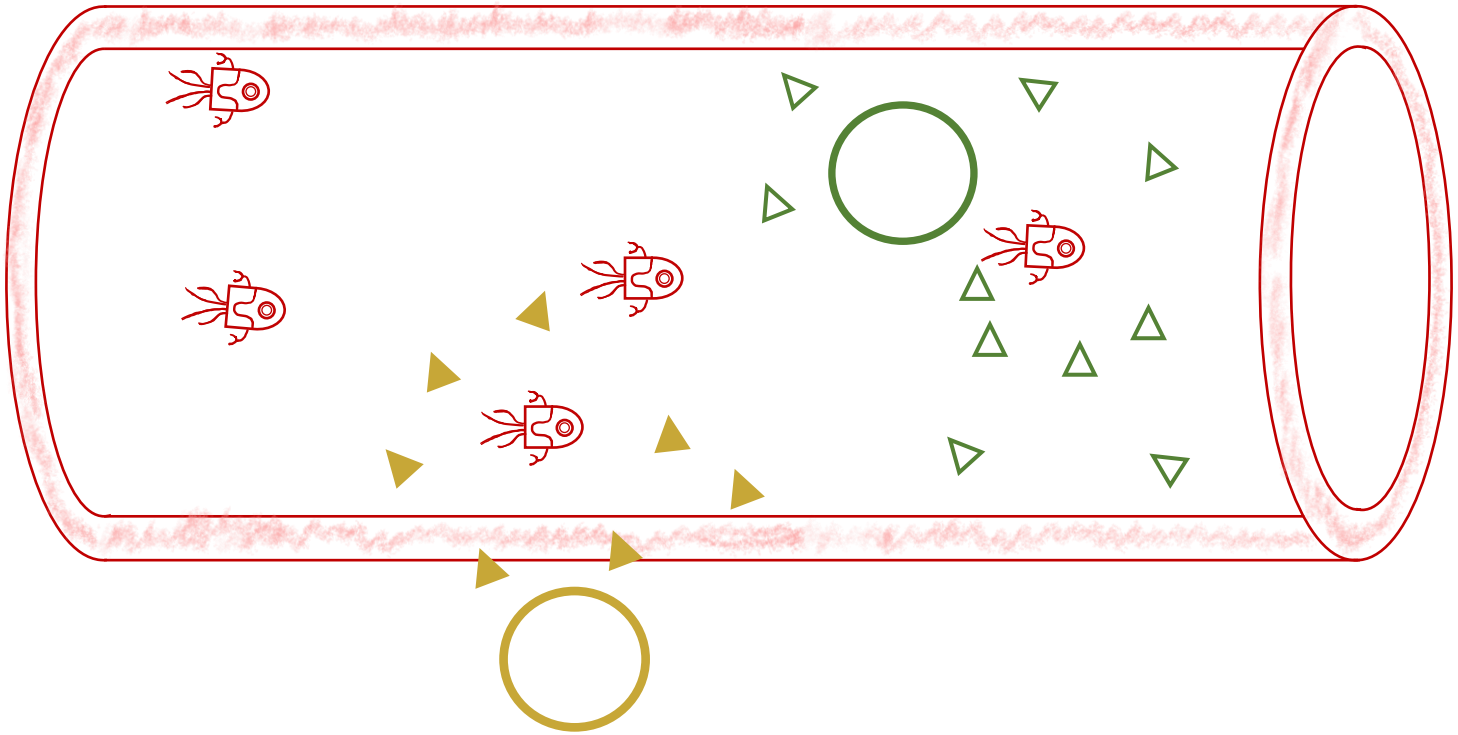


Molecular Communications

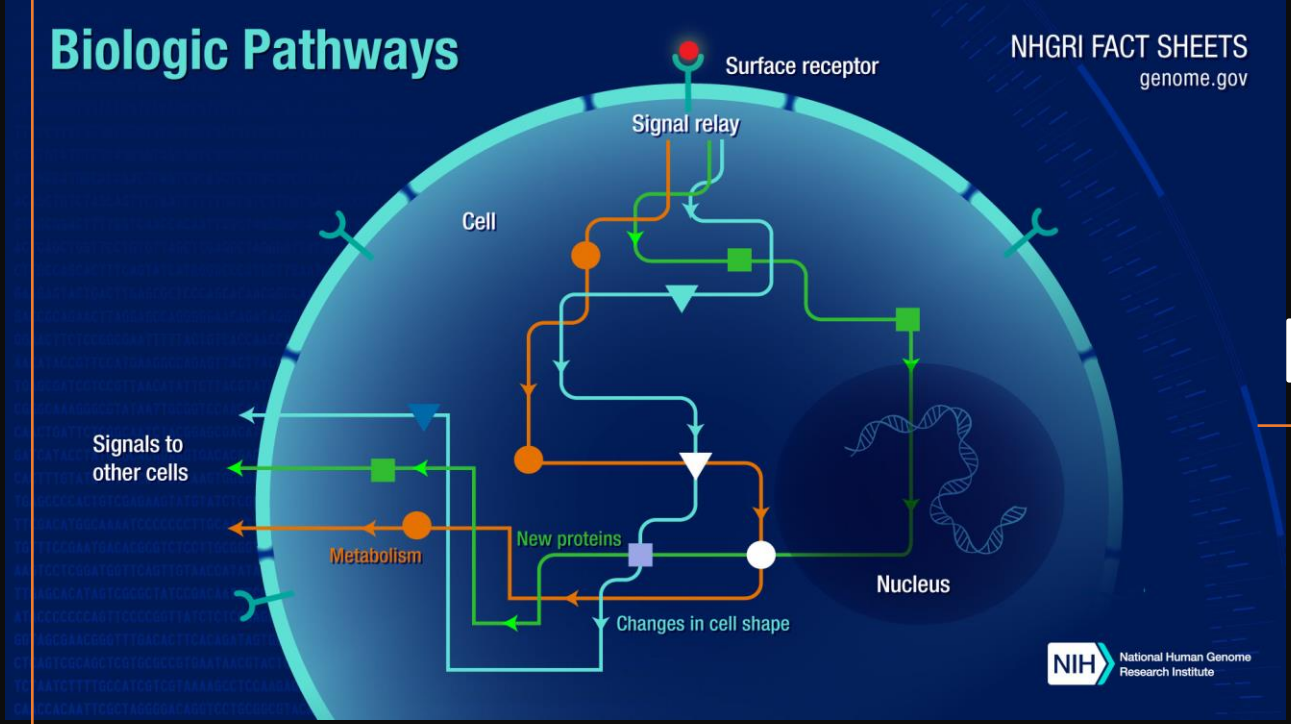
Molecular Communications



IoBNT network



[1] Jorge Torres Gómez, Joana Angjo and Falko Dressler, "Age of Information-based Performance of Ultrasonic Communication Channels for Nanosensor-to-Gateway Communication," IEEE Transactions on Molecular, Biological and Multi-Scale Communications, vol. 9 (2), pp. 112–123, June 2023.



Biochemical Pathways

[1] https://www.genome.gov/about-genomics/fact-sheets/Biological-Pathways-Fact-Sheet

[2]https://bionumbers.hms.harvard.edu/bionumber.aspx?id=104756&ver=1&trm=life+cycle+gene+regulation+homo+sapiens&org=

[3]https://bionumbers.hms.harvard.edu/bionumber.aspx?id=106404&ver=2&trm=life+cycle+metabolism&org=

[4] A. McMichael and P. Bowness, 'HLA-B27: natural function and pathogenic role in spondyloarthritis', Arthritis Res, vol. 4, no. Suppl 3, pp. S153–S158, 2002, doi: 10.1186/ar571.

Component	Lifecycle
Mitosis HeLa cells	1.10 hours [2]
Protein HLA-B27 [3]	4 hours [4]

Human Microbiome

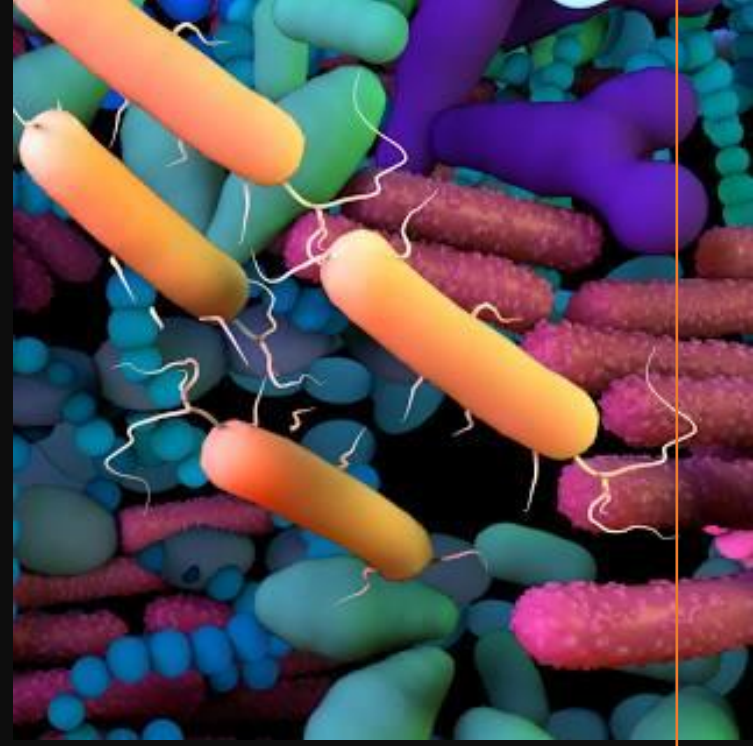
[1] https://www.genome.gov/about-genomics/fact-sheets/Biological-Pathways-Fact-Sheet

[2]https://bionumbers.hms.harvard.edu/bionumber.aspx?id=104756&ver=1&trm=life+cycle+gene+regulation+homo+sapiens&org=

[3]https://bionumbers.hms.harvard.edu/bionumber.aspx?id=106404&ver=2&trm=life+cycle+metabolism&org=

[4] A. McMichael and P. Bowness, 'HLA-B27: natural function and pathogenic role in spondyloarthritis', Arthritis Res, vol. 4, no. Suppl 3, pp. S153–S158, 2002, doi: 10.1186/ar571.

[5] I. F. Akyildiz, M. Ghovanloo, U. Guler, T. Ozkaya-Ahmadov, A. F. Sarioglu, and B. D. Unluturk, 'PANACEA: An Internet of Bio-NanoThings Application for Early Detection and Mitigation of Infectious Diseases', IEEE Access, pp. 1–1, 2020, doi: 10.1109/ACCESS.2020.3012139.



Component	Lifecycle
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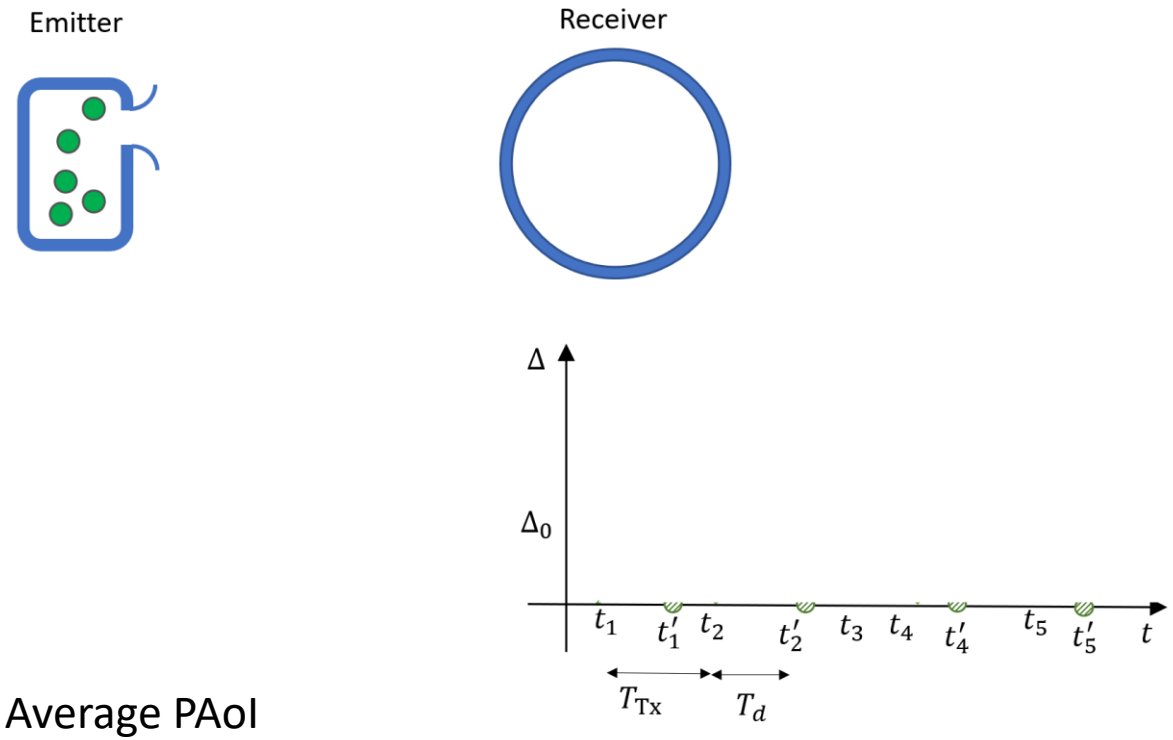
Protein HLA-B27 [3]	4 hours [4]
Bacteria P. Aeruginosa	1.5 – 2 hours [5]

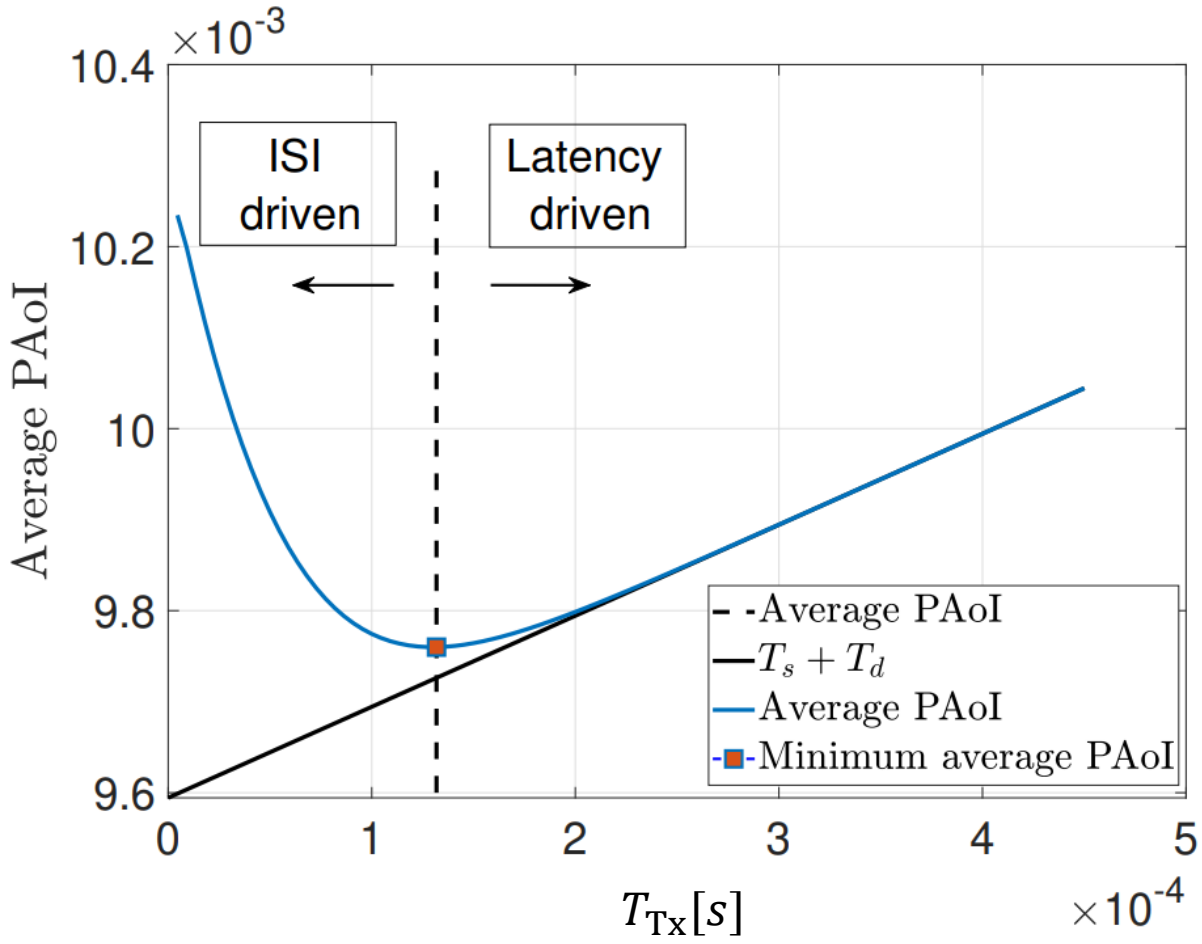
Molecular Communication Channels



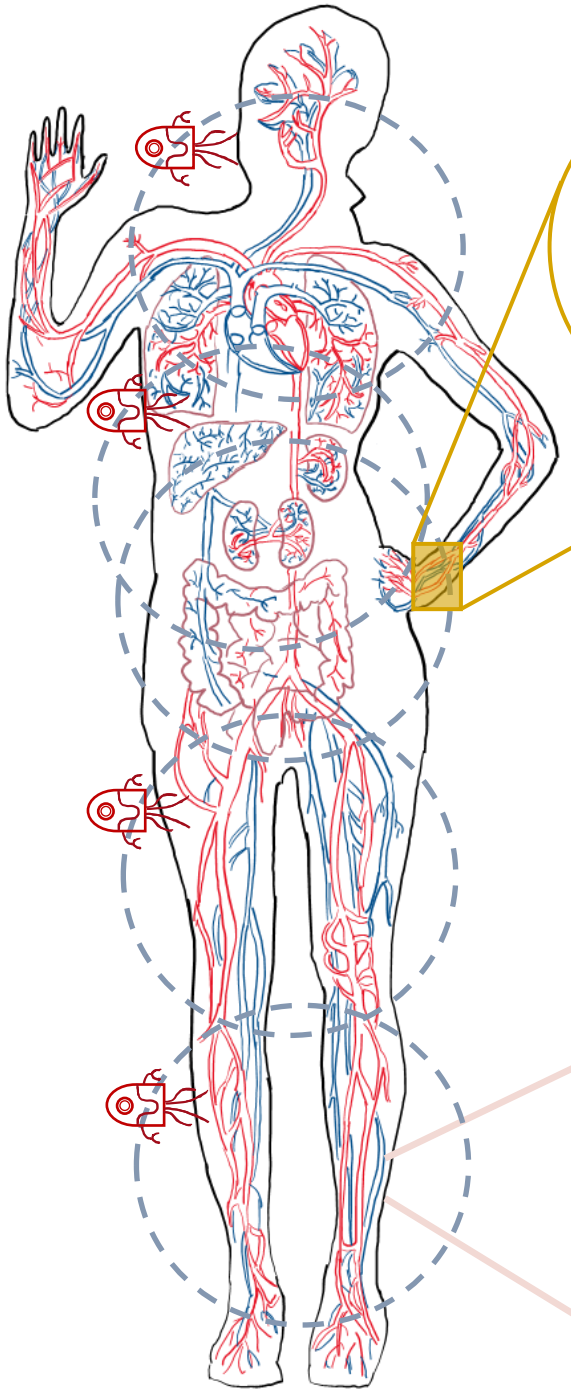
Average PAoI

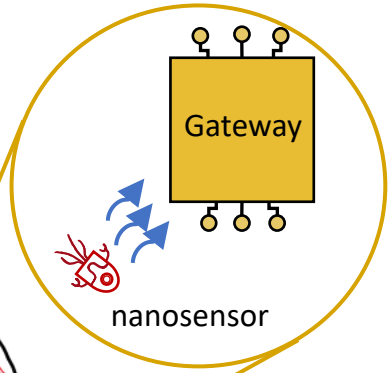
$$\Delta^{(p)} = \frac{1}{T}\sum_{i=1}^{N(t)} A_i = \mathbb{E}[T_{\mathrm{Tx}}] + \mathbb{E}[T_d] \qquad (1)$$

$$= T_{\mathrm{Tx}} + \frac{1}{1-p_e}\frac{d^2}{6D} \qquad (2)$$

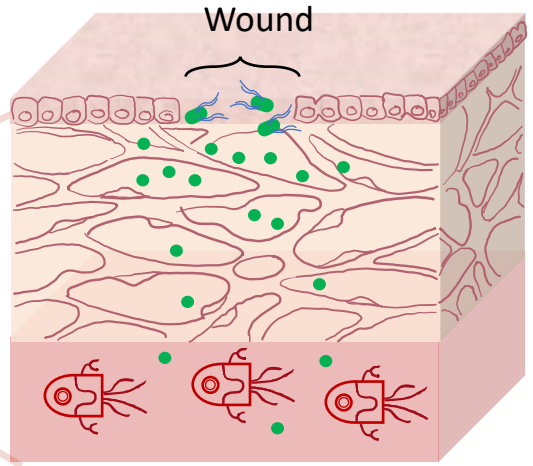


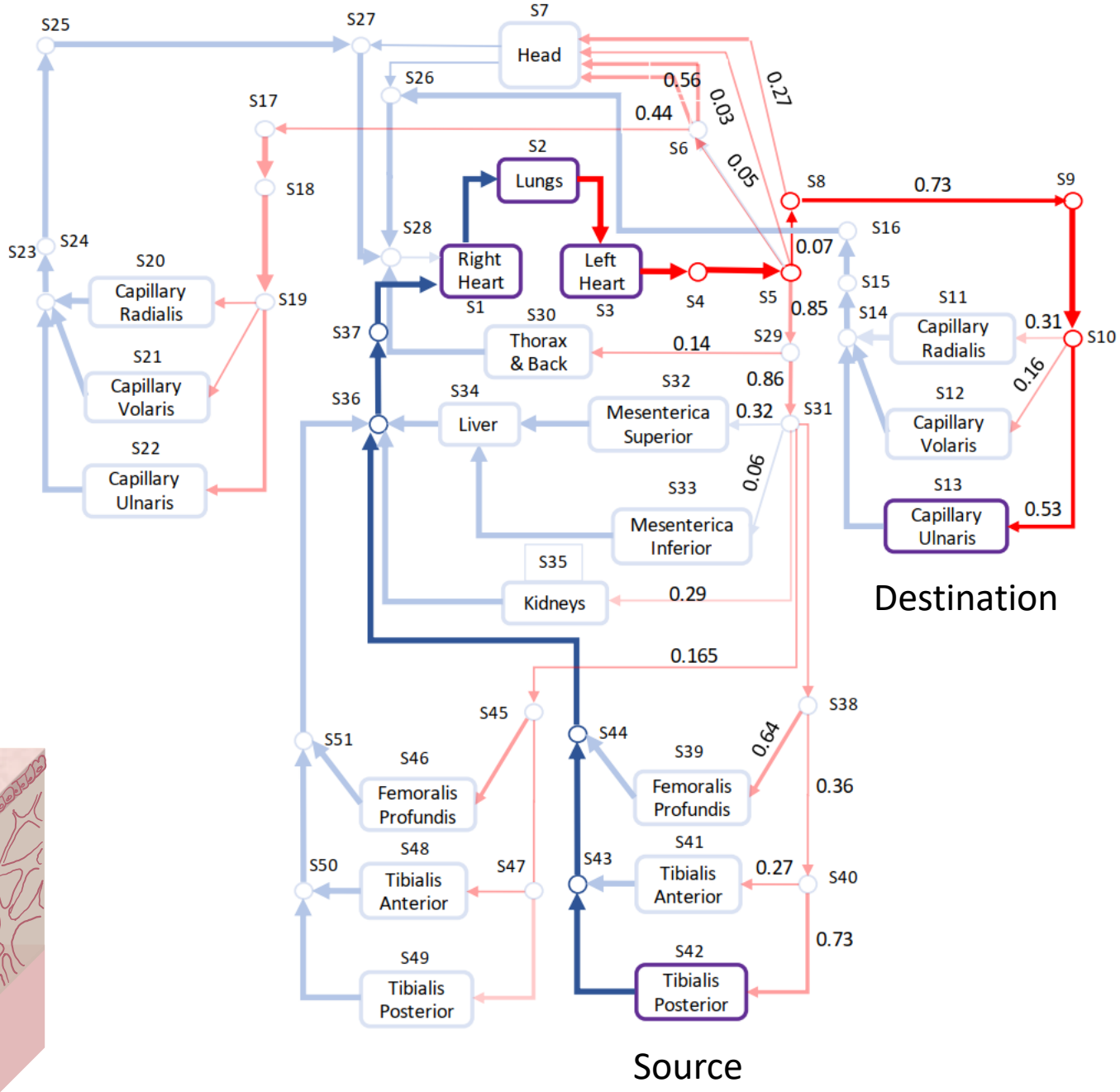
[1] Jorge Torres Gómez, Ketki Pitke, Lukas Stratmann and Falko Dressler, "Age of Information in Molecular Communication Channels," Elsevier Digital Signal Processing (DSP), Special Issue on Molecular Communication, vol. 124, pp. 103108, May 2022.

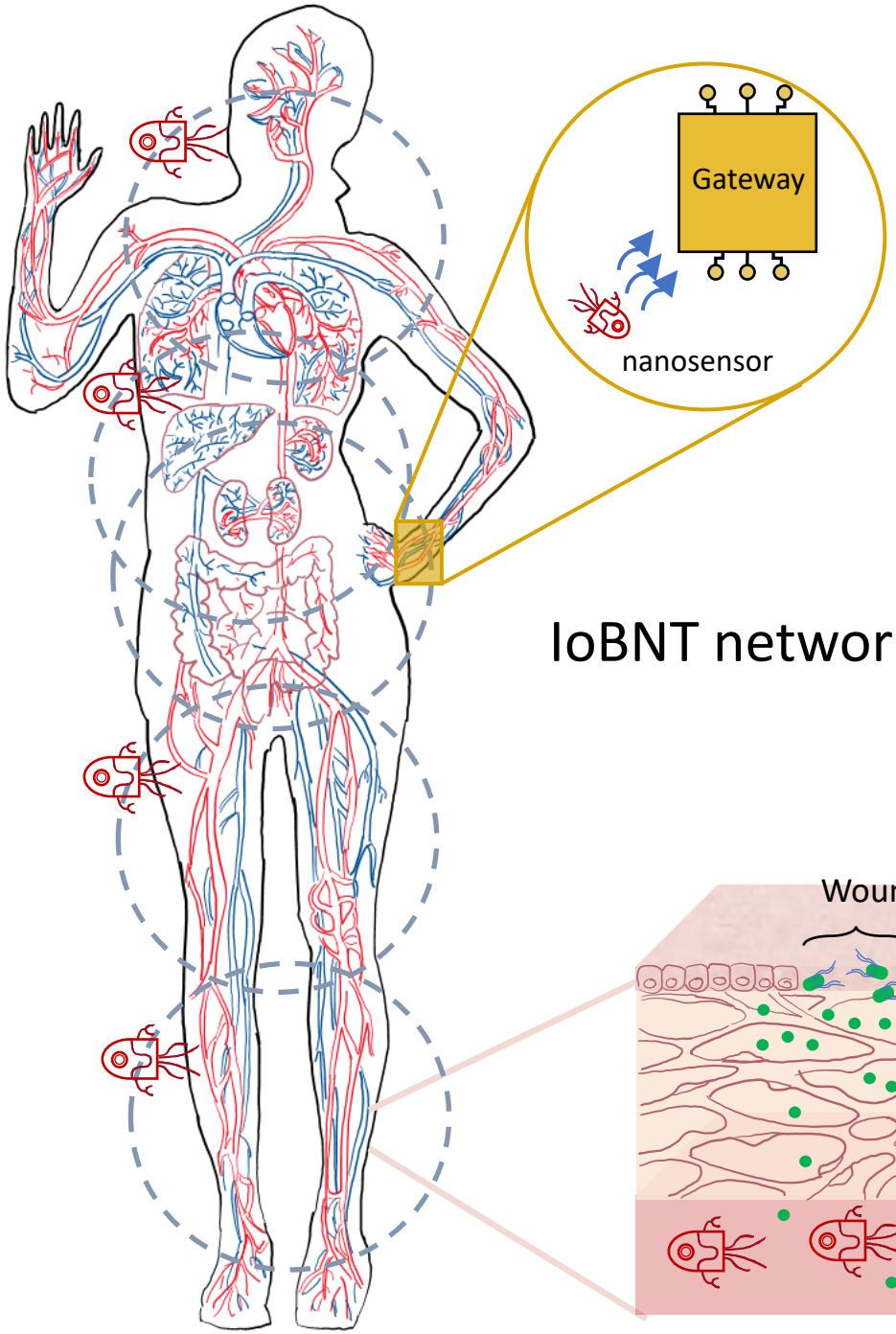




IoBNT network







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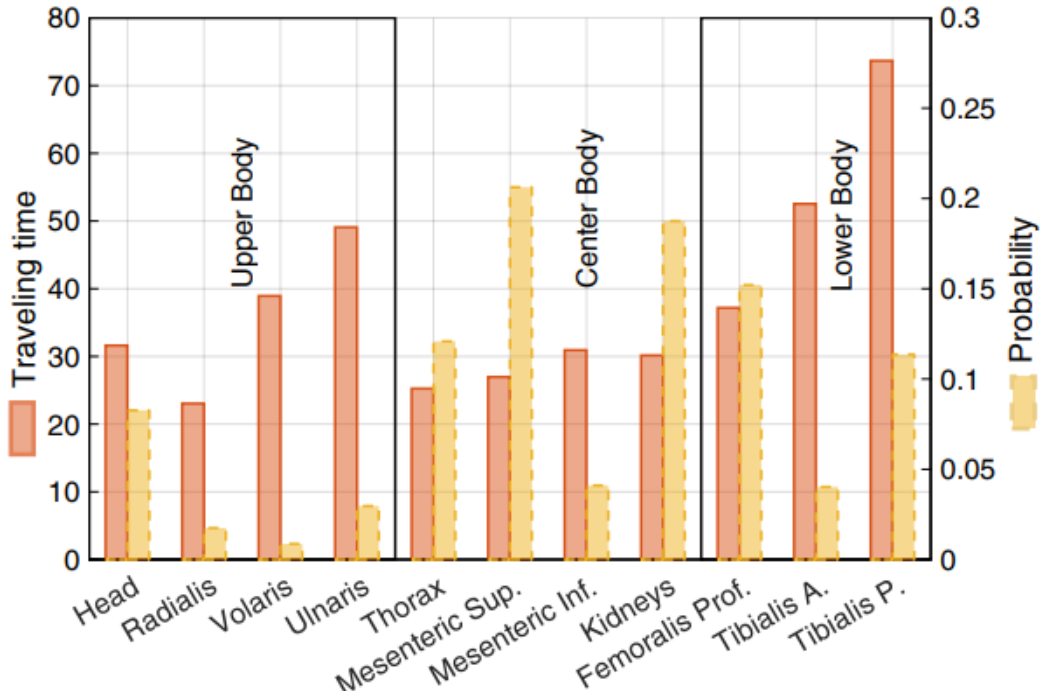

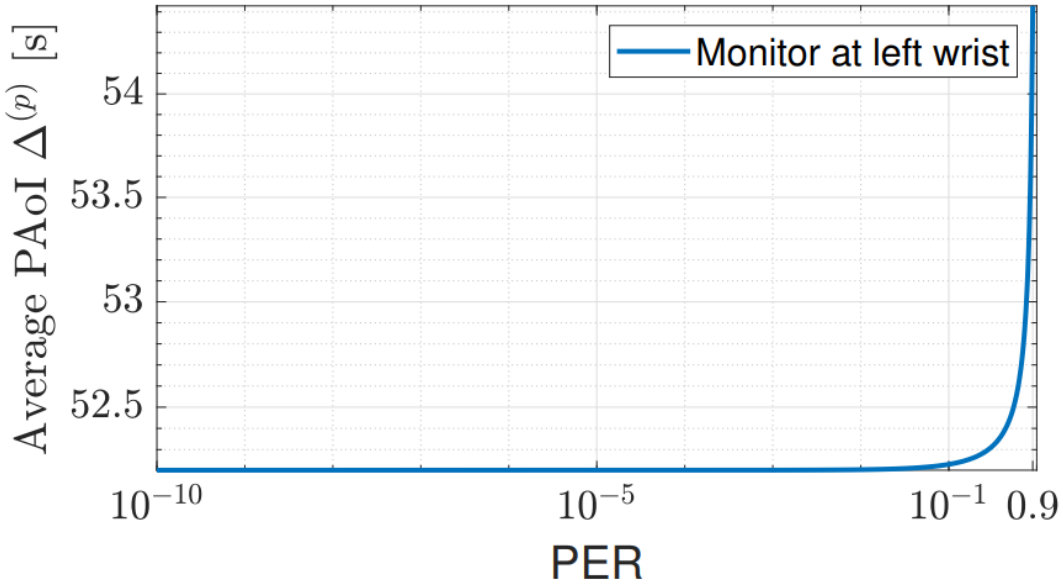

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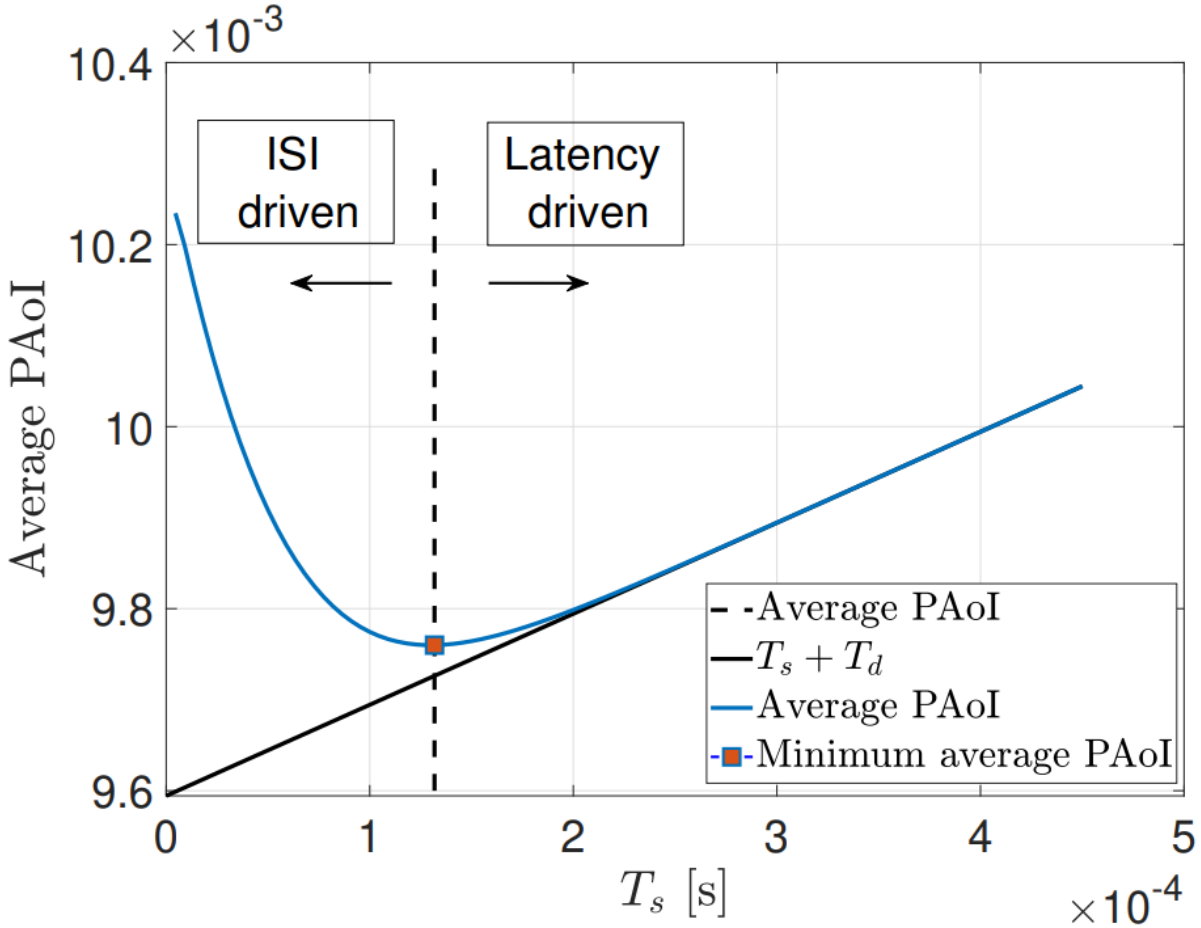
Research Directions: Age of Information

Thermodynamic limits

- Unit of information vs Energy
- Unit of AoI vs Energy



[1] Andrew W. Eckford, Benjamin Kuznets-Speck, Michael Hinczewski, and Peter J. Thomas. 2018. Thermodynamic Properties of Molecular Communication. In IEEE International Symposium on Information Theory (ISIT 2018). IEEE, Vail, CO. https://doi.org/10.1109/isit.2018.8437793

Part II: Domain Specific Applications

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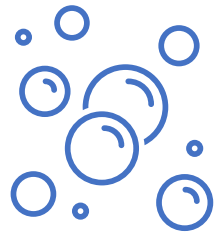
Vehicular Networks

Satellite Networks



Molecular Communications

[1] N. Pappas, M. A. Abd-Elmagid, B. Zhou, W. Saad, and H. S. Dhillon, *Age of Information: Foundations and Applications*. Cambridge University Press, 2023.