

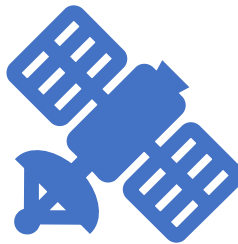
Jorge Torres Gómez
TU Berlin

Nikolaos Pappas
University of Linköping

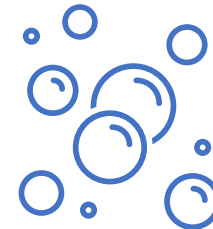
Part II: Domain Specific Applications



Vehicular Networks

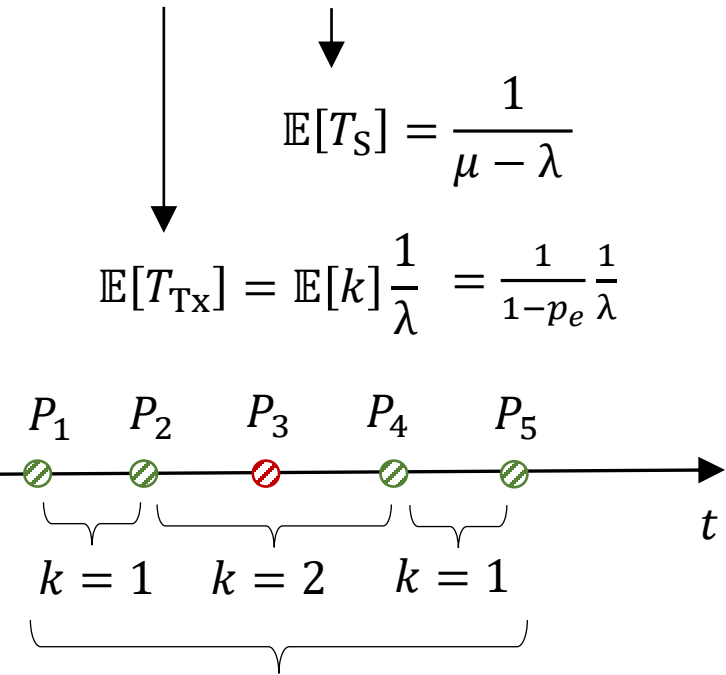
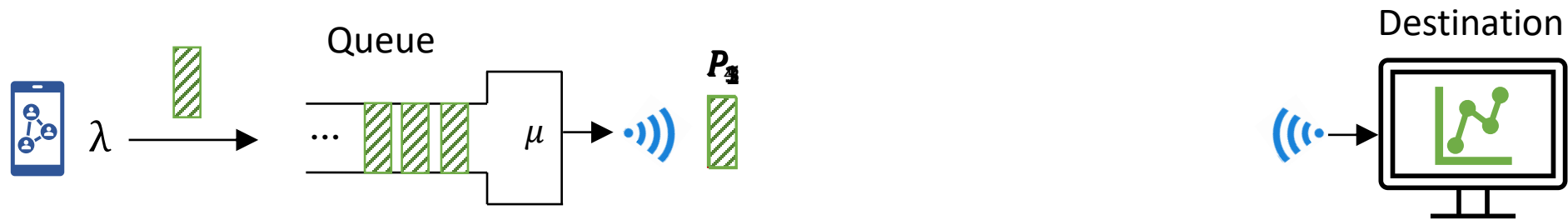


Satellite Networks

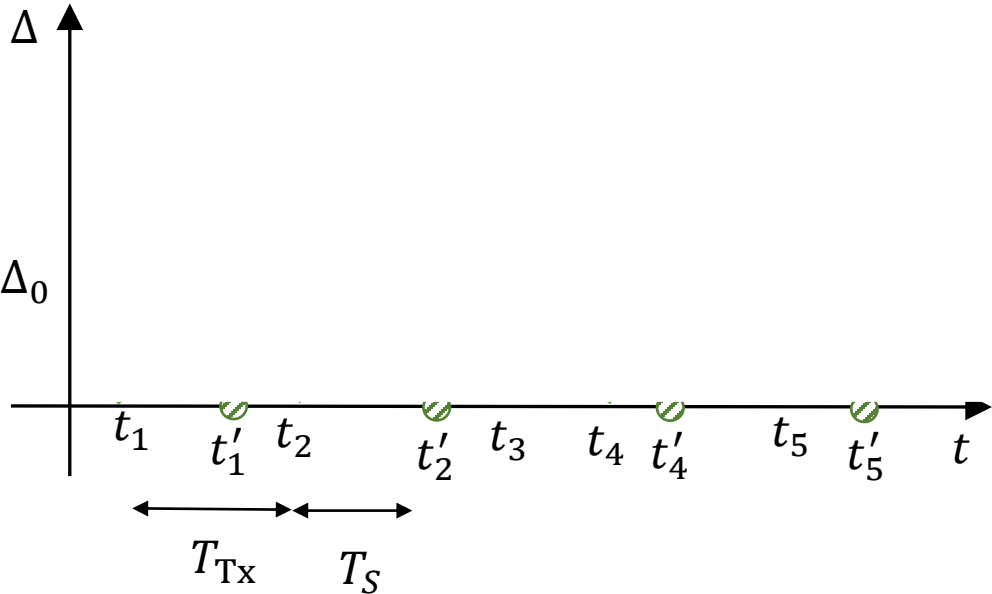


Molecular Communications

Erasure channels



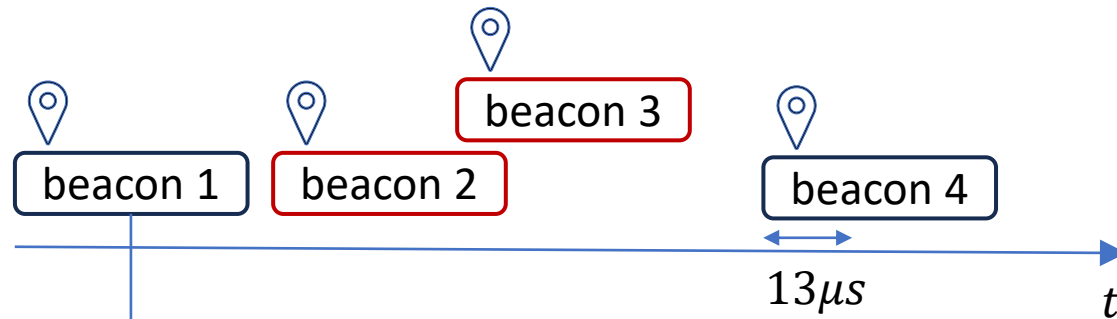
The random variable k follows a negative binomial distribution



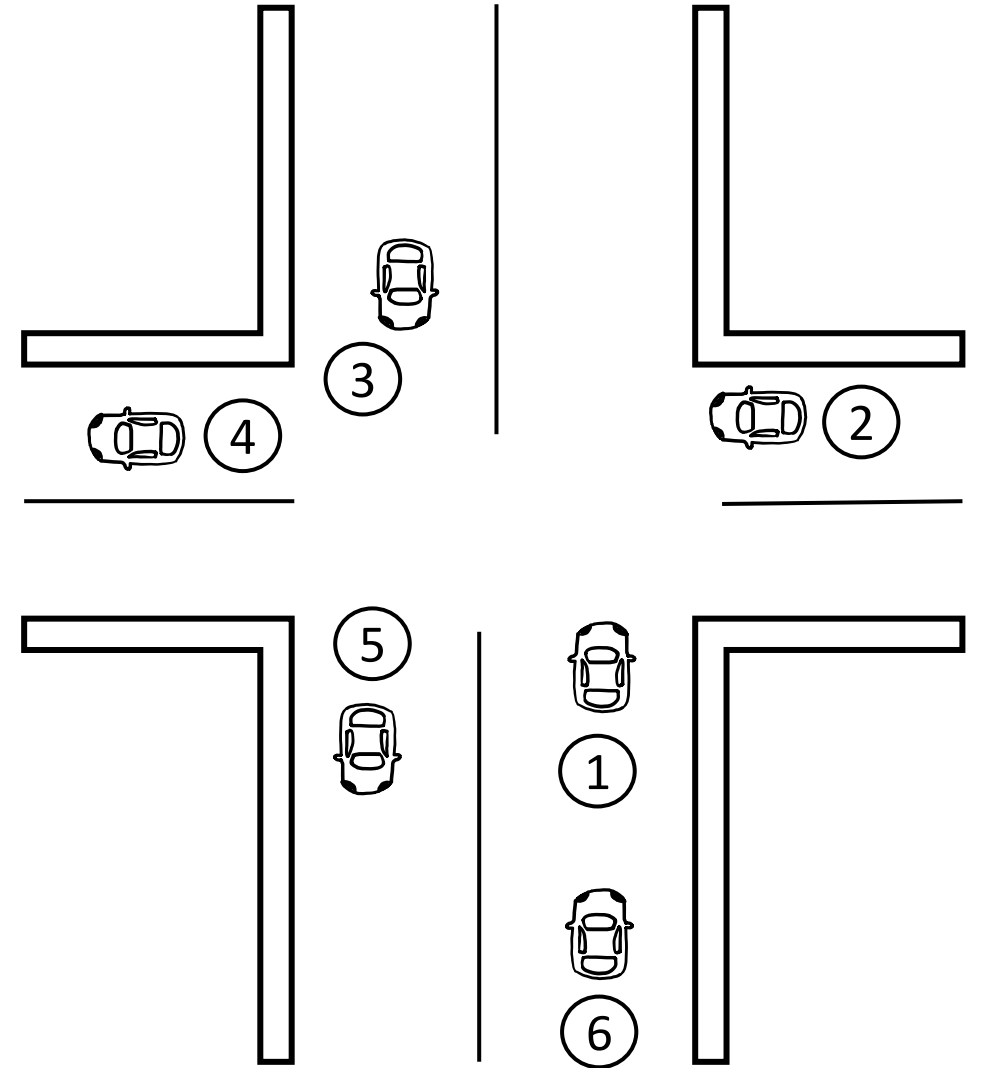
$$\Delta^{(p)} = \frac{1}{N(t)} \sum_{i=1}^{N(t)} A_i = \mathbb{E}[T_{Tx}] + \mathbb{E}[T_S]$$

[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.

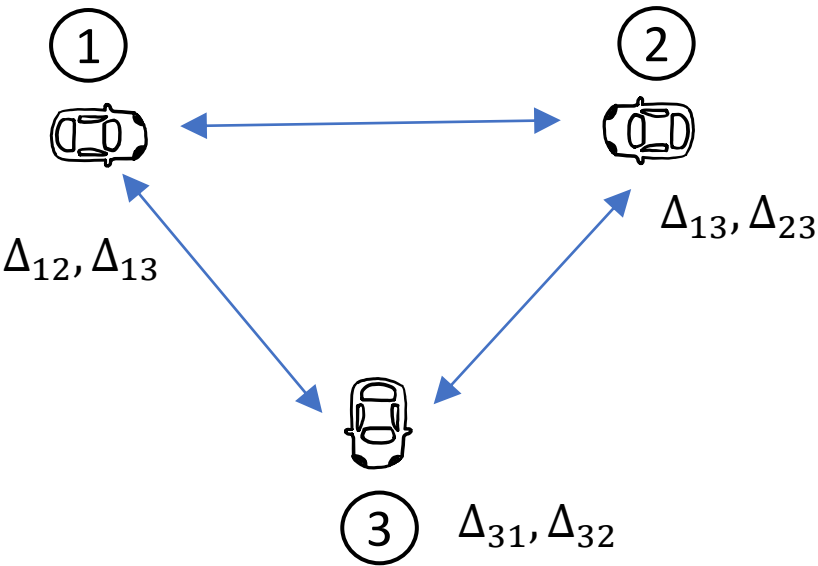
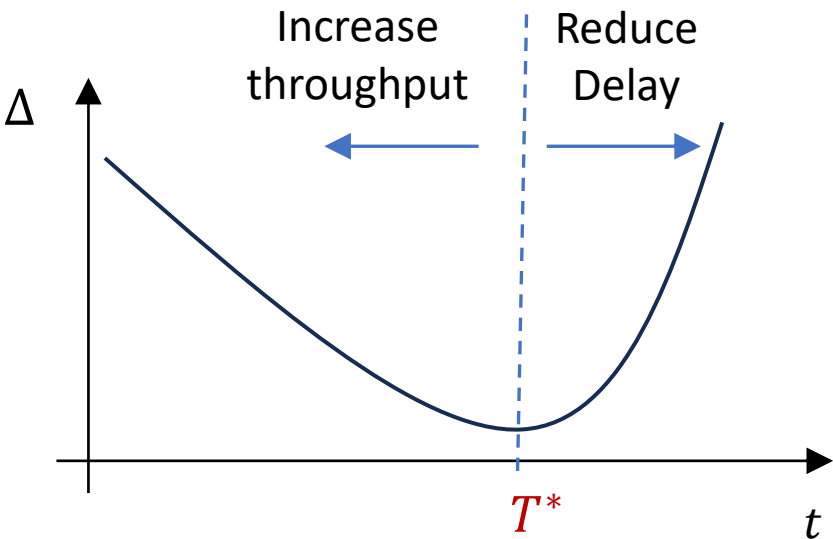
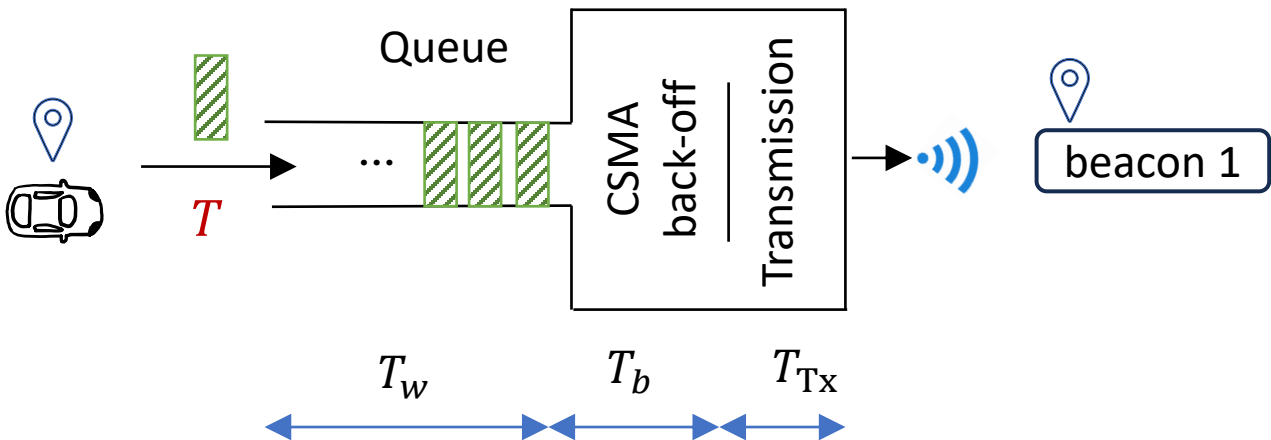
Vehicular Networks (VANETS)



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



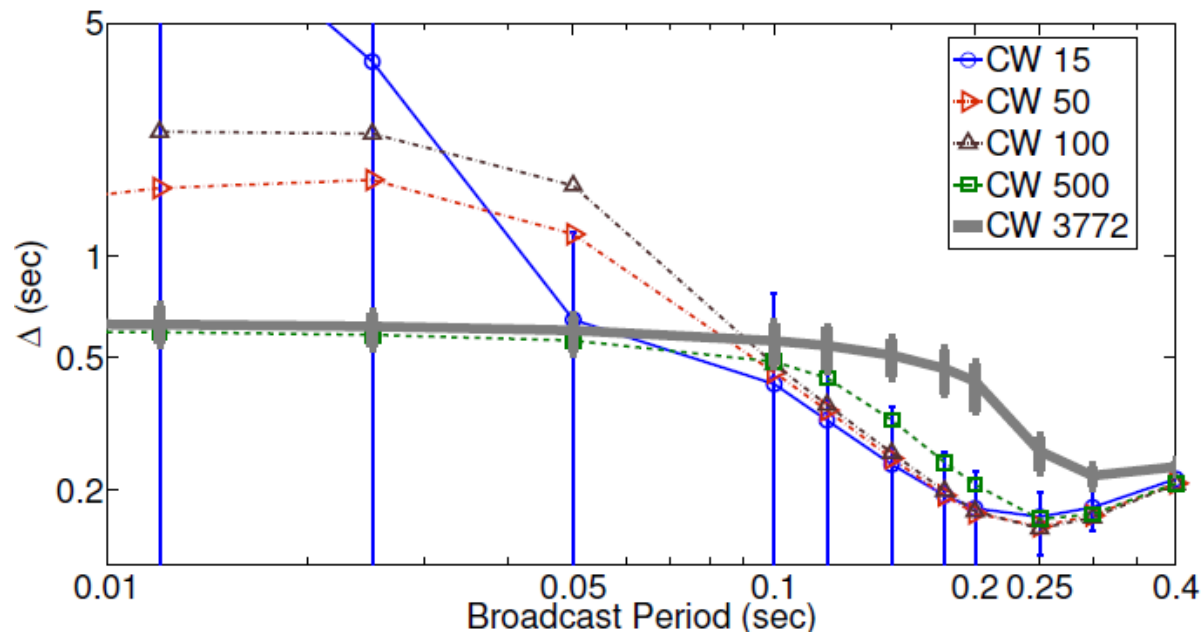
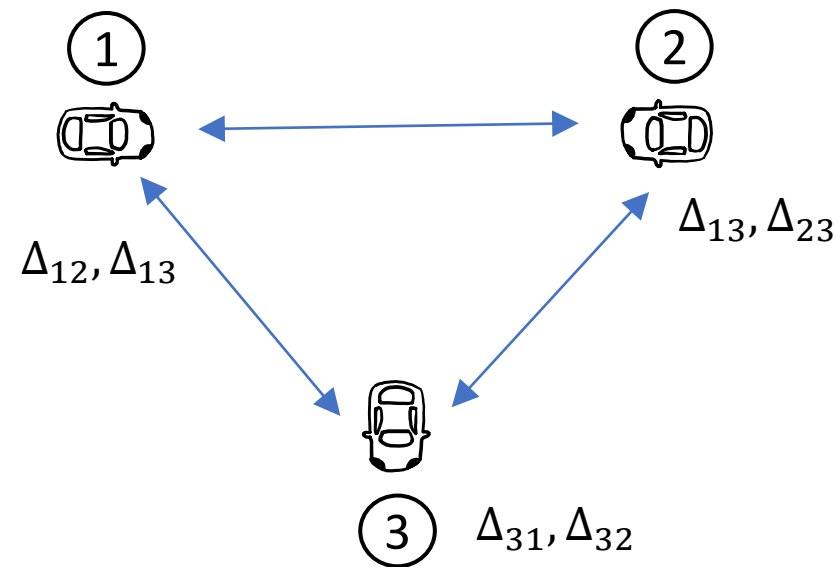
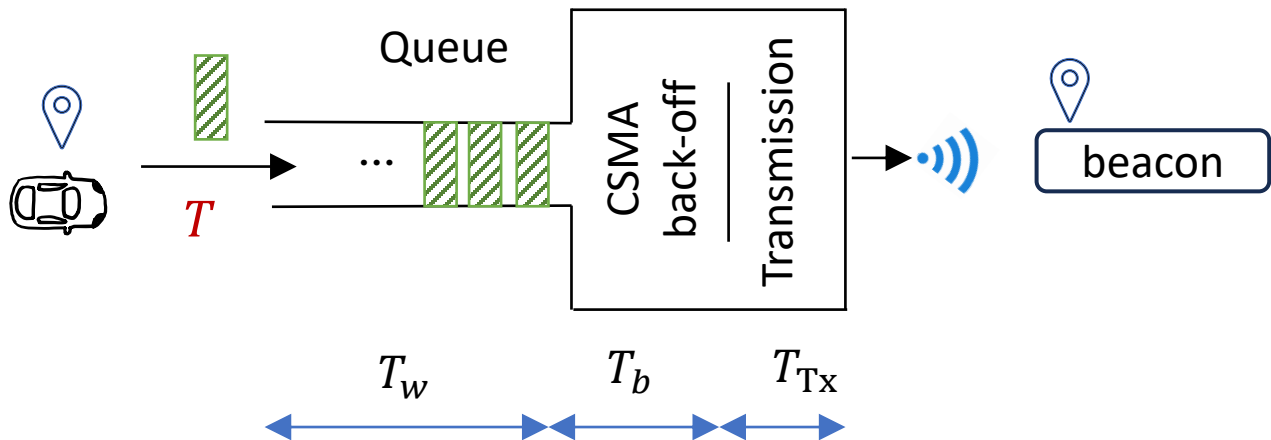
Vehicular Networks (VANETS)



System Age

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

Vehicular Networks (VANETS)



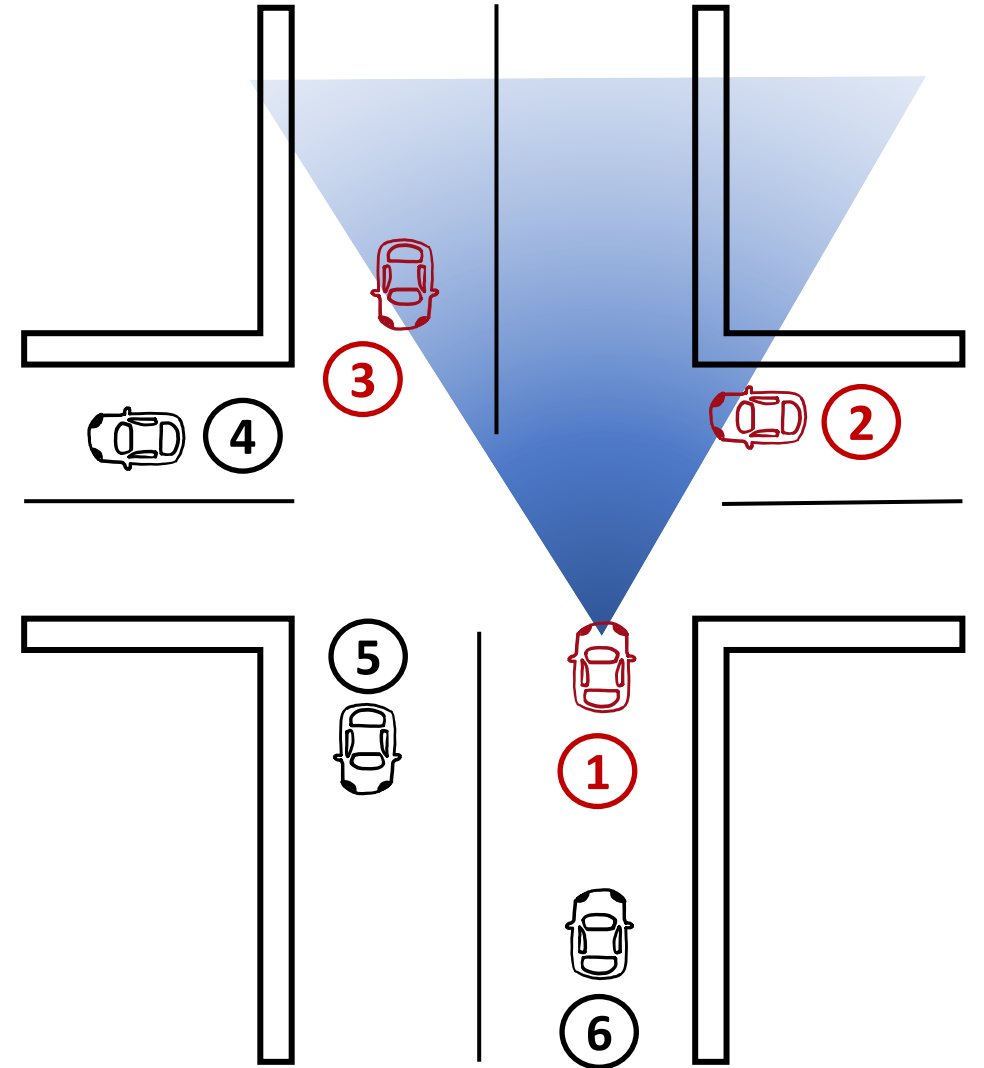
System Age

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

Vehicular Networks at Interceptions

System Age

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

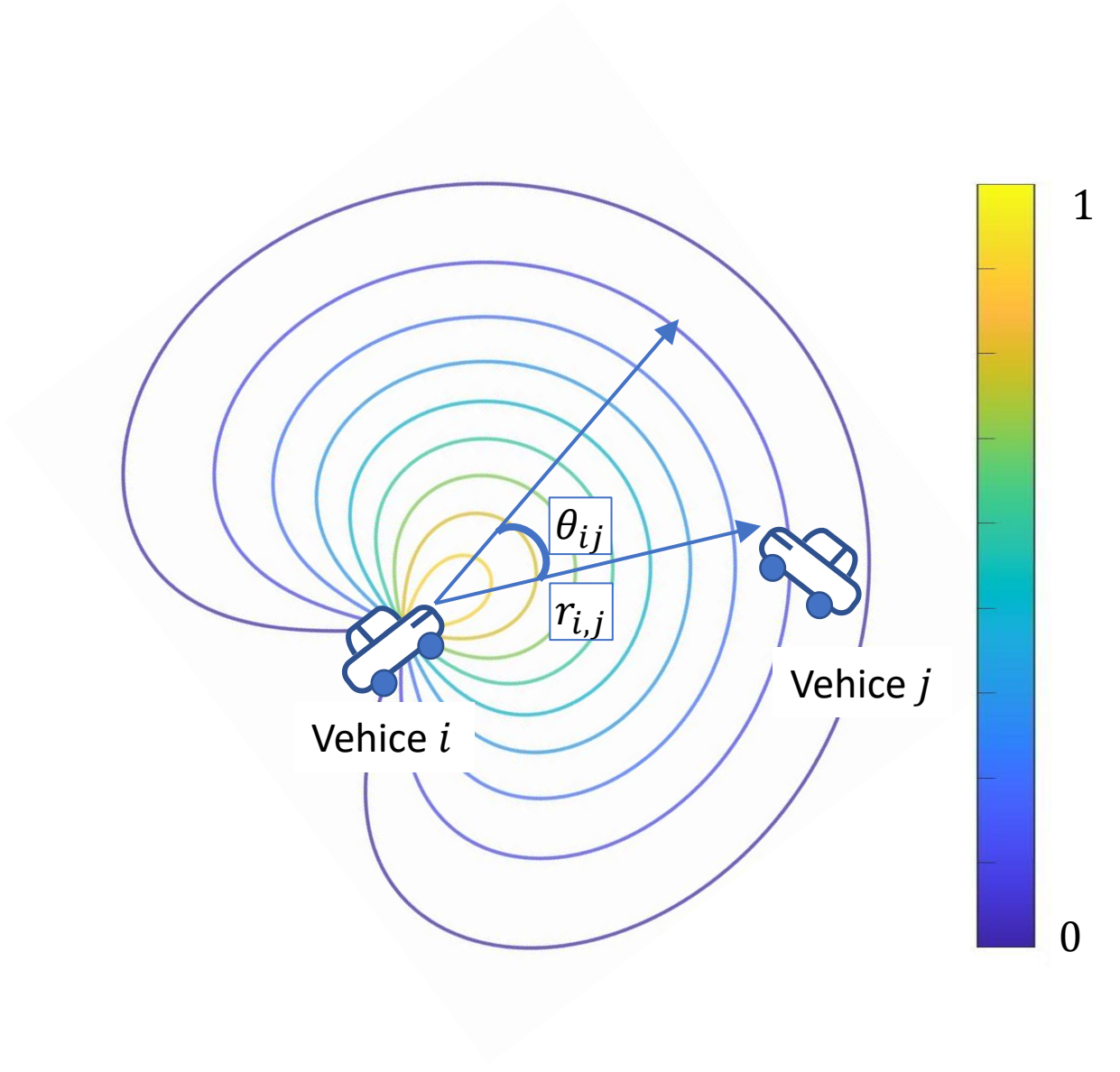


Vehicular Networks at Interceptions

System Age

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

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

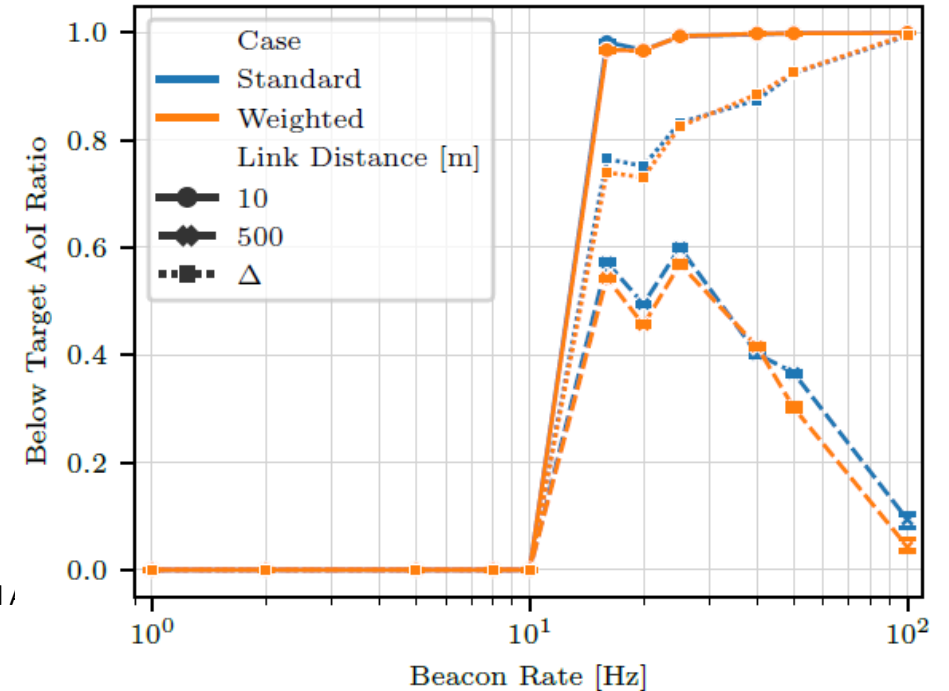
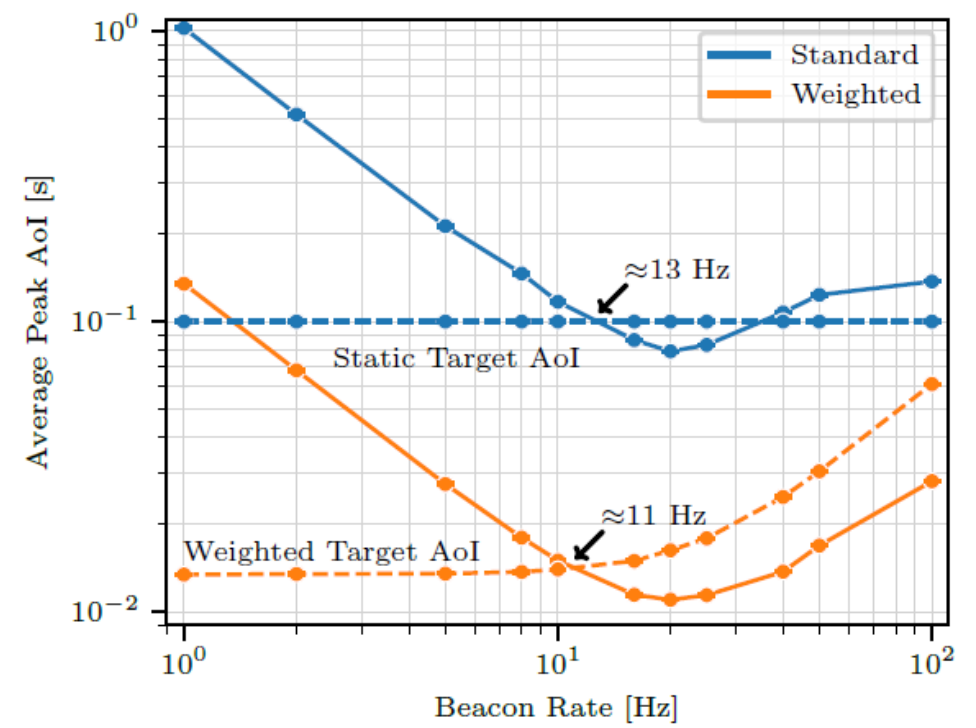


Vehicular Networks at Interceptions

System Age

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

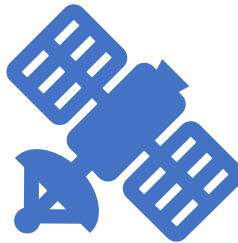
$$\omega_{u,v} = \frac{1}{2} (1 + \cos(\alpha \theta_{u,v})) e^{-\beta \|d_{u,v}\|} \quad (2)$$



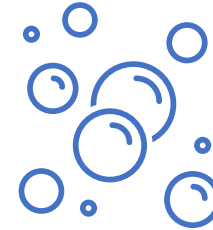
Part II: Domain Specific Applications



Vehicular Networks



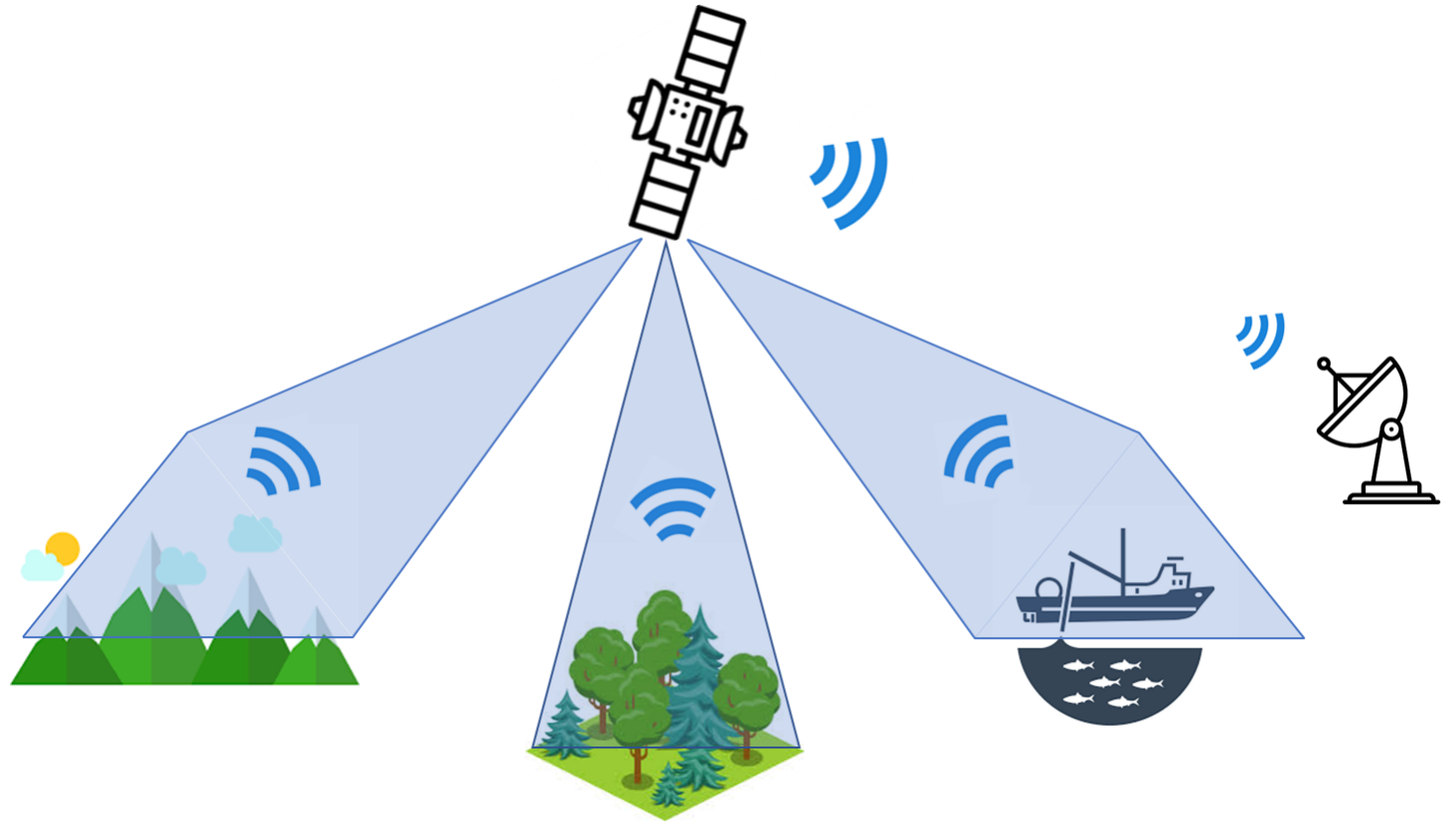
Satellite Networks



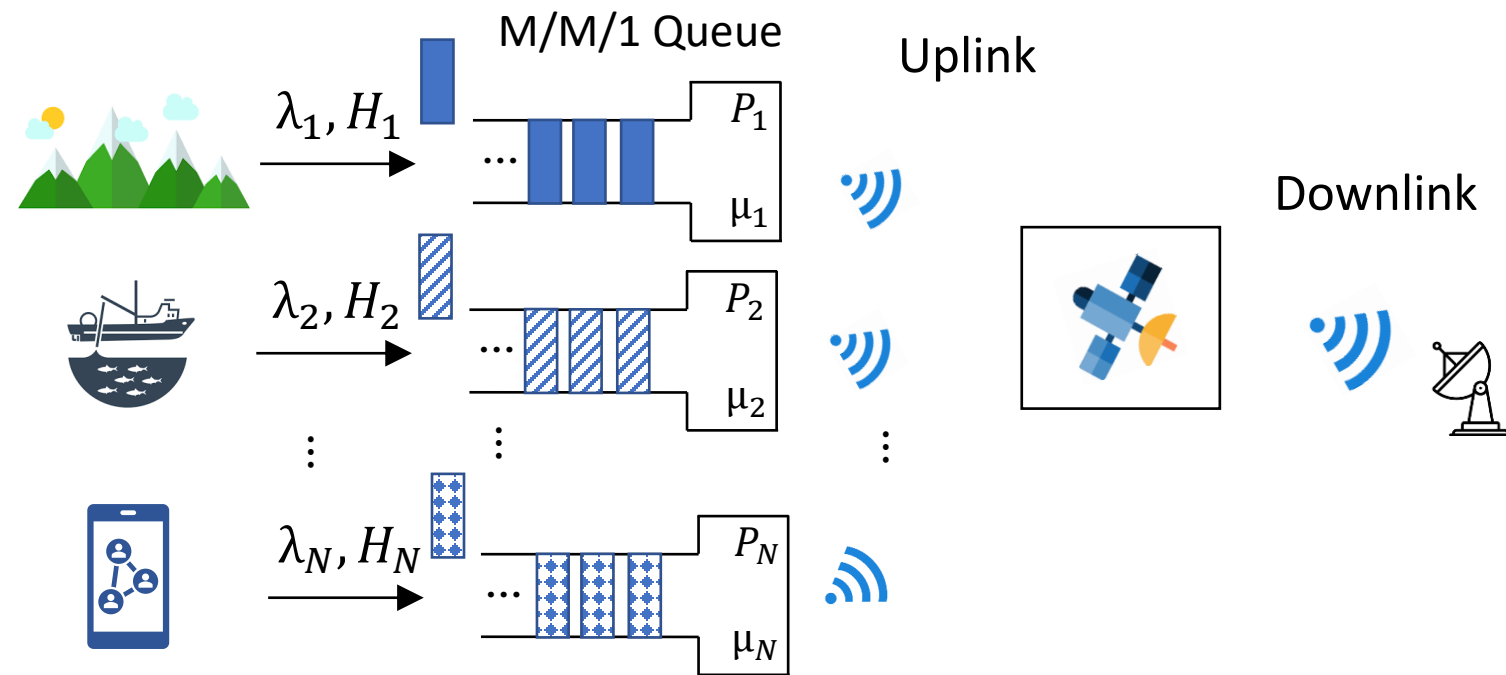
Molecular Communications

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

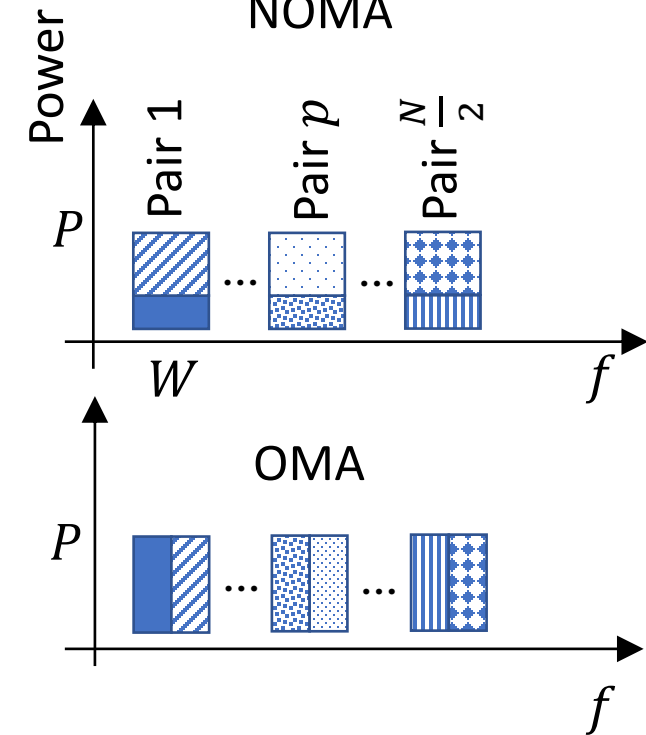


Transmitter



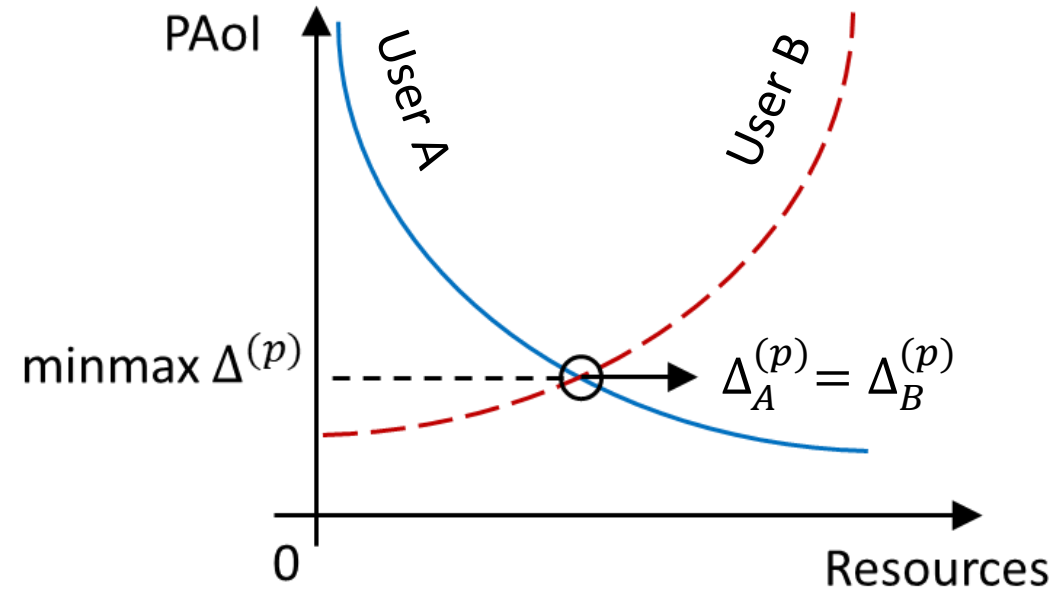
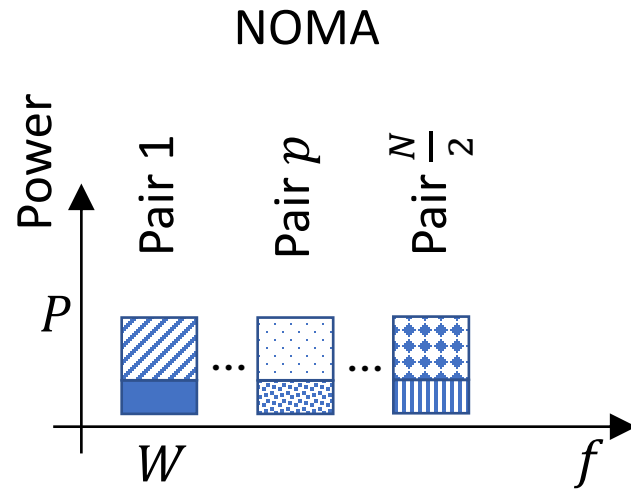
λ : rate of transmissions
 H : Source Entropy

NOMA



Problems:

- Resource allocation per frequency band.
- User pairing.

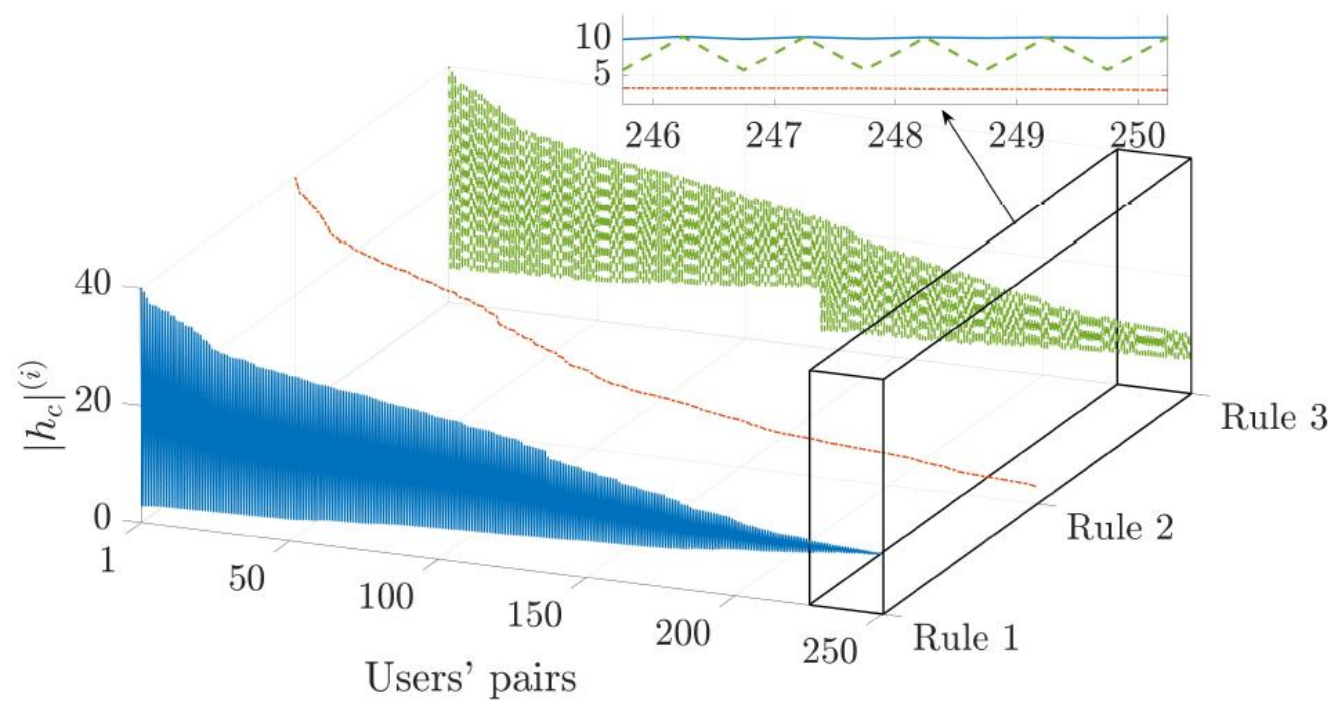
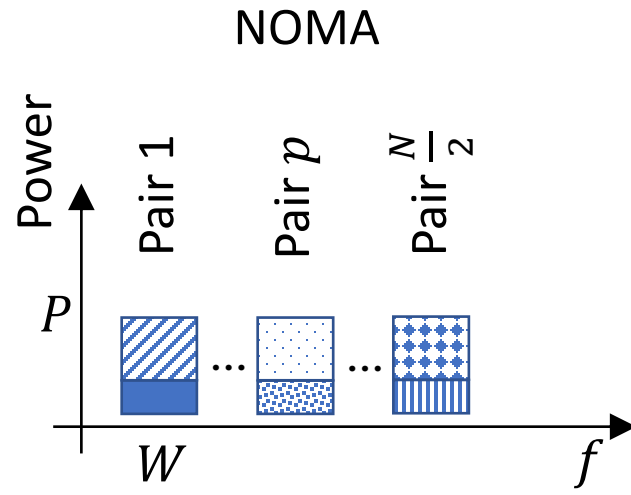


Fairness PAol: $\Delta_k^{(p)}$

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

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

[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)

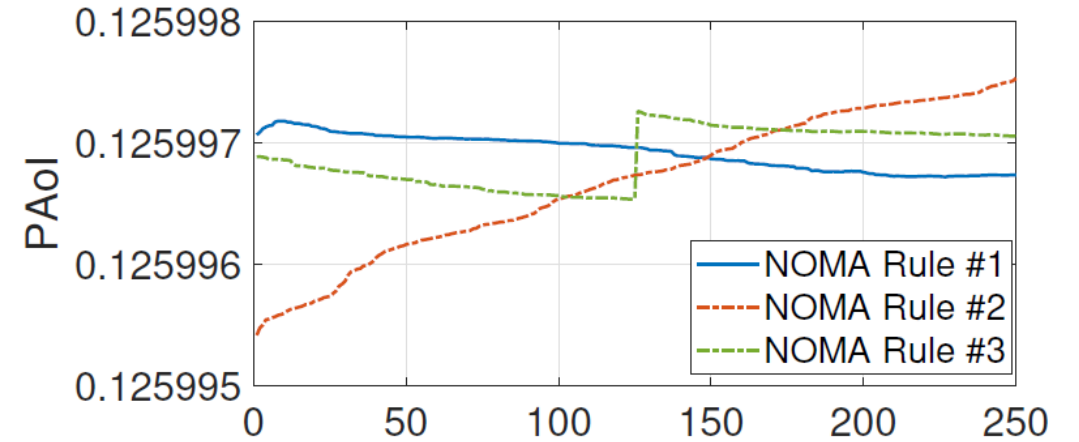


Fairness

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

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

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

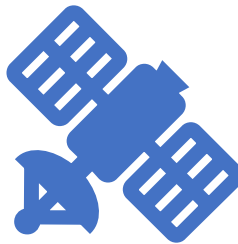


[1] Jorge Torres Gómez, Maximo Morales-Céspedes, Musbah Shaat, Ana I. Pérez Neira and Ana García Armada, "Power and Bandwidth Allocation based on Age of Information metrics in Satellite Uplink Channels," Proceedings of 21st IEEE Mediterranean Electrotechnical Conference (MELECON 2022)

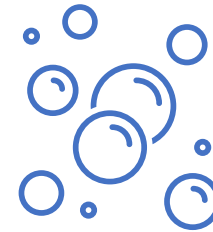
Part II: Domain Specific Applications



Vehicular Networks

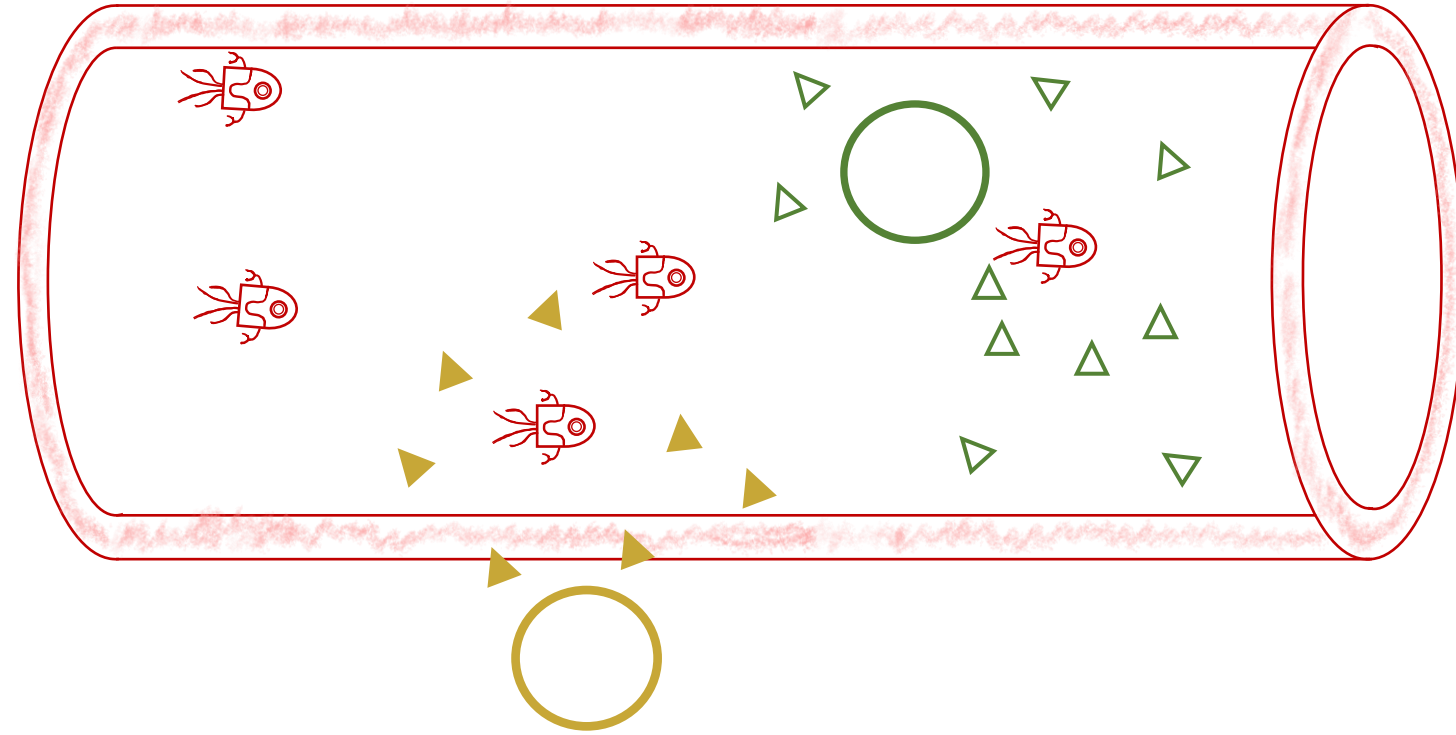
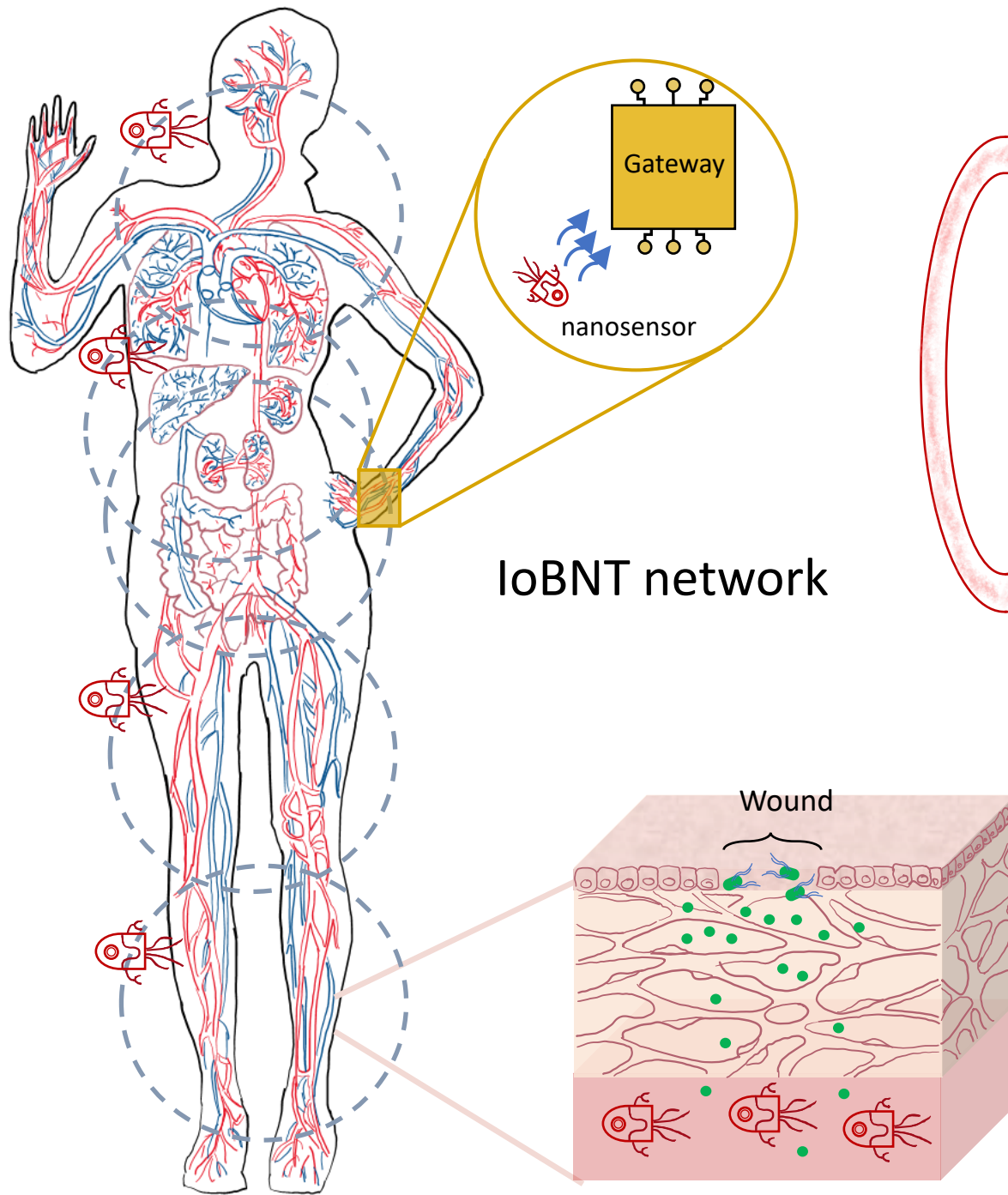


Satellite Networks

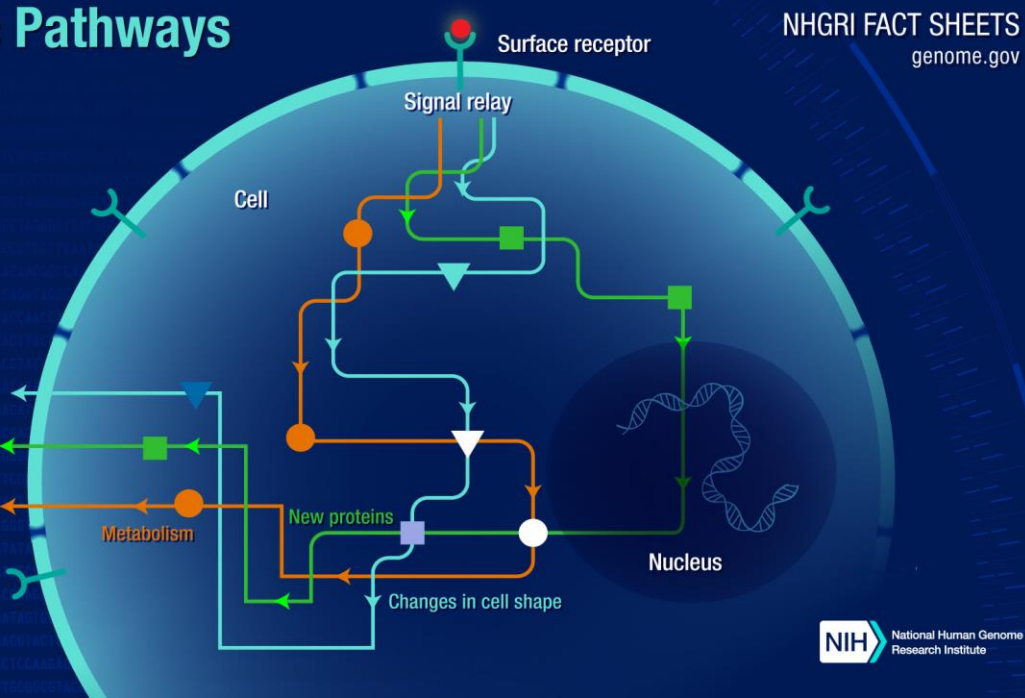


Molecular Communications

Molecular Communications



[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

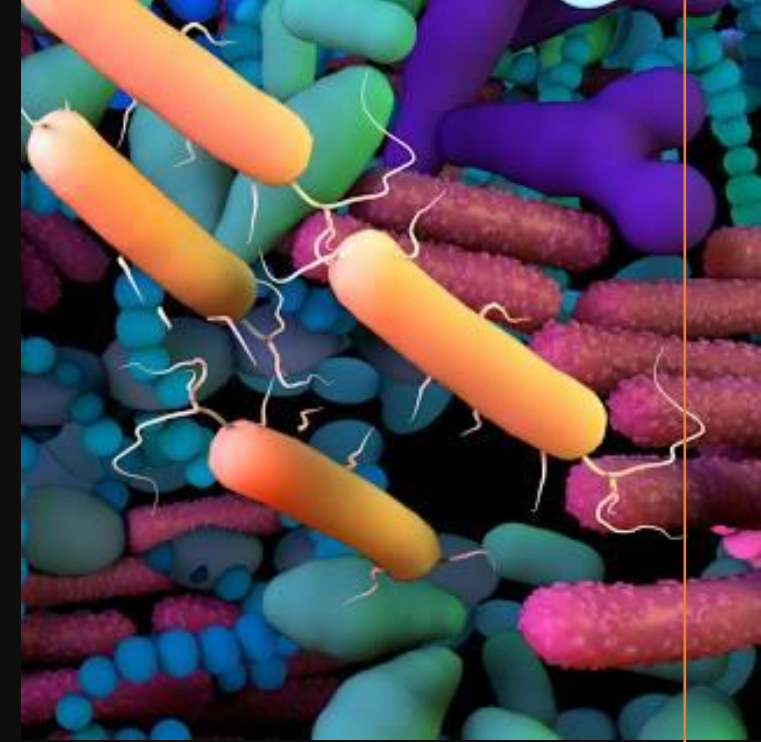
[1] <https://www.genome.gov/about-genomics/fact-sheets/Biological-Pathways-Fact-Sheet>

[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.



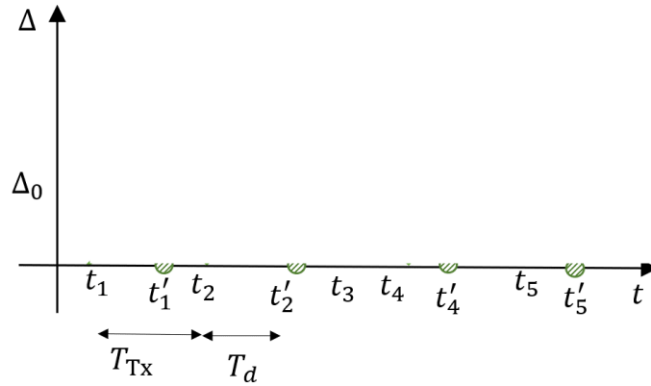
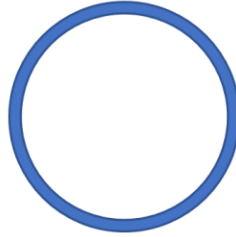
Component	Lifecycle
Mitosis HeLa cells	1.10 hours [2]
Protein HLA-B27 [3]	4 hours [4]
Bacteria P. Aeruginosa	1.5 – 2 hours [5]

Molecular Communication Channels

Emitter



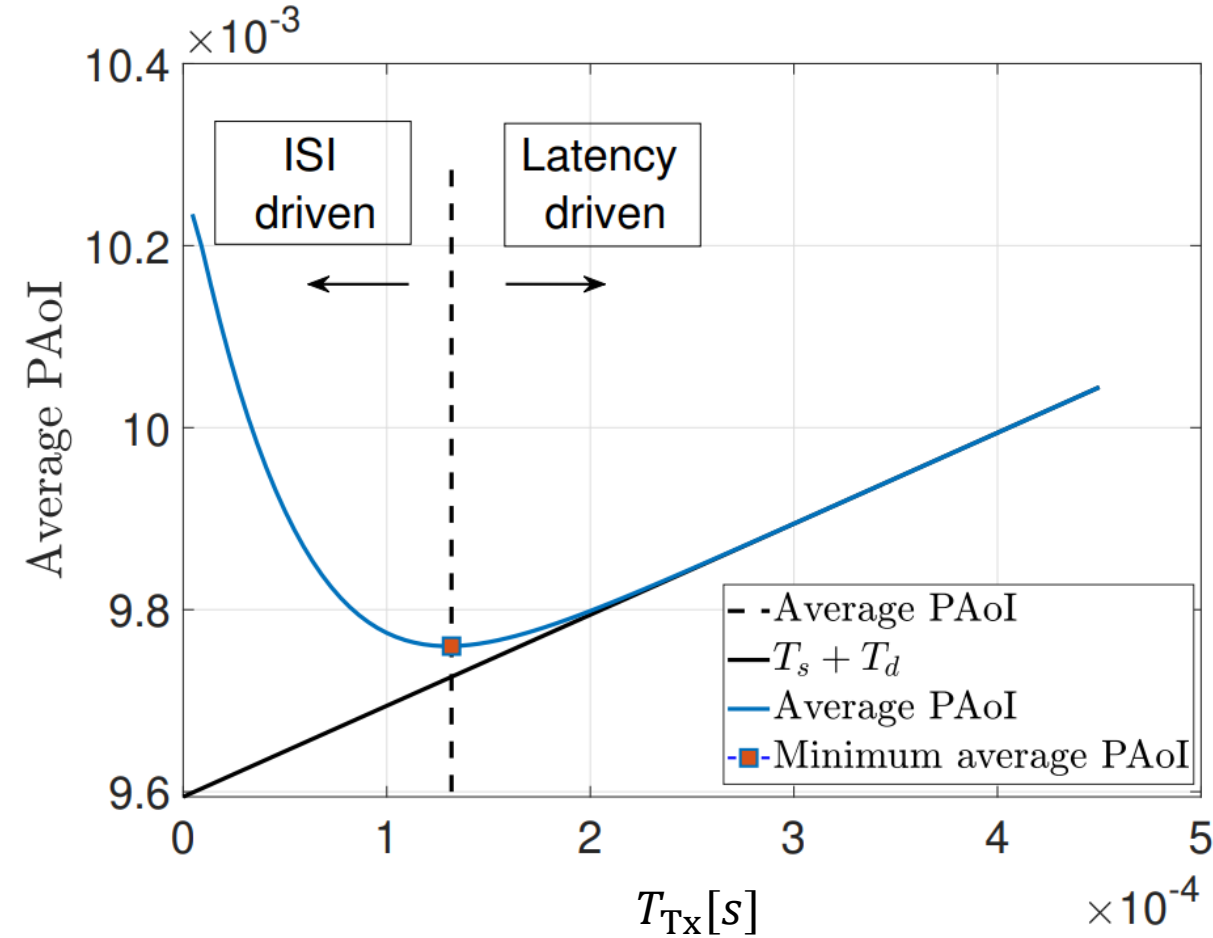
Receiver

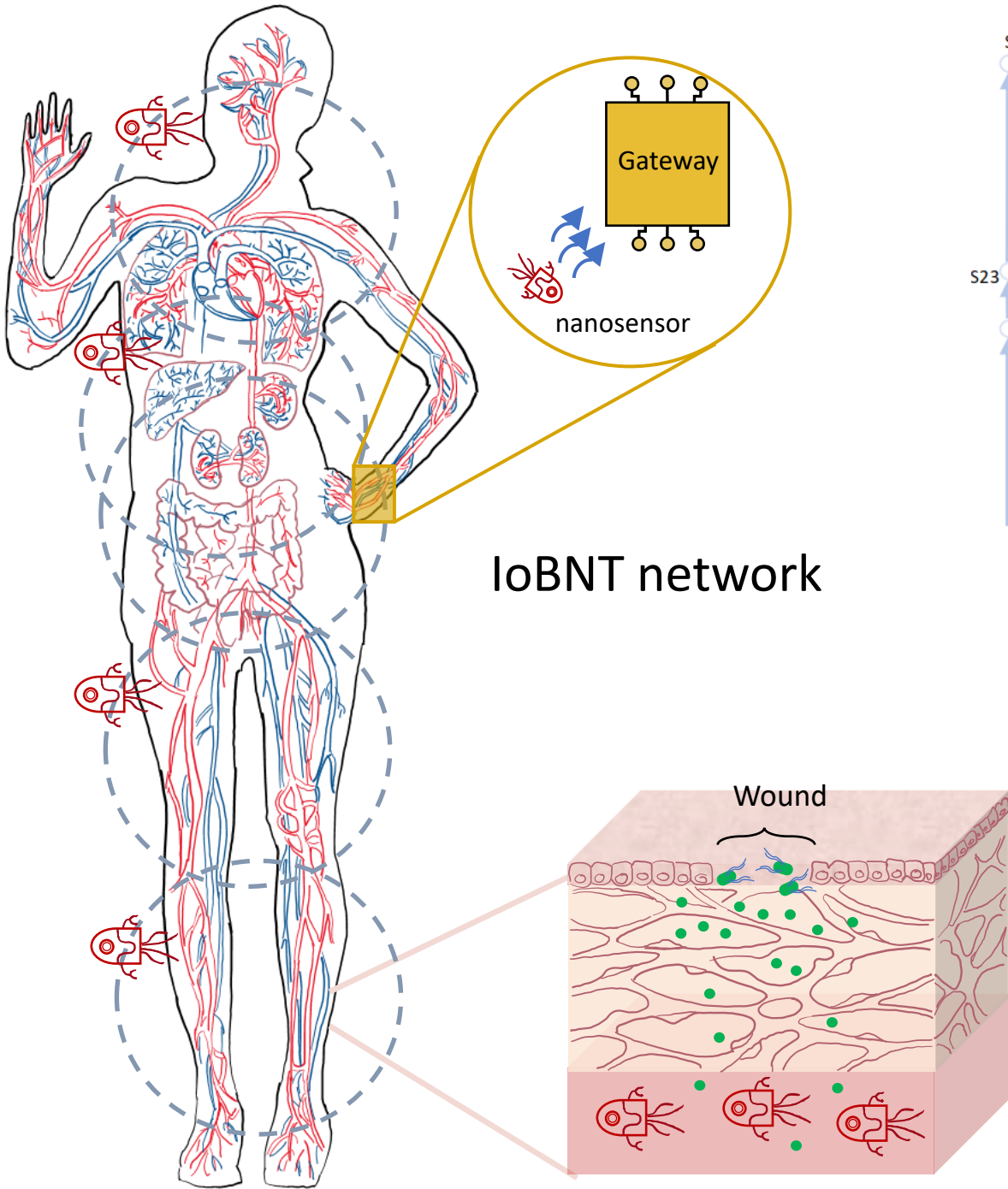


Average PAoI

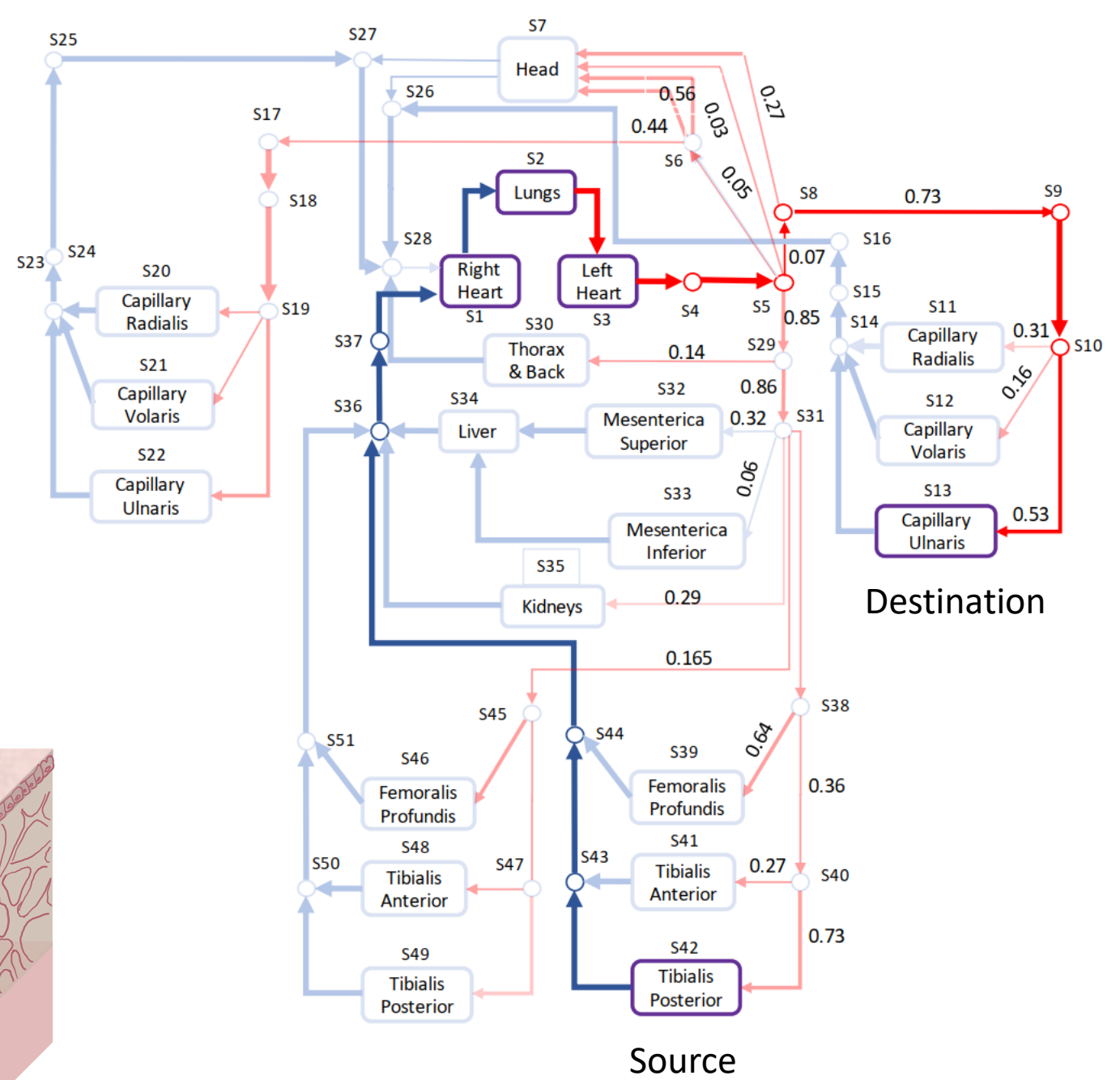
$$\Delta^{(p)} = \frac{1}{T} \sum_{i=1}^{N(t)} A_i = \mathbb{E}[T_{Tx}] + \mathbb{E}[T_d] \quad (1)$$

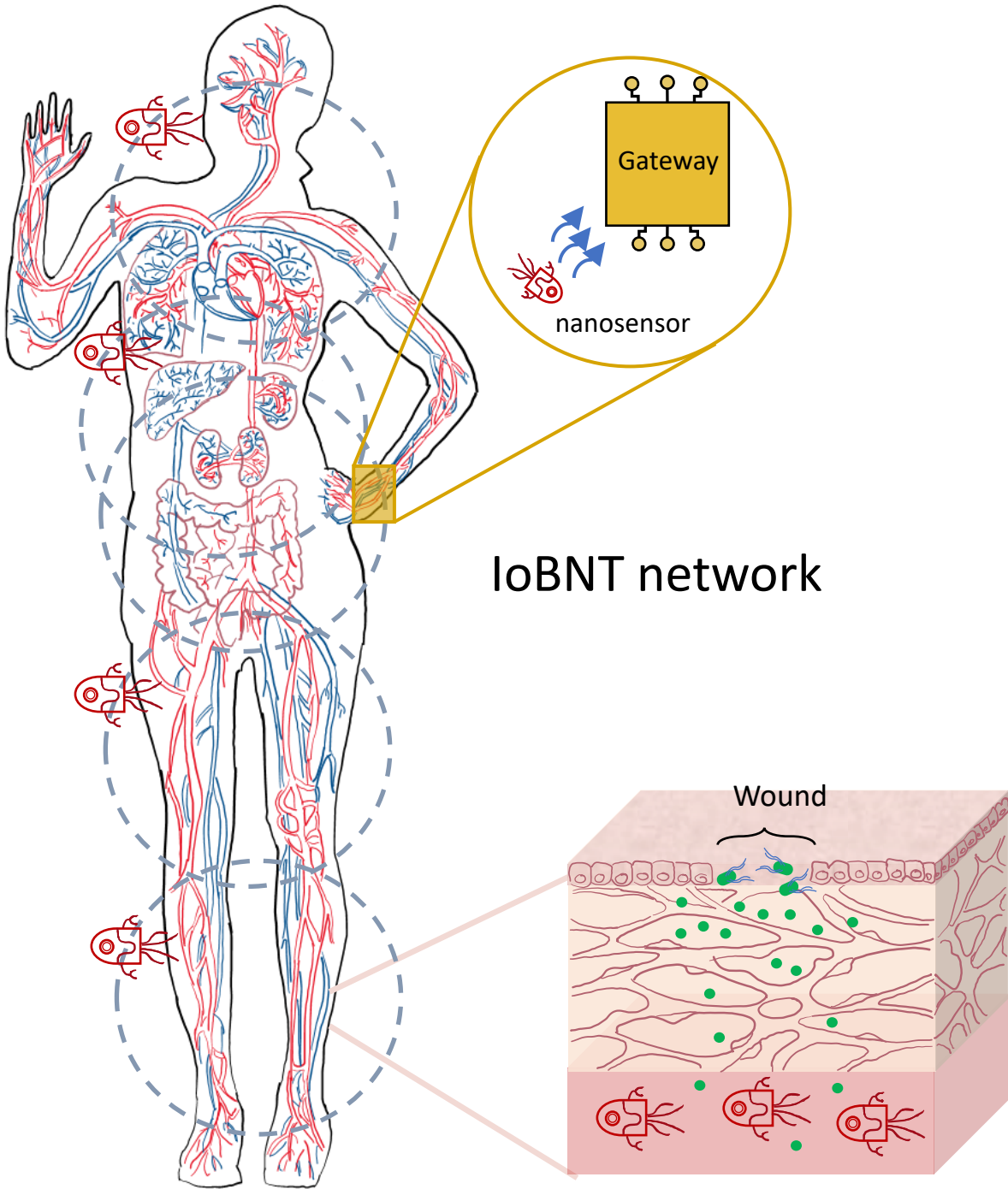
$$= T_{Tx} + \frac{1}{1 - p_e} \frac{d^2}{6D} \quad (2)$$



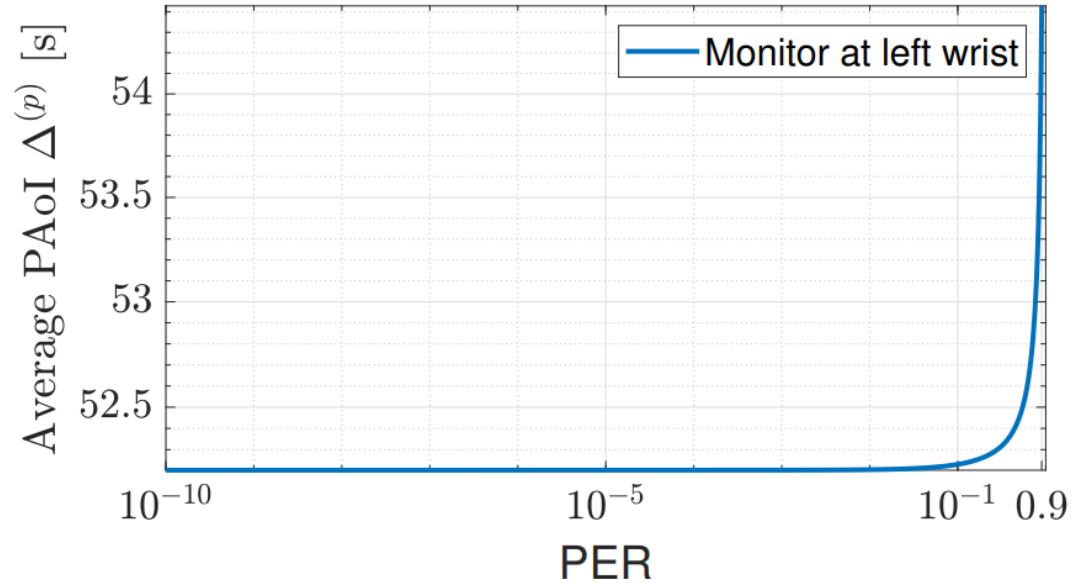
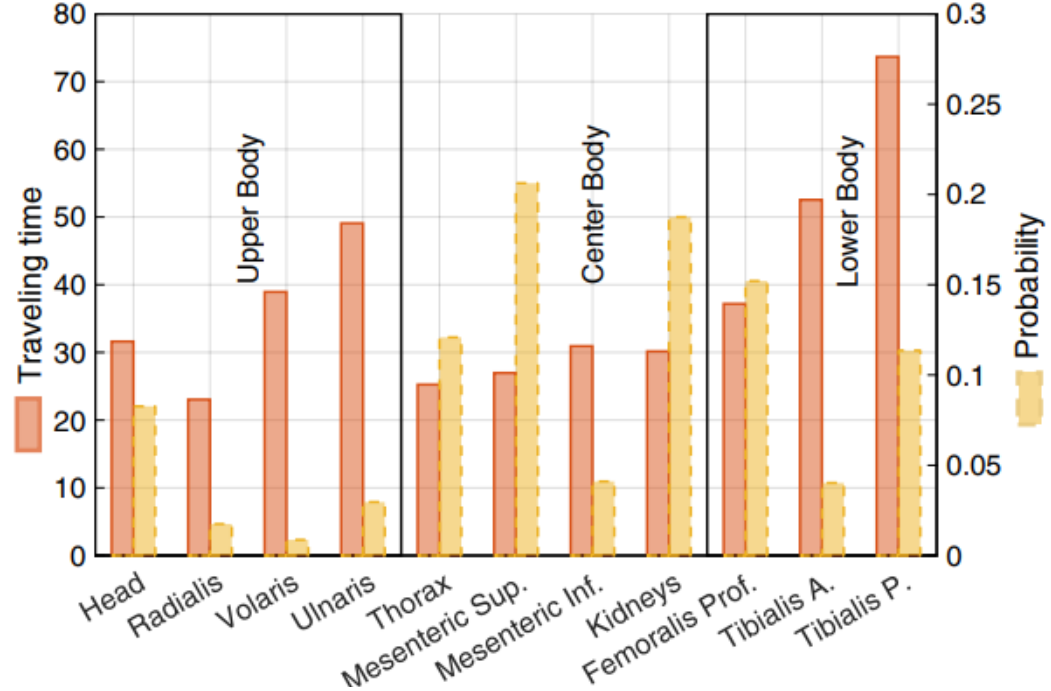


IoBNT network





IoBNT network

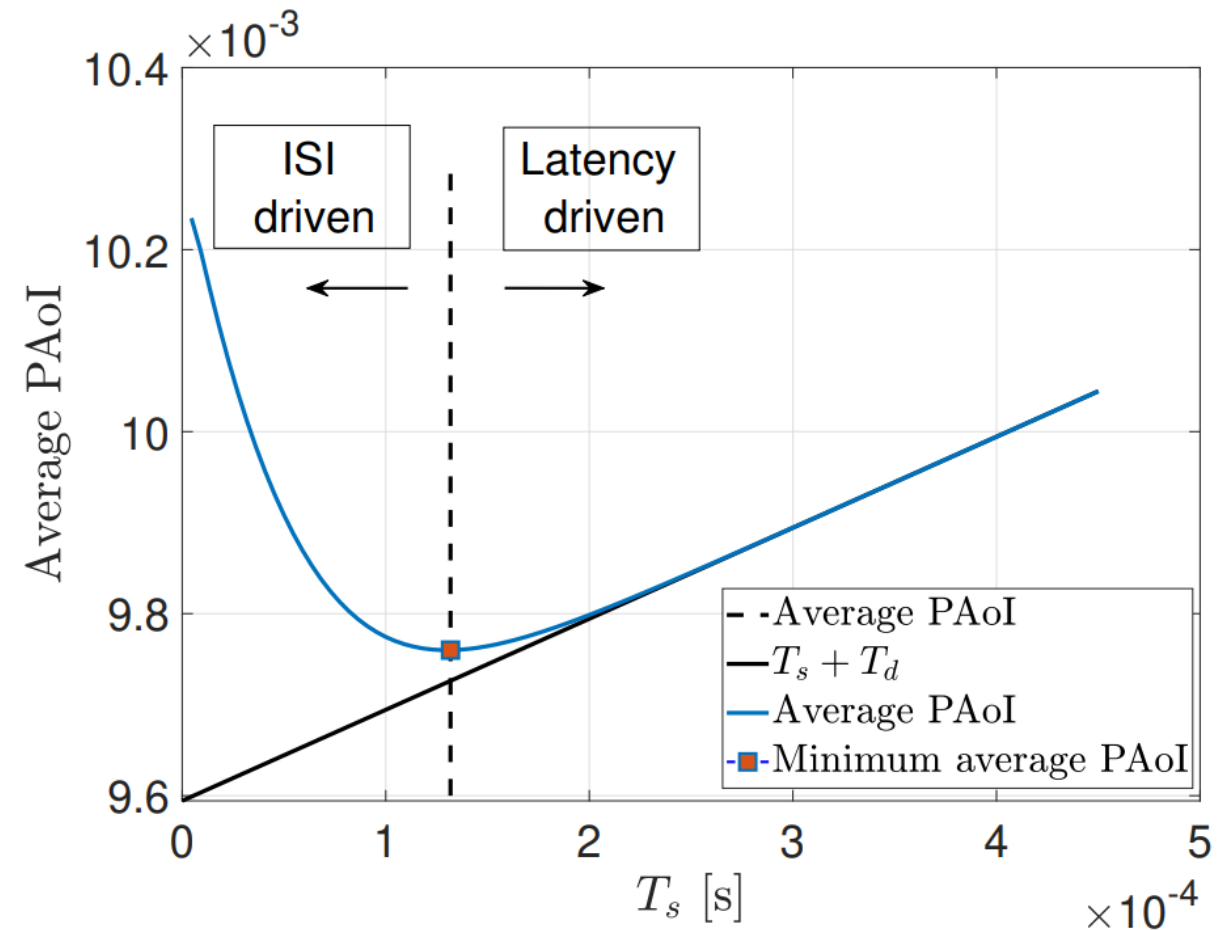


[1] Jorge Torres Gómez, Joana Angjo and Falko Dressler, "Age of Information-based Performance of Ultrasonic Communication Channels for Nanosensor-to-Gateway Communication," IEEE Transactions on Molecular, Biological and Multi-Scale Communications (T-MBMC), vol. 9 (2), pp. 112–123, June 2023.

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>

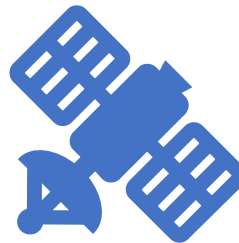
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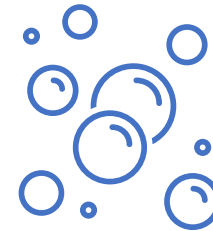
Part II: Domain Specific Applications



Vehicular Networks



Satellite Networks



Molecular Communications