Jamming Avoidance: Bat Behavior Inspired Models

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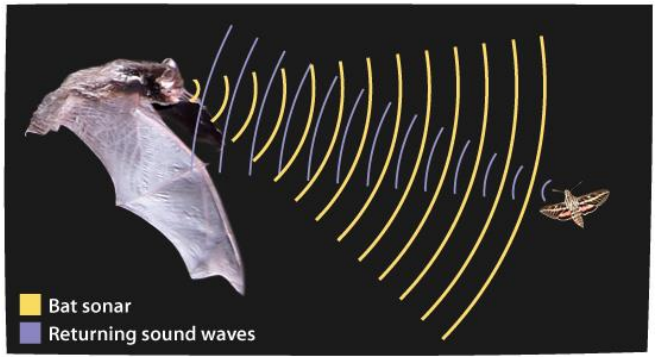
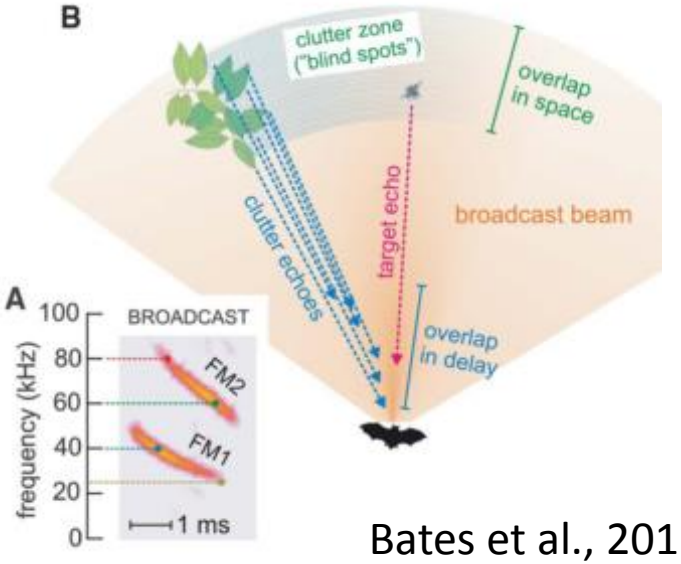
Bats, Clutter, and Jamming

- Each species has its own distinct call.[8]
- Challenges
  - Clutter[2]
  - Jamming[9]



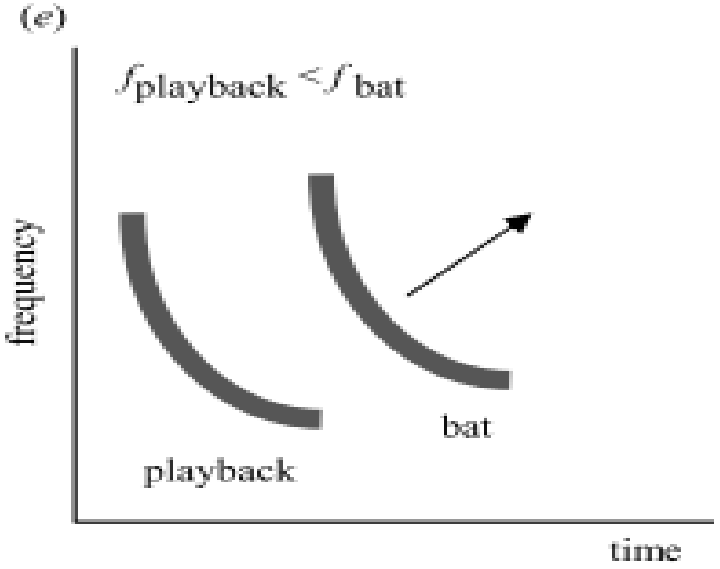
http://askabiologist.asu.edu/echolocation



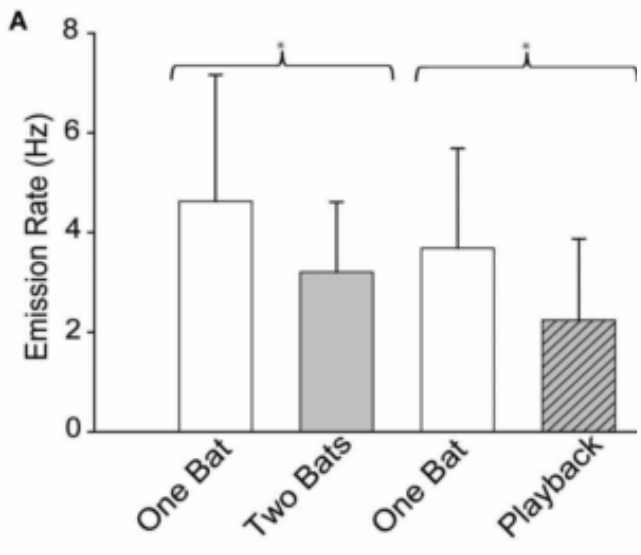
Bates et al., 2011

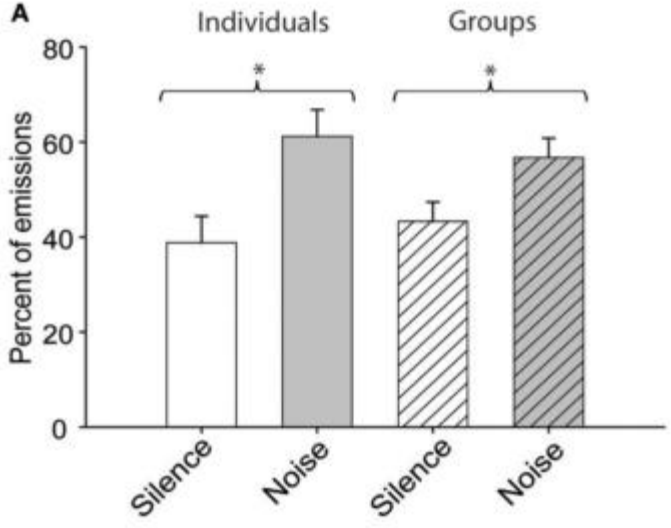
Jamming Avoidance Response (JAR)

- Shift Call Frequency [5,9]
- Small groups
  - Silence or decrease in emissions [4,7]
- Large Groups
  - Increase in emissions [7]



Gilman et al., 2007

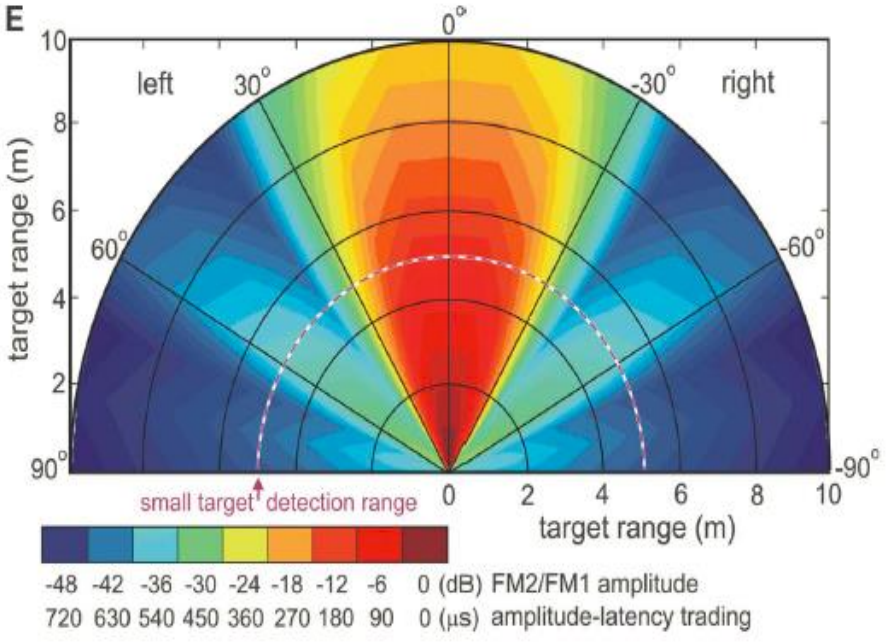




Jarvis et al., 2013

Applying Echolocation to Models

- Has a broad range, but due to the effect of clutter the effective range is much smaller. [1,2]



Bates et al., 2011

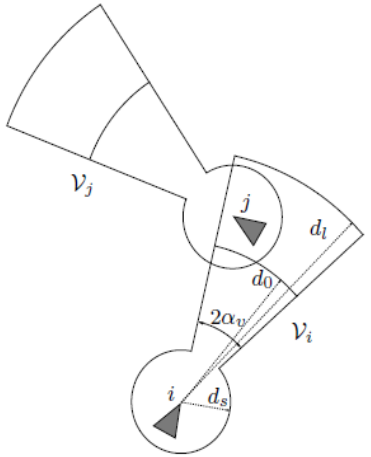


Figure 5: Visibility region of i-th and j-th vehicle.

Cecarrelli et al., 2008

Mexican Free-Tail Bats, Bracken Cave TX, USA

Modeling this Behavior

Collective circular motion of multi-vehicle systems☆

N. Ceccarelli [1], M. Di Marco, A. Garulli *, A. Giannitrapani

Dipartimento di Ingegneria dell'Informazione, Università di Siena, Italy

Bats Use Echo Harmonic Structure to Distinguish Their Targets from Background Clutter

Mary E. Bates,[1*] James A. Simmons,[2,3] Tengiz V. Zorikov[4]

FLIGHT PATTERNS OF BATS

By Clyde F. Herreid II and Richard B. Davis

Single Vehicle Control Laws

$$\begin{aligned}\dot{x}(t) &= v\cos\theta(t)\\ \dot{y}(t) &= v\sin\theta(t)\\ \dot{\theta}(t) &= u(t);\end{aligned}$$

$$u(t) = \begin{cases} k\cdot g(\rho(t))\cdot\alpha_d(\gamma(t)) & \text{if } \rho(t) > 0\\ 0 & \text{if } \rho(t) = 0\end{cases}$$

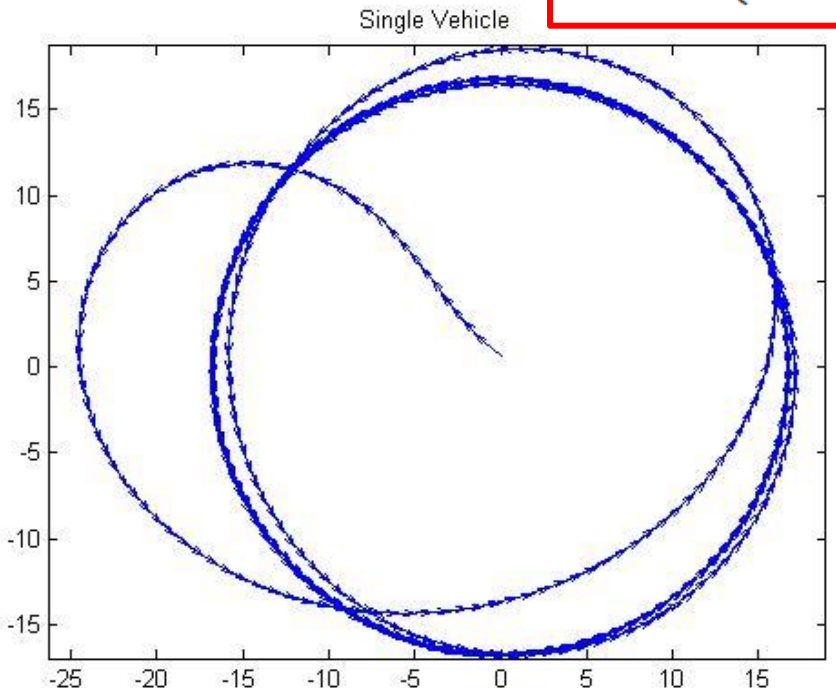
Angular velocity

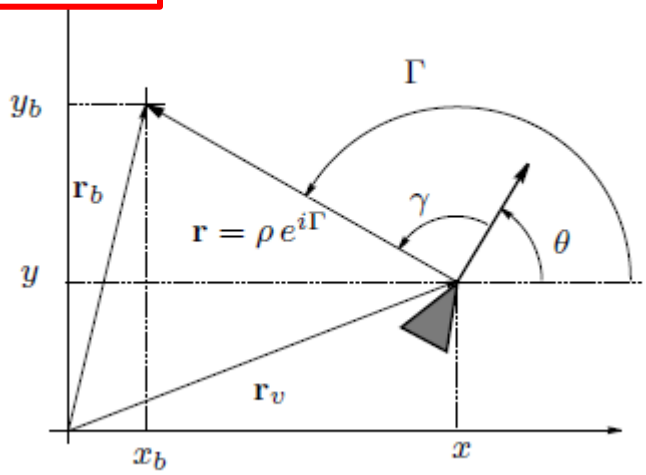
$$g(\rho) = \ln\left(\frac{(c-1)\cdot\rho+\rho_0}{c\cdot\rho_0}\right)$$

Control of position w.r.t. beacon; ρ_0 is the tuning radius

$$\alpha_d(\gamma) = \begin{cases} \gamma & \text{if } 0\le\gamma\le\psi\\ \gamma-2\pi & \text{if } \psi<\gamma<2\pi\end{cases}$$

Ordains counter-clockwise motion





Ceccarelli et al., 2008

Multiple Vehicle Control Laws

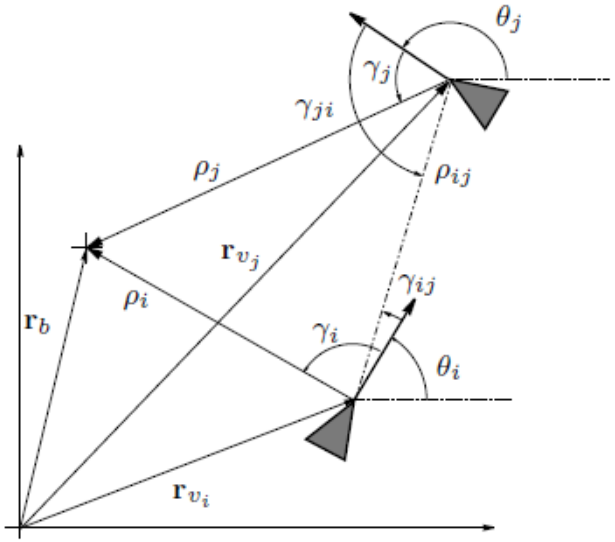
$$\begin{aligned}\dot{x}_i(t) &= v\cos\theta_i(t)\\ \dot{y}_i(t) &= v\sin\theta_i(t)\\ \dot{\theta}_i(t) &= u_i(t),\end{aligned}$$

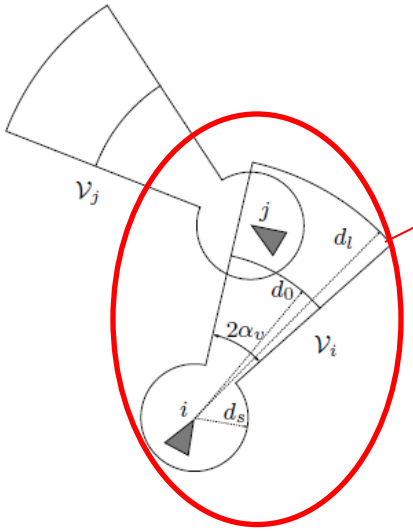
$$u_i(t) = f_{ib}(\rho_i,\gamma_i) + \sum_{\substack{j\neq i\\ j\in\mathcal{N}_i(t)}} f_{ij}(\rho_{ij},\gamma_{ij}).$$

$$f_{ib}(\rho_i,\gamma_i) = \begin{cases} k_b\cdot g(\rho_i,c_b,\rho_0)\cdot\alpha_d(\gamma_i) & \text{if } \rho_i>0\\ 0 & \text{if } \rho_i=0,\end{cases}$$

$$f_{ij}(\rho_{ij},\gamma_{ij}) = k_v\cdot g(\rho_{ij},c_v,d_0)\cdot\beta_d(\gamma_{ij}),$$ — Collision Avoidance

$$\beta_d(\gamma_{ij}) = \begin{cases}\gamma_{ij} & \text{if } 0\le\gamma_{ij}\le\pi\\ \gamma_{ij}-2\pi & \text{if } \pi<\gamma_{ij}<2\pi.\end{cases}$$



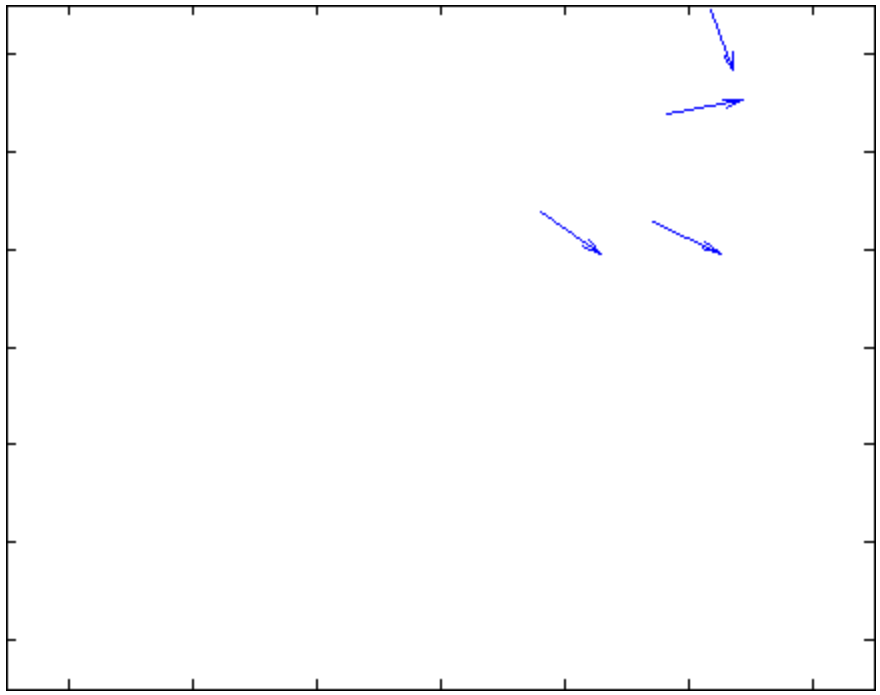


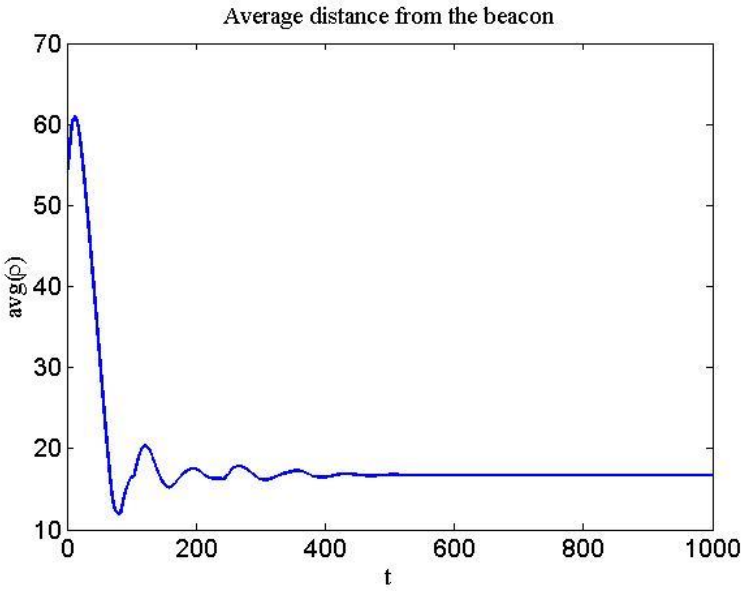
Sensing space

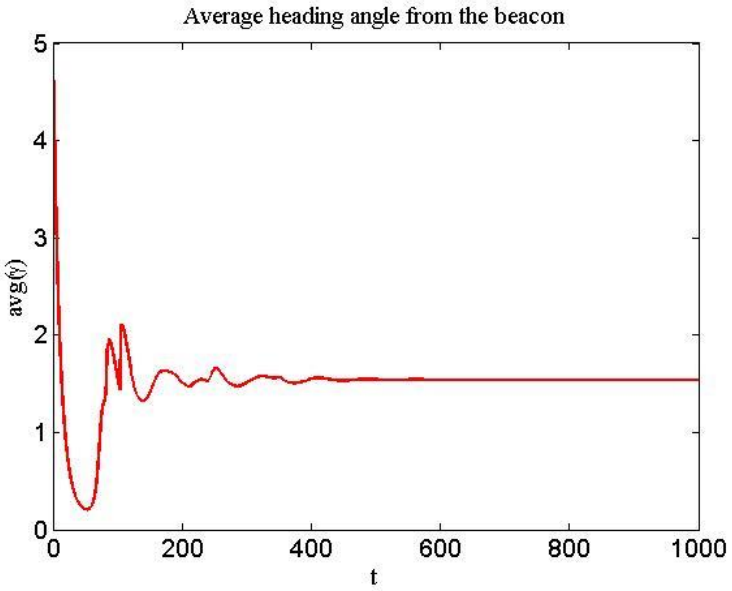
Figure 5: Visibility region of i-th and j-th vehicle.

Ceccarelli et al., 2008

4 Vehicle Model



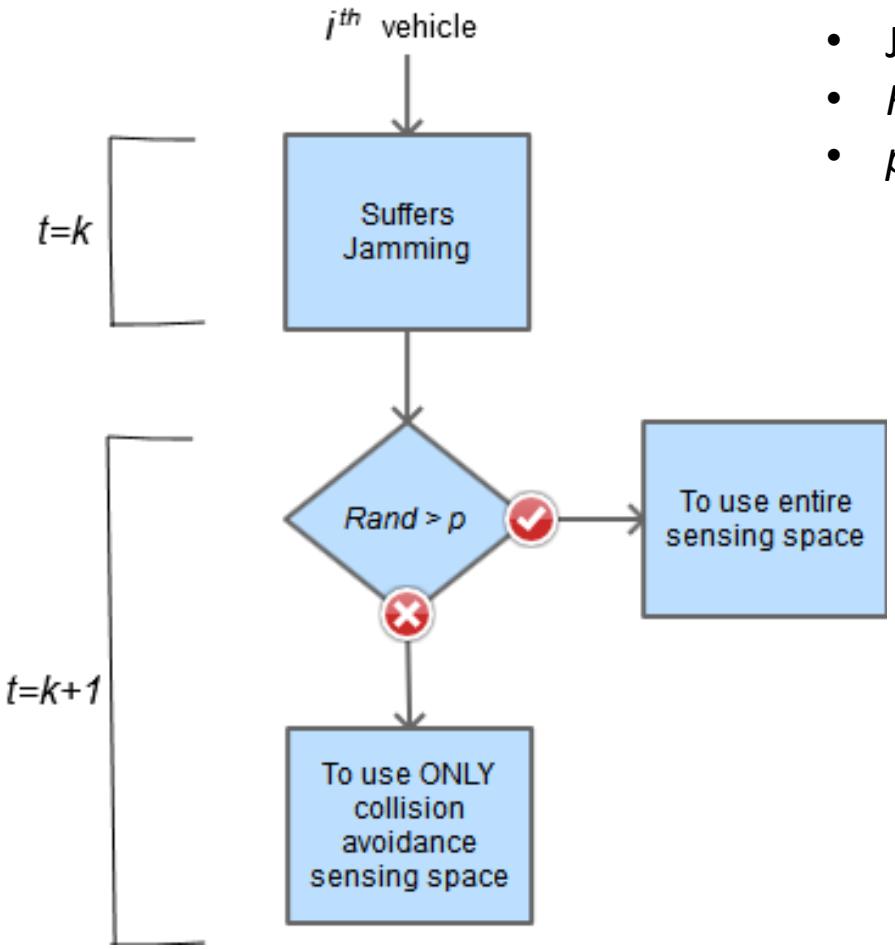




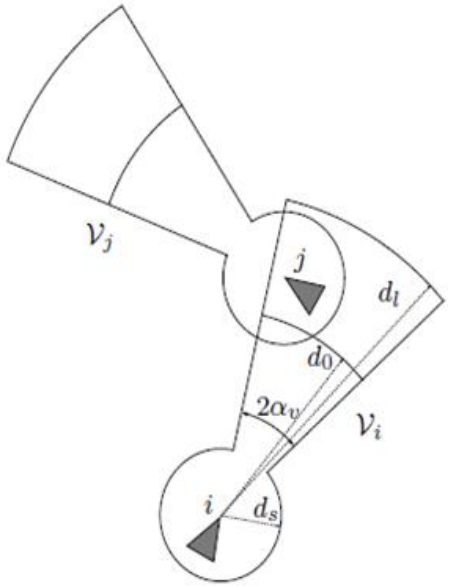
$$\frac{v}{\rho_e} - k\, g(\rho_e)\, \frac{\pi}{2} = 0$$

Ceccarelli et al., 2008

Modeling of Jamming Strategy

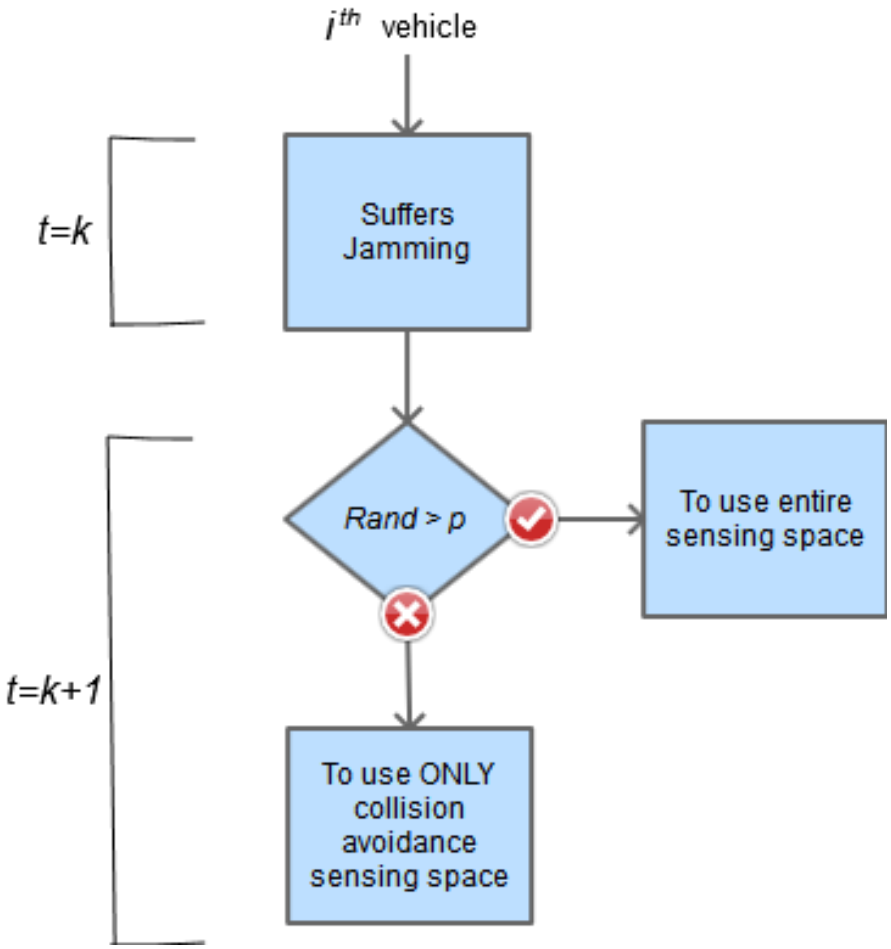


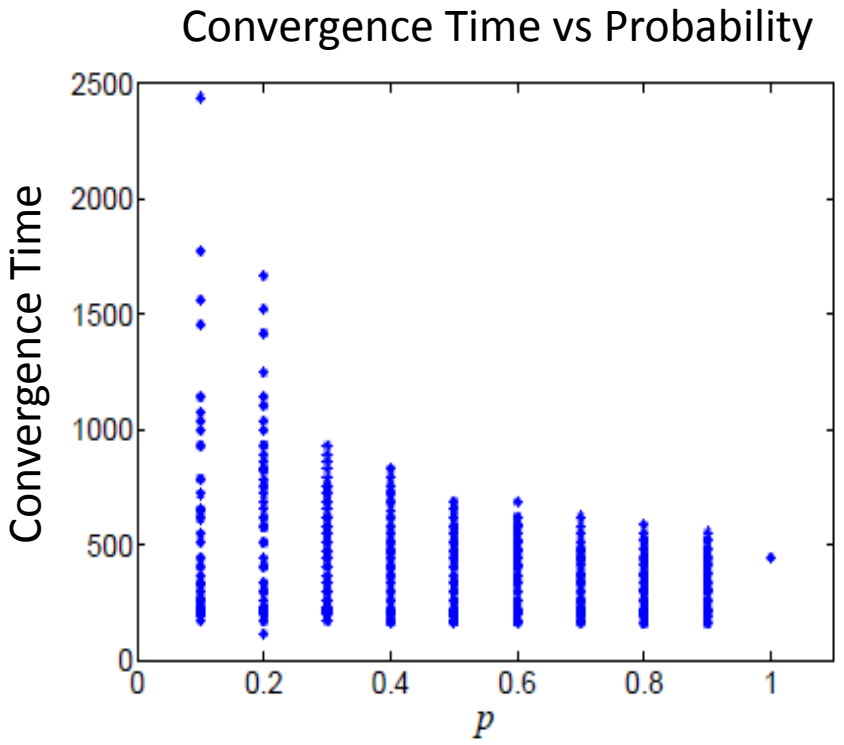
- Jamming => sensing space overlap
- *Rand* ~ uniform (0,1)
- *p* = specified probability



Ceccarali et al., 2008

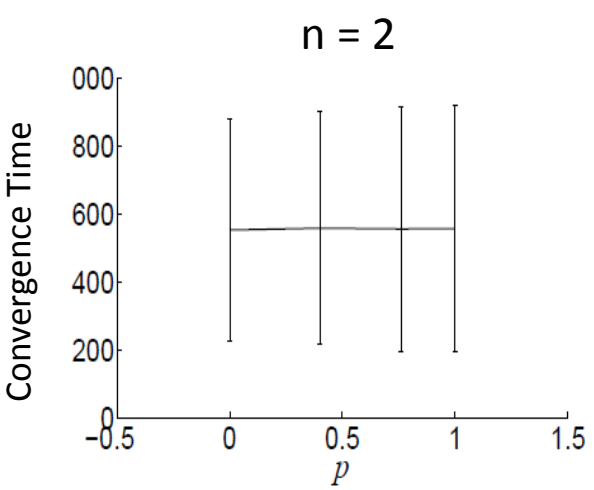
Modeling of Jamming Strategy

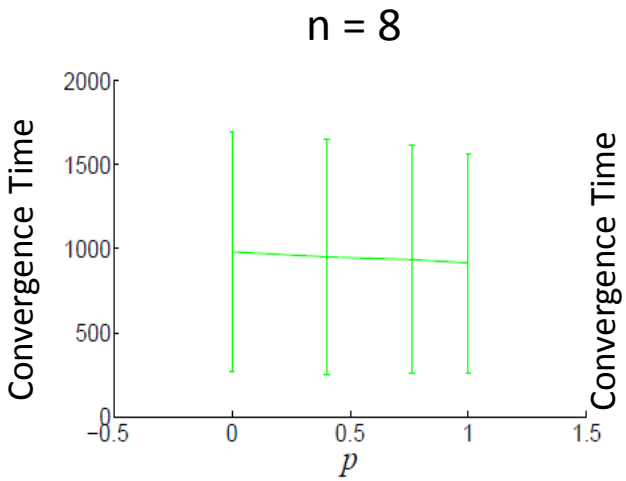


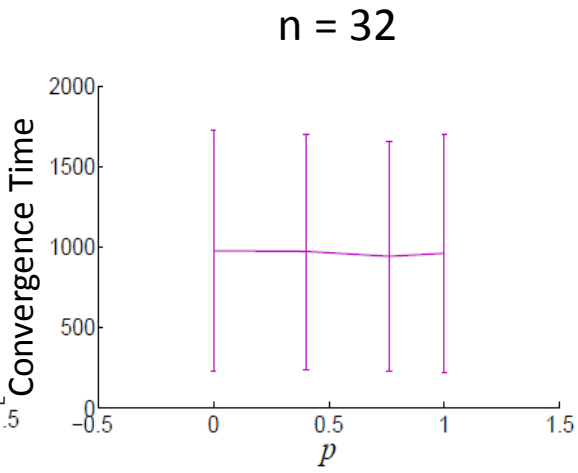


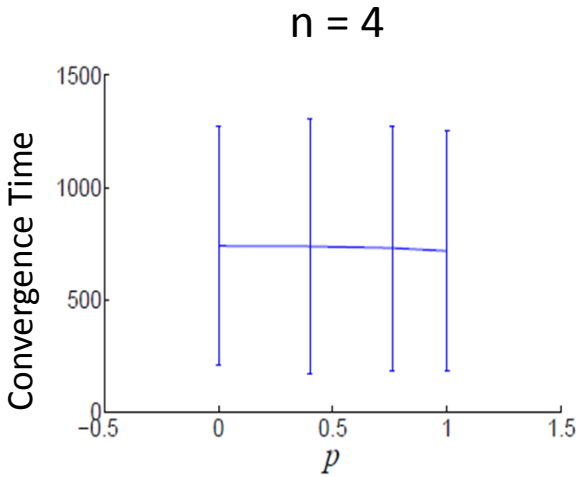
- n = 4
- Fixed initial conditions
- For 1000 simulations at each *p*

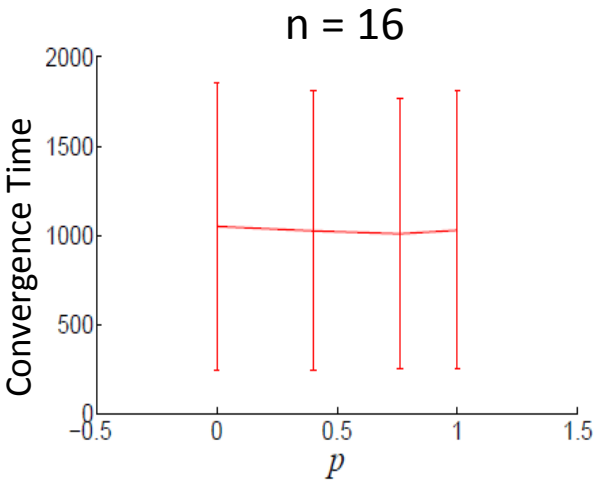
Results(Mean Convergence Time)











- Trend showing convergence time increases as *n* increases
- Within groups there is no significant trend generated from jamming avoidance

10,000 simulations for each *p* with a fixed tuning radius of 15.

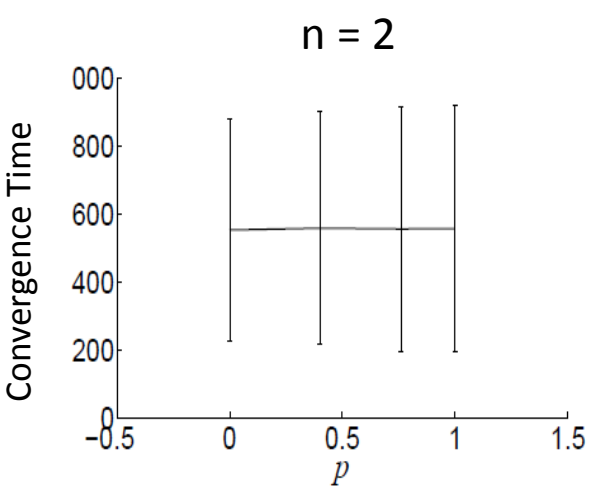
Results - ANOVA

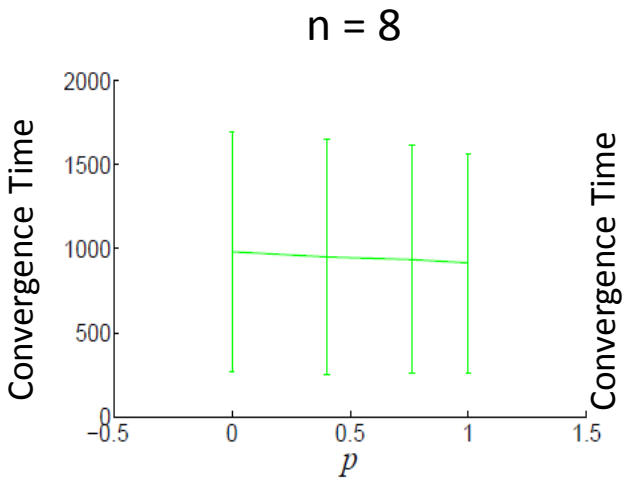
One-Way ANOVA was used to compare the variance between the different probabilities within the different populations.

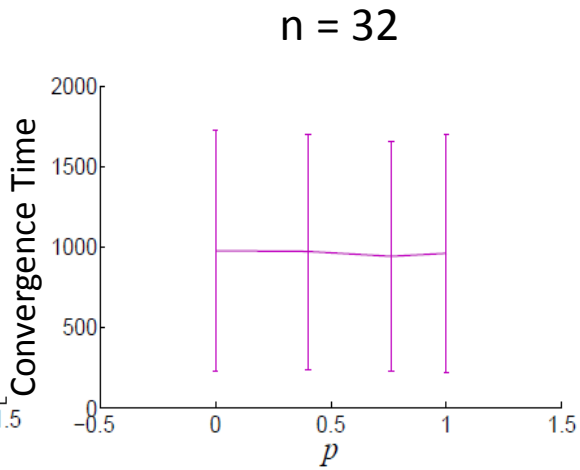
- Only at an N=2 was the variation likely due to chance.

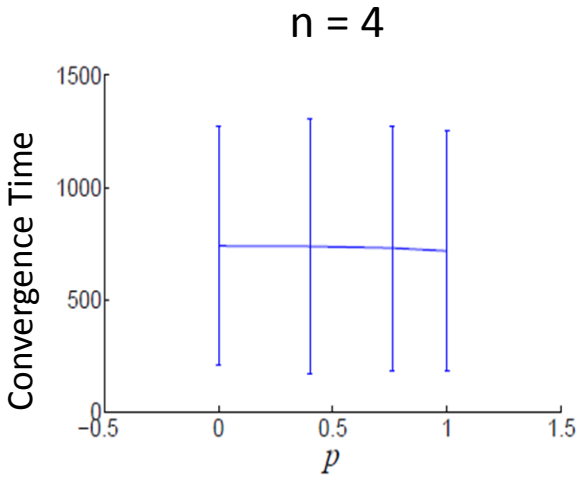
N	F –Value (3, 39996)	P-Value
2	0.63	0.59
4	4.19	< 0.01
8	14.02	< 0.001
16	3.69	= 0.01
32	4.4	< 0.01

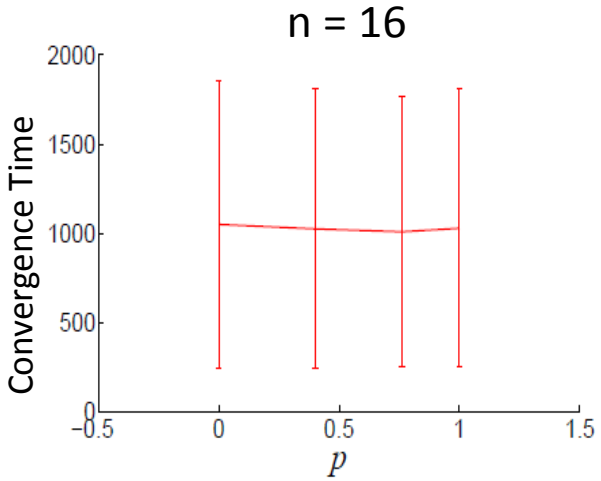
Discussion







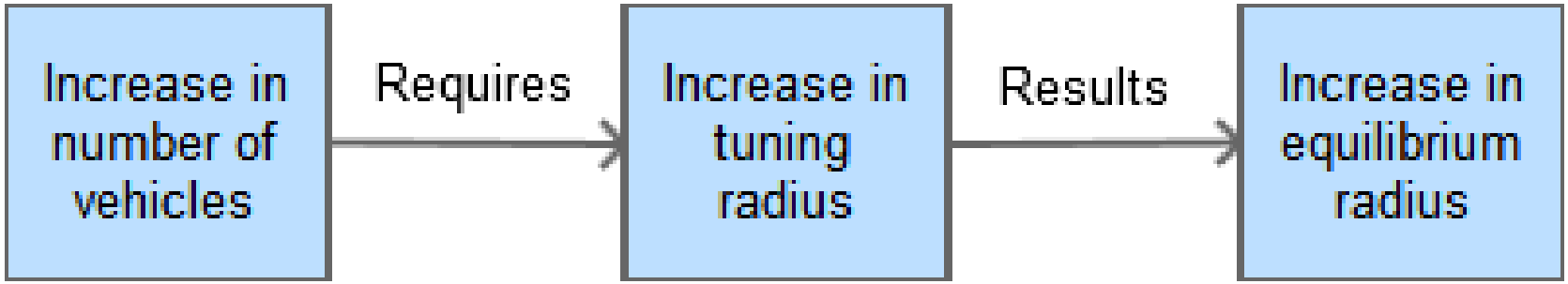




- Variation between the means not due to chance
- Trends may be an effect of jamming avoidance

10,000 simulations for each *p* with a fixed tuning radius of 15.

Conclusion



$$\text{density} = \frac{n}{\rho_e}$$

Limitations of the model used:

- To ensure an equilibrium state is reached, the tuning radius is constrained based on the highest number of vehicles used.
- This constrains the density that can be reached within this model while still attaining an equilibrium state.

References

[1] Arlettaz, R., Jones, G., & Racey, P. A. (2001). Effect of acoustic clutter on prey detection by bats. *Nature*, *414*(6865), 742–5.

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[3] Ceccarelli, N., Marco, M. Di, Garulli, A., & Giannitrapani, A. (2008). Collective circular motion of multi-vehicle systems. *Automatica*, *44*(12), 3025–3035.

[4] Chiu, C., Xian, W., & Moss, C. F. (2008). Flying in silence: Echolocating bats cease vocalizing to avoid sonar jamming. *Proceedings of the National Academy of Sciences of the United States of America*, *105*(35), 13116–21.

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[6] Herreid, C. F., & Davis, R. B. (1966). Flight Patterns of Bats. *Journal of Mammalogists*, *47*(1), 78–86.

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[8] Siemers, B. M., & Shnitzler, H.-U. (2004). Echolocation signals reflect niche differentiation in five sympatric congeneric bat species. *Nature*, *429*(June), 657–661.

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Questions or Comments

8 Vehicle Model