Sensing Enhancement on Social Networks: Heterogeneity and Optimality

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Individuals in many collectives, ranging from various examples in the animal world to human society and engineering examples in swarm robotics, are faced with the requirement to gather and process information in uncertain environments. Very often in such scenarios, individual sensing might be costly and individuals' sensing capabilities tend to be error prone. In this context, the question arises whether peer communication can allow for an overall information state in a collective that is more accurate than individuals' sensing abilities. Investigating the mean-field scenario [2] and spatial grids [1], previous work has shown that this can indeed be the case when individuals have some tendency to adopt the majority opinion and balance a trade-off between individual sensing and peer communication close to the bifurcation of the resulting bi-stable system (see Fig. 1(top)).

In recent work [3] we have shown that the sensing enhancement a collective can achieve is strongly dependent on the structure of the social network that constrains peer communication. In the talk, we will discuss two main effects. First, observing that agents with many connections tend to be able to source superior estimates from the collective, albeit at the cost of much poorer information availability for low-connectivity agents, we present arguments that overall sensing enhancement is generally impeded by degree heterogeneity. Second, we have investigated the effects of spatial structure and clustering in small-world networks and find that maximum sensing enhancement can typically be achieved in the small-world regime (see Fig. 1(bottom)).

Beyond the work presented in [3], some of our recent work has explored heterogeneity in individual trade-offs between peer communication and sensing. Results indicate that particular correlations of sensing intensities of individual agents can improve a populations' overall sensing. We find that such correlations depend on network structure and allow to formulate general rules of how collectives can achieve optimality on different types of social networks.

In the talk, we discuss implications of our results for swarm engineering [4].

References

[1] Salahshour, M., Rouhani, S., Roudi, Y.: Phase transitions and asymmetry between signal comprehension and production in biological communication. Sci. Rep. 9, 3428 (2019).

[2] Salahshour, M.: Phase Diagram and Optimal Information Use in a Collective Sensing System. Phys. Rev. Lett. 123, 068101 (2019).

[3] Brede M. and Romero-Moreno, G.: Sensing enhancement on social networks: The role of network topology. Entropy 24, 738 (2022).

[4] Brambilla, M., Ferrante, E., Birattari, M.,Dorigo, M.: Swarm robotics: A review from the swarm engineering perspective. Swarm Intelligence 7, 1-41 (2013).

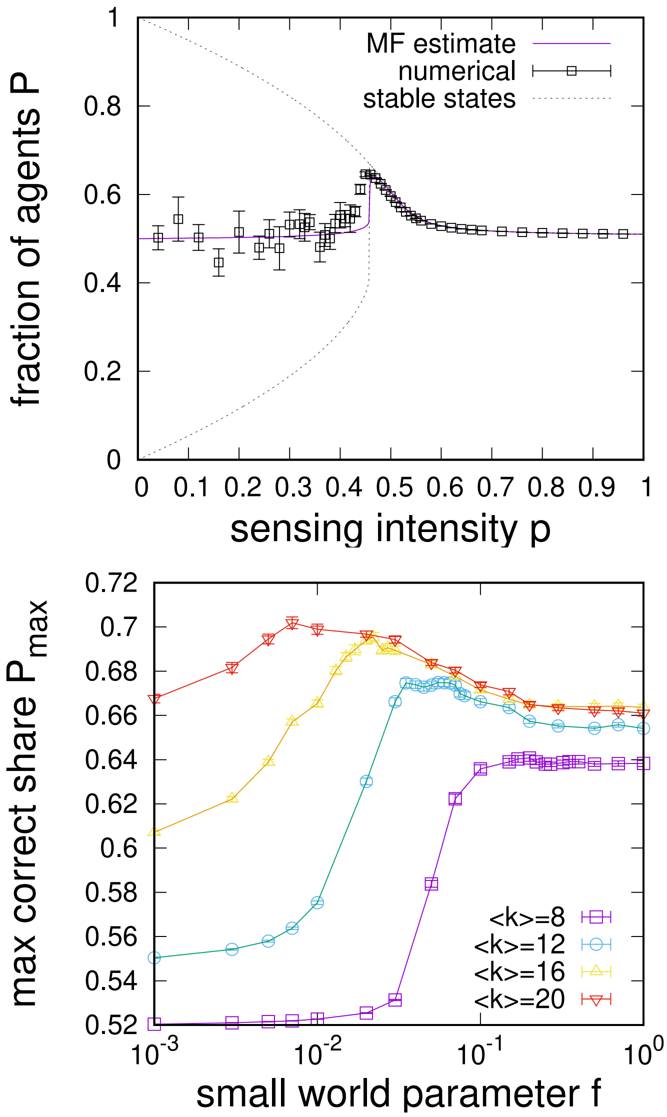

Figure 1: (top) Dependence of the average fraction of correctly sensing agents P on the sensing intensity p. Comparison of numerical data (black squares) to the mean-field orbit diagram for the bi-stable system and a mean-field estimate for $P(p)$ f (dotted lines) along with an estimate of the stationary outcome when including environmental change (magenta line). (bottom) Dependence of the maximum achievable share of correctly sensing agents P_{max} on the small-world parameter f used to construct the social network for networks of different average connectivity $\langle k \rangle = 8$ to $\langle k \rangle = 20$. See [3] for details.