DYNAMIC TREATMENT ALLOCATION FOR EPIDEMIC CONTROL IN ARBITRARY NETWORKS

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CONTRIBUTION

While static epidemic control, e.g. using *vaccination*, has been extensively studied for various network types, controlling epidemics dynamically remains an open issue.

1) We propose a general model formulation for the ***dynamic treatment allocation problem*** for the Susceptible-Infected-Susceptible diffusion model.

2) We investigate dynamic control strategies and propose the novel ***Largest Reduction in Infectious Edges*** **(LRIE)** heuristic that gives priority to the treatment of nodes that have both a high dissemination rate of the infection to many healthy nodes, and low reinfection probability after recovery.

Experiments on random and real networks reveal significant differences between the dynamic and the vaccination problems, while the proposed LRIE is effective under various initial infection conditions.

MODEL FORMULATION

■ **Diffusion model:** *Continuous-time Markov Process* (*N-intertwined SIS*).

■ **Dynamic control:** is achieved via a *dynamic treatment allocation* (DTA) approach: a set of nodes is determined to receive medicine to recover more quickly.

For an undirected network of N nodes, let:

✔ A the $N \times N$ adjacency matrix

✔ $X(t)$ the nodes' infection state vector at time t

✔ $M(t)$ the vector with the distribution of medicines in the network.

The overall dynamics of the system are described by:

$$X_i(t) = \begin{cases} 0 \rightarrow 1 & \text{at rate } \beta \sum_j A_{ij} X_j(t) \\ 1 \rightarrow 0 & \text{at rate } \delta + \rho M_i(t) \end{cases} \quad (1)$$

SCORE-BASED STRATEGIES

■ **Dynamic treatment allocation (DTA):** Strategies are dynamic and make use of ***all the information*** at time t (the whole graph adjacency matrix A, and the current infection state vector $X(t)$).

■ **Score-based strategies:** DTA strategies can be written as selecting nodes that minimize a score $S(X(t))$ which depends on the current infection state $X(t)$.

■ **Only infected nodes receive a treatment:** giving a treatment to a healthy node does not change its behavior, thus we restrict ourselves to strategies that focus on infected nodes.

■ **Experimentally compared heuristics:**

✔ Random score (**RAND**)

✔ Most neighbors (**MN**)

✔ Largest reduction in spectral radius (**LRSR**)

✔ Pagerank centrality (**PRC**)

✔ Most susceptible neighbors (**MSN**)

✔ Least infected neighbors (**LIN**)

✔ **Largest Reduction in Infectious Edges (LRIE)**

Our heuristic focuses on the most ***viral and safe*** nodes of the network, and proved to perform better than its competitors for a wide range of scenarios.

DYNAMIC STRATEGIES IN A TOY NETWORK

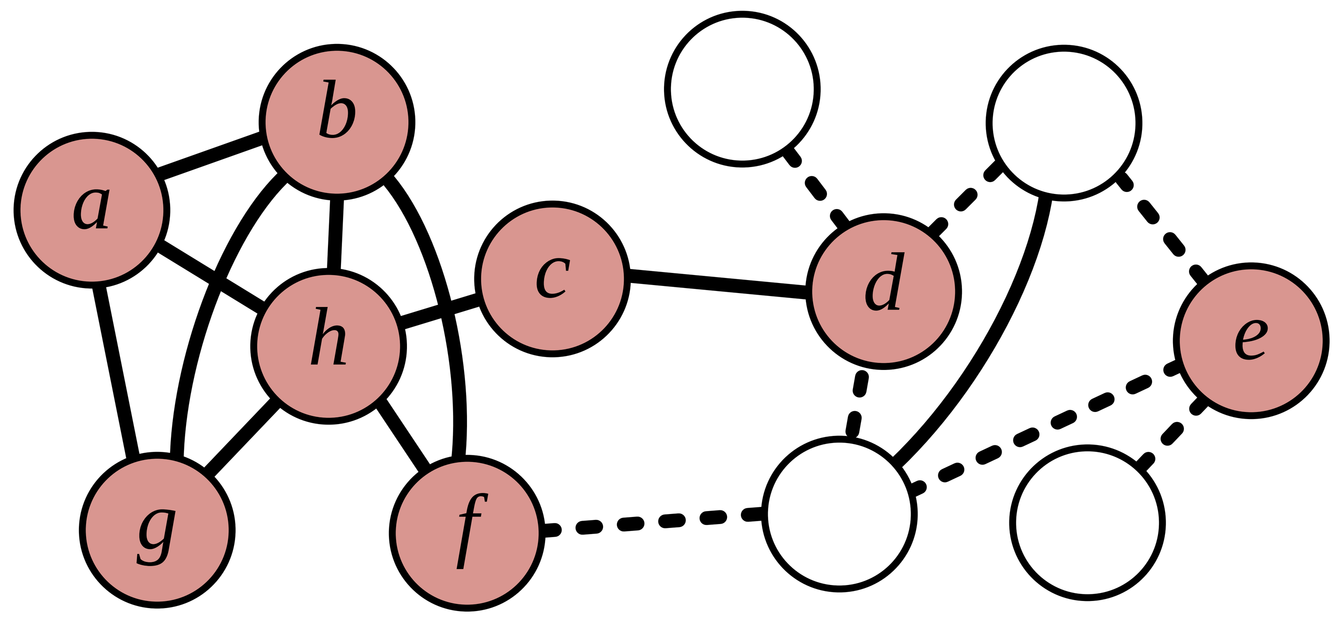

Fig. 1: Example network with healthy (*white*) and infected (*red*) nodes. *Dashed* edges denote *infectious edges* on which the disease might spread.

■ **MN**, **LRSR**, **PRC** focus on the most central node **h**.

■ **MSN** focuses equally on **d** and **e**, which are the most viral nodes.

■ **LIN** focuses on the safest infected node **e**.

■ **LRIE** focuses on node **e**, which is the most safe and viral.

EXPERIMENTAL RESULTS

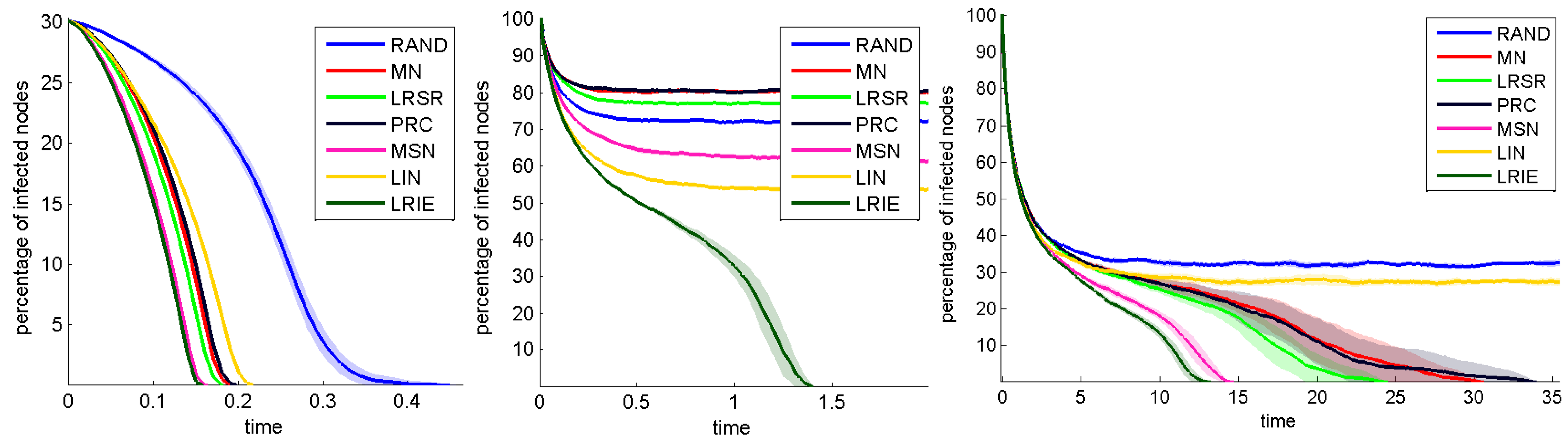

Fig. 2, 3, 4: Dynamic treatment allocation simulations for Erdös-Rényi networks (N=10^4, p=0.001).

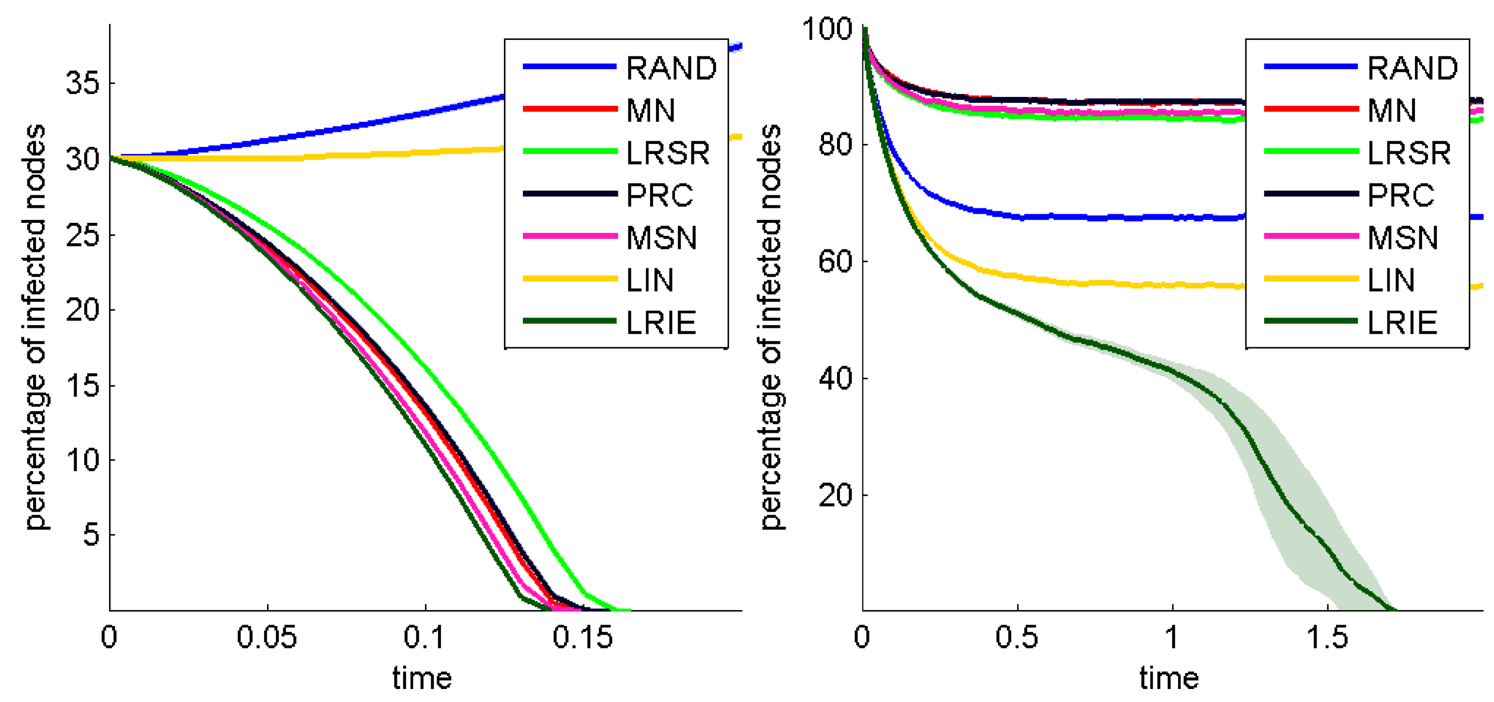

Fig. 5,6: Dynamic treatment allocation simulations for scale free networks (N=10^4, m=5).

■ **LRIE is more efficient** than the competitors, in a wide range of parameters, initial infected population size, and network type settings.

■ For high initial infection sizes, most competing heuristics are not powerful enough to suppress the epidemic.

■ In certain cases, **centrality-based heuristics are counter-productive** as they perform worse than the random strategy.

A REAL DATASET: THE AIR TRAFFIC NETWORK

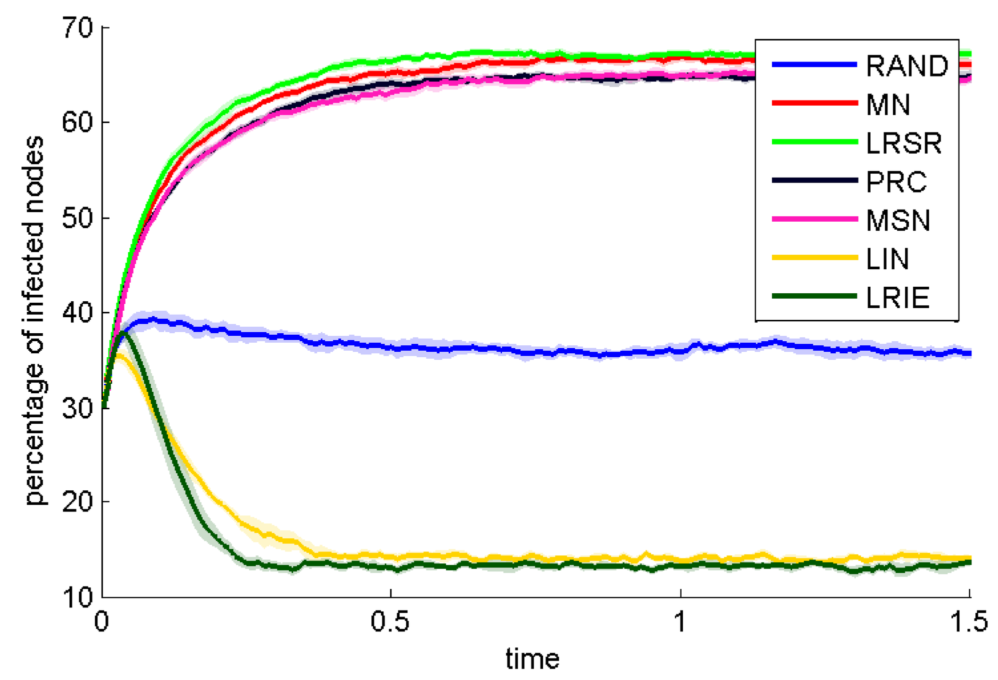

Fig. 7: Epidemic simulation in the US air traffic network: N=1574 nodes, r=2, e=600, b_{tot}=10 medicines.

■ **Real US air traffic network** for the year 2010.

■ **Large difference** between the competing strategies.

■ **Persistence of the epidemic at low rates**, which is typical of scale-free networks.

CONCLUSION

■ **Dynamic vs Static Control:** Dynamically allocating treatments in a network is **fundamentally different** to the static vaccine allocation problem.

■ **Centrality-based strategies** can be **counter-effective** in the DTA setting.

■ **The proposed LRIE strategy is more efficient** than intuitive heuristics, taken from the literature of static epidemic control, in a wide range of experimental scenarios.