COMP 323 PRESENTATION

SIMULATING SPREAD OF INFECTION ON DIFFERENT NETWORK TOPOLOGY*

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** project topic changed*

PROBLEM STATEMENT

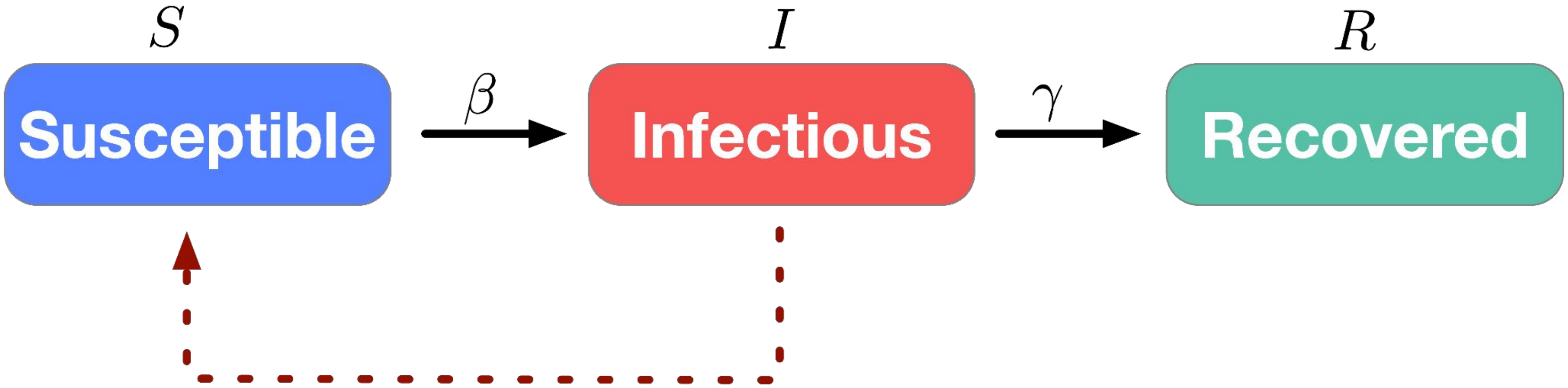
The rapid spread of infectious diseases varies significantly across different network topologies, making it challenging to determine effective intervention strategies for minimizing outbreaks. Identifying the most effective containment methods for diverse network structures remains a critical issue for public health management.

OBJECTIVE

To determine the most effective intervention strategies for minimizing disease spread across different network topologies using SIR model simulations.

INTRODUCTION

THE SIR MODEL



β = the contact rate between the Susceptible and Infectious groups

γ = the transition rate between the Infectious and Recovered groups

INTERVENTION IN THE SIR MODEL

Types of interventions considered:

- Random Intervention: a random selection of nodes is vaccinated or quarantined.

- Hub Intervention:targets nodes with the highest degree (number of connections).

- Cluster Intervention: targets nodes with high clustering coefficients.

METHODOLOGY

Methodology

- ➔ Graph representation using networkx
- ➔ Node attribute definition (S,I,R)
- ➔ Parameter definition (β,γ)
- ➔ Implement simulation
- ➔ Visualization and Interpretation

The spread of the disease can be analyzed through properties of the graph such as connectivity, degree distribution, and centrality measures which are different across different graph topologies.

Graph topologies considered:

1. Erdős–Rényi (Random Graph)

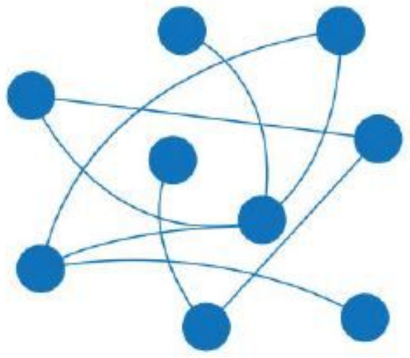
   random graph where each possible edge between a pair of nodes is included with a fixed probability p.

2. Barabási–Albert (Scale-Free Network)

   new nodes are more likely to attach to existing nodes with higher degrees.

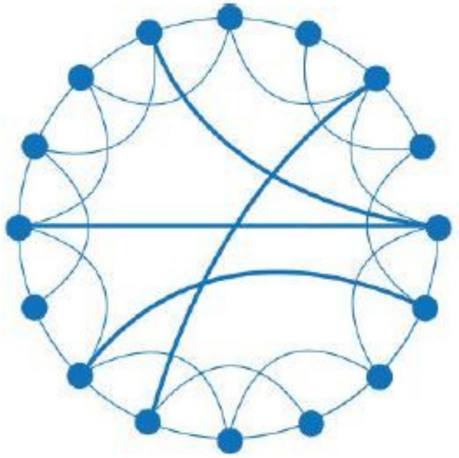
3. Watts–Strogatz (Small-World Network)

   networks that have a high clustering coefficient and short average path lengths, exhibiting small-world properties.



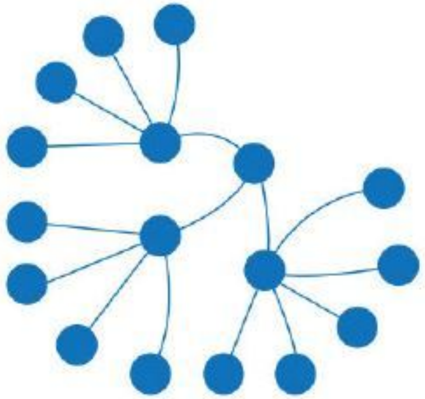
Random

Average distributions.
No structure or hierarchal patterns.



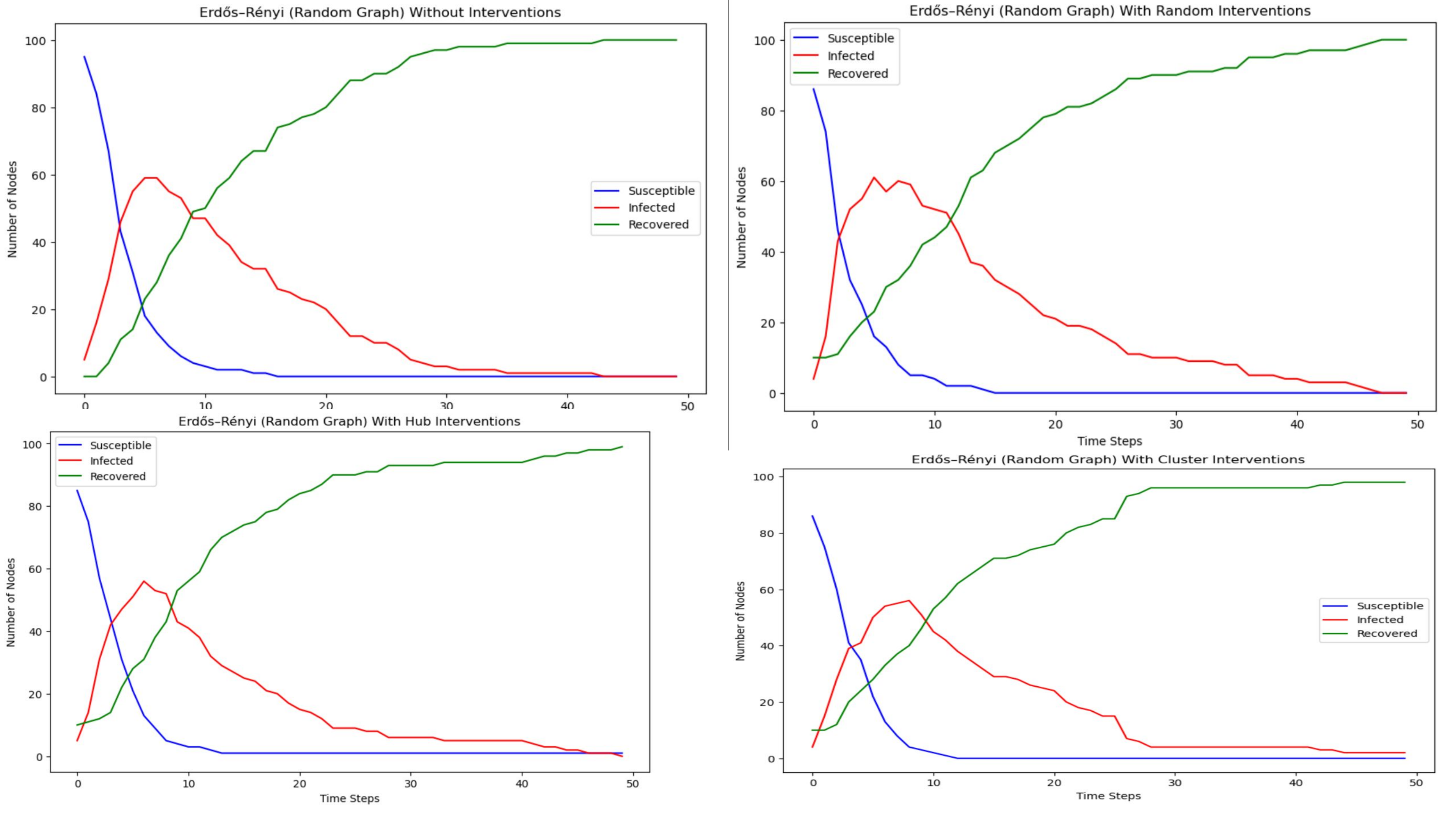
Small-World

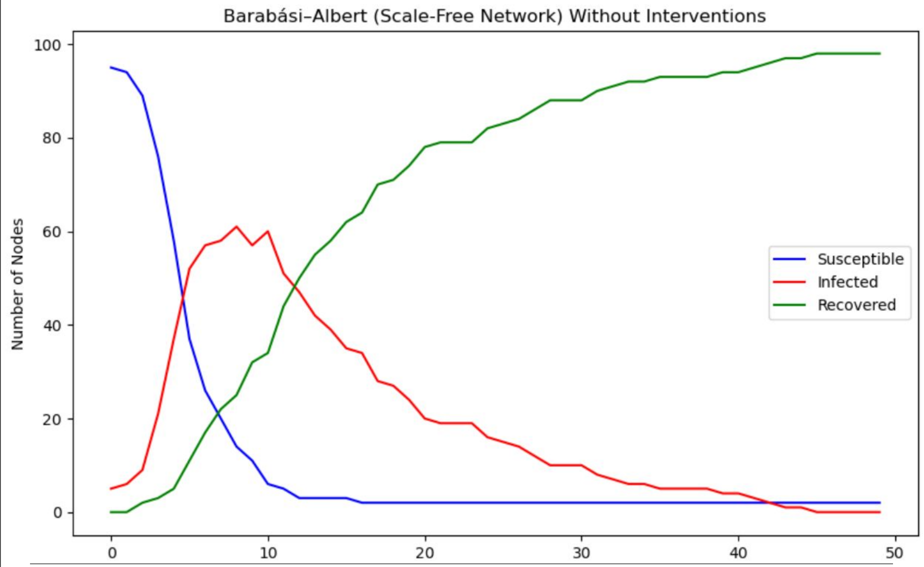
High local clustering and short average path lengths.
Hub-and-spoke architecture.

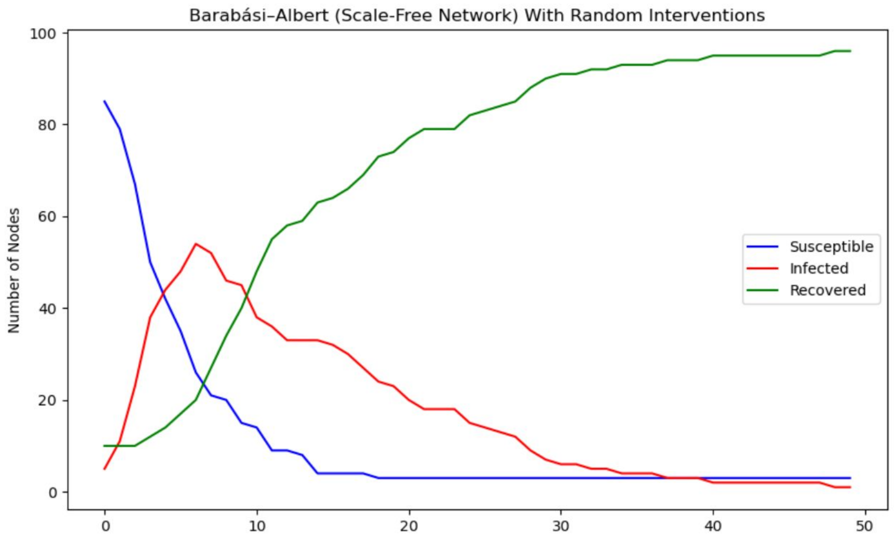


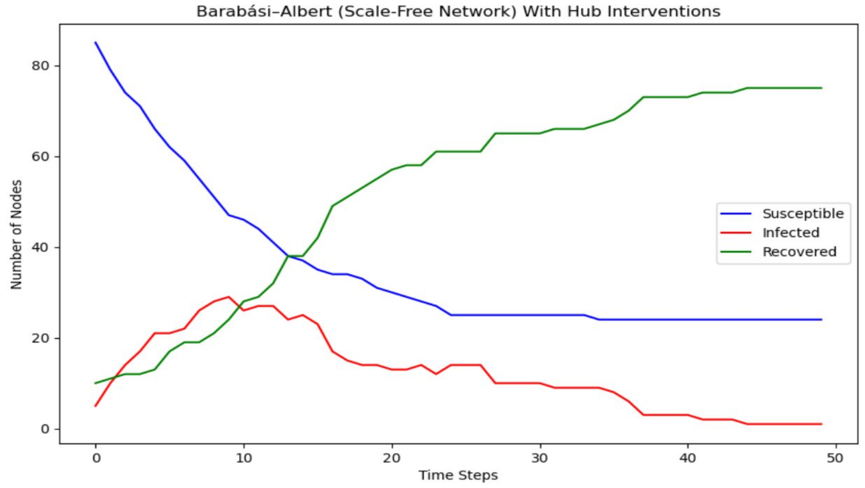
Scale-Free

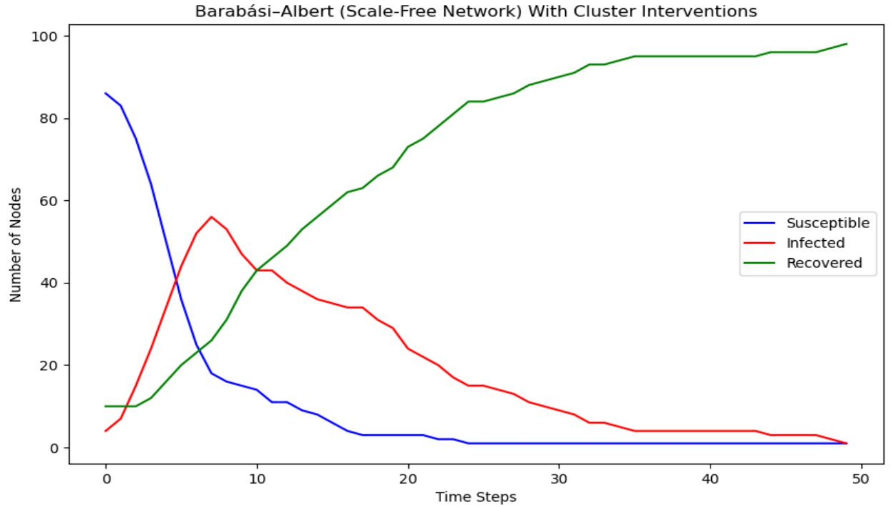
Hub-and-spoke architecture preserved at multiple scales.
High power law distribution.

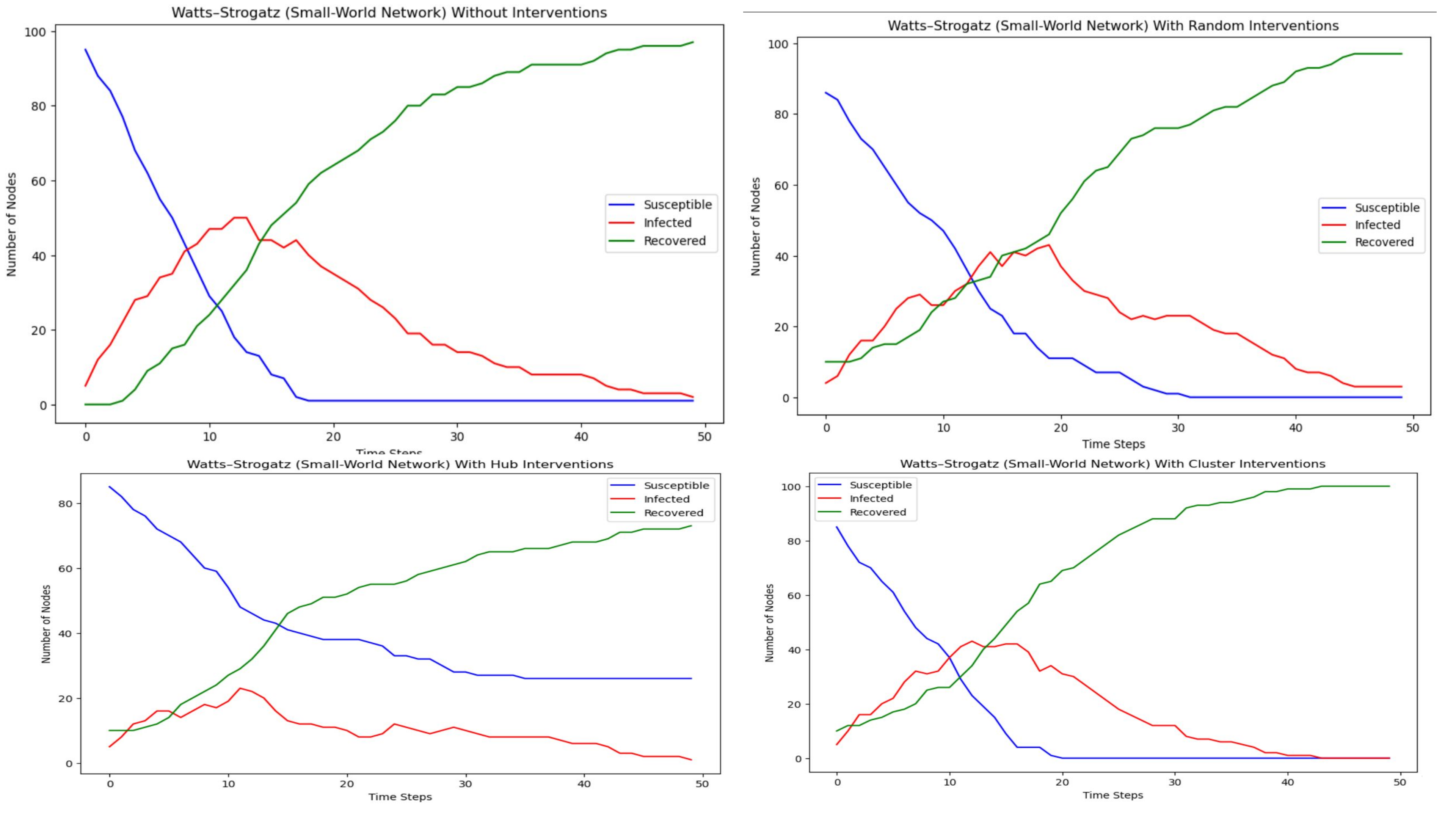

Erdős–Rényi (Random Graph) Without Interventions
Number of Nodes
Susceptible
Infected
Recovered
Erdős–Rényi (Random Graph) With Random Interventions
Number of Nodes
Time Steps
Susceptible
Infected
Recovered
Erdős–Rényi (Random Graph) With Hub Interventions
Number of Nodes
Time Steps
Susceptible
Infected
Recovered
Erdős–Rényi (Random Graph) With Cluster Interventions
Number of Nodes
Time Steps
Susceptible
Infected
Recovered


Barabási–Albert (Scale-Free Network) Without Interventions
Number of Nodes
Susceptible
Infected
Recovered


Barabási–Albert (Scale-Free Network) With Random Interventions
Number of Nodes
Susceptible
Infected
Recovered


Barabási–Albert (Scale-Free Network) With Hub Interventions
Number of Nodes
Time Steps
Susceptible
Infected
Recovered


Barabási–Albert (Scale-Free Network) With Cluster Interventions
Number of Nodes
Time Steps
Susceptible
Infected
Recovered



Watts–Strogatz (Small-World Network) Without Interventions
Number of Nodes
Time Steps
Susceptible
Infected
Recovered
Watts–Strogatz (Small-World Network) With Random Interventions
Number of Nodes
Time Steps
Susceptible
Infected
Recovered
Watts–Strogatz (Small-World Network) With Hub Interventions
Number of Nodes
Time Steps
Susceptible
Infected
Recovered
Watts–Strogatz (Small-World Network) With Cluster Interventions
Number of Nodes
Time Steps
Susceptible
Infected
Recovered

General Observations Without Interventions

	Infection Spread:	**Peak:**	**Duration:**
Erdős–Rényi (Random Graph)	Fairly uniform due to random connections.	Moderate peak of infections.	Infection spread and recovery phases are moderate in length.
Barabási–Albert (Scale-Free Network):	Rapid due to hubs with many connections.	High peak of infections quickly.	Rapid initial spread with a sharp decline as hubs recover or become immune.
Watts–Strogatz (Small-World Network):	Combination of high clustering and short path lengths leads to rapid spread.	High peak due to quick spread through clustered nodes.	Moderate length due to clustering and local spreading before moving to other clusters.

General Observations With Random Interventions

	Effectiveness:	**Peak:**	**Duration:**
Erdős–Rényi (Random Graph)	Some reduction in infection spread.	Lower than without interventions.	Longer recovery phase due to fewer infections.
Barabási–Albert (Scale-Free Network):	Less effective as random interventions might miss hubs.	Still high if hubs are not targeted.	Rapid spread initially, similar to without interventions.
Watts–Strogatz (Small-World Network):	Moderate reduction in spread due to disrupted clusters.	Lower but still significant due to local clustering.	Longer overall infection period due to mixed effectiveness.

General Observations With Hub Interventions

	Effectiveness:	**Peak:**	**Duration:**
Erdős–Rényi (Random Graph)	More effective as hubs are still present but less pronounced.	Lower, significant reduction in infections.	Longer recovery phase as key nodes are immune.
Barabási–Albert (Scale-Free Network):	Highly effective, targeting hubs drastically reduces spread.	Significantly lower peak, often much smaller outbreak.	Infection spread is minimized, quick recovery.
Watts–Strogatz (Small-World Network):	Moderately effective, as targeting high-degree nodes disrupts some clusters.	Lower than without interventions.	Spread slows down considerably, longer recovery.

General Observations With Cluster Interventions

	Effectiveness:	**Peak:**	**Duration:**
Erdős–Rényi (Random Graph)	Moderately effective due to random structure.	Lower peak as clustered nodes are targeted.	Longer recovery phase with fewer infections.
Barabási–Albert (Scale-Free Network):	Less effective if clusters are not aligned with hubs.	Moderate reduction if targeting non-hub clusters.	Spread still follows hub-centric pattern, similar to random interventions.
Watts–Strogatz (Small-World Network):	Highly effective due to inherent clustering.	Significant reduction in peak infections.	Longer infection period but fewer overall cases.

ACHIEVEMENTS

Best Strategies for Containment

1. Random Networks (Erdős–Rényi): Random interventions and hub interventions can both be effective. However, hub interventions might still be slightly more efficient if there are any nodes with higher degrees than average.

2. Scale-Free Networks (Barabási–Albert): Hub interventions are the most effective. By targeting hubs, you drastically reduce the spread of the disease due to the critical role these nodes play in connecting the network.

3. Small-World Networks (Watts–Strogatz): Cluster interventions are highly effective. Targeting nodes with high clustering coefficients disrupts the local spread and limits cross-cluster transmission.

CONCLUSION

The insights from these simulations emphasize the importance of network topology in disease spread and the effectiveness of targeted interventions. By understanding the structure of social interactions, public health strategies can be tailored to more effectively contain outbreaks, focusing on key nodes or clusters within the network.

THANK YOU

References

Kasis, A., Timotheou, S., Monshizadeh, N., & Polycarpou, M. (2022). Optimal intervention strategies to mitigate the COVID-19 pandemic effects. *Scientific reports*, *12*(1), 6124. https://doi.org/10.1038/s41598-022-09857-8

UCLAML Combating COVID-19

Random graph - Wikipedia

Barabási–Albert model - Wikipedia

Watts–Strogatz model - Wikipedia