Modeling, Estimating, and Minimizing Average New Infections of COVID-19 Based on Information Theory and Social Networks

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Introduction

- CORONAVIRUS disease of 2019 or (COVID-19) is a disease caused by the SARS Cov2 virus [1].
- On January 31st, 2020, the World Health Organization (WHO) declared that the entire world would be suffering a new pandemic caused by the COVID-19 virus [1].
- Since this declaration and at the time of writing the article, the virus has affected more than 20 million people worldwide, resulting in more than 800K deaths, of which more than five million cases and 163K deaths are from the USA alone [1].
- Moreover, many reports around the world have predicted a second wave of the pandemic [2]. Therefore, restrictions have been issued by governments to attenuate the effects of the virus wave.
- So far, neither an ideal cure nor a vaccine or even a reliable road map for the treatment is available, although the number of cases has increased recently [3].

Problem

1. Modeling and estimating the spreading behavior of COVID-19 within a population.
2. Minimizing the virus spreading in that population.

Method

1. Adopting the Channel capacity equation of information theory , also known as Shannon's equation, to specify the virus spreading.

$$C \geq I(X,Y) = B\log_2\left(1+\frac{S}{N_0 B}\right) \quad (1)$$

C represents the channel capacity,

B the bandwidth,

N_0 the noise power spectral density, and

S/N_0B the signal-to-noise power ratio.

2. Optimizing Shannon's equation by proposing a mobility model based on the focal structure analysis of social networks.

Assumptions: Modeling;

While applying equation (1) to model COVID-19,

we let C or $I(X,Y)$ represents the average number of new infections in a population,

S the virus power, and

B the population of a city, state, or country;

$$C \geq I(X,Y) = B\log_2\left(1+\frac{S}{N_0 B}\right) \quad (1)$$

N_0, the noise power spectral density, now represents in some form the power of the mitigation techniques employed.

Unlike in communication theory, the mutual information needs to be minimized such that the spreading of the virus is reduced or slowed. While the virus power S and the population B are uncontrollable factors, N_0 is controllable and is the critical variable to minimize the spreading of the virus.

Critical key: $B \rightarrow \infty$, estimating;

- ❑ To estimate the average number of new infections, we assume the population approaches infinity.
- ❖ In this case, as the analysis reveals, the curve of mutual information exhibits two distinct phases.
- ❖ While, during the beginning phase of the pandemic, the curve exhibits a logarithmic increment in the average number of new infections,
- ❖ beyond a certain threshold determined by the total number of infections exceeding a critical percentage of the population, a semi-stable new infections case can be reached.

Optimization!

- An optimized mobility model based on social networks is used to break the spreading chain of the virus such that there is no virus particle carried through the community by maximizing N_0, alternatively, by minimizing mutual information (X, Y).
- The model employs social network analysis to study the relationships among individuals and their implications. A combination of social networks and smartphone networks examine the users' face-to-face interactions.

System Model: Spreading behavior

- Let $X = [x_1, x_2, x_3, \ldots\ldots, x_n]$ be a vector of n components that represents the sources of the virus,
- and each component is an independent and identically distributed (i.i.d) Gaussian random process.
- By considering the population approaches infinity [10], and denoting $\frac{S}{N_o B} = x$, the Shannon's equation (1) can be written as

$$\lim_{x\to 0} I(X,Y) = \frac{S}{N_0} \lim_{x\to 0} \frac{1}{(1+x)\ln(2)} \qquad (2)$$

- Equation (2) shows that at the beginning of the pandemic, the number of new infections increases logarithmically.

$$\lim_{x\to 0} I(X,Y) = \frac{S}{N_0} \frac{1}{\ln(2)} \cong 1.44 \frac{S}{N_0} \qquad (3)$$

- However, equation (3) shows that the average number of new infections is a semi-linear function depends on S and N_0 as the value of x increased.

System Model: Optimizing N_0 Values

Days	Number of connected nodes used in the model over time.	N_0	
1	413	327	$I(X,Y)$ Readings as presented in curves in Fig. 2 based on the population (B)
2	779	611	
3	1286	1013	
4	1832	1393	
5	2181	1598	
6	2736	1989	
7	3254	2375	
8	3913	2877	
9	4575	3301	
10	5140	3548	
11	5371	3690	
12	5580	3843	
13	5753	3941	
14	5953	4065	
15	6173	4162	
16	6420	4292	
17	6638	4444	
18	6787	4519	
19	6876	4579	
20	6933	4604	

Results

1. Two different population are used in this work; however, the results show that applying the proposed model on huge population has a better result.
2. Each curve in the side figures is the average number of new infections in the community based on the optimized N_0 values.
3. The upper curve is the results of the first day, the second curve is the results of day 2, so on to the last day is the result of day 20.

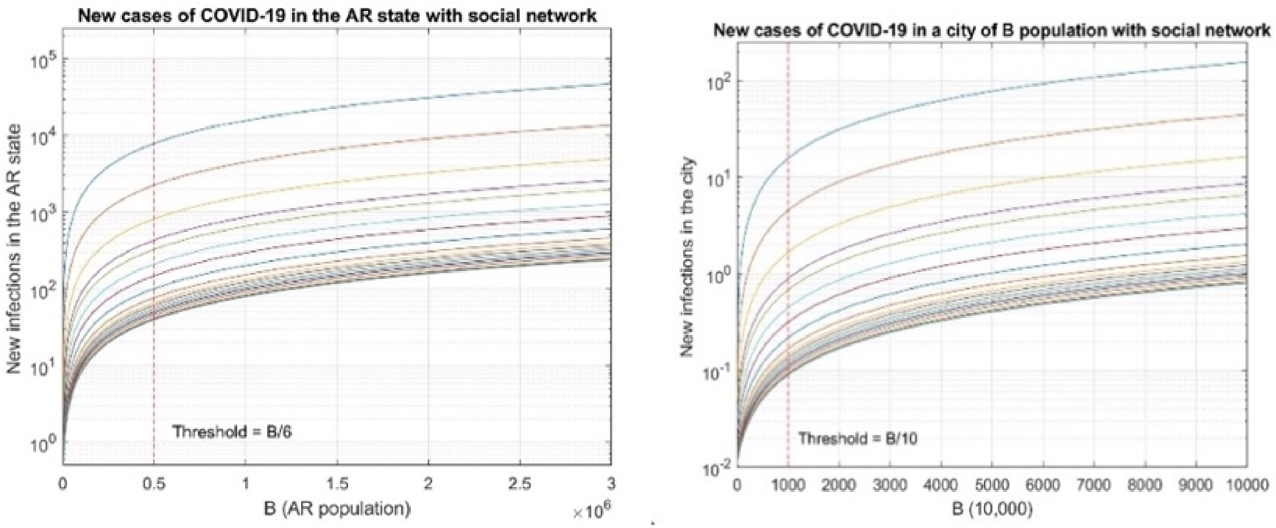

Fig. 2. Left side, the average number of new infections in the AR state. Right side, the average number of new infections in a city of 10,000 population.

Conclusion

- The information-theoretic model based on the mobility optimization model of social networks has been proposed for modeling and mitigating the spreading of COVID-19 virus within a population such that the health systems can tackle and overcome the current pandemic.
- The simulation results show that when the spreading techniques and early detections of COVID-19 cases have been adopted early, the proposed model ensures a massive of lives saving in the population;
- However, when the spreading techniques increased, lifesaving is not increased accordingly. This shows that not all the city or the state should go to shut down, but only the main hotspots such as (shopping centers, restaurants, subways, big groceries, and economic centers) in any city that people are using daily.

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