Original Article

A Novel Model and Relay-Based Research for Epidemic COVID-19 Transmission

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Abstract

Background: COVID19 a new disease that comes from novel corona virus; In spite of declaring it a pandemic and providing number of guidelines for prevention and treatment; it is still a wild goose chase to get rid from it. In the present paper, we propose a general model for the spread of COVID19. **Material and Methods:** For the entire statistical calculations and plotting the graphs MATLAB was used. We look for a broad model for the COVID-19 spread via mathematical modeling. It is considered that an infected individual is the source of the infection. It has the ability to propagate COVID-19 infection in any way. Its spread rate is negatively correlated with an exponent of the source's distance. **Results:** The impact of social distancing is evaluated, and simulation results along with existing data indicate that an increase in social distancing leads to a reduction in the number of patients. Additionally, it is demonstrated that when the infection chain initiates, certain infected individuals (either persons or carriers) act as relay nodes, i.e., they acquire the infection and subsequently pass it on to additional individuals. The paper illustrates that as the quantity of relay nodes rises, the rate of spread will also escalate swiftly. **Conclusion:** Simulation experiments have led to the conclusion that the existence of several relay nodes may greatly enhance the infection. These findings provided a strong base to the hypothetical role of social distancing in prevention of COVID 19.

Keywords: COVID19, source of infection, modeling, relaying.

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Introduction

COVID19 a new disease that comes from novel corona virus has become the latest thread for mankind of unknown origin with various scientific and conspiracy theories to support.[1] The World Health Organization (WHO) declared COVID-19 to be a pandemic and provided guidelines for handling it.[2] Despite it, COVID19 has turn out to be a potent treat for life on earth.[3] Different scientific theories about origin and spreading of COVID19 are floating.[4,5]

Various types of measurements like use of sanitizer, social distancing and lock down etc have been applied to prevent or slow down the spread of COVID19 as par requirement country to country.[3] Presumably, it seems to be the first time in human history that worldwide population is facing such a dangerous and swiftly mutating virus species.[4]

In spite of declaring it a pandemic and providing number of guidelines for prevention and treatment; it is still a wild goose chase to get rid from it.[6] People who already have chronic illness, elderly, or people with low immunity are more vulnerable for the disease.[7] Hypothetically social distancing has been suggested as the main preventing measure against COVID 19 since its onset without any supportive scientific theory.[8]

In order to effectively analyze COVID-19, it is crucial to simulate its distribution. To simulate the spread of COVID-19, two mathematical models have been put forth.[9,10] Similarly, a probability based statistical model has been presented for the limited testing kits for COVID19 in the hospitals.[11]

In the present paper, we introduce a comprehensive model for the transmission of COVID-19, where the rate of spread is determined by the distance of an individual from the source, specifically an infected person. Subsequently, a relay-based model is introduced to elucidate the transmission dynamics, wherein the infected individual has no travel history and has not had direct contact with COVID-19 positive patients. Additionally, the study takes into account multiple relays in its analysis.

Materials and Methods

The goal of the current study was to develop a mathematical model for the propagation of COVID-19 in India. The Indian government's statistical data was utilized for the computations and evaluation of the mathematical model's effectiveness. This work is the first of its kind to suggest a solid foundation for

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social distancing in the form of mathematical modeling. Since the current study has no negative effects on living or non-living things, ethical clearance was not required. MATLAB was utilized for all statistical computations and graph plotting.

A. Overall Framework for COVID-19 Transmission: We examine the following model, in which the distance from the source affects the rate of infection and spread. In particular, the rate of spread "R" can have any positive value and is inversely proportional to tod^n , where d is the distance from the source and n is the exponent. Consequently, we may express the rate of spread "R" as

R=1/d^n , Eq (1)

It can be noted from this correlation that as the distance increases, the rate of spread diminishes. It indicates that if a healthy individual is sufficiently distanced from an infected person, the likelihood of the healthy individual contracting the infection will be significantly reduced, thereby providing a fundamental basis for social distancing. If the distance value ‘d’ is considerably large, for instance, 5 meters or more, then even with n=1, the rate R will be minimal. It is presumed that there exists an infected individual/source (with COVID-19) at the center of the circle as illustrated in [Figure 1] and it is surrounded by several individuals. The rate of COVID-19 transmission adheres to the relationship expressed in equation (1). From Eq (1), it can be discerned that ‘R’ is dependent on the distance of a person (who is not infected with COVID-19) from the source and the exponent ‘n’. The value of ‘n’ can vary across different regions or scenarios. In densely populated areas, the value of ‘n’ will be lower, resulting in a higher rate of spread. Conversely, if a source is located near unhealthy individuals, the exponent ‘n’ will also be lower. Similarly, in regions where individuals are healthy with robust immunity or where the population density is low, the value of ‘n’ will be higher, leading to a rapid decline in the spread.

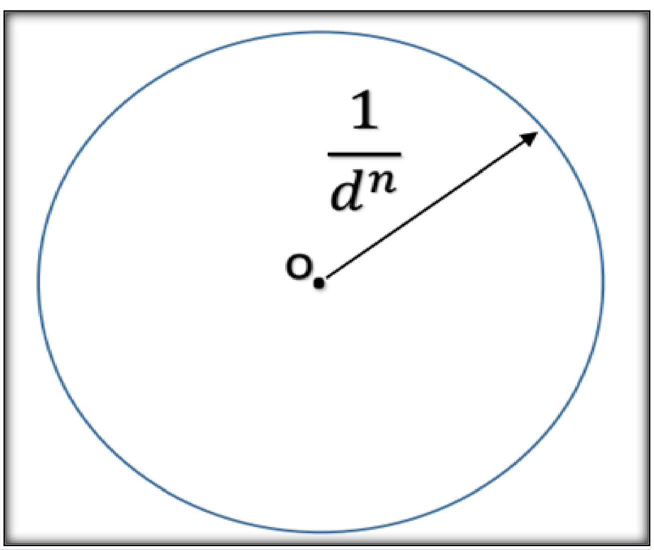

Figure 1: Proposed model for the spread of COVID19.

B. Relay-Based Model for COVID-19 Transmission: **Let's examine the following findings:**

1. The data presented by the Indian government regarding COVID-19,[12] indicates that "Out of 5,911 SARI patients tested, a total of 104 (1.8%) were found to be positive for COVID-19. These cases were documented across 52 districts in 20 States/Union Territories. The positivity rate for COVID-19 was notably higher among males and individuals over the age of 50. In total, 40 (39.2%) of the COVID-19 cases did not have any reported history of contact with a confirmed case or international travel."
2. Reports indicate that a pizza delivery person (in Delhi) and a vegetable vendor (in Delhi) have contracted COVID-19. Neither of them has any travel history nor have they been in direct contact with any COVID-19 patients.[13]
3. Additionally, it has been reported that in slum areas such as Dharavi in Mumbai, the number of COVID-19 cases is increasing daily.[14] From the observations above, it can be inferred that direct contact with an infected individual is not evident. This raises the question: where does the infection originate? To address this question, we propose a relay-based model for the transmission of COVID-19. The model we propose is illustrated in [Figure 2]. In this model, there is a source, namely an infected individual with COVID-19, who transmits the infection to a relay node or carrier. This relay node can be an active relay, such as a person who may be asymptomatic or moving about, or a passive relay, such as metal surfaces, plastic items, or food products. Literature 2 indicates that the incubation period of the novel coronavirus is 14 days, meaning it remains active in humans for fourteen days. Since COVID-19 is an infectious disease, this infected individual may serve as a relay node or carrier of COVID-19, potentially infecting other healthy individuals. Similarly, a passive relay node, such as a metal surface or plastic, can also function as a carrier of COVID-19.

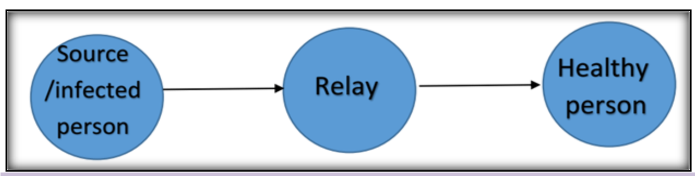

Figure 2: Proposed relay based model for the spread of COVID19.

The rate of spread at relay node can be written as

R_1=1/〖d_1〗^(n_1), Eq (2)

where n_1 is the exponent and d_1 is the relay node's distance from the source. The relay node will now propagate the infection by acting as a new source. The rate of spread at the destination or among healthy individuals can thus be expressed as

R_2=1/〖d_2〗^(n_2), Eq (3)

Where d_2 is the distance of relay node from the source and n_2is the exponent.

Example 1: Let us examine a scenario where a source is encircled by 15 individuals at a distance of five meters. We assumen_(1=1). From (2), the transmission rate is 1/5. Consequently, the number of infected individuals equals 1/5*15=3. This indicates that there are three relay nodes positioned five meters away. Furthermore, if we presume that there are 15 individuals at a distance of five meters from the relay nodes and n_(2=1), the transmission rate of the relay nodes at five meters remains 1/5. Thus, the total number of newly infected individuals due to the three relay nodes will be 3*(1/5*15), which amounts to 9, and the number of infected individuals from the source at ten meters is 1.5 (1/10*15). It can be noted that within a ten-meter radius, the total number of infected individuals is 1 (source) + 3 (relay) + 9 (infected due to relay) + 1.5 (from the source at ten meters) = 14.5. In contrast, if there are 15 individuals at a distance of five meters and another 15 individuals at ten meters, assuming no relaying occurs, the total number of infected individuals would be 5.5 (1 (source) + 1/5*15 + 1/10*15 = 5.5). This example clearly illustrates that the relaying phenomenon accelerates the increase in the number of infected individuals. In Example 1, the count with relay nodes is approximately 2.6 times greater than that without relaying. Even if the transmission rate of relay nodes is considered to be lower than that of the source, for instance, 1/ 〖d_2〗 ^2 , the number of infected individuals will still be higher in the case of relaying. Additionally, it can be observed from the example that if a healthy individual is situated far from the source, and it is assumed that the transmission rate from the source is nearly negligible, the healthy individual may still contract the infection through relay nodes. Therefore, it is plausible that an infected individual may not have direct contact with any COVID-19 positive patient yet still acquire the infection.

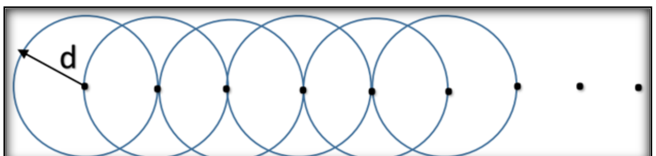

Figure 3: Proposed relay based model with multiple relays

C. Model of Spread for the Spread of COVID19 with Multiple Relays: In this subsection, we consider the presence of multiple relays situated between the source and the destination (healthy individual). It is posited that there exists a source (patient 0), which disseminates the infection as described by (1). This source subsequently generates relay nodes (layer 1); these relay nodes then function as sources themselves, propagating the infection and producing new relay nodes (layer 2), and this process continues iteratively. In practical scenarios, not all relay nodes will function as sources. Only a certain percentage of relay nodes (potentially due to lockdowns or quarantines, etc.) will contribute to the spread of the disease. This model illustrates that the range of infection spread can increase significantly.

Example 2: Let us examine a practical situation where a single source node is present, surrounded by fifteen individuals within a three-meter radius. Utilizing (1), it can infect five individuals within this range with n=1, meaning one infected individual can transmit the disease to five additional individuals. We assume that only 40% of the relay nodes are active and responsible for further transmission. Consequently, there are five relay nodes (infected individuals), but only 40% of these nodes are active, while the remaining 60% are inactive. Thus, only two relay nodes will function as sources and can subsequently generate ten relay nodes (at the second layer). Again, only four nodes are active, leading to the generation of twenty relay nodes at the third layer, and this pattern continues. If we consider ten layers of relay nodes, the total number of infected individuals within a 30-meter radius can be calculated as. Total no. of infected persons= 1+5+10+20+40+80+160+320+640+1280+2560=5116. It has been reported,[15] that a single infected individual can potentially transmit the infection to around 5400 individuals, which closely aligns with the aforementioned calculation. The proportion of active nodes may vary across different layers of relay nodes. It is conceivable that one relay node is encircled by unhealthy individuals, while another may be in proximity to healthy individuals or situated in an isolated area.

Results

[Figure 4] illustrates the relationship between the total number of infected individuals and distance 'd' for various exponent values 'n'. We consider a total of 100 individuals present at each distance 'd'. The graph is generated using (1) with n values of 0.3, 0.5, 1, 2, and 5. It is evident from [Figure 4] that the total number of infected individuals declines as the values of 'n' increase. This indicates that if a source is located in a sparsely populated area or in a setting with adequate social distancing, such that n=5, the transmission will be minimal after three or four units of distance. Conversely, if the exponent is low, for instance, n=0.3, then at a distance of thirty units, the number of infected individuals is roughly 36. This demonstrates the influence of the exponent on the spread.

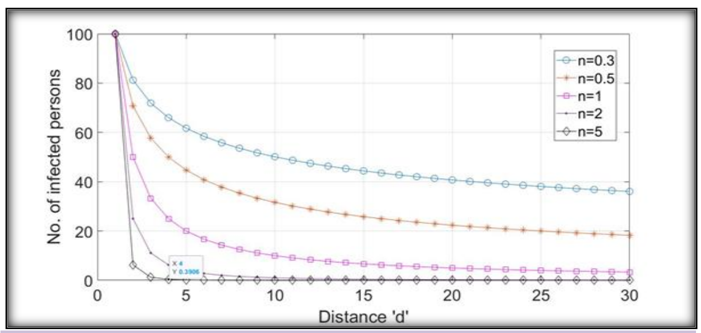

Figure 4: Spread of COVID19 as implied by (1) with different values of n

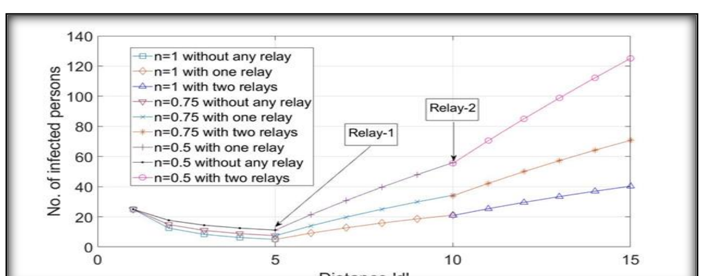

Figure 5: Spread of COVID19 as implied by (2) and (3) with different values of n

The rate of spread with one and two relays with n=0.5, 0.75, and 1 is displayed in Figure 5. At each unit distance, it is assumed that there are 25 people from d=1 to 5 meters, 25 people from 5 to 10 meters, and 40 people from 10 to 15 meters. The figure illustrates the relay's effect. The first relay is positioned at d=5 meters, while the second relay is positioned at d=10 meters. [Figure 5] shows a rise in the number of infected individuals at relay nodes. There will be fewer infected individuals if there is only one relay node as opposed to two.

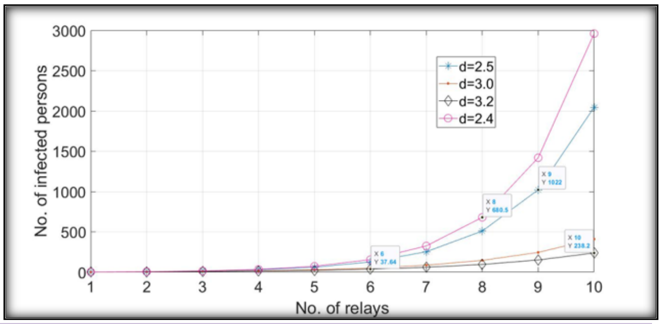

Figure 6: Spread of COVID19 as with different number of relays

It demonstrates how relaying multiplies the spread in any location. Any place with several relay nodes may be a hotspot for the COVID-19 virus. Additionally, it is evident that the effect of spread will become insignificant only after 6 meters if there is no relay node. It demonstrates that the spread of COVID-19 can be reduced if social separation is appropriately maintained. The impact of several relays on COVID-19 transmission is depicted in [Figure 6]. For every relay node, we assume that the exponent value is n=1. Relay nodes are expected to be 2.4, 2.5, 3.0, and 3.2 meters apart. The figure shows that there will be more infected people if there is a shorter distance between relay nodes. For instance, the total number of infected individuals for d = 2.5 and nine relays is 1022, but the total number of infected individuals for d = 3.2 meters and ten relays is 238, which is significanty fewer than the previous scenario. It demonstrates the significance of the distance between relay nodes. The propagation of COVID-19 will be minimal if relays are positioned far enough apart. Additionally, it validates the idea of social separation.

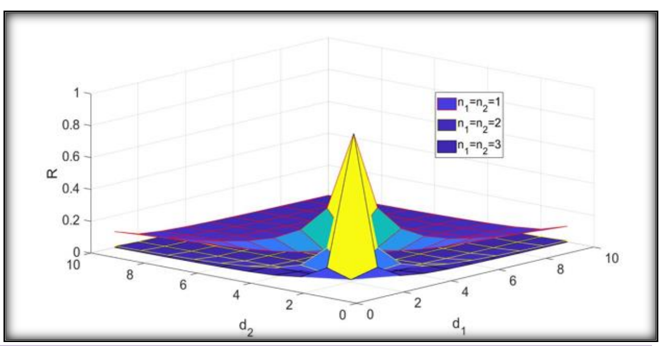

Figure 7: Rate of Spread of COVID19 with varying distances of two relays

[Figure 7] illustrates how the rate of COVID-19 spread varies depending on how far two relays are from the origin, with n_(1=) n_(2=) n_(3=) 1,2,3; d_1 and d_2 are the distances of relay-1 and relay-2, respectively, from the origin. The formula for calculating the rate of spread is 1/(d_1^(n_1)) *1/(d_2^(n_2). The figure shows that if both relays are positioned close to the origin, or reference point, the rate of spread will be unity, i.e., that everyone in the vicinity will become infected. The rate of spread drops if one relay node remains close to the origin while another moves away. The rate of spread rapidly drops if both relays travel away from the origin. Only the distance of relay nodes from the origin is taken into account in [Figure 7] the sources position is not displayed. It demonstrates that an individual can contract the illness from relay nodes even if they are not in direct contact with the source.

Discussion

Results of the mathematical modeling presented in current study as shown in [Figure 4] revealed that number of infected person or speed of infection will depend on the density of the population.

Much the density, more the cases and vice versa. These findings are similar to the results of the previous study of Martins-Filho PR,[16] as he recorded a positive correlation between density population and incidence of COVID 19 cases in Brazilian population. Alike, Wong DWS et al,[17] found in their study in US population in later stage of infection number of infected person will be high in highly dense population whereas, in early stage spread of infection depends on the transportation or immigration of population. Once the infection reached at particular place; spread of it is directly proportion to density of population as it facilitates the infection swiftly.[17]

These findings suggest that speed of infection is greatly depends on the density of inhabitants; more the speed of spreading will require more medical facilities to combat the infected persons.[18] Highly populated countries may face the horrible situation in dealing with such type of infectious anomalies.[19]

Further, present study reported in figure 5 that spread of COVID 19 depends on the infectious persons with other subjects. Less the distance, high the incidence. These results are in consistent with the earlier study of Nande A et al,[20] as they showed that social distancing is effective in slow down the multiplication of COVID 19. Similarly, Thu TPB et al,[21] recorded distances from primary source of infection play an extremely important role in transmission or spread of COVID-19.

Distance from the infectious subject might an important factor in the spread of COVID 19 as the primary source of COVID 19 infection is the transmission of the virus from person to person via respiration.[22] Various other method of transmission of COVID 19 like coughing, touch, contaminated surface, discharges of mouth, eyes, nose etc may be approximately prohibited by keeping social distancing.[4,21-23]

Further, it is shown in results that as the chain of infection starts, some infected nodes (persons or carriers) behave as a relay node, i.e., they receive the infection and then transmit it to some more people. It is recorded in current study that as the number of relay nodes increases, the spread will also increase rapidly. Moreover, the effect of the distance of relay node from source is also discussed. As the distance of relay node increases from the source, the spread decreases.

All these findings of the current study support the role of social distancing from the diseased person and each other. These results are consistent with the findings of earlier study of Zhao T et al,[24] and Qian M et al,[25] as they observed social distancing has been found effective in preventing the spread of COVID 19. However, present model also suggested that a person can be infected even though he is far away from the source or can get infection indirectly. These results are similar to the studies of Oran DP et al,[26] as they showed that in their studies that asymptomatic patients played a pivotal role in spread of COVID 19 pandemic.

Conclusion

A novel relay-based model for COVID-19 transmission has been put forth. The distance from the Source has an inverse relationship with the rate of spread. The spread of COVID-19 has been found to be significantly influenced by the distance between the source and a healthy individual. The present research paper considers both single and multiple relays. The research paper has shown that relaying causes the range of spread to rise extremely quickly. Further, the effect of the distance of relay nodes from the source on the spread of COVID19 has been studied. It has been concluded from simulation results that presence of multiple relay nodes may increase the infection many folds. These findings provided a strong base to the hypothetical role of social distancing in prevention of COVID 19. However, a mathematical model on viral load and its relation with distance is warranted.

Limitations

One of the limitations of the current study is that it addresses only one factor responsible for the spread of COVID 19. However, other multiple factors are also play an important role spread of this viral disease. Another limitation is it does not explore the relation of viral load of patients and its relation with social distancing.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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