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Numerical Computing Paradigm for the Analysis of Mobile Virus Propagation Model with Restraining Impact

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ABSTRACT

As mobile viruses proliferate, critical challenges have been raised in maintaining security, including data breaches, unauthorized charges, remote eavesdropping, and privacy violations, which are all critical trials of mobile automation and security. Understanding and mitigating the propagation mechanisms in vulnerable and exposed systems would require governing these intimidated threats. In this paper, mathematical model is being used to stimulate the propagation of viruses with restoration impact that focuses on the key parameters such as susceptible, infected and recovered populations. The model is solved using Adam numerical solver as well as explicit and implicit Runge-Kutta methods to analyze the dynamics of the spread of the virus and their comparative analyses. We present detailed solution graphs and assess the absolute error between the methods to measure computational efficiency and accuracy. The results provide insight into the driving factors behind virus propagation, as well as the reliability and robustness of the Adam solver. Furthermore, our results and findings serves as a foundation for developing progressive and liberal strategies to confine virus propagation and enhance the pliability of mobile networks.

Keywords: Adam numerical solver; Implicit Runge-Kutta method; Explicit Runge-Kutta method Mobile virus propagation; Numerical computing; Mobile computing.

NOMENCLATURE

S(t)	Number of susceptible devices at t
I(t)	Number of infected devices at t
R(t)	Number of Recovered devices at t
β	Infection per interaction likelihood, referred to as transmission rate.
γ	Rate at which infected devices are recovered or have infection removed.

INTRODUCTION

The emergence of mobile communication and the continual advancement of smartphone technology have let consumers demand more and expect more [1-3]. However, it has necessitated the invention of newer and more advanced technologies [4-5]. These technologies have brought out more cyber risks and attacks such as mobile virus and their legitimate access to mobile technology [6-9]. Unlike traditional computer viruses, mobile viruses take advantage of vulnerability in mobile devices like Bluetooth, Short Messaging Service –SMS and applications, and so on, to binge very drastically in the networking modules [10-15]. These viruses become dangerous as they can infringe privacy, commit fraud financially, and monitor without authorization, hence their study to prevent them [16-19]. Fixed viruses have limitations because of their comportment, they are just capable of infecting the system they have started from [20]. The mobile viruses on the other hand seem to have exploited the behavior and operation of the users of the device as well as the device's behavior to the maximum limitations thus enhancing their ability to spread [21-22]. It is common for users to be unaware that they are helping propagate the virus; they may use unsafe networks, share files infected with the virus, or use apps infected with the virus [23-24]. Also, the topology of mobile networks is highly dynamic in which nodes' mobility and connection with other nodes are very frequent and random, which makes it difficult to contain the virus [25-26]. Thus, the need surfaces for infusing more rigor into mobile virus propagation mathematical models to cover the mentioned challenges adequately.

Long have been that mathematical modeling has served as a powerful means to understand the spread of infectious diseases and such modeling approaches have also found application for the study of cyber threats in mobile networks [27-29]. We can see how basic virus spread models, e.g. Susceptible-Infected-Recovered (SIR) framework, separate the population into key compartments [30-31]. Nevertheless, there exist limitations in the application of such models to mobile viral propagation, mainly due to human mobility patterns, alienation of Bluetooth and SMS transmission channels, and device connectivity behaviors. Existing studies exploring the dynamics of virus spread on mobile networks frequently resort to simulation-based approaches [33]. These methods' general limitation is that they depend on predefined parameters and do not generalize to the rich class of network conditions. Ad-

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ditionally, existing studies are almost entirely concerned with virus propagation mechanisms but do not address the accuracy and reliability of the numerical methods that are used for simulations [34]. That leaves unanswered how the results of propagation models and their subsequent application in real-world scenarios are influenced by computational solvers [35].

To overcome these latter limitations, this paper presents a novel design of mobile virus propagation with the assistance of the Adam numerical solver via the Mathematica software. An Adam solver that uses explicit and implicit Runge-Kutta methods provides a flexible and reliable framework to solve the output differential equations from virus propagation models [36-37]. We combine this solver with the SIR framework to provide a deeper understanding of the spread of mobile viruses and the driving factors of their dynamics. The analysis of the numerical accuracy and performance of the Adam solver is one of the key contributions to solving the task in the paper. We compare explicit and implicit methods and use them to simulate virus propagation under widely varying network conditions [38]. Solution graphs and absolute error computations continue the quantitative part of the study and provide a rigorous method to assess the solver's reliability [39-40]. The level of detail is essential so that the proposed model is not only theoretically sound but also practically applicable. To capture the virus propagation stage in our system, we use our model with susceptible, infected and recovered populations. Devices that are susceptible to infection, referred to as devices that can be infected; devices that actively extend the virus are referred to as infected devices; and devices that are recovered may either become immune to the virus or be removed from the network. Through simulation of interactions between these populations, we can identify critical factors that affect virus spread, such as infection and recovery rates, and the effects of external interventions. The role of human behavior in the propagation of viruses is another major aspect of this study. User mobility, device interaction frequency, and security measure response to mobile viruses are all factors whose spread varies significantly [41]. We combine these behavioral dynamics with the model, bringing a more realistic picture of how a virus propagates in actual mobile networks. This holistic view bridges the gap between models borrowed from the research literature and their use in practice. It helps to translate the findings to policymakers and network administrators more directly.

This study has far-reaching implications for research and practice in various fields, including blockchain, efficient energy, and data-driven [42-45]. On one side of research, our model can help develop more elaborate models to study mobile virus propagation. The results also demonstrate the necessity for the accuracy of the numbers in computational modeling and urge us to explore alternative solvers and methods further. The implications of the findings for practical solutions, including pre-immunization, adaptive dissemination, and real-time monitoring, prove useful from a practical standpoint. Research in mobile virus propagation is a critical area of research concerning network security, user privacy, and system resilience. In this paper, we contribute to understanding virus dynamics by introducing a new mechanistic modeling approach, analyzing the numerical performance of the Adam solver, and presenting actionable insights from parameter identification using experimental data. Through this work, we hope to advance our understanding of mobile virus propagation and support the development of effective defenses against this emerging threat.

The study charities are summarized as follows:

- In this paper, the proposed mathematical model is being used to stimulate the propagation of viruses that focuses on the key parameters such as susceptible, infected and recovered populations.
- The model is solved using Adam numerical solver with explicit and implicit Runge-Kutta methods to analyze the dynamics of the spread of the virus. We present detailed solution graphs and assess the absolute error between the methods to measure computational efficiency and accuracy.
- The results provide insight into the driving factors behind virus propagation, as well as the reliability and robustness of the Adam solver.
- Furthermore, our results and findings serves as a foundation for developing progressive and liberal strategies to confine virus propagation and enhance the pliability of mobile networks.

The paper arrangement is demonstarted as follows: Mathematical models addressed in Section 2. Section 3 designates the Methodologies Solutions. Section 4 presents the results of the simulation research. Section 5 signifies the conclusions of the study.

MATHEMATIC REPRESENTATION

To model the propagation of mobile viruses, we adopt a compartmental approach, categorizing devices in the network into three primary populations: We have S, I and R in this case. Each of these compartments represent devices that can become infected, spread the virus actively, become immune or removed from the network as shown in eq (1). We describe these populations as evolving through a system of ordinary differential equations (ODEs) that we then solve with advanced numerical techniques. For further study about the mathematical structure and context of the given scenarios, brief explanations have been given in the reference paper for interest paper [46].

$$\begin{aligned} \frac{dS}{dt} &= \beta * \frac{S}{N} * I \\ \frac{dI}{dt} &= \beta * \frac{S}{N} * I - \gamma * I \\ \frac{dR}{dt} &= \gamma * I \end{aligned} \tag{1}$$

The Adam solver uses these approaches to provide excellent flexibility and accuracy in general. The first part of our work begins with an initial number of susceptible (S), infected (I), and recovered (R) devices S_0, I0 and R_0 respectively. The values are chosen based on that network's initial state. We adjust the parameters β and γ to mimic real-world virus transmission and recovery rates. A solution graph is then generated, which illustrates how the virus progresses — but first, the simulation computes populations S(t), I(t) and R(t) over a specified period as shown in equation (2).

$$\begin{aligned} \frac{dS}{dt} &= \beta * \frac{S}{N} * I & S(0)&=S_0 \\ \frac{dI}{dt} &= \beta * \frac{S}{N} * I - \gamma * I & I(0)&=I_0 \\ \frac{dR}{dt} &= \gamma * I & R(0)&=S_0 \end{aligned} \tag{2}$$

To ensure the correctness and maintainability of the Adam numerical solver in mobile virus propagation, five scenarios were created each with one case demonstated. Use of appropriate coefficient values for a proposed system of equations. Changes of the values for the variables S, I, and R with respect to the time, and the following equations (3–7) provide the values of these variables.

Adam solver mathematical model in scenario-1, case 1 expressed as:

$$\begin{aligned} \frac{dS}{dt} &= 0.003*\frac{S}{200}*I && S(0)=150 \\ \frac{dI}{dt} &= 0.003*\frac{S}{200}*I-0.1*I && I(0)=30 \\ \frac{dR}{dt} &= 0.1*I && R(0)=20 \end{aligned} \tag{3}$$

Adam solver mathematical model in scenario-2, case 1 expressed as:

$$\begin{aligned} \frac{dS}{dt} &= 0.004*\frac{S}{1000}*I && S(0)=900 \\ \frac{dI}{dt} &= 0.004*\frac{S}{1000}*I-0.01*I && I(0)=80 \\ \frac{dR}{dt} &= 0.01*I && R(0)=20 \end{aligned} \tag{4}$$

Adam solver mathematical model in scenario-3, case 1 expressed as:

$$\begin{aligned} \frac{dS}{dt} &= 0.0025*\frac{S}{15000}*I && S(0)=150 \\ \frac{dI}{dt} &= 0.0025*\frac{S}{15000}*I-0.05*I && I(0)=400 \\ \frac{dR}{dt} &= 0.05*I && R(0)=100 \end{aligned} \tag{5}$$

Adam solver mathematical model in scenario-4, case 1 expressed as:

$$\begin{aligned} \frac{dS}{dt} &= 0.0001*\frac{S}{10000}*I && S(0)=500 \\ \frac{dI}{dt} &= 0.0001*\frac{S}{10000}*I-0.003*I && I(0)=500 \\ \frac{dR}{dt} &= 0.003*I && R(0)=0 \end{aligned} \tag{6}$$

Adam solver mathematical model in scenario-5, case 1 expressed as:

$$\begin{aligned} \frac{dS}{dt} &= 0.0001*\frac{S}{10000}*I && S(0)=3333 \\ \frac{dI}{dt} &= 0.0001*\frac{S}{10000}*I-0.0001*I && I(0)=3333 \\ \frac{dR}{dt} &= 0.0001*I && R(0)=3334 \end{aligned} \tag{7}$$

With the same values, the next equations are demonstrated for the Explicit Runge-Kutta Method. Although the explicit method was computationally feasible it could only handle stiff systems or rapid changes in variable value at higher transmission rates. Equations (8-11) represent the equations for this model.

Explicit Runge-Kutta solver mathematical model in scenario-1, case 1 expressed as:

$$\begin{aligned} \frac{dS}{dt} &= 0.003*\frac{S}{200}*I && S(0)=150 \\ \frac{dI}{dt} &= 0.003*\frac{S}{200}*I-0.1*I && I(0)=30 \\ \frac{dR}{dt} &= 0.1*I && R(0)=20 \end{aligned} \tag{8}$$

Explicit Runge-Kutta solver mathematical model in scenario-2, case 1 expressed as:

$$\begin{aligned} \frac{dS}{dt} &= 0.004*\frac{S}{1000}*I && S(0)=900 \\ \frac{dI}{dt} &= 0.004*\frac{S}{1000}*I-0.01*I && I(0)=80 \\ \frac{dR}{dt} &= 0.01*I && R(0)=20 \end{aligned} \tag{9}$$

Explicit Runge-Kutta solver mathematical model in scenario-3, case 1 expressed as:

$$\begin{aligned} \frac{dS}{dt} &= 0.0025*\frac{S}{15000}*I && S(0)=150 \\ \frac{dI}{dt} &= 0.0025*\frac{S}{15000}*I-0.05*I && I(0)=400 \\ \frac{dR}{dt} &= 0.05*I && R(0)=100 \end{aligned} \tag{10}$$

Explicit Runge-Kutta solver mathematical model in scenario-4, case 1 expressed as:

$$\begin{aligned} \frac{dS}{dt} &= 0.0001*\frac{S}{10000}*I && S(0)=500 \\ \frac{dI}{dt} &= 0.0001*\frac{S}{10000}*I-0.003*I && I(0)=500 \\ \frac{dR}{dt} &= 0.003*I && R(0)=0 \end{aligned} \tag{11}$$

Explicit Runge-Kutta solver mathematical model in scenario-5, case 1 expressed as:

$$\begin{aligned} \frac{dS}{dt} &= 0.0001*\frac{S}{10000}*I && S(0)=333 \\ \frac{dI}{dt} &= 0.0001*\frac{S}{10000}*I-0.0001*I && I(0)=3333 \\ \frac{dR}{dt} &= 0.0001*I && R(0)=3334 \end{aligned} \tag{12}$$

Lastly, to assess performance in solving the system of equations for this model, we also utilize the Implicit Runge Kutta method for superior stability, especially for stiff scenarios with high sensitivity to parameter changes. Equations (13-17) demonstrate these cases.

Implicit Runge-Kutta solver mathematical model in scenario-1, case 1 expressed as:

$$\frac{dS}{dt} = 0.003 * \frac{S}{200} * I \qquad S(0)=150$$
$$\frac{dI}{dt} = 0.003 * \frac{S}{200} * I - 0.1 * I \qquad I(0)=30 \tag{13}$$
$$\frac{dR}{dt} = 0.1 * I \qquad R(0)=20$$

Implicit Runge-Kutta solver mathematical model in scenario-2, case 1 expressed as:

$$\frac{dS}{dt} = 0.004 * \frac{S}{1000} * I \qquad S(0)=900$$
$$\frac{dI}{dt} = 0.004 * \frac{S}{1000} * I - 0.01 * I \qquad I(0)=80 \tag{14}$$
$$\frac{dR}{dt} = 0.01 * I \qquad R(0)=20$$

Implicit Runge-Kutta solver mathematical model in scenario-3, case 1 expressed as:

$$\frac{dS}{dt} = 0.0025 * \frac{S}{15000} * I \qquad S(0)=150$$
$$\frac{dI}{dt} = 0.0025 * \frac{S}{15000} * I - 0.05 * I \qquad I(0)=400 \tag{15}$$
$$\frac{dR}{dt} = 0.05 * I \qquad R(0)=100$$

Implicit Runge-Kutta solver mathematical model in scenario-4, case 1 expressed as:

$$\frac{dS}{dt} = 0.0001 * \frac{S}{10000} * I \qquad S(0)=500$$
$$\frac{dI}{dt} = 0.0001 * \frac{S}{10000} * I - 0.003 * I \qquad I(0)=500 \tag{16}$$
$$\frac{dR}{dt} = 0.003 * I \qquad R(0)=0$$

Implicit Runge-Kutta solver mathematical model in scenario-5, case 1 expressed as:

$$\frac{dS}{dt} = 0.0001 * \frac{S}{10000} * I \qquad S(0)=3333$$
$$\frac{dI}{dt} = 0.0001 * \frac{S}{10000} * I - 0.0001 * I \qquad I(0)=3333 \tag{17}$$
$$\frac{dR}{dt} = 0.0001 * I \qquad R(0)=3334$$

SOLUTION METHODOLOGY

Mathematical framework and numerical solvers of the methodology used to model and analyze mobile virus propagation. The structure is such that the interplay: facilitates a robust, accurate, and stable simulation of virus dynamics. We solved the ODE system using the Adam numerical solver that combines an explicit and implicit Runge-Kutta methods. The methodology is divided into three phases:

ADAM SOLVER

The equations were solved using the Adam solver that combines an explicit and implicit approach to obtain stability and accuracy. Using a solver, virus dynamics are precisely tracked by iteratively computing the values of S,I and R for different time steps. The computational efficiency and robustness of this hybrid approach enable it to be used as a viable method for modeling mobile virus propagation.

EXPLICIT RUNGE KUTTA

A standalone numerical solver for the explicit Runge-Kutta method was implemented which was used to evaluate the performance. It is computationally efficient for non stiff equations, and this solution is approximated with forward step predictions. The behavior of the sampler under varying parameter conditions was observed and its performance was analyzed.

IMPLICIT RUNGE KUTTA

An independent study of the stability and, in particular, of the accuracy, particularly for stiff systems, was also performed by using the implicit Runge-Kutta method. It differs from the explicit method in that at each step it finds a set of equations by given future states information. Such an equiugency model fits better when scenario of rapid change of value of the variables is given.

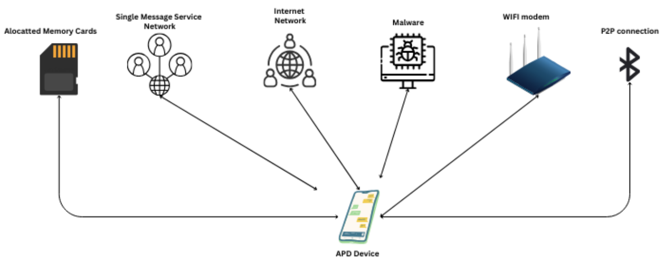


Fig. 1 Virus propagation through different mediums

RESULTS AND DISCUSSION

The simulation results of the proposed mobile virus propagation model using the Adam numerical solver are presented in this section and implications of the results discussed. The dynamics of the virus over multiple scenarios is analyzed and the explicit and implicit Runge Kutta methods are evaluated for solving the system of equations. Adam solver solution graphs show the temporal evolution of the susceptible *(S)*, infected *(I)*, and recovered *(R)* populations. In every case, the infection rate rises sharply initially, driven by infections occurring between susceptible and infected devices. The infected population grows, reaches a peak, then goes down, either as devices recover or are removed. The population becomes steadily less susceptible and more recovered until the system stabilizes. In the case of moderately high transmission (β) and recovery (γ) rates, the infected population peaks early and stays put; most of the network is immune or recovered. When β is bigger, we get faster and broader infection and slower falling of susceptible population. A longer time to recovery is seen with lower γ values, and a longer infection peak is produced. These variations indicate the impact of parameters on virus propagation and support the importance of system dynamics for effective mitigation.

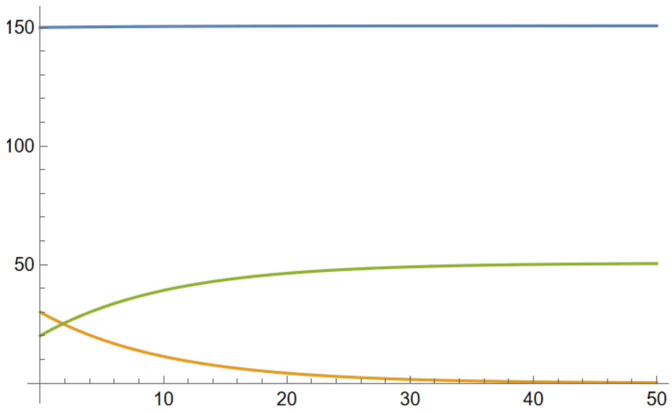
NUMERICAL ACCURACY AND STABILITY BACKGROUND

Adam Solver: We show that the hybrid solver effectively captures the propagation dynamics while maintaining numerical stability across all scenarios. By using a combination of explicit and implicit methods it minimizes computational errors.

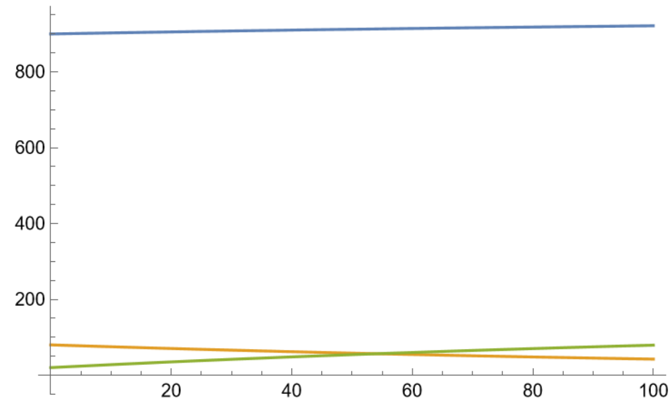
Explicit Runge-Kutta Method: This method is efficient for nonstiff systems, however, it is unstable in cases with fast changing (t) in situations with high β.

Implicit Runge-Kutta Method: In stiff systems, the implicit approach shows significantly superior stability. Nevertheless, its computational complexity grows with the higher order calculation.

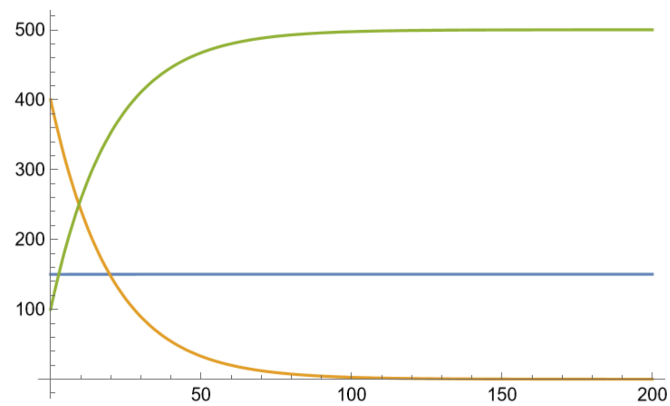
It was determined that the numerical unreliability was afforded through the computation of the absolute error between the explicit and implicit solutions. It was found that the Adam solver had minimal error compared to its standalone explicit or implicit counterparts and, despite a dynamic or stiff system with no equilibrium, always returned results that converged to machine zero. Practical implications of this study for designing strategies to limit mobile virus propagation are practically obtained. Critical thresholds for β and γ. Targeted immunization and recovery protocols can be developed by network administrators, with γ. Also, by integrating a suite of such robust numerical solvers, such as the Adam method, predictive models can increase their accuracy in real-time decision-making during outbreaks. The results illustrate the sensitivity of the system to β (infection rate) and γ (recovery rate): High β: Rapid outbreaks are typical in networks with high infection rates, and these quickly depress the susceptible population before recovery mechanisms can make an impact. It echoes real world situations where a hot mobile virus spread rapidly through smart media like Bluetooth or SMS there are no bounds. Low γ: This slows down the recovery rates of infection peaks, making an overall impact of an outbreak larger. The emphasis here is on efficient recovery mechanisms ones that mitigate spread such as antivirus updates or device immunization protocols. Five scenarios designed for validation of the proposed model verify the versatility of the proposed model. The model captures diverse propagation patterns, from mild outbreaks to rapid, large scale infections, by varying the initial conditions and parameter values. This also demonstrates the solver's consistency in producing the same results across these scenarios, indicating a useful applicability in the real world mobile network environments. More critical it is for modeling dynamic systems to balance computational efficiency with stability. Hybrid solvers such as Adam are preferred for mobile virus propagation studies for real networks, since they provide flexibility in terms of conditions to handle. It is possible for future work to further improve model accuracy and applicability by introducing heterogeneous networks, more sophisticated recovery mechanisms, and implicit user behavior patterns. Dynamic behavior of mobile virus propagation under varying parameter values is visualized by the solution graphs for the susceptible (S), infected (I), and recovered (R) populations. It is clear from these graphs, how infection progresses over time with the effect of the transmission (β) and recovery (γ) rates in determining the how much the virus spreads and how much of it can be contained. A steeper infection peak is shown in these scenarios when they have high transmission rates, while recovery rates are slower affecting the duration of outbreaks. Following solution graphs will demonstrate the findings obtained from the following parameters for each solver.



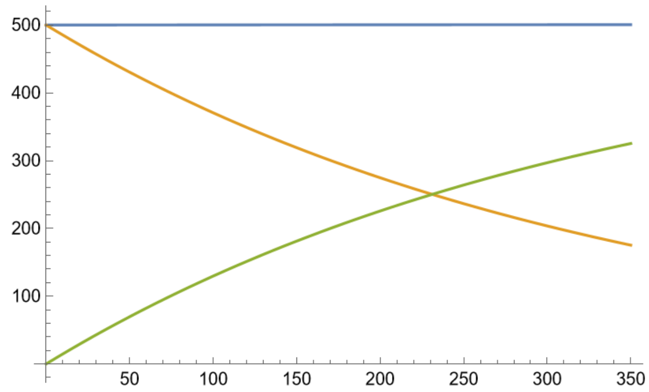
Solution graph-1



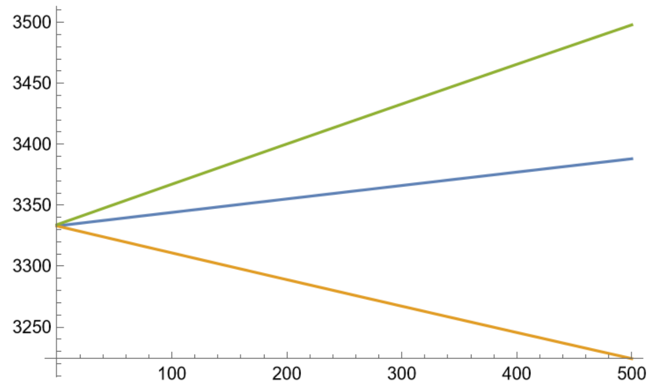
Solution graph-2



Solution graph-3



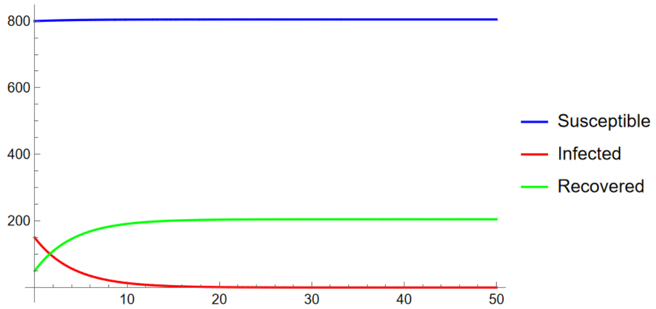
Solution graph-4



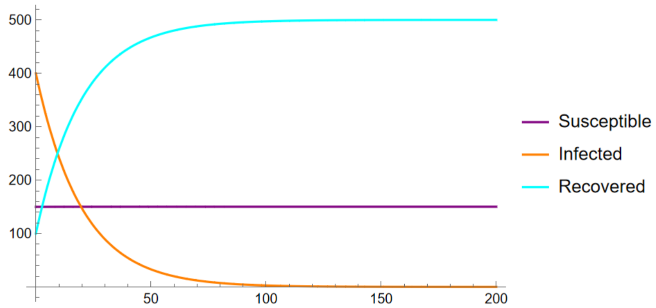
Solution graph-5

Fig. 2 Adam Solver Solution Graphs

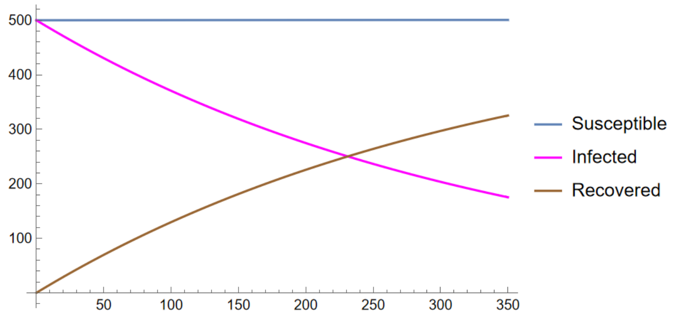
The explicit Runge Kutta method is used to generate solution graphs which present the temporal evolution of the susceptible (S), infected (I), and recovered (R) populations. For nonstiff systems, this method captures the virus propagation dynamics well in terms of clear infection peaks, and steady transitions between states.



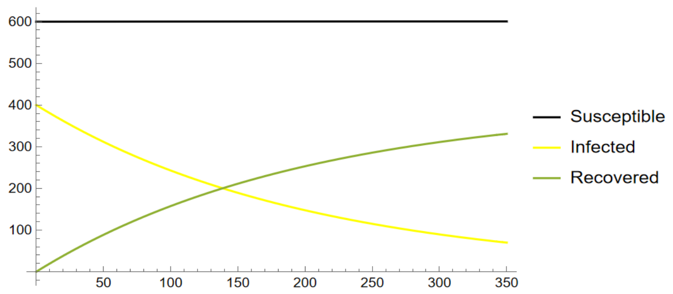
Explicit solution graph-1



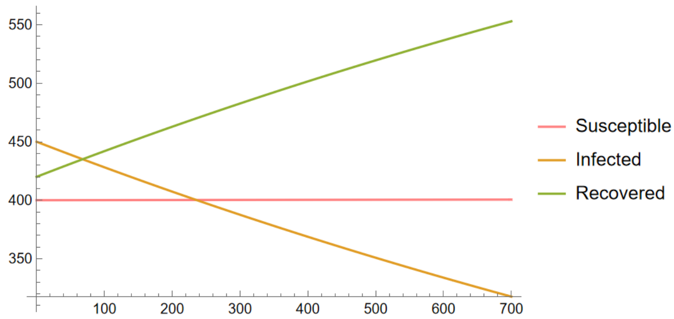
Explicit solution graph-2



Explicit solution graph-3



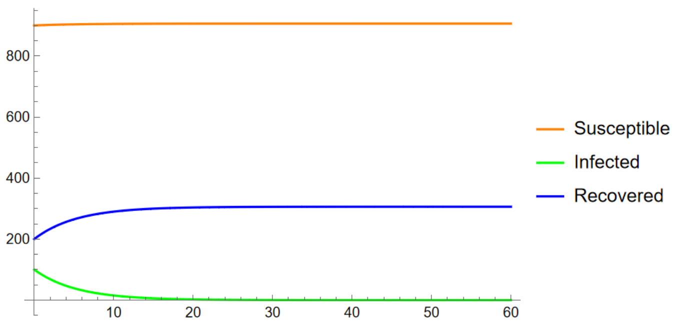
Explicit solution graph-4



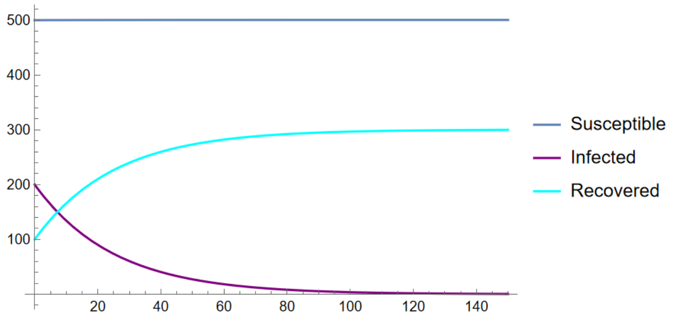
Explicit solution graph-2

Fig. 3 Adam Solver Solution Graphs Ising Explicit Runge Kutta Method

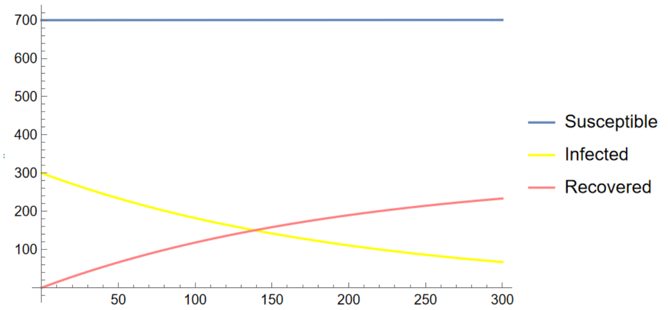
The solution graphs produced using implicit Runge-Kutta method illustrate stability and accuracy, particularly in scenarios with rapidly changing system diminuendos. Population declines smoothly for susceptible; steady rise to peak shows the infected curve before slowly settling down to recovered. It differs from the explicit method in the approach that handled high transmission rates and delayed recover rates without showing any sort of unpredictability that gives dependable explanations even in the critical and difficult scenarios.



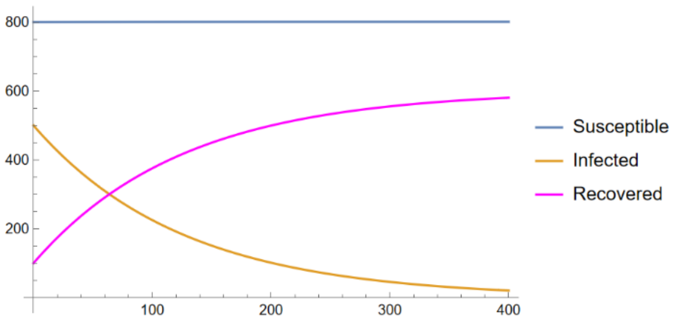
Implicit solution graph-1



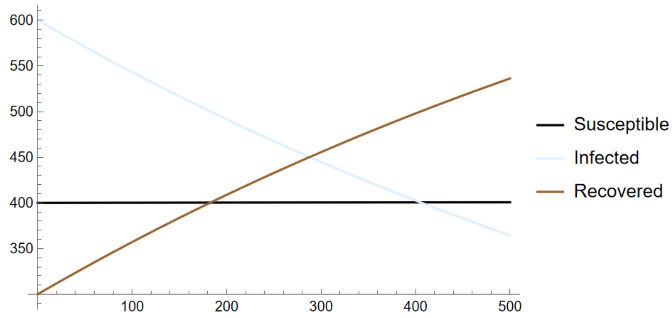
Implicit solution graph-2



Implicit solution graph-3



Implicit solution graph-4



Implicit solution graph-5

Fig. 4 Adam Solver Solution Graphs Ising Implicit Runge Kutta Method

The Absolute errors for the Adam technique, explicit and implicit Runge Kutta have been shown for the comparison between each other that how the deviations are being showcased in Figures. The first comparison demonstrates the time intervals that explains the sensitivity in step size between adam and explicit. The second assessment between explicit and implicit, is demonstrating robustness while the third figure shows comparison between adam and implicit, picturizing high accuracy and dynamics of the system.

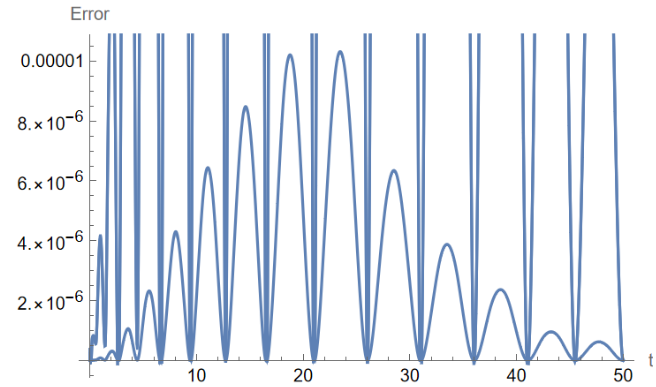


Fig.5 Absolute Error between Adam and Explicit

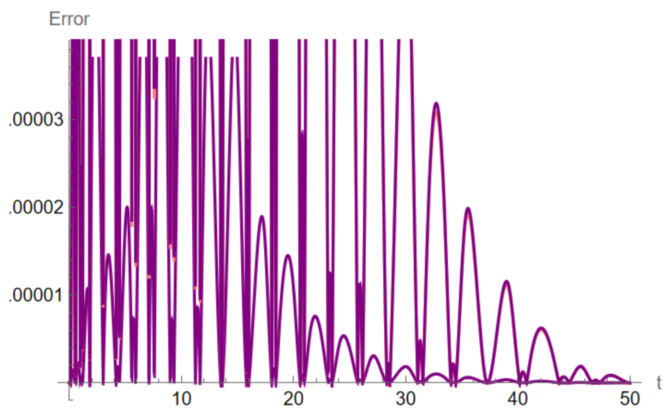


Fig. 6 Absolute Error between Explicit and Implicit

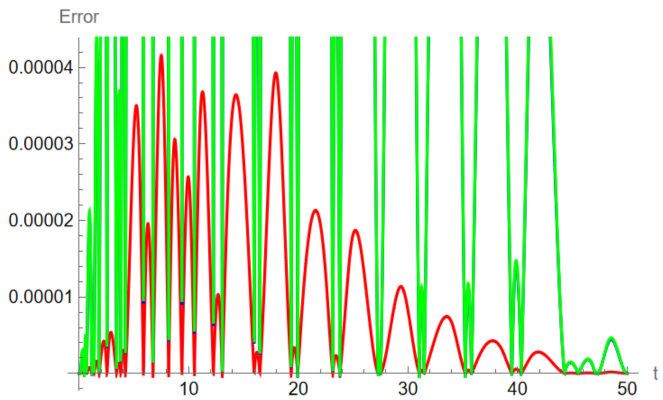


Fig.7 Absolute Error between Adam and Implicit

Lastly all three numerical methods: Adam solver, Explicit Runge-Kutta, and Implicit Runge-Kutta was visualized in one graph to validate comprehensive assessment. The errors between the three methods showed distinct error patterns highlighting their stability and precision. This unified graph emphasized the relative performance and appropriateness for each method. Figure (8-12) illustrates the current context.

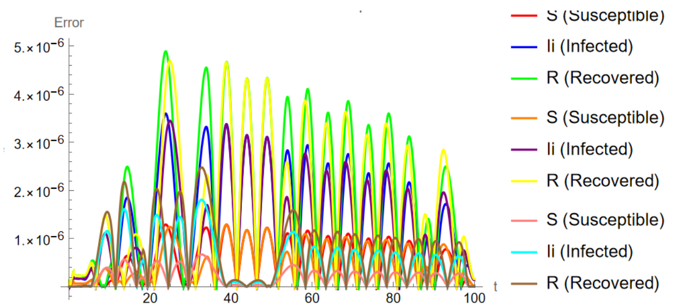


Fig. 8 Absolute Error between Adam and Implicit

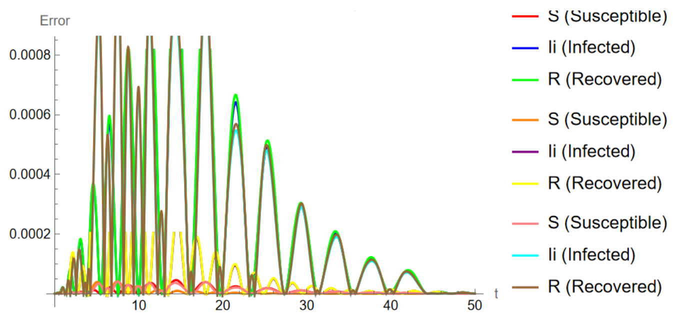


Fig. 9 Absolute Error between Adam and Implicit

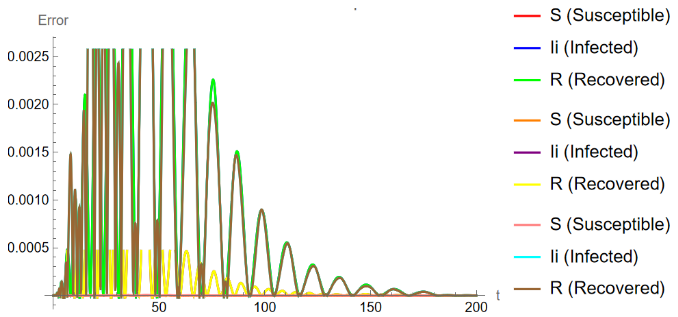


Fig. 10 Absolute Error between Adam and Implicit

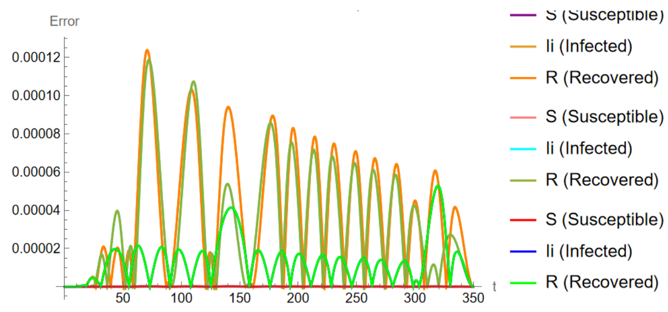


Fig. 11 Absolute Error between Adam and Implicit

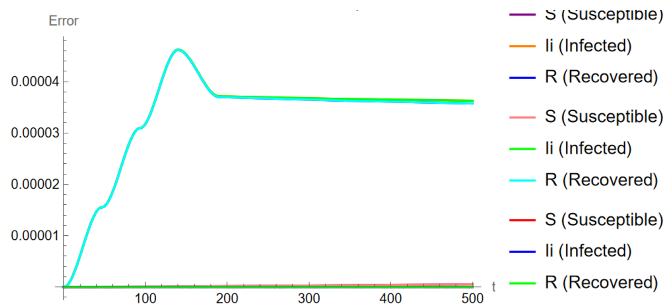


Fig. 12 Absolute Error between Adam and Implicit

CONCLUSION

In this study, we examined and demonstrated the changing aspects of mobile virus propagation using a theoretical as well as a compartmental approach, that includes integrating the SIR framework for Susceptible, Recovered, and Infected parameters. Using Adam Solver for obtaining the numerical solutions with Explicit and Implicit Runge Katta methods. Simulations were taken through the rigorous, arduous setting by we assessed the stability, accuracy, and performance of these methods by examining the solution graphs for each and through the evaluations of the Absolute errors. The acquired results demonstrated all the methods, Explicit Runge Kutta shows efficiency in the computational results. Less robustic in nature for certain parameter conditions as compared to the Implicit method and the Adam solver that given high precision and stability. The unified error graph further emphasized Adam solver's preeminence against implicit techniques. Overall, treasured understandings have been obtained in the numerical modeling of propagation of virus also validates its importance in selecting suitable solvers based on correctness and strains. These findings can be extended to similar epidemic models, aiding in more effective prediction and containment strategies in complex networks.

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