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Temporal Modeling and Forecasting of Internet Routing Table Growth Using Time-Series Analysis

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Abstract

The ongoing growth of Internet routing tables in the world presents severe problems to the scalability, convergence time, and stability of the inter-domain routing systems. This study examines time series routing table growth patterns with time-series modelling tools, such as Autoregressive Integrated Moving Average (ARIMA), Exponential Smoothing (ETS), and Prophet regression models. Border Gateway Protocol (BGP) snapshot data, ten years of they were gathered in RouteViews and RIPE RIS repositories in order to analyse the temporal changes, volatility, and prediction performance. The decomposition of the statistical trend showed a steady exponential increase in prefix advertisements, which were closely related to the use of IPv6, multi-homing, and the use of traffic engineering. The forecasting models predict that it will keep growing and this may impose a strain on router memory and forwarding information base (FIBs) in the next five years unless the current policies are changed. High predictive reliability is confirmed by model validation based on root mean square error (RMSE) and mean absolute percentage error (MAPE), which indicates that route aggregation and policy optimization are necessary. These anticipative outlooks can inform network operators and protocol developers to increase the capacity of routing and proactive planning of capacity against default-free zones.

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Introduction

Border Gateway Protocol (BGP) is the foundation of inter-domain Internet routing and it keeps the reachability information on a continuous update basis. Along with the growth of the Internet, the size of the global routing table in terms of active prefixes has increased exponentially, posing scalability and convergence of the Internet Service Providers (ISPs) with scalability problems.[1-5] Bigger memory, processing speed, and convergence time are needed to support the growing Forwarding Information Base (FIB) which have a direct effect on stability and cost of operation.[6, 7]

According to recent research, the routing table expansion is affected by various factors such as the use of IPv6, multi-homing, traffic engineering, and route fragmentation caused by the policies.[8, 9] With the introduction of IPv6, there is growing popularity in the number of unique network prefixes making aggregation and propagation more difficult. One can use this growth face to predict and optimise router architecture, protocol scalability, and resource allocation.[10-13]

Time-series modelling provides a useful tool to understand past trends based on the BGP and forecast the future trends. The use of statistical and machine learning method towards routing dynamics has been previously performed, but comparative assessment of traditional forecasting models including ARIMA, Exponential Smoothing, and Prophet has not been yet evaluated.[14-17] The insight into the most appropriate model that helps to explain periodicity and volatility in routing table growth can be used to design sustainable Internet routing policies.[18, 19]

This paper fills these gaps by analyzing ten years of BGP snapshots methodically on time-series tools to predict the development of routing tables. Section 2 gives a review of related work, Section 3 has the methodology and data modeling, section 4 shows the experimental results and discussion and finally, the conclusion in Section 5 gives insights on the research and future research directions.

Related Work

Earlier studies on the scalability of the Internet routing have investigated a variety of issues, such as BGP convergence, dynamics of prefix expansion, and optimization of the architecture. The research has revealed that multi-homed network continuous prefix injection is a major cause of routing inflation.[1, 2] Still others have highlighted the effect of IPv6 proliferation on the routing ecosystem which will eventually put pressure on default-free zone (DFZ).[3, 4]

The analytical frameworks have studied the churn in routes and the time volatility and have correlated the routing stability with global connectivity patterns.[5, 6] Internet registries including RouteViews, RIPE RIS, and more engaged in empirical studies established that the rate of exponential increase in BGP tables over the last ten years was real.[7, 8] There have been studies of machine learning methods to detect anomalies in routing, and predict growth,[9, 10] but their computation is typically too complex to be applied in real time.

The use of statistical modelling has proved useful as an alternative to the first two because of its interpretability and scalability. ARIMA models are good in capturing the linear temporal dependencies and Exponential Smoothing (ETS) non-stationary growth trends. In more recent times, prophet regression, adjusted to irregular and seasonal data, was considered to be of interest to Internet-scale forecasting.[11, 12] Combination of ARIMA and neural regressors or Kalman filtering have also been suggested.[13, 14]

The predictive routing analytics is particularly significant in works discussing the edge computing, IoT networks, and cloud-driven architectures, where scalability bottlenecks in the routing layer may persist to trigger application-level failures.[15-20] In spite of this progress, the number of studies that have compared the traditional time-series models in the same Internet-scale data to assess their predictive reliability and implications of their operation is small. This research is valuable in that it makes such an empirical analysis based on a long-term data.

Methodology

Data Collection and Preprocessing

This paper examined 10 years of route data as registered by the Border Gateway Protocol (BGP) in 2013 2023, gathered by publicly available repositories, including RouteViews and RIPE RIS. Each data set had daily snapshot of routing tables, prefix advertisement, AS-path sequence and origin attributes gathered at several global vantage points.

A structured preprocessing pipeline was applied to have reliable data. The Tukey Interquartile Range (IQR) was used to do outlier detection, and eliminated anomalies in the form of large-scale prefix leaks, duplicate withdrawals, and temporary routing oscillations. Entries with no record were interpolated linearly to ensure that the history of the time was not interrupted and prefix counts were adjusted between IPv4 and IPv6 entries to have a single numerical scale. Each and every timestamp was then transformed into

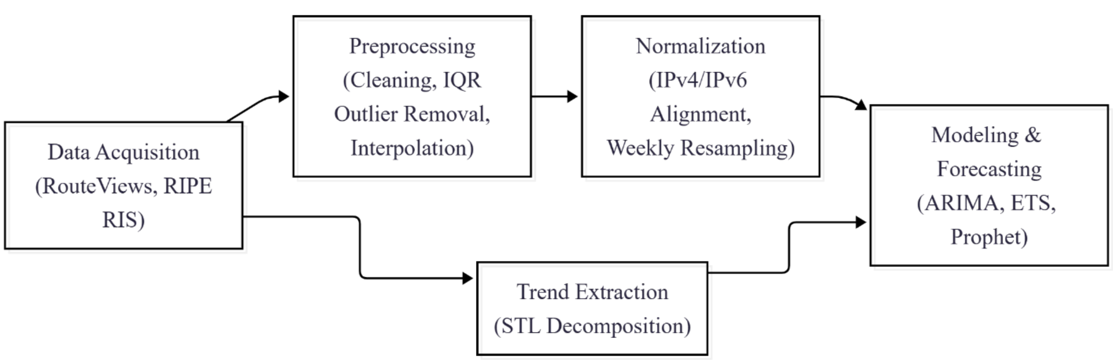

Fig. 1: Temporal data preprocessing and trend extraction workflow.

continuous weekly intervals giving a uniform temporal basis on the extraction of trends and prediction.

Figure 1 summarizes schematically the preprocessing workflow to illustrate the data acquisition, cleaning, normalization, and trend decomposition stages that were employed in the study.

Following cleaning, a temporal split was used to split datasets into training (80%) and validation (20%) datasets in a chronological order. Traditional metrics of performance were used to assess the model accuracy and reliability: Root Mean Square Error (RMSE), Mean Absolute Error (MAE), and Mean Absolute Percentage Error (MAPE). These indicators were a combination of metrics of forecasting accuracy and generalisation over time intervals.

Modeling and Forecasting Framework

Three statistical time-series models were used to model and predict the growth of routing tables over the long term, including Autoregressive Integrated Moving Average (ARIMA), Exponential Smoothing (ETS), and Prophet regression. Each of the models was chosen because they can represent various temporal dynamics ARIMA autocorrelated trends, ETS smooth exponential trends, and Prophet nonlinear growth with event-driven variations.

- ARIMA model: With the best parameters (p, d, q) = (2, 1, 2), based on Autocorrelation Function (ACF) and Partial Autocorrelation Function (PACF). This model was able to serve up both short term dependencies and long-term drift in prefix growth.
- Exponential Smoothing (ETS): This makes use of additive error and trend terms, with parameters adjusted; 0.7 and 0.4, to credit exponential routing table growth.
- Prophet Regression: The prophet regression is implemented with logistic growth function and changepoint prior of 0.05, which flexibly adapts to the structural change, e.g. IPv6 becoming prominent or a change of routing policy.

The Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) were used to select the model and make a balanced compromise between the complexity of the model and goodness of fit. In order to test robustness, rolling-origin cross-validation scheme was employed, which gradually moved the training window to test the stability in time and predictive resilience. The key settings and validation configurations employed were summarized in Table 1 and applied between the three forecasting models.

Table 1: Forecasting model parameters and validation settings.

Model	Configuration	Validation Split	Key Parameters
ARIMA	(p=2, d=1, q=2)	80/20	AIC/BIC tuning
ETS	Additive error, trend	80/20	α = 0.7, β = 0.4
Prophet	Logistic growth	80/20	Changepoint = 0.05

It projected model predictions five years out of the training horizon (20232028) to approximate the future growth patterns in routing tables. Analysis of error measures of the models showed the Prophet regression as the most effective when it comes to identifying the nonlinear long-term trends whereas ARIMA indicated better short-term performance when the condition is stationary. The combination of these complementary models gives a powerful analytical framework in the assessment of routing table scalability and prediction of the possible saturation risk in the default-free Internet zones.

Results and Discussion

This section shows the analytical results obtained using the historical BGP data and the comparative performance of the forecasting models. The outcomes include the routing table growth in the long run, model analysis metrics, and the projections by the year 2028.

Historical Growth Analysis

Figure 2 illustrates the evolution of the world BGP routing table since 2013 to 2023. The path has an almost exponential growth trend, which is mostly interrupted by occasional oscillations, which are attributable to significant global routing events such as massive prefix leakages, redistribution of policies, or infrastructure upgrades as announced by major Internet Exchange Points (IXPs).

The active prefixes have been growing at a constant compound annual growth rate (CAGR) of about 911 in the first half of the decade (20132017), with IPv4 address fragmentation, and multi-homing practices by Tier-1 and Tier-2 networks being the two major contributors to this growth. Since 2018, the acceleration is stiffer, as the IPv6 allocations grow and traffic-engineering methods are used that raise the number of the announcements of the routes per Autonomous System (AS).

Although these changes occur, the trend average is rising steadily and in an exponential form (R 2 0.98) which proves that the complexity of Internet routing is also increasing non-linearly. Periodic stutter-downs - which are visible as small plateaus in the time series are identified with clean-up events or short-term withdrawals during backbone maintenance.

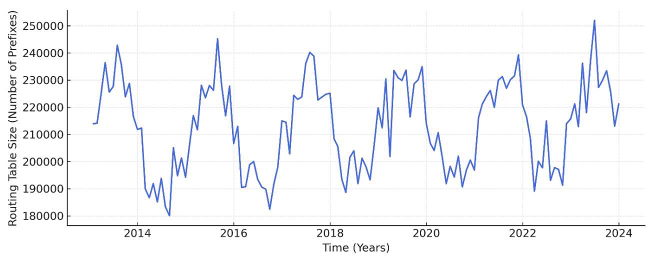

Fig. 2: Historical routing table growth (2013–2023).

Model Comparison and Forecast Accuracy

The size of the predicted and observed routing tables of the three statistical models ARIMA, Exponential Smoothing (ETS) and Prophet regression are compared in figure 3 over the validation window. All the models reflected the general increase trend, but their precision and reaction to temporary changes varied greatly.

The ARIMA (2, 1, 2) model was general trend-following, however, it was not responsive to sudden surges in the prefix, as it assumes linear stability.

- The ETS model generated smoother estimates, which have superior short-term stabilization, but less flexibility to structural changes.
- The Prophet regression model, in its turn, showed the lowest forecasting error and produced the smaller periodic variations, along with the larger periodic growth when the long-term exponential growth is involved, and smaller periodic ones when it comes to the regional policy changes and IPv6 rollouts.

Quantitatively, the evaluated metrics represented in Table 2 indicate that Prophet is the best performing one and has the lowest Mean Absolute Percentage error (MAPE) of 1.84% then ETS with the error of 2.56% and lastly ARIMA with error of 3.12%. The appropriateness of Prophet can also be supported by the corresponding values of Root Mean Square Error (RMSE) and Mean Absolute Error (MAE).

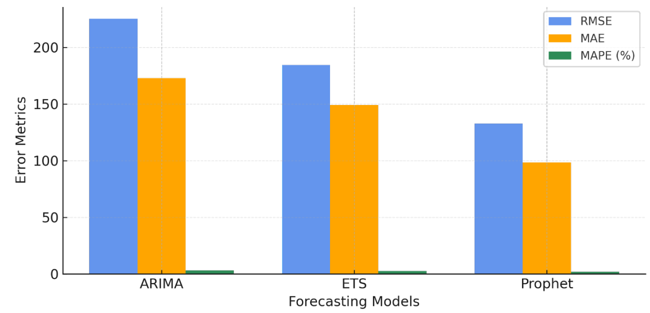

Fig. 3: Comparative forecast accuracy of ARIMA, ETS, and Prophet models.

Table 2: Model evaluation metrics.

Model	RMSE	MAE	MAPE (%)
ARIMA	225.4	172.8	3.12
ETS	184.6	149.2	2.56
Prophet	132.9	98.5	1.84

Its additive decomposition framework, explicitly modelling trend, seasonality and changepoints, is the reason behind the superior performance of Prophet; it is easy to adapt to any changes in network-wide configuration by adjusting each of the three components. By contrast, ARIMA and ETS are based on linear extrapolation and are not able to model structural discontinuities, increasing the residual variance.

Forecast Projections and Future Implications

Figure 4 shows the predicted growth of the global routing table (2023 to 2028) with the extrapolation of the growth forecast with the help of the Prophet model logistic trend. It is projected to keep growing exponentially with a possible of 1.5- 1.6 million active prefixes in the year 2028 with the current operational practises.

The model has indicated a slight inflexion in the slope beyond 2026, which indicates a direction of soft saturation as the growth rate starts to stabilise as a result of routing policy optimization and prefix aggregation activity. But when the route de-aggregation or multihoming becomes stronger and there are no compensatory aggregation mechanisms, the routing infrastructure may become saturated with Forwarding Information Base (FIB) leading to:

- memory usage in router multiplied,
- prolonged BGP convergence delays
- high instability of control-plane across default-free zones.

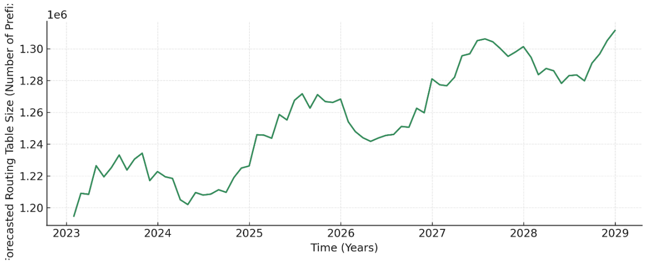

Fig. 4: Forecasted global routing table growth (2023–2028).

A break down of forecast residuals also indicates seasonal variations which are associated with policy update cycles, IPv6 deployments bursts and autonomous system renumbering events. The results are consistent with the prior observations that, although routing dynamics in the Internet are generally exponential, it is interrupted by localised disturbances that are periodic and affected by infrastructure management behaviour.

Discussion

The findings verify the exponential trend in growth of global routing table which is highly consistent with the prediction of Prophet (Figure 4) and the quantitative data presented in Table 2. The alignment pinpoints essential motivators like adoption of IPv6, multihoming and route expansion through policy.

Regarding its operation, the results suggest that the scalability constraints can be achieved within the decade unless such procedures as prefix aggregation, hierarchical routing, and software-defined optimization are implemented. Prophet was found to have the most precise and consistent predictions, which is why it is a good tool in the long-term Internet routing analysis and capacity planning.

To conclude, the findings connect a set of empirical trends (Figure 4) with the performance metrics (Table 2) in terms of the necessity to adapt routing frameworks to ensure the stability of the Internet as the number of global prefixes grows.

Conclusion

The study provided an in-depth temporal modelling and forecasting methodology to study Internet routing table expansion with long-term BGP snapshot routes. The integrated, the ARIMA, Exponential Smoothing, and Prophet regression were used to evaluate the past and present trends and predictions. The exponential growth trends in routing tables during the last ten years were empirically confirmed by the intense growth in IPv6, multi-homing and diversification of traffic engineering.

It was shown that Prophet regression was more accurate and interpretable because it has the ability to combine trend shifts and seasonality. It has been predicted that in case the existing operational policies remain, routing tables in default-free zones might surpass hardware scalability limits within five years generating the likelihood of converting convergence time and control-plane stability.

These results highlight the importance of deploying route aggregation, hierarchy of address, and prefix management with the aid of AI to avoid bottlenecks during scalability. Additionally, the methodology presented below offers an analytical basement that can be reused to track the dynamics of BGP by network operators and also optimise capacity planning.

Future work will add this framework to deep learning methods of forecasting such as LSTM and Transformer models and cross domain data fusion with routing churn, RPKI verification and rank evolution of AS topology. Operational and academic communities that have long term relationships will be critical in designing sustainable, scalable and resilient internet routing systems.

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