

A Regression based approach for link residual time prediction in MANETs *

Surabhi Patel¹ and Dr Heman Pathak²

¹ Gurukul Kangri Vishwavidyalaya, Uttarakhand

² surabhipatel130@gmail.com

³ Gurukul Kangri Vishwavidyalaya, Uttarakhand

hpathak@gkv.ac.in

Abstract. Mobile ad-hoc network (MANET) is a collection of mobile terminals forming an infrastructure less and quick deployable network, which can communicate to each other via multiple hops or single hop. Such ad-hoc networks have always been important for various applications like defence applications especially for countries like India having boundaries and regions with large geographical diversity. Mobility attribute is a notable one in MANETs, as this leads to frequent topology changes which are the primary cause of route failure. A route is an ordered set of links, hence for predicting future availability of any particular route, it is important to estimate the availability of its currently available constituent links. This paper explores various link availability prediction model and proposes a least square polynomial regression-based statistical approach to predict the availability of link. Proposed approach assumes that movement of nodes are based on column mobility model i.e each node in the network is linearly moving with constant speed. Each node in the network periodically broadcasts hello packets to its neighbours to inform it's availability in the network. Neighbour node receives hello packet and uses its signal strength to estimate distance between sender and receiver of hello packet. A monotonically decreasing signal strength of hello packets at receiver node indicates that nodes are moving away from each other and link between them may break in future so it starts link residual time prediction algorithm to predict the time when the distance between them will exceed the pre-defined threshold value. The proposed algorithm is simulated using NS 2.35. The performance of the algorithm has been analyzed for identified parameters. The results are also been compared by simulating other existing link prediction approaches based on interpolation.

Keywords: Ad Hoc Networks · MANET · Mobility · Link prediction.

1 Introduction

Mobile ad-hoc network (MANET) is a collection of mobile nodes and operates in a self-organised manner. The nodes move in an arbitrary manner and routes

* Gurukul Kangri Vishwavidyalaya, Uttarakhand

are prone to frequent breakage. Lack of central control and frequent breakage of routes make a big challenge for routing protocols.

Routing protocols in MANETs are classified into three categories: proactive, reactive and hybrid [8]. Proactive protocols such as distance vector routing protocol maintain a database of route information at each node in the network before routing starts. Reactive protocols do not maintain route information, it only identifies routes that are required to carry data in the network. AODV [12] is an example of reactive routing protocols. Hybrid protocols combine the best features of proactive and reactive routing protocols such as zone routing protocol.

Frequent change in topology caused by the mobility of nodes affects QoS (Bandwidth, delay, jitter, throughput, etc.) requirements in MANET application [9]. Routing protocols should adapt dynamic change in topology. Majority routing protocols are designed to find out the shortest path, but due to the mobility of nodes links on the shortest route may fail. This failure causes data loss and connection interruption if rediscovering of the route is not done rapidly. The availability of routes can be estimated by predicting the availability of the links between nodes which are forming the route. When a link failure is expected, then upstream nodes find a new route within link residual time. If the new route is not found upstream nodes propagate warning message to the source node before the link residual time.

Manet protocols are based on layered architecture, for optimization of protocols need to go for cross-layer architecture. A notable amount of research has been done on cross-layer approaches [2, 13] in order to improve the performance of protocols. Cross-layer approach uses the interaction between non- adjacent layers with different objectives. In the proposed approach also cross-layer interaction between physical and network layers is utilized for link failure prediction. Network layer utilizes received signal strength (from the physical layer) of hello packets for optimizing AODV routing protocol.

In this paper, least square polynomial regression approach [10, 11] is discussed for estimating for how much time any particular link will be active. Monotonically decreasing received signal strengths of hello packet is used as the dataset for discussed regression-based statistical approach.

2 literature survey

In this approach, [16] monotonically decreasing received signal strength is used for predicting the availability of link. Prediction is done by one mathematical model which is based on the Newton divided difference method.

Stability of the link for the flow of data in multimedia is an important issue. This paper [15] presented a scheme for estimating link lifetime. Newton interpolation polynomial mathematical tool is used to approximate received signal strength within limited samples and link lifetime estimation is done by interception and middle value.

This paper [14] presented the statistical parametric model to distributions of the link lifetime for different-2 mobility pattern. Four-link lifetime distribution pattern are discussed (Gamma, Weibull, Lognormal, Exponential) based on mobility pattern (Manhattan, low speed, high speed).

In this paper [4] original AODV routing protocol is used. Authors are estimating link expiration when a node is in the preemptive region. Preemptive region means, when a node is receiving packet signal strength from the upstream node is less than threshold signal strength. When a node is in the preemptive region, the signal strength of the last three consecutive packets and their arrival time are used in Lagrange interpolation for predicting link expiration.

3 Regression based approach for link residual time prediction(RLRP)

MANET is infrastructure less network form by mobile nodes. These mobile nodes communicate to each other via single hop or multiple hops. Mobility is a key attribute, this causes route failure because the topology of the network changes frequently. So for predicting the future of network topology, link residual time prediction is an important field.

Proposed approach is based on column Mobility Model [1] of mobile nodes it assumes that each node broadcast hello packets to inform its availability in the range. When neighbour node receives hello packet from a sender it uses its signal strength (RSSI Value) to estimate the distance between them. — monotonically decreasing sequence of RSSI indicates that nodes are moving away from each other and link between them may break down in future. —.

Regression-based approach for link residual time prediction(RLRP) is based on least square polynomial regression. Regression is a better approach than interpolation [17] because interpolation looks for the predicted form of function but in regression looks for a function that minimizes error, this needs a good approximation.

The following steps are discussed below:

1. Let node i and j are any two neighbour nodes of MANET.
2. Node i broadcasts hello packets of constant predefined signal strength at periodic intervals.
3. Neighboring node j receives these packets and maintains a record of RSSI (received signal strength indication) and packet arrival time in a table. RSSI is a measurement of the signal strength in recieved radio signal. Let $RSSI_{i,j_1}, RSSI_{i,j_2}, \dots, RSSI_{i,j_m} \dots$
 $\dots, RSSI_{i,j_n}$ are signal strengths of recieved hello packets by j th node transmitted from i th node recieved at time $t_{i,j_1}, t_{i,j_2}, \dots, t_{i,j_m} \dots, t_{i,j_n}$ respectively.
4. When node j observes a monotonically decreasing pattern of received signal strengths of hello packets as in equation 1; In considered case let m th onward packets have monotonically decreasing RSSI values then:

$$RSSI_{i,j_m} > RSSI_{i,j_{m+1}} > RSSI_{i,j_{m+2}} \dots > RSSI_{i,j_{m+n}} \quad (1)$$

A set $\mathfrak{R}_{i,j}$ as equation 2 is formulated with above monotonically decreasing hello packet signal strengths and times as elements.

$$\mathfrak{R}_{i,j} = \{(RSSI_{i,j_m}, t_{i,j_m}), (RSSI_{i,j_{m+1}}, t_{i,j_{m+1}}), \dots, (RSSI_{i,j_{m+p}}, t_{i,j_{m+p}}), \dots, (RSSI_{i,j_{m+n}})\} \quad (2)$$

5. Least square polynomial regression based link failure prediction module is invoked.

- Following is the representation of quadratic model which relates elements of set 2.

$$\begin{bmatrix} RSSI_{i,j_m} \\ RSSI_{i,j_{m+1}} \\ \vdots \\ RSSI_{i,j_{m+p}} \\ \vdots \\ RSSI_{i,j_{m+n}} \end{bmatrix} = \begin{bmatrix} t_m^2 & t_m & 1 \\ t_{m+1}^2 & t_{m+1} & 1 \\ \vdots & \vdots & \vdots \\ t_{m+p}^2 & t_{m+p} & 1 \\ \vdots & \vdots & \vdots \\ t_{m+n}^2 & t_{m+n} & 1 \end{bmatrix} * \begin{bmatrix} a_{ij} \\ b_{ij} \\ c_{ij} \end{bmatrix} \quad (3)$$

- Equation: 4 is simplified representation of equation: 3.

$$\Upsilon_{ij} = \Phi_{ij} * \Theta_{ij} \quad (4)$$

where

$$\Upsilon_{ij} = \begin{bmatrix} RSSI_{i,j_m} \\ RSSI_{i,j_{m+1}} \\ \vdots \\ RSSI_{i,j_{m+p}} \\ \vdots \\ RSSI_{i,j_{m+n}} \end{bmatrix}, \Phi_{ij} = \begin{bmatrix} t_m^2 & t_m & 1 \\ t_{m+1}^2 & t_{m+1} & 1 \\ \vdots & \vdots & \vdots \\ t_{m+p}^2 & t_{m+p} & 1 \\ \vdots & \vdots & \vdots \\ t_{m+n}^2 & t_{m+n} & 1 \end{bmatrix}, \Theta_{ij} = \begin{bmatrix} a_{ij} \\ b_{ij} \\ c_{ij} \end{bmatrix} \quad (5)$$

- Least Square estimate [6] $\hat{\Theta}_{ij}$ of vector parameter Θ_{ij} of equation: 4 is following:

$$\hat{\Theta}_{ij} = (\Phi^T \Phi)^{-1} \Phi^T \Upsilon_{ij} \quad (6)$$

- In this way one can estimate values of $\hat{a}_{ij}, \hat{b}_{ij}$ and \hat{c}_{ij} and express signal strength of $i \Leftrightarrow j$ th link $RSSI_{ij}$. Equation: 7 represents best fit quadratic polynomial of signal strength with respect to time.

$$RSSI_{ij} = \hat{a}_{ij}t^2 + \hat{b}_{ij}t + \hat{c}_{ij} \quad (7)$$

- By antenna characteristics threshold value of signal strength $RSSI_{thresh}$ [3], min signal strength required to be detected by receiver antenna is a known parameter. Solution of equation: 8 will provide estimate of time $\tau_{i,j,break}$ when link will break.

$$RSSI_{thresh} = \hat{a}_{ij}t^2 + \hat{b}_{ij}t + \hat{c}_{ij} \quad (8)$$

Value of $\tau_{i,j_{break}}$ can be calculated with help of Sridharacharya formulae [7].

$$\tau_{i,j_{break}} = \frac{-\hat{b}_{ij} \pm \sqrt{\hat{b}_{ij}^2 - 4\hat{a}_{ij}\hat{c}_{ij}}}{2\hat{a}_{ij}} \quad (9)$$

This computed value $\tau_{i,j_{break}}$ is the estimated time when link between i_{th} and j_{th} node will break.

6. When Current time = $\tau_{i,j_{break}} - \delta$, where δ is very small time; corrective action is taken to prevent packet drop.

4 Simulation Results and Analysis

The proposed approach is based on AODV routing protocol. NS-2.35 [5] tool is used for simulation. NS2.35 is an open source tool which is used for research in networking.

4.1 Experimental setup

Column Mobility Model [1] is used for representing mobility of node. In column mobility model, a set of mobile nodes are moving linearly from one location to another location. Velocity of nodes varies from 2 m/s to 10m/s. The simulation area is 500*500, omni-direction antenna model and two-way ray ground radio propagation model are used. In Table 1 detailed parameters for simulation are summarized.

Table 1. Simulation parameters

Parameters	Values
Size	500 m by 500 m
Simulation Time	500 s
Velocity	2,4,6,8,10 m/s
Packet length	512 bytes
Traffic pattern	TCP
MAC protocol	IEEE 802.11

4.2 Analysis of results

Table 2 is representing a comparison of estimated link residual time with actual link residual time for a 5 node manet with node velocity 2m/sec. On observing the data one can conclude that the present algorithm is generating remarkable performance in terms of accurate estimation of link residual time.

Table 2. Comparison of estimated vs actual link residual time

Link No	Estimated Residual Time	Actual Residual time
1	252.2639 sec	251.9715 sec
2	227.7949 sec	226.4358 sec
3	209.076 sec	207.9343 sec
4	204.8224 sec	204.0284 sec
5	168.5515 sec	167.4681 sec
6	97.8936 sec	96.5896 sec

Root-mean-square error (RMSE) of link residual time calculated as following equation: 10 is chosen as performance measure:

$$RMSE_v = \sqrt{\frac{1}{L} \sum_{k=1}^L (\tau_{k,v_{break}} - \tau_{k,v_{actual}})^2} \quad (10)$$

where $RMSE_v$ is Root-mean-square error (RMSE) of link residual time at node velocity v m/sec, $\tau_{k,v_{break}}$ and $\tau_{k,v_{actual}}$ are estimated and actual link residual times of any k_{th} link of MANET of total L links with node velocity v respectively.

Fig: 1 shows the comparison of RMSE for the different sets of n points with monotonically decreasing pattern of received signal strengths of hello packet used in the least square polynomial regression wrt velocity of nodes. It can be concluded that increasing node velocity is not directly affecting RMSE value of link residual time; means estimated link residual time is immune to node velocity scaling.

There are three different curves showing RMSE vs node velocity relationship with varying number of hello packets of monotonically decreasing RSSI appearing in the figure: 1. It can be concluded that with an increasing value of n there is again in RMSE value of error but since computational overhead is also increasing with n . Hence in this algorithm, an optimal value $n = 5$ has been chosen.

Fig. 2 shows a comparison between regression and interpolation based approaches of link residual time estimation. From the figure, it can be concluded that by adapting regression-based approaches one can have an edge over interpolation based approaches. Mathematically, regression-based approaches uses a polynomial pattern within considered points; means there is no guarantee that polynomial will pass through at least one chosen point. On the other hand, interpolation provides curve fitting type solution; means it is guaranteed that a n_{th} degree polynomial will pass through n selected points. In this, although it is guaranteed that there will be zero error at considered n points but for other points in the domain this polynomial will not provide a solution with the optimal error. Although in both cases this polynomial is extrapolated as in equation: 8

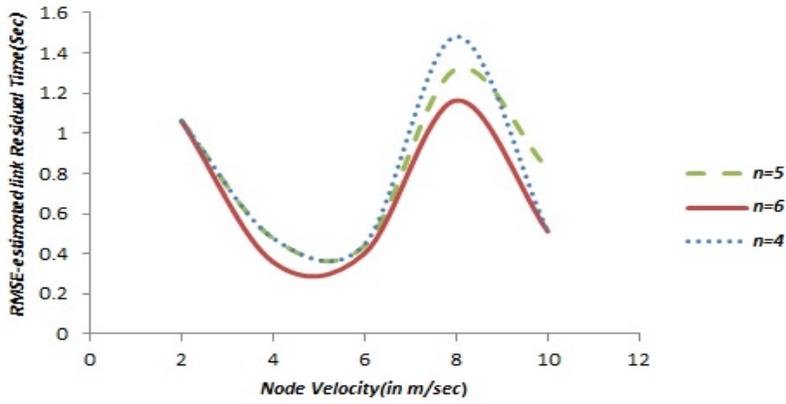


Fig. 1. RMSE vs node velocity

to find a solution for link residual time, yet the regression polynomial is better approximated for this point.

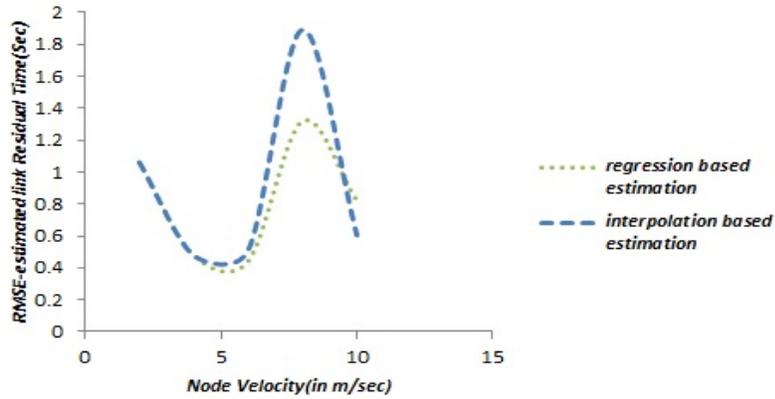


Fig. 2. Comparison between RMSE of Interpolation vs Regression based residual time estimation

5 Conclusion

The authors have presented a novel approach for link residual time prediction based upon cross-layer optimization and least square quadratic regression. Although these approaches are very powerful tools of contemporary researchers of

networking community yet there are very limited examples of simultaneous use of both for link residual time prediction. Results are very promising and the algorithm is very simple in terms of implementation.

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