International Journal of Research
Available at https://edupediapublications.org/journals
p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 03 Issue 11
July 2016

# Forecasting Residual Link Lifetime in MANET

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*Abstract*— We have studied the estimation of residual link lifetime (RLL) in mobile Adhoc networks (MANETs) using the distances between the links of nodes. First of all, we need to demonstrate that to compute uniquely the RLL; at least four distance measurements are required. We also revealed that random measurement errors are the dominant factor in prediction in accuracy and that systematic errors are always negligible. We then suggested a mobile projected trajectory (MPT) algorithm that estimates the correlative path between two nodes from periodical measurements of the distances between nodes.

Using the correlative trajectory, the algorithm estimates the RLL of the link between the two nodes. For comparison purposes, we need to obtain a theoretical upper bound on the achievable prediction in accuracy by any of the distance based RLL prediction algorithm with unspecified but finitely bounded measurement error distribution. To account for velocity changes, the MPT is increased with velocity change detection (VCD) test. Performance evaluation reveals robustness in RLL prediction for piecewise linear path and multiple velocity changes during the link lifetime.

*Keywords*— Linear curve fitting, link lifetime, mobile ad hoc network (MANET), prediction, residual link lifetime (RLL), velocity-change detection (VCD).

## I.INTRODUCTION

Recent years have seen increasing interest in multimedia and real-time applications in mobile ad hoc networks (MANETs). These applications require indisputable Quality of service (QoS) features, such as minimal end-to-end packet delay and tolerable data loss. The provision of QoS necessitates the availability of long-lived reliable pawhich is known as the multichip path. Due to the inherently dynamic creation of the network topology, the current lths along which robust data communications can be supervised. Data packets routed between the sender node (source) and a receiver node (destination) of a MANET often traverse along a path spanning multiple links, inks are frequently broken, and new links are frequently established. Consequently, the challenge is to recognize and select those paths in the network that are most stable and, thus, are most likely to please the QoS requirements. In the wireless environment, a number of factors such as mobility, physical obstructions, noise, and weather conditions contribute to the difficulty of accurately modelling the behaviour of the lifetime of a link between two mobile nodes. In this project, we concentrate on the effects of mobility on the link lifetime.

That is, a link is examined as alive or up when the Euclidean distance between the link's two nodes is lesser than the minimum of the two transmission span of the nodes; otherwise, the link is supposed to be broken or down. The full link lifetime (FLL) is defined as the time duration from the moment the two nodes enter each other's transmission range until the time that the link smash. The residual link lifetime (RLL) at some time t($0 \leq t \leq$FLL), denoted as RLL(t), is the time duration from t until the time at which the link is cracked, i.e., RLL(t)+t=FLL.

Fort>FLL, RLL(t)=0. The residual path lifetime (RPL) at some time t is the minimum of the RLLs of its constituent links, and it is denoted as RPL (t).

The capacity to characterize statistically RPL (t) would facilitate better prediction of the times at which a path breaks, allowing us to plan and to act appropriately of protecting data in transit before the breakage occurs. Such a prediction would first require the residual lifetime estimation of the constituent links of the path. In this project, we suggest a mobile-projected trajectory (MPT) algorithm that estimates the relative trajectory between two nodes of a link from periodically rated distances between the nodes.

Using the comparative trajectory, the MPT estimates the link's RLL. To account for velocity changes during the link's lifespan, the MPT is augmented with a velocity-change detection (VCD) test. The new algorithm, which is referred to as MPT-VCD, significantly boosts the RLL prediction accuracy. As we shall see, neither MPT nor MPT-VCD requires any data about node velocity or its position.

In the future, MANETs are expected to be deployed in myriads of scenarios having complex node mobility and connectivity dynamics. For example, in a MANET on a battlefield, the movement of the soldiers will be influenced by the commander. In a city-wide MANET, the node movement is restricted by obstacles or maps. The node mobility characteristics are very application specific. Widely varying mobility

characteristics are expected to have a significant impact on the performance of the routing protocols like DSR [2], DSDV [3] and AODV [4]. Random Waypoint is a well designed model but it is insufficient to capture the following characteristics: 1) Spatial dependence of movement among nodes.

2) Temporal Dependence of movement of a node over time.
3) Existence of barriers or obstacles constraining mobility.

In this study, we focus on the impact of the above mentioned mobility characteristics on protocol performance. While doing so, we propose a generic framework to systematically analyse the impact of mobility on the performance of routing protocols for MANETs. This analysis attempts to answer the following questions:

1) Whether mobility affects routing protocol performance?
2) If the answer to 1 is yes, why?
3) If the answer to 1 is yes, how?

To answer *Whether*, the framework evaluates the performance of these routing protocols over different mobility patterns that capture some of the characteristics listed above.

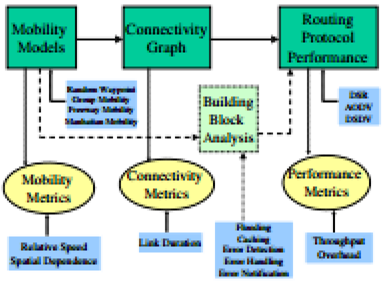

Fig 1. Important framework

The mobility models used in our study include the Random Waypoint, Group Mobility [5], Freeway and Manhattan. To answer *Why*, we propose some protocol independent metrics such as mobility metrics and connectivity graph metrics. Mobility metrics aim to capture some of the aforementioned mobility characteristics. Connectivity graph metrics aim to study the effect of different mobility patterns on the connectivity graph of the mobile nodes. It has also been observed in previous works that under a given mobility pattern, routing protocols like DSR, DSDV and AODV perform differently [6] [7] [8]. This is possibly because each protocol differs in the basic mechanisms or "building blocks" it uses. For example, DSR uses route discovery, while DSDV uses periodic updates. To answer *How*, we want to investigate the effect of mobility on some of these "building blocks" and how they impact the protocol performance as a "whole"

## II. RELATED CONCEPTS

### A. Two Node Link Model

We define the link model between Nodes 1 and 2 as follows. Each node has a circular neighborhood with its radius being the transmission range *R*. A link is established when the two move into each other's transmission range. This *protocol model* makes relevant mathematics more tractable, and it has been widely employed in other works. Without loss of generality, we concentrate on the distance measurements measured by Node 1 between itself and Node 2, while Node 2 moves within Node 1's neighbourhood. Each node is equipped with the following three mechanisms.

First, it has an ID beacon that periodically broadcasts an ID signal to its neighbourhood. Node 1 hears this signal from Node 2 if and only if the distance between the two nodes is no more than *R*. Second, each node is equipped with a timer to keep track of the presence of the other node in its neighbourhood. Third, each node is equipped with a ranging mechanism to measure the distance between itself and another node. Well-known ranging techniques include *ToA* and *angle-of-arrival* (AoA).

One technology particularly suitable for ranging is the *ultra wideband* (UWB) communication because of its use of extremely short temporal pulses. The feasibility of UWB-based ranging has been explored in the literature, and several works have reported low-data-rate high-accuracy ranging results with this technique. Moreover, in UWB ranging, the data rate decreases as the distance increases. Since our proposed algorithm requires very low measurement rate, UWB ranging can be deployed in a node with a fairly large transmission range. We propose to employ the same UWB pulses for both ID signalling and ranging; this combination imposes no additional costs on ranging. However, the distance measurements contain measurement errors that must be taken into consideration when developing the distance measurement-based algorithm.

### B. Minimal Number of Distance Measurements

Consider our link model between Node 1 and Node 2, in which both nodes move at constant velocity during the entire link lifetime. For purposes of illustration, we tentatively assume the distance measurements are error-free. Node 1 measures the first distance, denoted as d0, at time t0 when Node 2 enters the transmission range of Node 1. Subsequently at times t0+Δt, t0+2Δt, and t0+3Δt, where Δt denotes the sampling period, three more distance measurements, d1, d2, and d3, are measured, Let dmin denote the minimal distance between the nodes given the relative direction of Node 2 with respect to Node 1. It can be seen that there exist exactly three possible scenarios for having four periodical distance measurements during the link lifetime: S1: d0 and d1 measured before dmin; d2 and d3 after dmin; S2: d0, d1, and d2 measured before dmin; d3 after dmin; and S3: d0, d1, d2, and d3 all measured before dmin. No other scenarios with four periodical distance measurements are possible. If only d0 were measured before dmin, this would result in at most three distances (i.e., d0, d1, and d2) measured before the link breaks. Similarly, it is not possible to measure all four distances after dmin is reached. Define the state in which the two nodes are moving towards each other at the time d2 is measured as the approaching state and the state in which they are moving away from each other when d2 is measured as the receding state. We present the following theorem for computing the RLL based on distance measurements.

Theorem. With our two-node link model, it is necessary to employ four periodically measured distances to uniquely compute a solution for the residual link lifetime.

Intuitively, it takes three distance measurements to yield a unique solution for the RLL that remains after the third Measurement. However, since each node has no notion of speed or direction, the third distance could be measured either before or after the two nodes have reached the minimum distance between them as they pass by each other, thus creating ambiguity in determining the RLL. This ambiguity can be resolved by measuring a fourth distance. Fig. 1 shows the measurement of the distances when the relative velocity of Node 2 with respect to Node 1 remain constant during the link lifetime. At time $t_0$, when Node 2 enters the transmission range of Node 1, Node 1 measures the first distance $d_0$. Subsequently, at times $t_0 + \Delta t$, $t_0 + 2\Delta t$, and $t_0 + 3\Delta t$, where $\Delta t$ is the *sampling period*, Node 1 measures $d_1$, $d_2$, and $d_3$, respectively.

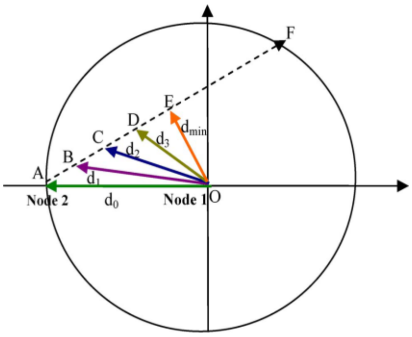

Fig 2. Approaching state at d2.

Let $d_{min}$ denote the minimal distance between the nodes. We note that there exist exactly three possible scenarios for the four periodical measurements taken during the link lifetime.

S1: $d_0$ and $d_1$ are measured before $d_{min}$, and $d_2$ and $d_3$ are measured after $d_{min}$.

S2: $d_0$, $d_1$, and $d_2$ are measured before $d_{min}$, and $d_3$ is measured after $d_{min}$.

S3: $d_0$, $d_1$, $d_2$, and $d_3$ are all measured before $d_{min}$.

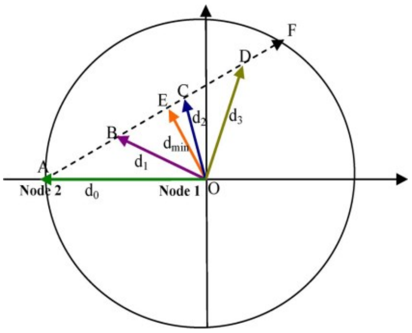

Fig 3. Receding state at $d_2$.

Define the state in which the two nodes move toward each other at the time $d_2$ is measured as the *approaching state* (Fig. 1, as described by S2 and S3) and the state in which they move away from each other when $d_2$ is measured as the *receding state* (see Fig. 2, as described by S1). Only these three cases exist, each of which can uniquely determine which state the two nodes are in after the third distance measurement. We present the following theorem for computing the RLL based on distance measurements.

Extensive research has been done in modeling mobility for MANETs. In this section, we mainly focus on experimental research in this area. This research can be broadly classified as follows based on the methodology used:

### C. *Random Waypoint Based Performance Comparisons*

Much of the initial research was based on using Random Waypoint as the underlying mobility model and CBR traffic consisting of randomly chosen source destination pairs as the traffic pattern. Routing protocols like DSR [2], DSDV [3], AODV [4] and TORA [9] were mainly evaluated based on the following metrics: packet delivery ratio (ratio of the number of packets received to the number of packets sent) and routing overhead (number of routing control packets sent). [6] concluded that on-demand protocols such as DSR and AODV performed better than table driven ones such as DSDV at high mobility rates, while DSDV performed quite well at low mobility rates. [7] performed a comparison study of the two on-demand routing protocols: DSR and AODV, using the performance metrics of packet delivery ratio and end to end delay.

### D. *Scenario Based Performance Comparisons*

Random Waypoint is a simple model that is easy to analyze and implement. This has probably been the main reason for the widespread use of this model for simulations. Realizing that Random Waypoint is too general a model, recent research has started focusing on alternative mobility models and protocol independent metrics to characterize them. [10] conducted a scenario based performance analysis of the MANET protocols. It proposed models for a few “realistic” scenarios such as a conference, event coverage and disaster relief. To differentiate between scenarios used, the study introduced the relative motion of the mobile nodes as a mobility metric. Their conclusions about the performance of proactive and reactive protocols were similar to [6]. [8] used a mobility model in which each node computes its next position based on a probability distribution. This model does not allow significant changes in direction between successive instants. It concluded that proactive protocols perform better than reactive ones in terms of packet delivery ratio and end-toend delay

### D. Forecasting

Predicting the future Not an exact science but instead consists of a set of statistical tools and techniques that are supported by human judgment and intuition.

Business forecasting generally attempts to predict future customer demand for a firm’s goods or services Macroeconomic forecasting attempts to predict future behavior of the economy and identify business cycle turning points. For our purpose forecasting can be defined as attempting to predict the future by using qualitative or quantitative methods. In an informal way, forecasting is an integral part of all human activity, but from the business point of view increasing attention is being given to formal forecasting systems which are continually being refined. Some forecasting systems involve very advanced statistical techniques beyond the scope of this book, so are not included.

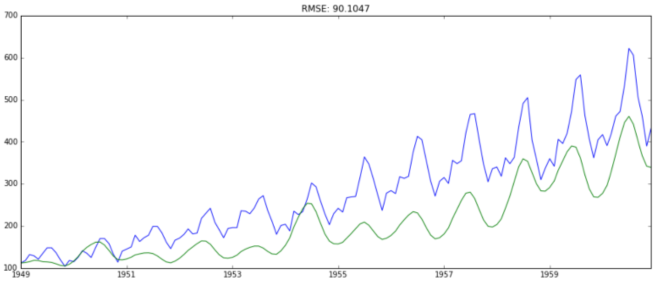

Fig 4. Forecasting analysis

## III. MOBILE PROJECTED TRAJECTORY WITH VELOCITY-CHANGE DETECTION

The operation of MPT was presented when the nodes' movement was assumed to induce linear trajectories, i.e., constant velocity throughout the link lifetime. In reality, velocity changes are a frequent occurrence that poses a challenge to the RLL prediction. We now augment the MPT with a *VCD* test. Instead of measuring only four distances at the beginning of the link lifetime, MPT-VCD periodically measures distances during the link lifetime. Concurrently, the VCD test is performed periodically to detect velocity changes. As explained here, MPT-VCD should be executed continuously while nodes are in motion to 1) provide progressively more accurate RLL estimations if velocity remains constant and 2) account for possible velocity changes.

In our link model, we simulate velocity changes by allowing Node 2's movements with respect to Node 1 to induce a *piecewise-linear trajectory*. That is, as observed by Node 1, Node 2 moves at constant velocity for some duration before randomly selecting a new velocity. Node 1 periodically measures distances at each time $t_k$, for $k = 0, 1, 2, \ldots$. Piecewise-linear trajectory has been adopted in a number of publications focusing on the MANET mobility.

### A. *Velocity-Change Detection Test*

The VCD test works as follows. Node 1 periodically measures distances to Node 2 at times tk = k · Δt, k = 0, 1, . . . throughout the lifetime of the link and stores the measurements in its memory cache. Every 3Δt [s], the VCD test is invoked to detect the occurrence of velocity change as follows. Denote Tacq(k) = tk − t0 = tk as the acquisition time at tk, where k is an integral multiple of three. Node 1 then draws four distance measurements measured at 0, Tacq(k)/3, 2Tacq(k)/3, and tk, denoted as ˆ d0, ˆ dk/3, ˆ d2k/3, and ˆ dk, respectively, and invokes MPT. In particular, the MPT computes the estimate ˜ dk. The MPT then decides whether velocity change has occurred by comparing ˆ dk and ˜ dk.

The VCD test:
if | ˜ dk − ˆ dk| ≤ δth, then no velocity change occurred at tk, else velocity change occurred at tk where δth denotes the detection threshold, which trades off the sensitivity (misses of velocity changes) versus specificity (false VCD) of the VCD test.

### B. *MPT-VCD Algorithm*

Once Node 2 enters its transmission range, Node 1 invokes the MPT-VCD to periodically measure distances (with periodicity Δt) and computes $d_k$ and the residual link lifetime ˆ $RLL_k$ (with periodicity 3Δt). If a velocity change is detected at time $t_{vcd}$ (which is initialized to t0), the MPT-VCD will employ the distance measurements that are measured after tvcd to compute the RLL. When Node 1 receives a RLL-prediction request at a time treq, the algorithm draws four periodical distance measurements from $t_{vcd}$ to $t_{req}$ to compute the RLL and reports it to Node 1. In practice, such a request could arrive at a random time either before or after the velocity-change detection. Reporting the currently predicted RLL before velocity change occurs would likely result in erroneous RLL prediction. We first define a separation time threshold $\Delta\tau_{req}$, a minimal time duration between $t_{vc}$ and $t_{vcd}$. When responding to a prediction request, the MPT-VCD needs to consider the following three cases with respect to the velocity change detection time versus the time of prediction request arrival:

1) If the prediction request arrives at Node 1 after a velocity change was detected at $t_{vcd}$, and the difference between treq and tvcd is at least Δτreq (i.e., $t_{req}t_{vcd} \geq \Delta\tau_{req} > 0$ and $t_{vcd} > t_0$), the algorithm computes the RLL at $t_{req}$ and reports it to Node 1.

2) If the request arrives after a velocity change was detected at $t_{vcd}$, and the time difference between $t_{req}$ and $t_{vcd}$ is less than Δτreq (i.e., $0 < t_{req} - t_{vcd} t_0$), the algorithm updates $t_{req} = t_{vcd} + \Delta\tau_{req}$, and continues measuring new distances until the new treq, at which time it computes the RLL and reports it to Node 1.

Once Node 2 enters Node 1's transmission range, Node 1 periodically measures the distance between the two nodes every Δt [s]. Every 3Δt [s], MPT-VCD is invoked to compute ˜ dk and RL^Lk. If a velocity change is detected at some time tvcd, the MPT-VCD is initialized, and the algorithm will employ only the distance measurements obtained after tvcd to compute the RLL. When an RLL-prediction request arrives at Node 1 at time treq, the MPT-VCD draws four distance measurements periodically measured between tvcd and treq to compute the RLL and reports it to Node 1.

When the MPT-VCD is invoked at time tk, every two consecutive distance measurements of the four that are employed by the algorithm are separated by the time period (tk − t0)/3 (or by the time period (tk − tvcd)/3 in case velocity change was detected at tvcd). As time progresses, this time period increases. This leads to an increasing accuracy in the algorithm's prediction performance, even if Δt is very small.

Therefore, the MPT-VCD algorithm eliminates the need to judiciously choose a Δt value to achieve robust prediction performance. An RLL prediction request could arrive at any time while the link persists. If the algorithm reports the current predicted RLL to the request before velocity change occurs, it would likely result in an erroneous RLL prediction.

## IV. CONCLUSION

There is a growing interest in the wireless research community to understand the characteristics of multi-hop path lifetime that may be exploited for QoS provisioning in the MANET. Some works proposed the use of the mean residual path lifetime as a parameter to measure path reliability. We examined the relationship between the mean RPL and each constituent link lifetime, and investigated the effects of mobility under three mobility models: Random Mobility, Random Waypoint, and Gauss-Markov. Through extensive simulations, we concluded that the mean RPL in these mobility models is an invariant quantity and unreliable parameter for predicting path lifetimes.

We studied the problem of intelligent best-path selection in the MANET. By associating the reliability of a multi-hop path with its lifetime, we proposed three path-selection algorithms based on link age that were aimed at choosing the best path from a set of available paths between a source-destination pair. We defined the “best path” as either a path among all available paths that would most likely meet a specified requirement for a desired minimal path lifetime, or one that would be the longest-living path among all available paths. Furthermore, we developed two corresponding performance metrics to evaluate these path-selection algorithms. The metrics also allow the algorithms to be compared with a baseline

Random-selection algorithm, which arbitrarily chooses a path regardless of path reliability. Simulation results demonstrated that the performance of all three algorithms improved over the baseline algorithm as the size of the path set increased. Furthermore, these algorithms performed better in a high-mobility environment than in a low-mobility environment.

We have studied the problem of RLL prediction in MANET based on distance measurements. We have first proved that, when mobile nodes do not possess any knowledge of their speed, direction, or position, it is necessary to periodically measure only four distances to compute a unique RLL solution. We then proposed the MPT algorithm to compute the RLL. MPT performs linear curve fitting based on the periodical distance measurements. If sampling becomes non periodic, its negative effects on the computed RLL could be mitigated by sampling more than four distance measurements. We analytically derived an upper bound on RLL prediction inaccuracy when the distribution of measurement errors is unknown but finite; under such conditions, the performance of any distance based RLL prediction algorithm with unknown but finitely bounded measurement-error distributions is upper bounded by our derived bound.

## ACKNOWLEDGMENT

We would like to thank the publication who has reviewed this technical paper. We would also like to thank Sri Jayachamarajendra College of Engineering for providing this opportunity for carrying out this work. Lastly we extend our warm thanks to Dr. H C Vijayalakshmi, Head of CS&E for her enlightening guidance.

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