國立交通大學

資訊科學與工程研究所

碩士論文

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中文摘要

在無線行動隨意網路中，由於網路連線與拓樸狀態具有隨時都在改變的特性，而這樣的情況將使得網路效能明顯地下降。在這篇論文裡，我們建立了連線生命週期的模型並藉由分區的觀念區分為穩定區域與不穩定區域的網路連線生命週期，同時我們提供一個理論分析的數學型態表示式去分析連線的生命週期。而我們也藉由 NS2 的模網路模擬程式去驗證我們的連線生命週期模型與模擬的結果相當一致。

目前已存在的行動無線隨意網路的繞徑演算法，只能在連線中斷以後才能夠察覺網路中的某一段連線已經中斷並重新初始另一個繞徑要求的訊息。然而一旦發生這樣的狀況，傳輸的封包必須馬上重新建立並往另一條繞送路徑傳送，而這樣因連線中斷而導致須重新繞送，將會導致一個潛在的且嚴重的封包重新傳輸成本與網路負擔。基於這樣的現象，我們善用以分區為基礎的連線穩定模型的公式與理論分析，發展出一套可以預先察覺網路連線即將中斷的狀態的適應性繞徑策略 ，並於網路連線真正中斷前，提出一個繞徑更新的訊息，進而通知來源端將封包的繞送路徑更新，藉此避免重新繞徑尋找與維護的成本，同時亦能提供一個更穩定的傳輸連線。

關鍵字：連線動態改變、理論連線生命週期模型、以分區為基礎的穩定連線、繞徑尋找與繞徑維護、適應性繞徑策略。

Zone-based Link Stability Model and Adaptive Routing Strategy in MANETs

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Abstract

Since the characteristic of link dynamics and network topology changing frequently in wireless Mobile Ad Hoc Networks (MANETs) and such a situation will cause the network performance decrease significantly. In this thesis, we establish an analytical link lifetime model considering link state in different zones (strong zone and weak zone) and derive formal expression for an expected link lifetime in strong and weak zones, respectively. In the meantime, we simulate this formulation model by using ns2 network simulator [19] to verify that the simulation results which are highly agreement with our model.

The existing routing algorithms in ad hoc networks initiate a route discovery only after one or more links of the routing path breaks. In case of this happens, data packets must be re-routed quickly, which potentially involves a serious overhead for all ad hoc networks and lead a high retransmission cost for all data packets. In view of this phenomenon, we make use of the formulation of the zone-based link stability model to develop an adaptive routing strategy, which could initiate a routing update message in advance and before link breaks, to warn the source to find another stable path which can avoid the overhead on both routing discovery and routing maintenance while providing more reliable transmission connections.

Keywords: link dynamics; analytical link lifetime model; zone-based link stability; route discovery and route maintenance; adaptive routing strategy

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Chapter 1: Introduction

Ad hoc wireless networks are expected to play an important role in future many fields, such as "natural disasters, conferences/lectures/meetings and military settings" are remarkable in this domain. At the same time, the use of portable laptops and hand-held devices are also increasing rapidly. With the more and more increasing demand for connection, the need for mobile wireless communication is necessary and ineluctable. Today most of the portable communication devices have the support of fixed base stations or access points for communication purposes. However, such a situation is not available in Mobile Ad-hoc Networks (MANETs) [8]. Therefore, A mobile ad-hoc network is a dynamically changing network of mobile devices that communicate without the support of a fixed structure (infrastructure network) and uses multi-hop peer-to-peer routing instead of static network infrastructure to provide network connectivity. In such networks, the quality of the connection links between any two network mobile devices will vary over time and it becomes an important research issue about the problems of link breakage. All communication links between two mobile nodes have a limited link lifetime that comes into and passes out of existence as mobiles nodes move towards and away from each other and this phenomenon will significantly affect the network performance. For this reason, we derive a theoretical model for communication links when both of mobile nodes are constantly moving and consider a differentiated zone-based link stability model to formulate some expressions about the link lifetime properties.

Nevertheless, the frequent link changes caused by node mobility make routing in ad hoc wireless networks a challenging problem. Since there is a direct communication among the neighboring devices, but non-neighboring devices requires a robust and intelligent routing strategy to ensure reliable and efficient communication. Based on the zone-based link stability model, we provide a highly adaptive routing scheme to deal with the frequent link changes. We derive a routing strategy that can utilize the ad hoc networks characteristics to select the most stable links through dynamics network and solve the problems that re-route causing a amount of network overhead because of communication links breakage on reactive (on-demand) routing protocol. Selecting the most stable links (i.e., those which exhibit the strongest signal strength for maximum amount of connection time) will lead a longer-lived routes and less route maintenance. On reactive routing protocol, a host initiates route discovery on demand: only when a source node needs to send packets. The source will broadcast a route request which will propagate to destination which allows the destination to choose a route and return reply. In this part, we choose a strong link to setup the routing path to provide a longer-lived route which can decrease the stage of route maintenance overhead. Second, when finding a link or more links break, the route error message will propagate the source and inform source re-establish a route path and this will cause amounts of network overhead and make packets cost increase due to packets retransmission. We make use of our zone-based link stability model that provides a prior route update message while a node is far from the weak zone and immediately inform next packets transfer through another routing path before node leaves the transmission range. By such a protection mechanism, it will efficiently reduce the network overhead and increase packets delivery benefits cause of the lower probability of packets retransmissions.

The organization of the rest of this paper is as follows. In Chapter 2, we discuss the related work on this field about the effect of mobility on link dynamics characteristics and routing strategy in ad hoc networks. We also present our motivation and the contribution that we do in this chapter. In Chapter 3 derives the theoretical analysis model on link lifetime considering strong and weak zone, respectively and simulation results to verify our model. In Chapter 4, we provide an adaptive routing strategy based on Chapter 3 Zone-Based Link Stability Model. Finally, we present the conclusions in Chapter 5.

Chapter 2: Background and related work

2.1 Background

Infrastructure free networks do not have designated stationary routers. Mobile Ad-hoc Networks (MANET) is a type of wireless network without an infrastructure support. The Mobile Nodes in a MANET operate as both a client and a router, which directly assumes that every mobile node has this capability. Instead of having Base Stations with only one important task MANETs introduces every mobile node as a potential router. Packets sent through the network will be forwarded to the destination through mobile node by mobile node. It is very likely that communication disruption will happen in both infrastructure-based and infrastructure-free networks. However, the mobility of the mobile nodes becomes an important factor in MANETs. Route discovery and choosing is of high importance and must handle a number of situations i.e. high mobility. A MANET is an appealing network but it needs efficient mechanisms that are able to handle the events that frequent links changes.

2.2 Related Work

In the literature, simulation has been the primary tool utilized to characterize and evaluate link dynamics in ad hoc networks. Some efforts have been adopted to design routing schemes that rely on identification of stable communication links in ad hoc networks.

In [1], the author presented a detailed analytic framework to investigate the behavior of the wireless communication links in mobile ad hoc or sensor networks. Analytical expressions characterizing various properties related to the formation, lifetime and expiration of links are derived. The derived framework can be used to design efficient algorithms for medium access, routing and transport control, or to analyze and optimize the performance of existing network protocols. A number of applications of the characteristics investigated, such as selection of stable routes, route lifetime optimization, providing Quality-of-Service (QoS) data communication and analysis of route lifetime are discussed. In particular, the author also focus on designing an efficient updating strategy for proactive routing protocols based on the derived statistics and by using simulations which show that the proposed strategy can lead to significant performance improvements in terms of reduction in routing overhead, while maintaining high data packet delivery ratio and acceptable latency.

In Signal Strength-based Adaptive Routing Protocol (SSA) [2], received signal strength and location stability is used to location stability to quantify the reliability of a link. A routing metric is employed to select paths that consist of links with relatively strong signal strength and having an age above a certain threshold. A route that is found through these strong links is known a more stable routing path than original one Both of these approaches suffer from the fact that a link which is considered stable based on past or current measurements may soon become unreliable as compared to those currently categorized as unstable, due to the dynamic nature of mobile environments. Although the author tried to setup a strong link route, he did not consider that the link will break and how long the link on this route will be broken.

The Route-Lifetime Assessment Based Routing (RABR) [20] uses an affinity parameter based on the measured rate of change of signal strength averaged over the last few samples in order to estimate the lifetime of a link. A metric combining the affinity parameter and the number of links in the route that are used to select routes for TCP traffic.

A random mobility model has been studied in [10], which is used to quantify the probability that a link will be available between two nodes after an interval of duration t, given that the link exists between them at time t_0. Then this probability is used to evaluate the availability of a path after a duration t, assuming independent link failures. This forms the basis of a dynamic clustering algorithm such that more reliable members get selected to form the cluster. However, selection of paths for routing using this criterion may be impractical since the model considers a link to be available at time $t_0 + t$ even when it undergoes failures during one or more intervals between t_0 and $t_0 + t$. When a link of a route actively being used breaks, it may be necessary to find an alternate route immediately, instead of just waiting indefinitely for the link to become available again. Nevertheless, in [3] the author tries to overcome this shortcoming by estimating the probability that a link between two nodes will be continuously available for a period T_p, where T_p is predicted based on the nodes' current movements. Latter, in [4] the author address an enhancement to the prediction-based link availability estimation originally proposed by [3]. This enhancement consists of the principle for the theoretical calculation of link availability, $L(T_p)$, and a better $L(T_p)$ estimation, which is expected to improve the adaptability of the estimation to other mobility models. Simultaneously, it averts the intuitive parameter setting used by the original one.

Although these works radiate some light, there are still many important issues related to the behavior of links remain largely unexplored. In this paper, we develop an analytical link lifetime considering different zone link stability in order to investigate link dynamics.

2.3 Motivation and Contribution

Due to node mobility, the connection link between two nodes may break. The characteristics of link frequent change will lead a potential overhead and decrease the network performance. Therefore, we need a deeper understanding the property of link dynamics in MANETs and the relationship on various network characteristics and parameters…etc. Based on this identification, we derive an analytical formulation model about link lifetime considering the link stability in different zone. By establishing such a zone-based link lifetime model, we can have some knowledge to know the mobile node is located either in strong zone or in weak zone. In this thesis, we develop a series of analytical expressions:

(1) An expected link lifetime in strong and weak zone；

(2) An PDF and CDF distribution in strong and weak zone, respectively；

(3) The residual link lifetime time distribution；

In such way, we can develop a highly efficient and adaptive routing strategy.

The existing on-demand routing protocol only can detect the link broken after the link is broken. Such as the popular on-demand routing protocol: AODV. If it found the link on the active routing path broken, the upstream node of the broken link will send an error message to the source. After receiving the route error message, it will re-initiate a route request if the source still desires the route. However, such a re-route mechanism will cause amounts of network overhead since the delivery packets need to be retransmission.

In order to improve this drawback, we develop Zone-Based Routing (ZBR) strategy based on our link stability model. Our scheme can provide a stale routing path on the routing discovery stage since we setup the routing path based on strong links. Furthermore, on the route maintenance stage we can decrease the network overhead and increase the packet delivery efficiency by providing a protection mechanism: prior route update message before the current link really breaks.

Our results indicate that this scheme: adaptive routing based on zone-based link stability model can reduce the network overhead and increase packet delivery benefit since decreasing the probability of packet retransmission.

Chapter 3: Zone-Based Link Stability Model and Analysis

3.1 Introduction

The design of ad hoc networks is a difficult task because of continuous change of network topology and many network environment parameters that are extremely random and highly dependent. Because of the complexity of ad hoc networks, current researches mainly focus on using simulations tools. However, our opinion is that besides simulation, it is still necessary to do a theoretical analysis in order to get deep understanding of statistic properties of mobile wireless ad-hoc network, e.g. network connectivity, network link changing rate and link lifetime…etc. In this thesis, we emphasize on the analysis of link lifetime of ad hoc networks. Moreover, we consider the properties of link lifetime in different zones to get more precise link stability information.

3.2 Model Assumption

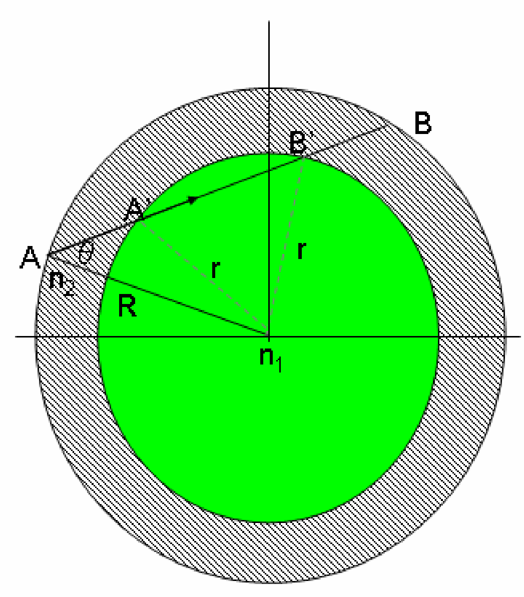
Real world wireless networks are influenced by many environment factors. Such as irregular terrain, asymmetry radio transmission, radio interference all of them can have a serious impact over the operation of the wireless networks. In this thesis, we make some assumptions to give a simply and reasonable model. In ad hoc networks that mobile nodes distribution usually exhibits some configurations. In order to simplify our model, we will make the assumptions that nodes are uniformly distributed. We also assume that the terrain is perfectly flat and all the mobile nodes have the same fixed transmission power and are equipped with omni direction antenna.

Therefore, each of them has an equal transmission range R. Our assumption simplifies a node's radio coverage shape to a perfect circle whose radius is R. The status of link between two nodes is also simplified. When the distance between two nodes is larger than R, they have no wireless link (which means the communication link is broken), whereas they have a wireless link when the distance is equal to or smaller than R. At the same time, we assume that each node moves at a randomly chosen velocity in our mobility model. Here velocity is a random vector, with direction and speed (the absolute value is also called magnitude) elements. We define $f_v(v, \theta)$ is a function of velocity that a mobile node is traveling with speed : v and direction : θ. Then we let the direction a random variable: θ, which is uniformly distributed between 0 and 2π. Simultaneously, we also make that the speed is a random variable: v, whose distribution can be arbitrary. So we can define the probability density function (PDF) of velocity at any angle is as the same as $f_v(v, \theta) = f_v(v, 0)$. Then we also assume that a mobile node in such a network moves with a constant velocity that is uniformly distributed between 0 meter/second and 20 meter/second. It is to be noted that the degree of mobility in a given application can be taken into account by choosing appropriate parameter velocity bounds.

Furthermore, we study on a simple mobility model, where the velocity is a uniformly distributed variable within the range from 0 to v_{max}. This mobility model can be supported to maintain the uniform distribution property.

The ad hoc network model described above is applied to the investigation of link availability properties in ad hoc networks, for both single-hop link and multi-hop path.

3.3 Expected Link Lifetime



Definition:

◎ Strong zone (Green area):

1. A strong connection existed between two mobile nodes in this area.
2. The effective transmission radius is r < R.

◎ Weak zone (Gray area) :

1. An unstable connection existed between two mobile nodes in this area.
2. The effective transmission radius is R-r.

Figure 1 The strong zone and weak zone of node n_1 at the center of the circle with node n_2 entering the zone at A' and A and exiting B' and B, respectively

3.3.1 Strong Zone and Weak Zone Model

Figure 1 shows the strong zone and weak zone of a node (we call it n_1) which is a circle of radius R centered at the node. This figure also shows that the trajectory of another node (we call it n_2) entering the strong (weak) zone of n_1 at A' (A), traveling along A'B' (AB), and exiting the strong zone at B' (B).

3.3.2 Relative Velocity Between two Mobile Nodes

In order to get the period time which two nodes are constantly connected, the relative velocity between two nodes is necessary to be considered [13]:

We take two neighbor nodes n_1 and n_2 and assume V_1 and V_2 is their velocity vector, respectively. From the concept of vector, we can obtain the relative velocity vector (see Figure 2):

$$\vec{V_r} = \vec{V_1} - \vec{V_2} \tag{1}$$

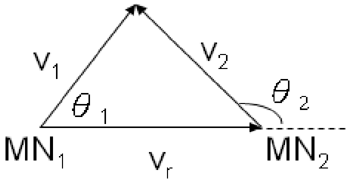


Figure 2 Relative velocity vector

Here we define some notations to obtain the PDF of relative velocity:

(1) Let $(v_x, v_y), (v_{x_1}, v_{y_1}), (v_{x_{2,}} v_{y_2})$ are the Cartesian forms of velocity vector V_r , V_1 ,and V_2
(2) Let $(v_r, \theta), (v_1, \theta_1), (v_{2,}\theta_2)$ are the polar forms of velocity vector V_r , V_1 ,and V_2
The relationship between PDF $f_{rv,XY}(v_x, v_y)$ of relative velocity in Cartesian form and PDF $f_{rv}(v_r, \theta)$ of that in polar form :

$$f(v_r,\theta) = f_{XY}(v_x = v_r\cos\theta, v_y = v_r\sin\theta)\cdot\frac{\partial(v_x,v_y)}{\partial(v_r,\theta)} = f_{rv,XY}(v_x,v_y)\cdot\begin{vmatrix}\frac{\partial v_x}{\partial v_r} & \frac{\partial v_x}{\partial\theta}\\ \frac{\partial v_y}{\partial v_r} & \frac{\partial v_y}{\partial\theta}\end{vmatrix}$$

$$= f_{XY}(v_x,v_y)\cdot v_r \qquad (2)$$

Furthermore, the PDF of relative velocity in Cartesian form equals the integral over all possible combination of V_1 and V_2 forming a triangle with V_r

$$\Rightarrow f_{rv,XY}(v_x,v_y) = \int\int f_{v1,XY}(v_{1x},v_{1y}) f_{v2,XY}(v_{2x},v_{2y}) dv_{2x} \mathrm{d}v_{2y} \qquad (3)$$

Since the relationship of these velocity vector is dependent (see in (1)), only two of them are independent. We can obtain the third one if we know the other two. Consequently, we can determine *(x1,y1)* from *(x2,y2)* , *(vx,vy)* and just need to integrate all possible value of *(x2,y2)*. The calculation of this procedure is as follows:

$$f_{rv}(v_r,\theta) = v_r\cdot f_{rv,XY}(v_x,v_y)$$

$$= v_r\cdot\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f_{v,XY}(v_{1x},v_{1y}) f_{v,XY}(v_{2x},v_{2y}) dv_{2x} dv_{2y}$$

$$= v_r\cdot\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f_{v,XY}(v_1\cos\theta, v_1\sin\theta) f_{v,XY}(v_2\cos\theta, v_2\sin\theta) v_2 dv_2 d\theta_2$$

$$= v_r\cdot\int_0^{2\pi}\int_0^{\infty}\frac{f_v(v_1,\theta_1)}{v_1}\frac{f_v(v_2,\theta_2)}{v_2} v_2 dv_2 d\theta_2$$

$$= \int_0^{2\pi}\int_0^{\infty}\frac{v_r}{v_1} f_v(v_1,\theta_1) f_v(v_2,\theta_2) dv_2 d\theta_2$$

$$= \int_0^{2\pi}\int_0^{\infty}\frac{v_r}{v_1} f_v(v_1,0) f_v(v_2,0) dv_2 d\theta_2 \qquad (4)$$

3.3.3 Link Lifetime Calculation and Expected Link Lifetime

Assume point A (A’) is the entry point of node n$_2$ entering the transmission (strong) zone of the circle centered at node n$_2$ and the moving direction of node n$_2$ makes an angle of θ with respective to node n$_1$. from the law of cosine, V_r can be expressed as a function of v_1,v_2,and θ :

$$v_r = \sqrt{v_1^2 + v_2^2 - 2v_1 \cdot v_2 \cdot \cos\theta} \tag{5}$$

According to the concept of Pythagoras's Theorem and trigonometry in Figure 1, we can calculate the distance which node n$_2$ travel with respect to node n$_1$ in transmission zone($\overline{AB}$), strong zone($\overline{A'B'}$), weak zone($\overline{AA'} + \overline{B'B}$), respectively :

(1) distance traveling in transmissio zone :$d_{\overline{AB}} = 2R|\cos\theta|$ (6)

(2) distance traveling in strong zone :$d_{\overline{A`B`}} = 2|\sqrt{(0.8R)^2 \text{-} (R\sin\theta)^2}|$ (7)

(3) distance traveling in weak zone :$d_{\overline{AA`}+\overline{B`B}} = 2(R|\cos\theta| - |\sqrt{(0.8R)^2 \text{-} (R\sin\theta)^2}|)$ (8)

Therefore, the time that node n$_2$ stayed in transmission zone, strong zone, weak zone, respectively

(1) Time in transmission zone: $t_{link_{\overline{AB}}} = \dfrac{d_{link_{\overline{AB}}}}{\overrightarrow{|v_r|}} = \dfrac{2R|\cos\theta|}{|v_r|}$ (9)

(2) Time in strong zone: $t_{link_{\overline{A'B'}}} = \dfrac{d_{link_{\overline{A'B'}}}}{\overrightarrow{|v_r|}} = \dfrac{2|\sqrt{(0.8R)^2 \text{-} (R\sin\theta)^2}|}{|v_r|}$ (10)

(3) Time in weak: $t_{link_{\overline{weak}}} = \dfrac{d_{link_{\overline{weak}}}}{\overrightarrow{|v_r|}} = \dfrac{2(R|\cos\theta| - |\sqrt{(0.8R)^2 \text{-} (R\sin\theta)^2}|)}{|v_r|}$ (11)

Hence we can obtain expected link lifetime of above links according probability:

(1) $\overline{T_{link_{\overline{AB}}}}(V_r) = E[t_{link_{\overline{AB}}}(v_r,\theta)] = \int_0^{2\pi}\int_0^{\infty} t_{link_{\overline{AB}}} \cdot \dfrac{v_r}{v_1} \cdot f_v(v_1,0) f_v(v_2,0) dv_2 d\theta_2$ (12)

(2) $\overline{T_{link_{\overline{A'B'}}}}(V_r) = E[t_{link_{\overline{AB}}}(v_r,\theta)] = \int_0^{2\pi}\int_0^{\infty} t_{link_{\overline{A'B'}}} \cdot \dfrac{v_r}{v_1} \cdot f_v(v_1,0) f_v(v_2,0) dv_2 d\theta_2$ (13)

(3) $\overline{T_{link_{\overline{weak}}}}(V_r) = E[t_{link_{\overline{weak}}}(v_r,\theta)] = \int_0^{2\pi}\int_0^{\infty} t_{link_{\overline{weak}}} \cdot \dfrac{v_r}{v_1} \cdot f_v(v_1,0) f_v(v_2,0) dv_2 d\theta_2$ (14)

From (9)、(10)、(11)and(12)、(13)、(14), we can get final expression about the expected link lifetime formulations in transmission, strong, and weak zone, respectively :

The expected link lifetime in transmission zone:

$$\overline{T_{link_{\overline{AB}}}}(V_r) = E[t_{link_{\overline{AB}}}(v_r,\theta)] = \int_0^{2\pi}\int_0^{\infty}\left(\frac{2R|\cos\theta|}{v_1}\right)\cdot f_v(v_1,0)f_v(v_2,0)dv_2d\theta_2 \qquad (15)$$

The expected link lifetime in strong zone:

$$\overline{T_{link_{\overline{A'B'}}}}(V_r) = E[t_{link_{\overline{AB}}}(v_r,\theta)] = \int_0^{2\pi}\int_0^{\infty}\left(\frac{2|\sqrt{(0.8R)^2-(R\sin\theta)^2}|}{v_1}\right)\cdot f_v(v_1,0)f_v(v_2,0)dv_2d\theta_2 \qquad (16)$$

The expected link lifetime in weak zone:

$$\overline{T_{link_{\overline{weak}}}}(V_r) = E[t_{link_{\overline{weak}}}(v_r,\theta)] = \int_0^{2\pi}\int_0^{\infty}\left(\frac{2(R|\cos\theta|-|\sqrt{(0.8R)^2-(R\sin\theta)^2}|)}{v_1}\right)\cdot f_v(v_1,0)f_v(v_2,0)dv_2d\theta_2 \qquad (17)$$

3.4 Link Lifetime Distribution

For a particular mobile node moving with a constant velocity, the cumulative distribution function (CDF) of the link lifetime in transmission zone can be defined as:

$$F_{link}(t) = \Pr\{t_{link} \le t\} \qquad (18)$$

Obviously, for t < 0, $F_{link}(t) = 0$. So for t ≥ 0, we have :

$$\begin{aligned} \mathrm{F}_{link_{\overline{AB}}}(t) &= \Pr\{t_{link_{\overline{AB}}} \le t\} = \Pr\{\frac{2R|\cos\theta|}{v_r} \le t\} \\ &= 1 - \Pr\{|\cos\theta| > \frac{v_r \cdot t}{2R}\} \end{aligned} \qquad (19)$$

Thus, we can calculate the CDF of link lifetime in transmission zone from (19):

$$\mathrm{F}_{link_{\overline{Transmission}}}(t) = 1 - \int_{\cos^{-1}(\frac{v_r \cdot t}{2R})}^{2\pi}\int_0^{\frac{2R}{t}} \frac{v_r}{v_1}\cdot f_v(v_1,0)f_v(v_2,0)dv_2d\theta_2 \qquad (20)$$

According this concept, we also can obtain the CDF of link lifetime in strong zone and weak zone:

The CDF of link lifetime in strong zone:

$$\begin{aligned} \mathrm{F}_{link_{\overline{Strong}}}(t) &= \Pr\{t_{link_{\overline{A'B'}}} \le t\} \\ &= \Pr\{\frac{2|\sqrt{(0.8R)^2\text{-}(R\sin\theta)^2}\,|}{t} \le v_r\} \\ &= 1 - \int_0^{2\pi}\int_0^{\frac{2|\sqrt{(0.8R)^2\text{-}(R\sin\theta)^2}\,|}{t}} \frac{v_r}{v_1}\cdot f_v(v_1,0)f_v(v_2,0)dv_2 d\theta_2 \end{aligned} \tag{21}$$

The CDF of link lifetime in weak zone:

$$\begin{aligned} \mathrm{F}_{link_{\overline{Weak}}}(t) &= \Pr\{t_{link_{\overline{weak}}} \le t\} \\ &= \Pr\{\frac{2(R|\cos\theta| - |\sqrt{(0.8R)^2\text{-}(R\sin\theta)^2}\,|}{t} \le v_r\} \\ &= 1 - \int_0^{2\pi}\int_0^{\frac{2(R|\cos\theta| - |\sqrt{(0.8R)^2\text{-}(R\sin\theta)^2}\,|)}{t}} \frac{v_r}{v_1}\cdot f_v(v_1,0)f_v(v_2,0)dv_2 d\theta_2 \end{aligned} \tag{22}$$

The Figure 3.、Figure 5.、 Figure7. show the CDF of link lifetime in transmission, strong, and weak zone, respectively. From these figures, we learn that the above formulations with respect to the CDF of link lifetime in different zone are exact. Each of the cumulative distribution function will be approximately to one under various relative velocities while the slower velocities have longer lifetime.

The probability density functions (PDF) $f_{link}(t)$ of link lifetime in transmission, strong, and weak zone can be calculated by differentiating (20)、(21)、(22) with respect to *t*. Figure 4、Figure 6、Figure8 plots the probability density function (PDF) by numerically differentiating the curves in Figure 3、Figure 5、Figure7,respectively. We can see that the maximum of the PDF curve that corresponds to the mode of the distribution and shifts towards the right as the relative velocity of mobile node decreases. We can see the same trend in strong zone and weak zone and the density function of link lifetime in strong zone (Figure 6) and weak zone (Figure 8) shifts towards the left opposite to the density function of link lifetime in transmission zone (Figure 4).

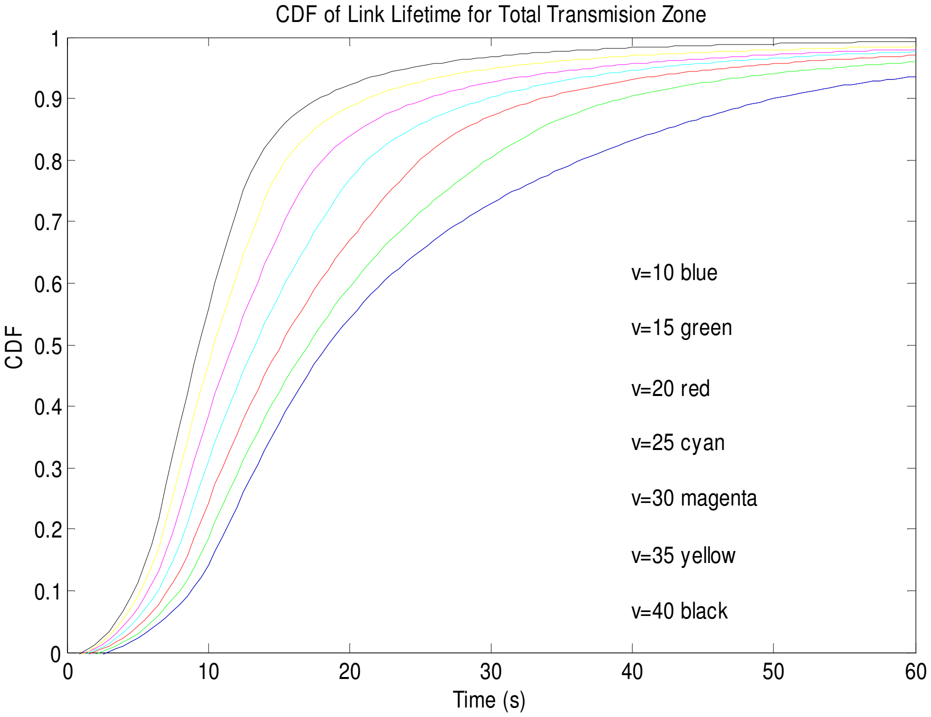


Figure 3 CDF in transmission zone

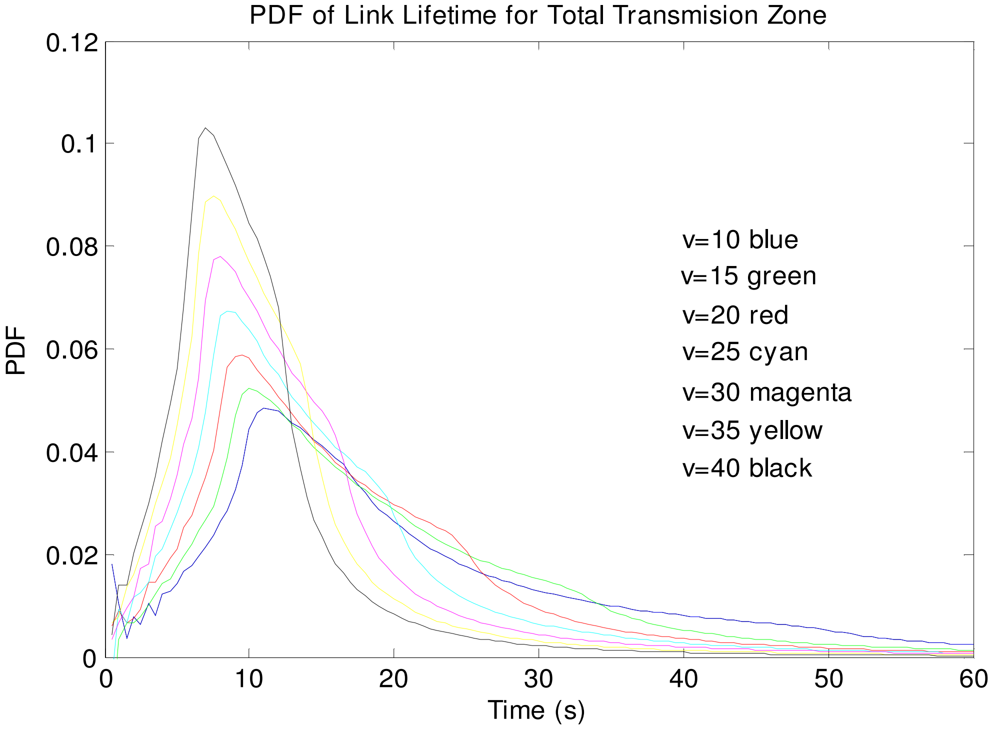


Figure 4 PDF in transmission zone

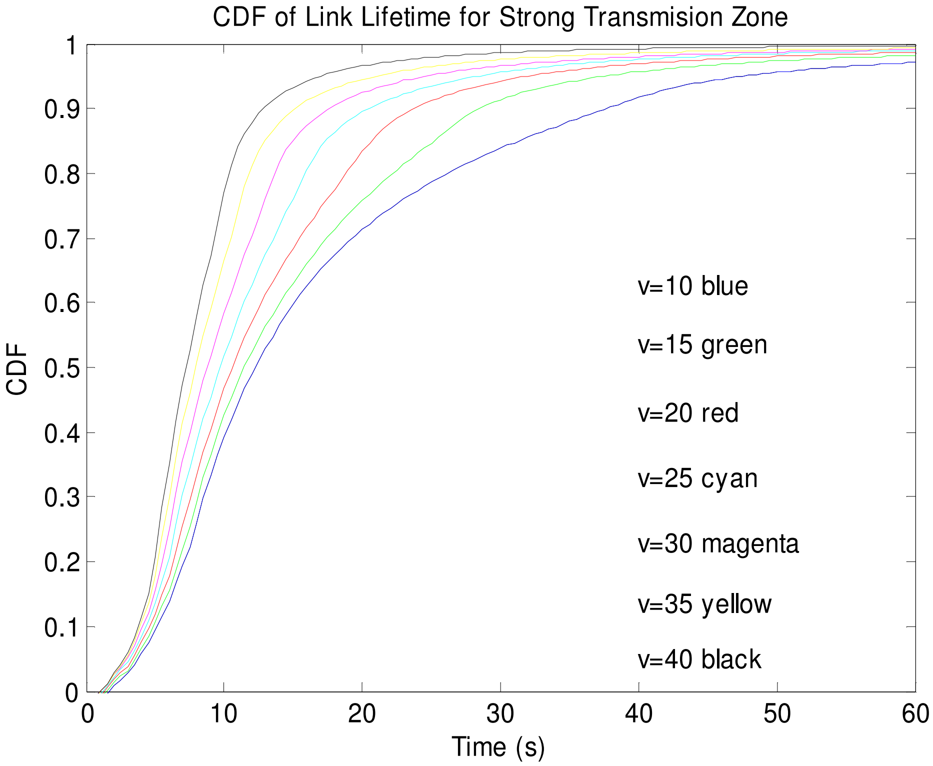


Figure 5 CDF in strong zone

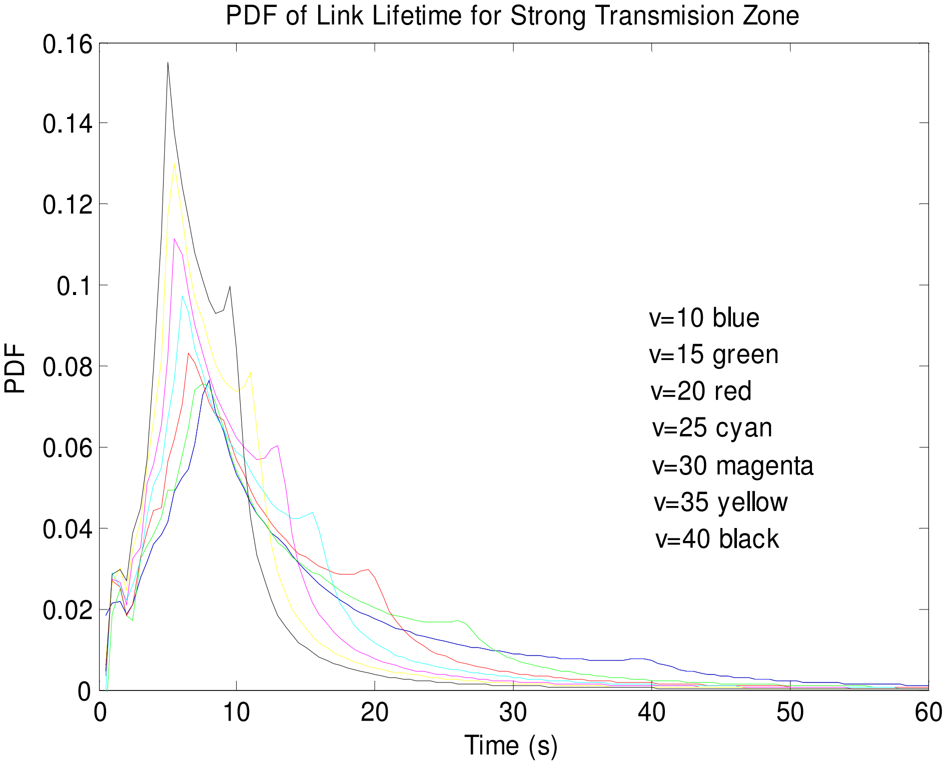


Figure 6 PDF in strong zone

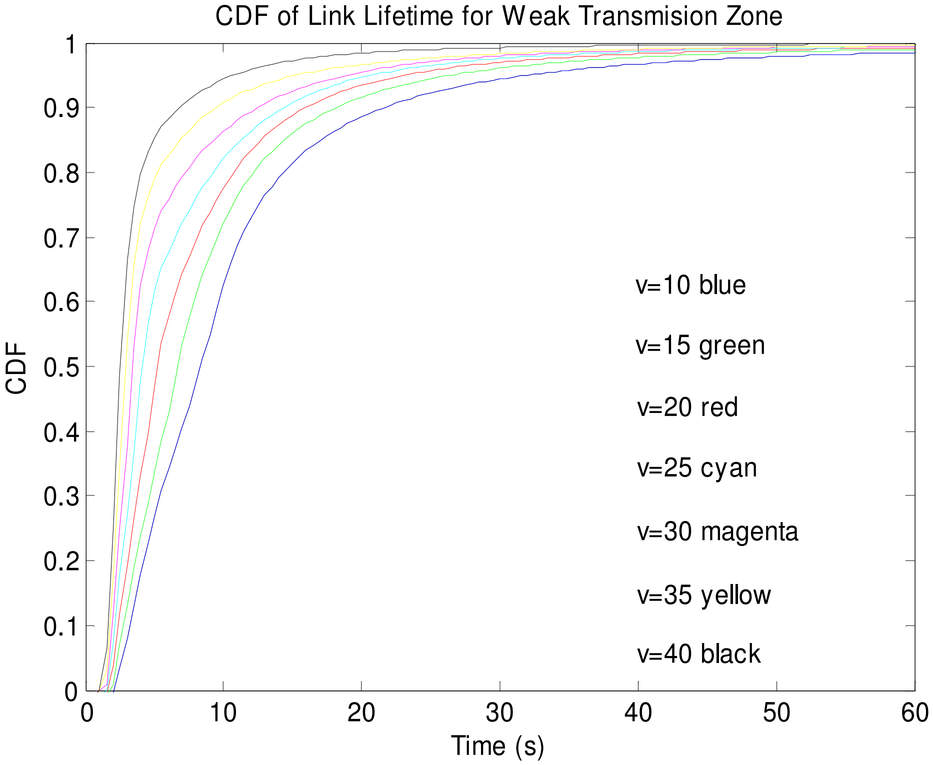


Figure 7 CDF in weak zone

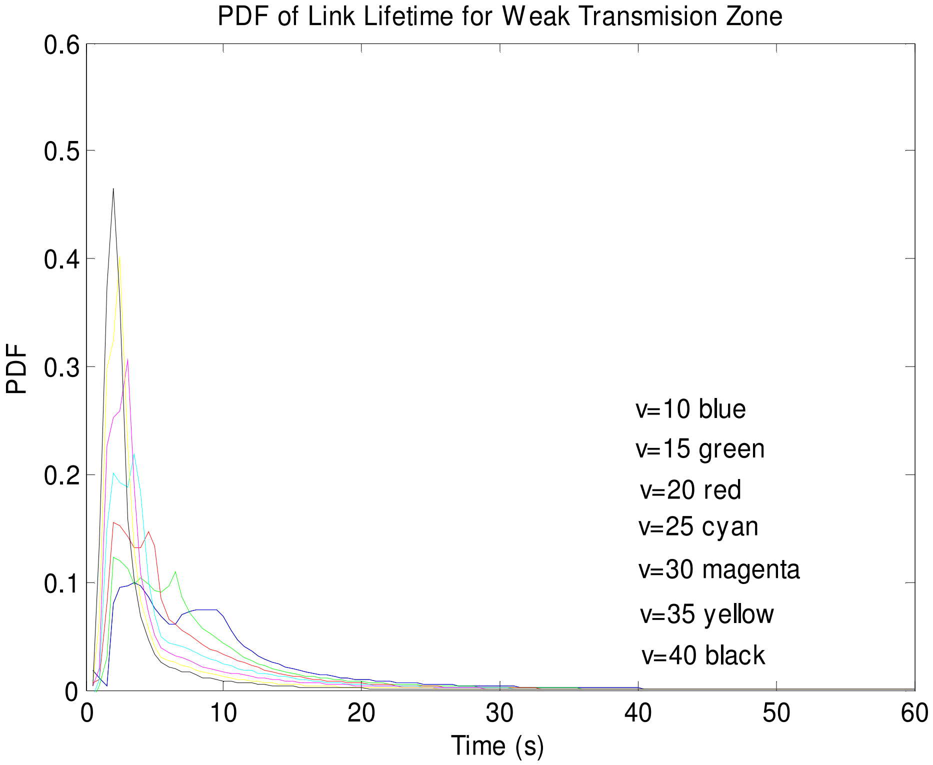


Figure 8 PDF in weak zone

3.5 Residual Link Lifetime

We can calculate residual link lifetime distribution [14] which is composed a function of the link lifetime distribution that can be used determine the link stability in the networks. Mathematically, the probability density function (PDF) of residual link lifetime given the link has been in existence for t_1 seconds can be expressed as below:

$$r_{t_1}^{V_r}(t_2)=\frac{f_{link}^{V_r}(t_1+t_2)}{1-F_{link}^{V_r}(t_1)}=\frac{f_{link}^{V_r}(t_1+t_2)}{\int_{t_1}^{\infty} f_{link}^{V_r}(t_2)dt} \tag{23}$$

Where $f_{link}^{V_r}(\cdot)$ and $F_{link}^{V_r}(\cdot)$ are the PDF and CDF of link lifetime, respectively as derived in Chapter 3.4.As the Figure 9 indicates the diagram, which has already existed t_1 seconds and remained t_2 seconds for traveling. The remained t_2 seconds means the residual link lifetime.

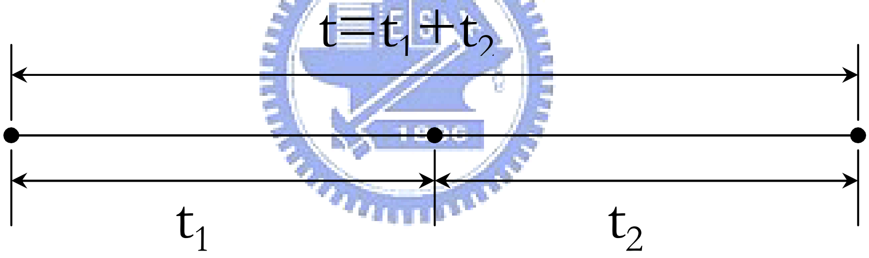


Figure 9 The Diagram of Residual Link Lifetime

As same as the conception, we can calculate the residual link lifetime distribution considering strong and weak zone. Here we only calculate the residual link lifetime in weak zone since we will only use this application in our routing strategy that will introduce in Chapter 4.3. From the same opinion, the residual link lifetime in weak zone can be expressed as below:

$$r_{t_1}^{V_r}(t_2)=\frac{f_{weak-link}^{V_r}(t_1+t_2)}{1-F_{weak-link}^{V_r}(t_1)}=\frac{f_{weak-link}^{V_r}(t_1+t_2)}{\int_{t_1}^{\infty} f_{weak-link}^{V_r}(t_2)dt} \tag{24}$$

Where $f_{weak-link}^{V_r}(\cdot)$ and $F_{weak-link}^{V_r}(\cdot)$ are the PDF and CDF of link lifetime, respectively as derived in Chapter 3.4. As the Figure 10 indicates the diagram, which has already existed *t_1* seconds in weak zone and remained *t_2* seconds for traveling in weak zone. The remained *t_2* seconds means the residual link lifetime in weak zone.

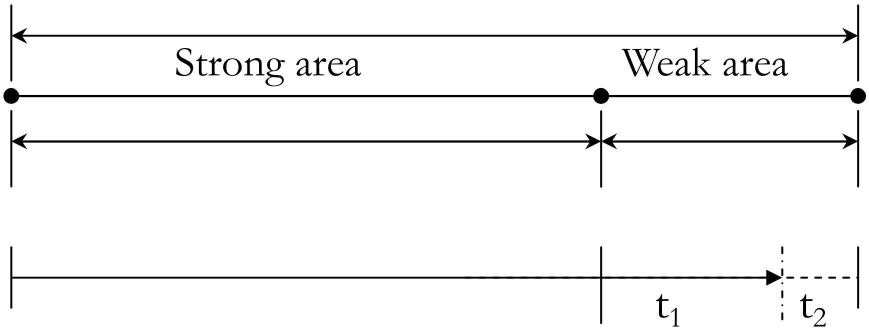


Figure 10 The Diagram of Residual Link Lifetime in weak zone

Since we have the probability density function of residual link lifetime of a link of age *t_1* seconds, we can calculate the expected residual link lifetime *t_2* seconds.

The average value E_{t_2} of the residual lifetime of a weak link of age t_1 is given by:

$$E_{t_2} = \int_0^\infty t_2 \cdot r_{t_1}^{V_r}(t_2)dt_2 = \int_0^\infty t_2 \cdot \left(\frac{f_{weak-link}^{V_r}(t_1+t_2)}{\int_{t_1}^\infty f_{weak-link}^{V_r}(t_2)dt_2}\right)dt_2$$

$$= \frac{\int_0^\infty t_2 \cdot f_{weak-link}^{V_r}(t_1+t_2)dt_2}{\int_{t_1}^\infty f_{weak-link}^{V_r}(t_2)dt_2} = \frac{\int_{t_1}^\infty t_2 \cdot f_{weak-link}^{V_r}(t_1+t_2)dt_2}{\int_{t_1}^\infty f_{weak-link}^{V_r}(t_2)dt_2} - t_1$$

$$= \frac{E(t_{weak}) - R_{t_1}^{V_r}(t_2)}{1 - R_{t_1}^{V_r}(t_2)} - t_1 \tag{25}$$

Where $R_{t_1}^{V_r}(\cdot)$ is the CDF of $r_{t_1}^{V_r}(\cdot)$ and $E(t_{weak})$ is expected link lifetime in weak zone.

Figure 11 shows the probability density of residual link lifetime under different relative velocity. From the Figure 11, we can see the higher residual link lifetime and probability as the lower relative velocity. Figure 12 indicates the expected residual link lifetime. As we expected, the residual link lifetime inverse the relative velocity and the expected residual link lifetime approximately equals to zero while the relative velocity more than 35 m/s.

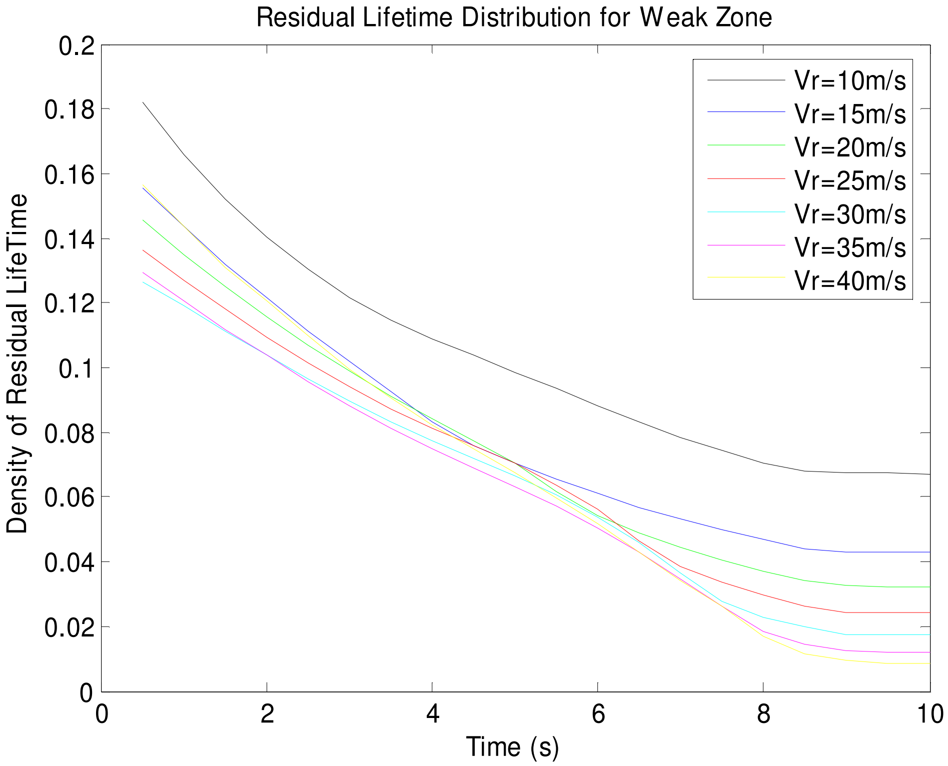


Figure 11 Residual Link Lifetime Distribution in weak zone

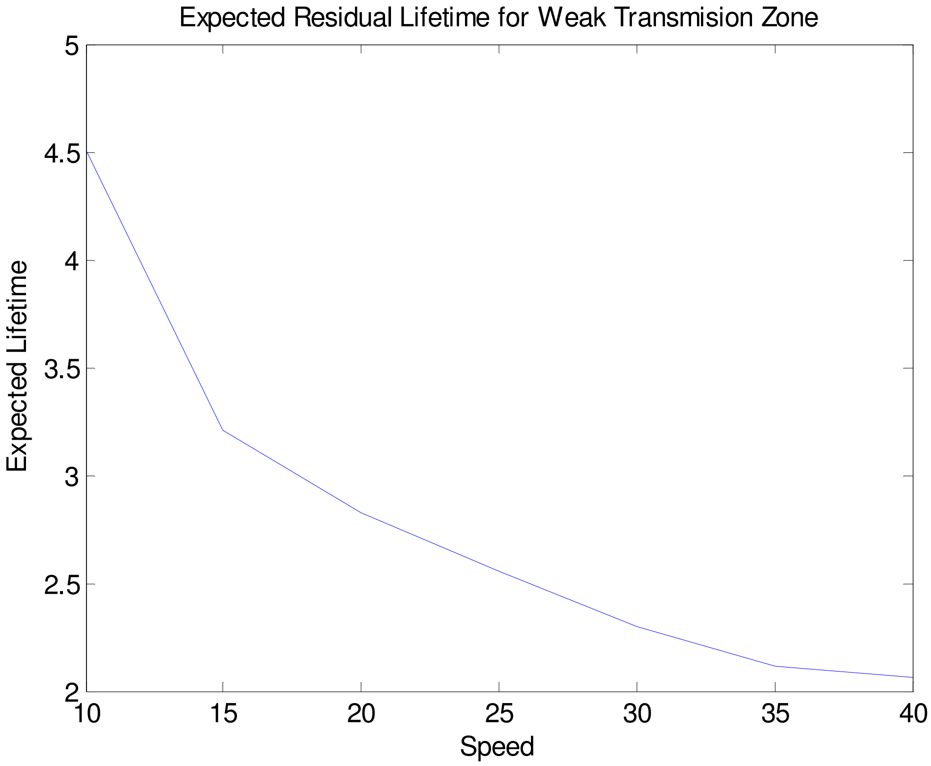


Figure 12 Expected Residual Link Lifetime in weak zone

3.6 Simulation Environment Setup

We use discrete event-driven simulator: ns2 developed by the University of California at Berkeley and the VINT project [19] to evaluate the performance and verify the theoretical model. Our simulated network consists of 50 mobile nodes, whose initial positions are chosen from a uniform random distribution over an area of 1500 m by 300 m, where each node has a unit communication radius *R*: 250 meters. The mobility pattern is random uniform model. All nodes move at a constant speed, υ ,with an initial direction, θ ,which is uniformly distributed between 0 and 2π . When a node reaches the edge of the simulation region, it is reflected back into the coverage area by setting its direction to (horizontal edges) or (vertical edges) in order to maintain node density.

The following Table I is the setting parameter value in this simulation environment:

TABLE I. SIMULATION PARAMETERS.

Simulation parameter	**Value**
Simulator	NS2 Simulator Version 2.28
Mobility Pattern	Random Uniform Model
Radio Transmission range	250 m
Position Distribution	Uniform
Node Number	50
Pause Time	0,50,100,200,300,…,800,900
Speed	0~20 m/s
Network Topology	1500 m x 300 m
Simulation Time	900 seconds

3.7 The Comparison of Theoretical Analysis and Simulation

In order to verify the analytically derived expressions for link lifetime in different zones, we compare each of them by using ns2 network simulator collected the statistic data from simulation. Figure9. (with strong zone range is 0.8R) and Figure10. (with strong zone range is 0.9R) compare the corresponding theoretical analysis with simulation results. As we expected, we can observe apparently the simulation results are in completely good agreement with the theoretical analysis. From these figures, we can see the closest transmission range (r=0.9R), the longer link lifetime in strong zone as a shorter link lifetime in weak zone with respect to a particular relative velocity.

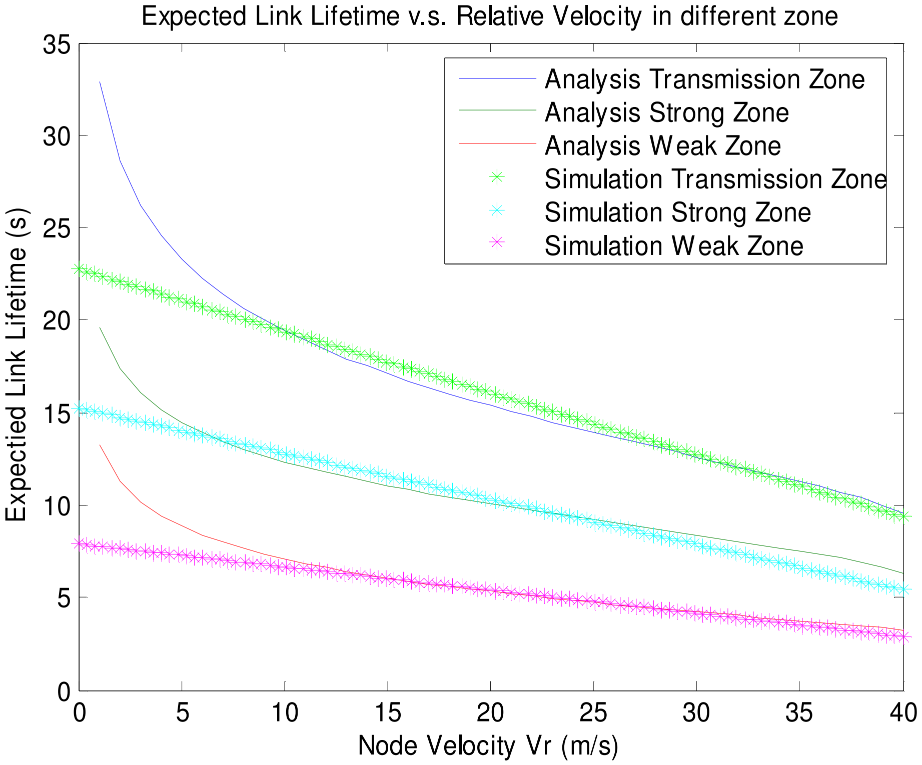


Figure 13 Expected link lifetime in transmission, strong, and weak zone (r=0.8R)

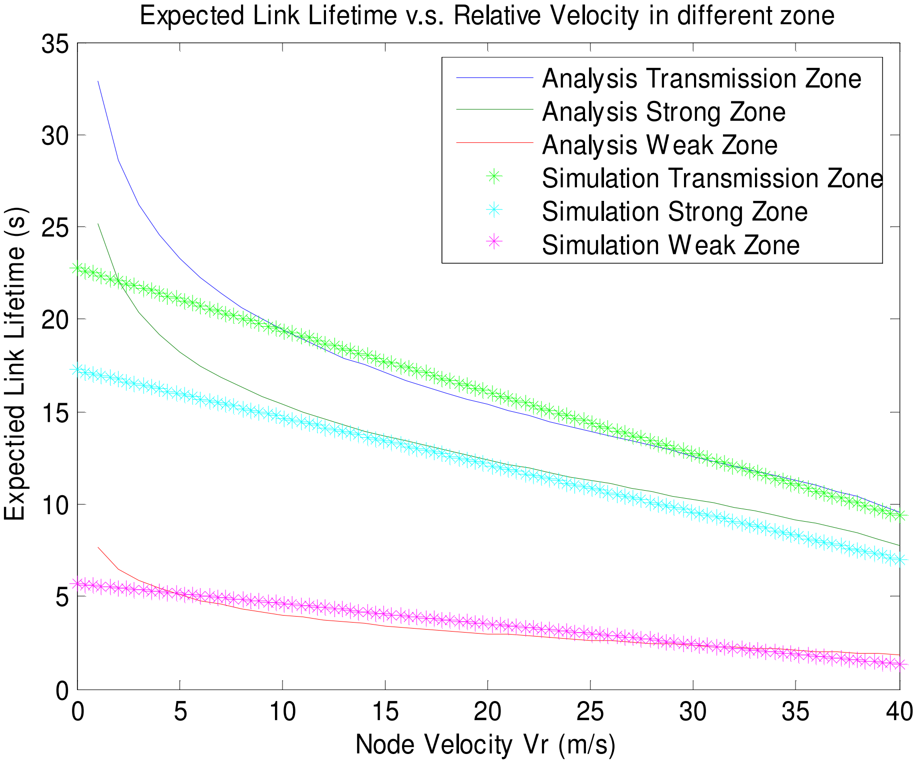


Figure 14 Expected link lifetime in transmission, strong, and weak zone (r=0.9R)

Chapter 4: An Adaptive Routing Strategy

4.1 AODV Routing Protocol

AODV(Ad Hoc On Demand Distance Vector) [18] is a distance vector routing protocol. It does note require nodes to maintain routes to destinations that are not actively used. As long as the endpoints of a communication connection have valid routes to each other, AODV does not play a role. The protocol uses different messages to discover and maintain links: Route Requests (RREQs), Route Replies (RREPs), and Route Errors (RERRs). These message types are received via UDP and IP header processing applies.

AODV uses a destination sequence number for each route entry. The destination sequence number is created by the destination for any route information it sends to requesting nodes. Using destination sequence numbers ensures loop freedom and allows to know which of several routes is more "fresh". Given the choice between two routes to a destination, a requesting node always selects the one with the greatest sequence number.

When a node wants to send data packets to another one, it broadcasts a RREQ to all the network till either the destination is reached or another node is found with a "fresh enough" route to the sequence (a "fresh enough" route is a valid route entry for the destination whose associated sequence number is as least as that contained in the RREQ). Then a RREP is sent back to the source and discovered route is made available.

Nodes that are part of an active route may offer connectivity information by broadcasting periodically local Hello messages (special RREP messages) to its immediate neighbors. If Hello messages stop arriving from a neighbor beyond some given time threshold, the connection is assumed to disconnect.

When a node detects that a route to a neighbor node is not valid it removes the routing entry and sends a RERR message to neighbors that are active and use the route (this is possible by maintaining active neighbor lists). This procedure is repeated at nodes that receive RERR message. A source that receives an RERR can re-initiate RREQ message.

4.2 Problem Statement

Existing on-demand ad hoc routing protocols will re-initiate route discovery only after the links on the routing path are broken. Once this situation occurs, there will be a significant cost both in detecting the disconnection (for example: AODV will send Hello message to check the links on the routing path whether broken or not) and re-establishing a new routing path (after found that the link is broken). The overhead for on-demand routing protocol is less than table-driven routing protocols since table-driven protocols attempt to maintain consistent and up-to-date routing information among all mobile nodes in the network. But for on-demand routing protocols, the overhead will occur while finding one or more links broken on the routing path since it needs to be re-initiate a route request procedure. Thus, we focus on how to reduce the overhead by developing our efficient adaptive routing strategy based on our zone-based link stability model. Specifically, when a mobile node with respective to another node are moving far from the strong zone and entering the weak zone (an unstable weak), a reroute update message is needed to be considered. By this protection mechanism in advance, we can reduce the overhead as a fail path occurs. With this early warning, the source can initiate route discovery early and switch to another more stable routing path.

4.3 An Adaptive Routing Strategy

In order to improve the drawback on reactive (on-demand) routing protocol, we develop Zone-Based Routing (ZBR) strategy based on our link stability model. Our basic idea is that we can obtain distinct knowledge that a mobile node is either in strong zone or in weak zone from our model to design a highly adaptive and efficient routing strategy. There are two stages in on-demand routing protocol: (1) Route Discovery; (2) Route Maintenance.

In route discovery stage, we adopt the routing mechanism in SSA [2]. A source node tries to search a shortest routing path to destination node with strong links (that is mobile node in strong zone) according our link stability model. If we could not find a routing path with all-strong links, we would find the shortest path with all available links with either strong or weak links. By establishing such a stable routing path, we will have a robust communication for delivering data packets.

In route maintenance stage, the link on the routing path may break since each mobile node is movable. In AODV routing protocol, it monitors this routing path whether valid or not at every time unit (the default value is one second). If it found one or more links on this routing path fail, it will re-initiate a route request message to re-establish a new routing path if the data packets desire this transmission. In our routing strategy: Zone-Based Routing (ZBR) will monitor the link status at every period: d second. Our scheme adopts "half link lifetime in strong zone" while mobile node is in strong zone and "half link lifetime in weak zone" while mobile node is in weak zone to be the monitoring period time. However, in order to avoid the mobile node existing out the transmission range with respect to another mobile node too fast with high velocity, once the mobile node enters the weak zone, we will add another constraint to avoid this situation occurring. While a mobile node is in weak zone, we will not only monitor the link status in every "half link lifetime in weak zone" but also add a mechanism: comparing the residual link lifetime (RLL) if RLL is greater than "half link lifetime in weak zone" at each monitoring. If this monitoring mechanism found the average monitoring period "half link lifetime in weak zone" is greater than residual link lifetime (RLL), then a route update message will be generated and send to source. Upon receiving this message, the source will find another stable routing path and delivery the later data packets on this routing path.

More specifically, the procedure of our ZBR routing strategy is as following flow chart:

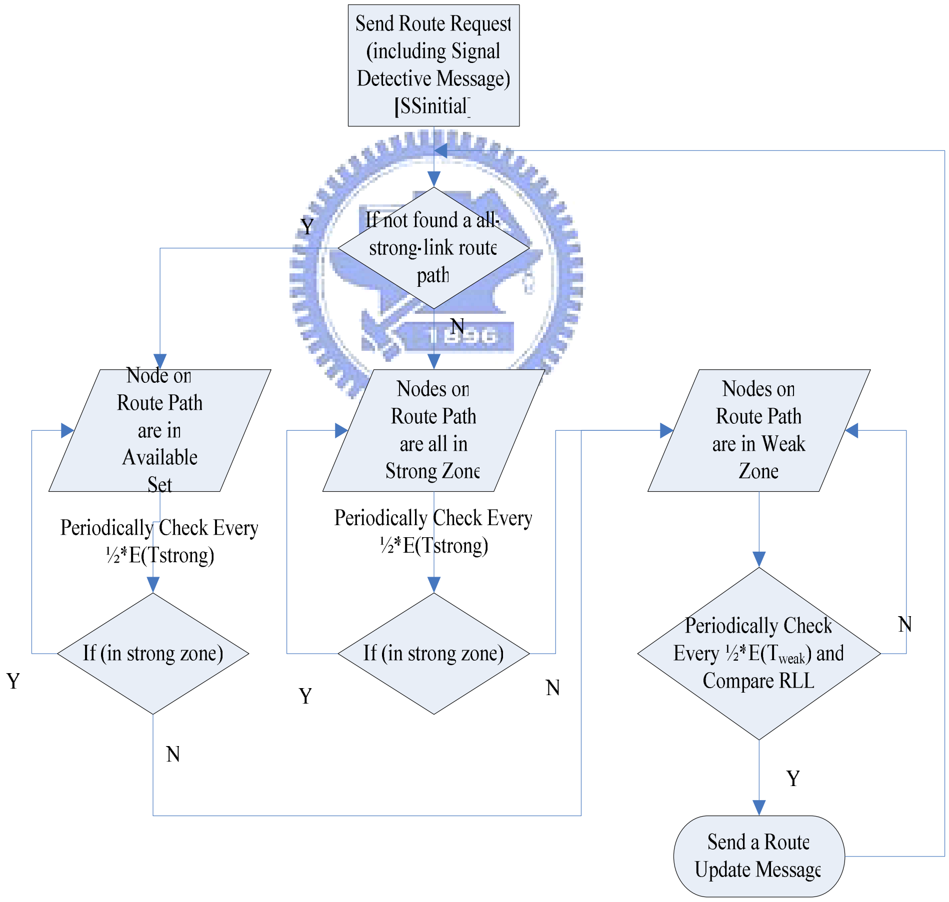


Figure 15 Zone-Based Routing (ZBR) Procedure Flow Chart

4.4 Simulation Results and Analysis

4.4.1 Performance Metrics:

There are three performance metrics to compare in our simulation. We evaluate our ZBR (Zone-Based Routing) scheme and AODV routing protocol according the following three metrics:

(1)*Packet delivery ratio*: The ratio between the number of packets originated by CBR sources and the number of packets received by the CBR sink at the final destination.

(2) *Average end-to-end delay:* The average time delay between the time when a data packet delivered from the source node and the time when the packet arrives at the destination node.

(3)*Routing overhead*: Packet overhead is the number of routing packets "transmitted" per data packet that is "delivered" at the destination node.

Packet delivery ratio is important as it describes the loss rate that will be seen by the transport protocols, which in turn affects the maximum throughput that the network can support. This metric characterizes both the completeness and correctness of the routing protocol.

Average end-to-end delay is a major parameter to measure latency time while delivering a packet whose time it takes. It dependents to overhead since a larger overhead may lead longer delay. However, a shorter delay may not necessarily imply a higher packet delivery ratio since delay is only measured on those successfully delivered packets.

Routing overhead is an important metric as it measures the scalability of a protocol, the degree to which it will function in congested or low-bandwidth environments. Protocols that send large numbers of routing packets can also increase the probability of packet collisions and may delay data packets in transmission queues of network interface.

4.4.2 Simulation Results and Analysis:

For all simulations, the communication patterns were peer-to-peer, with each run having either 10, 20, or 30 traffic sources sending 4 packets per second. Traffic sources are CBR (constant bit rate) traffics and each data packet size is 512 bytes. The source-destination pairs are distributed randomly over the network. The other simulation parameter setting is mentioned previously in Chapter 3.6.

Each node starts its journey from a random source location to a random destination with a random speed that is uniformly between 0–20 meter/second. Once the destination is arrived, another random destination will be chosen after a pause time. The total simulation time is 900 seconds and each data point in flowing figures is average of five runs with the same scenario configuration but with different random seeds.

In Figure 16、17、18, we plot the results we have obtained with respect to the packet delivery ratio with 10, 20, and 30 traffic sources. In all the testing scenarios, ZBR demonstrate high quality in delivering packets – most of all are more than 93%. Since our routing path setup on the strong link which is more stable than the ones on AODV (which only consider establishing a shortest path). Furthermore, AODV has difficulty when nodes are moving fast (corresponding to smaller pause time), with a packet delivery ratio less than 90%. However, our ZBR routing can keep a high packet delivery ratio above in all scenarios more than 90%.

In Figure 19、20、21, we portray the results we have obtained to capture the performance with respect to average delay metrics. The AODV have a shortest end-to-end delay since it setup the shortest path corresponding to less links on this routing path than our ZBR routing. Our ZBR routing path is composed of the strong link that may experience more hops. However, the average delay for our ZBR routing is more than AODV slightly. The delay cure for our ZBR routing is smoother than AODV that means we have a smaller jitter. Therefore, we have a more stable routing path and can provide some Quality of Service.

In Figure 22、23、24, we show the results we have obtained to present the overhead metrics to both of AODV and ZBR in 3 scenarios. As we can see, without the frequent periodic hello message to monitor the link status, our ZBR routing outperforms AODV. Compared to AODV (the default checking period to check link is one second each time), our ZBR routing strategy takes much less times to check link status by half expected link lifetime in strong and weak zones depending on the mobile node located in strong zone or weak zone. Moreover, under the scenario of 10 traffic sources, our ZBR routing perform very well, it will have a performance that approximates to zero overhead.

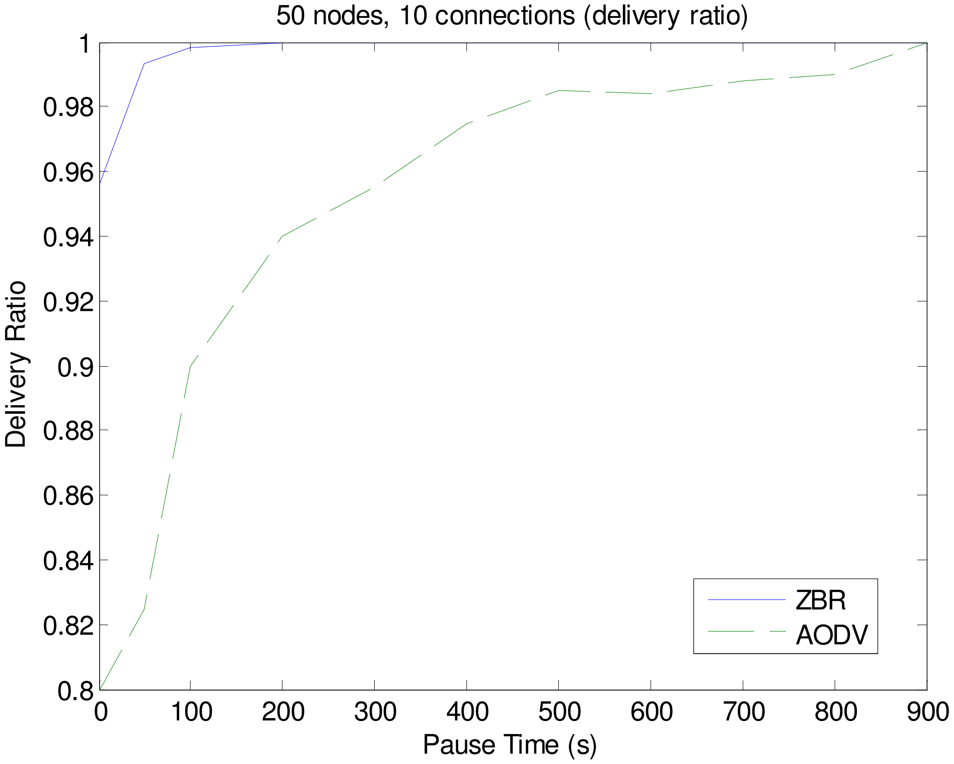


Figure 16 Packet delivery ratio with 10 connection traffic sources

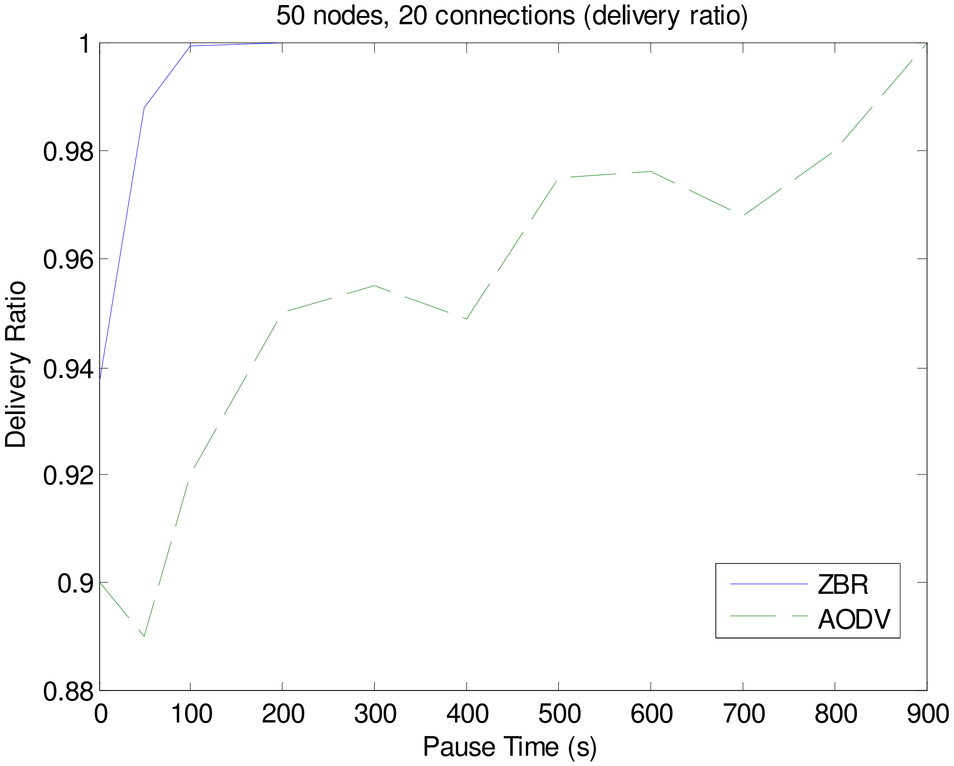


Figure 17 Packet delivery ratio with 20 connection traffic sources

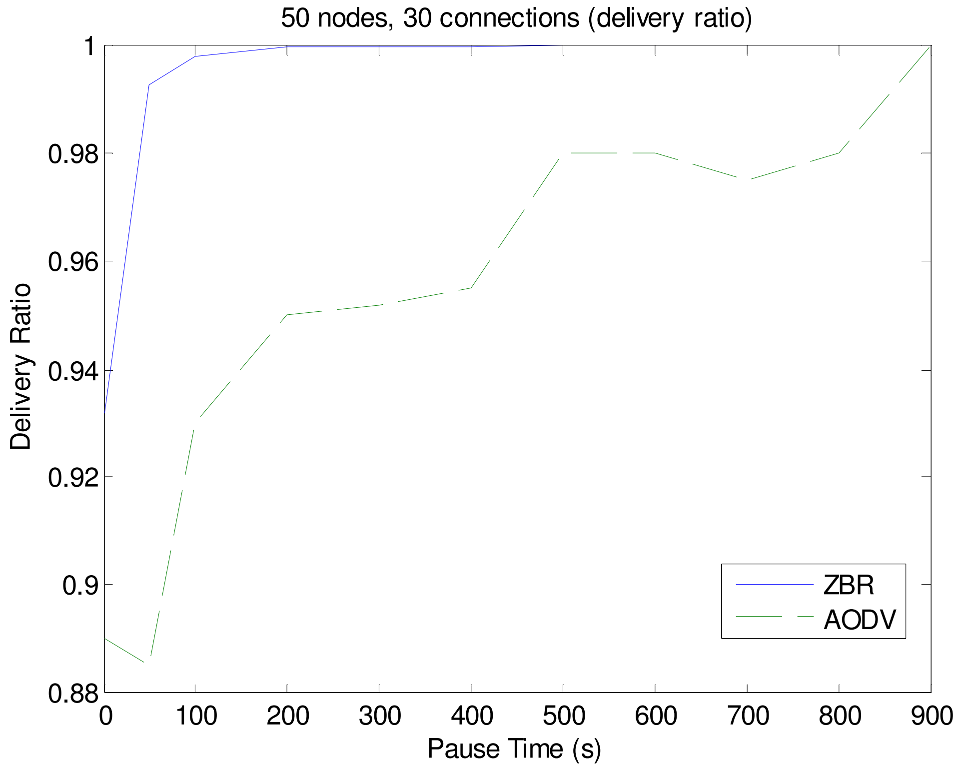


Figure 18 Packet delivery ratio with 30 connection traffic sources

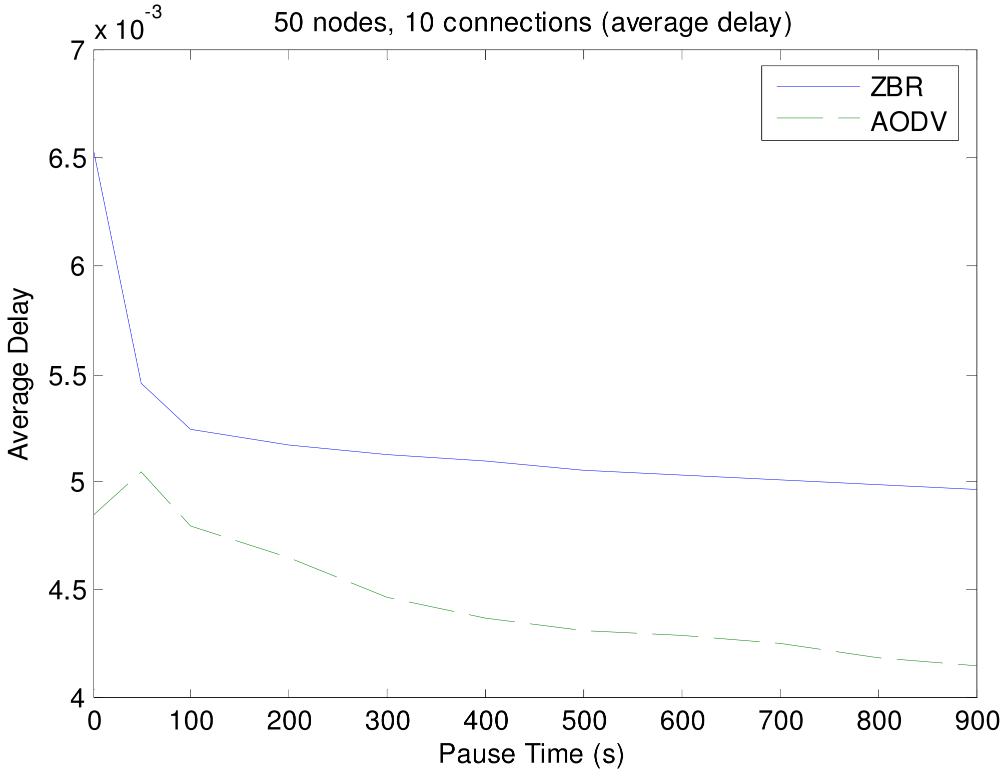


Figure 19 Average delay with 10 connection traffic sources

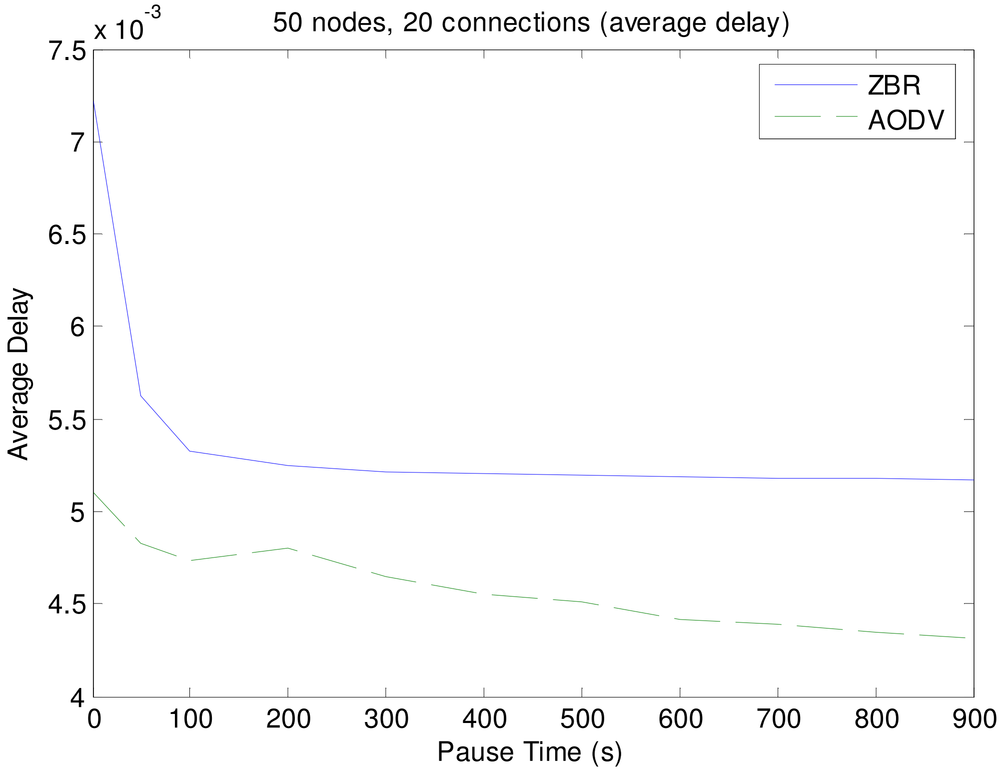


Figure 20 Average delay with 20 connection traffic sources

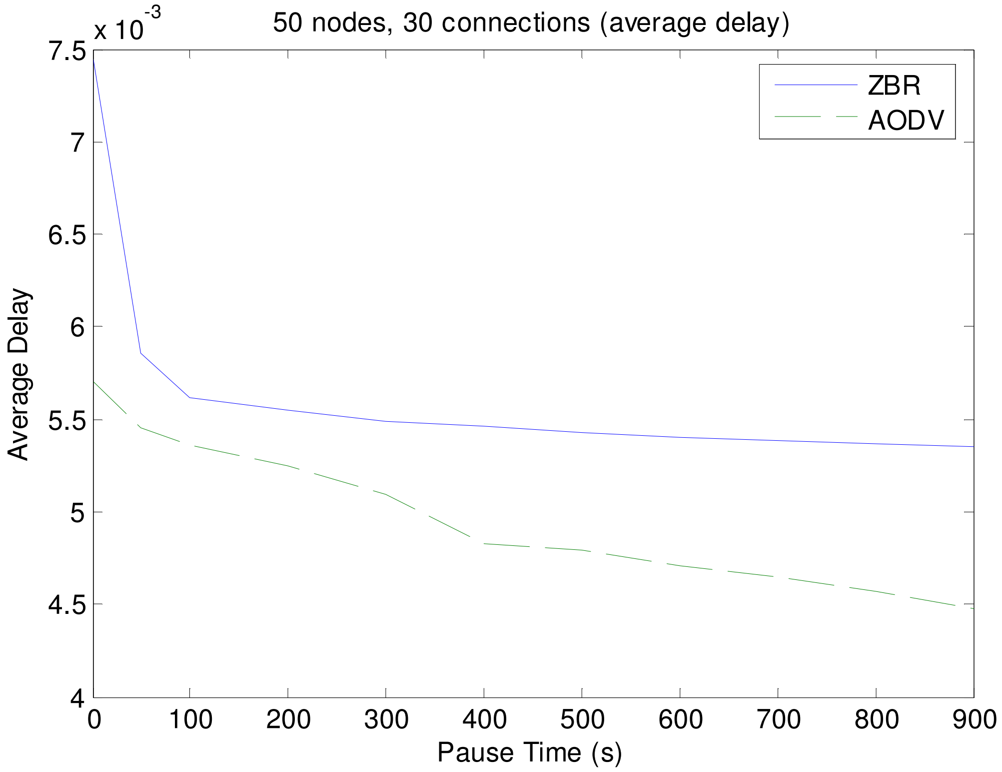


Figure 21 Average delay with 30 connection traffic sources

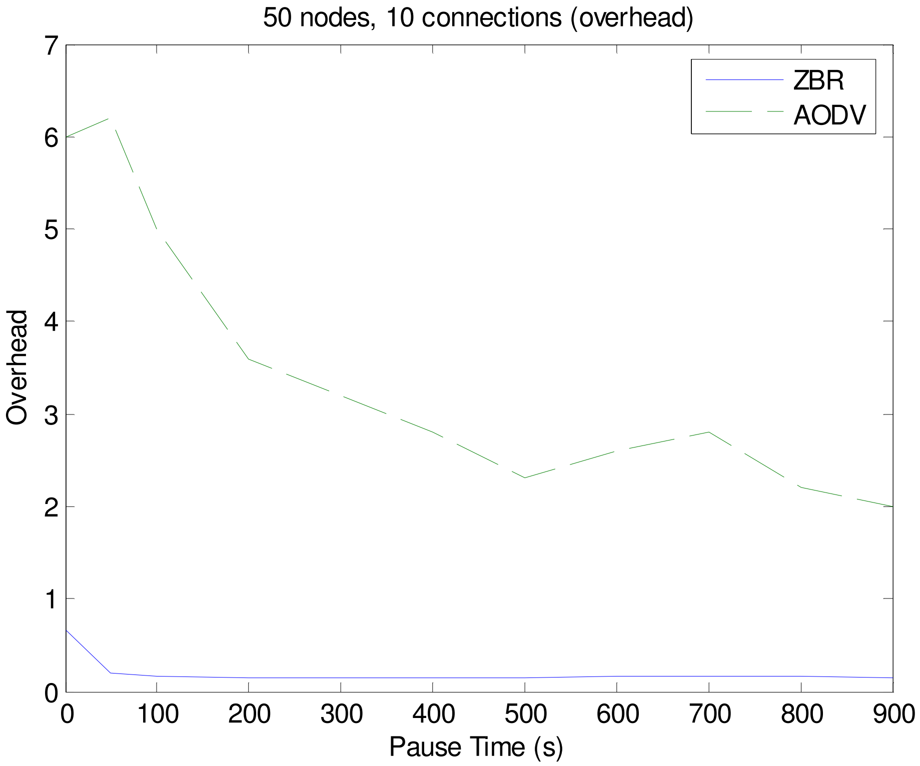


Figure 22 Packet overhead with 10 connection traffic sources

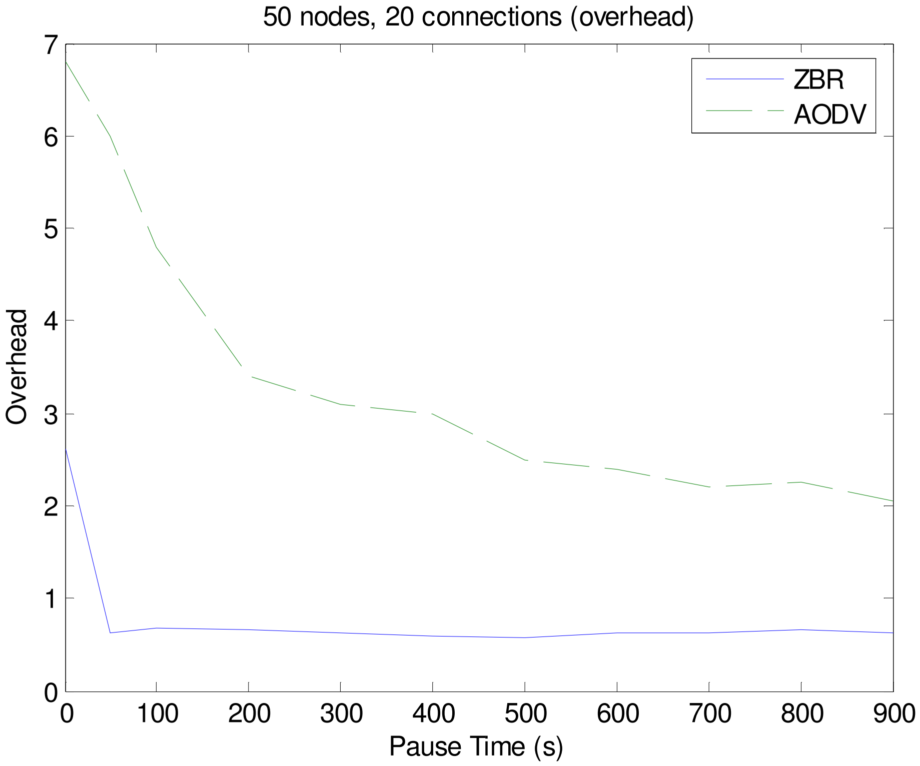


Figure 23 Packet overhead with 20 connection traffic sources

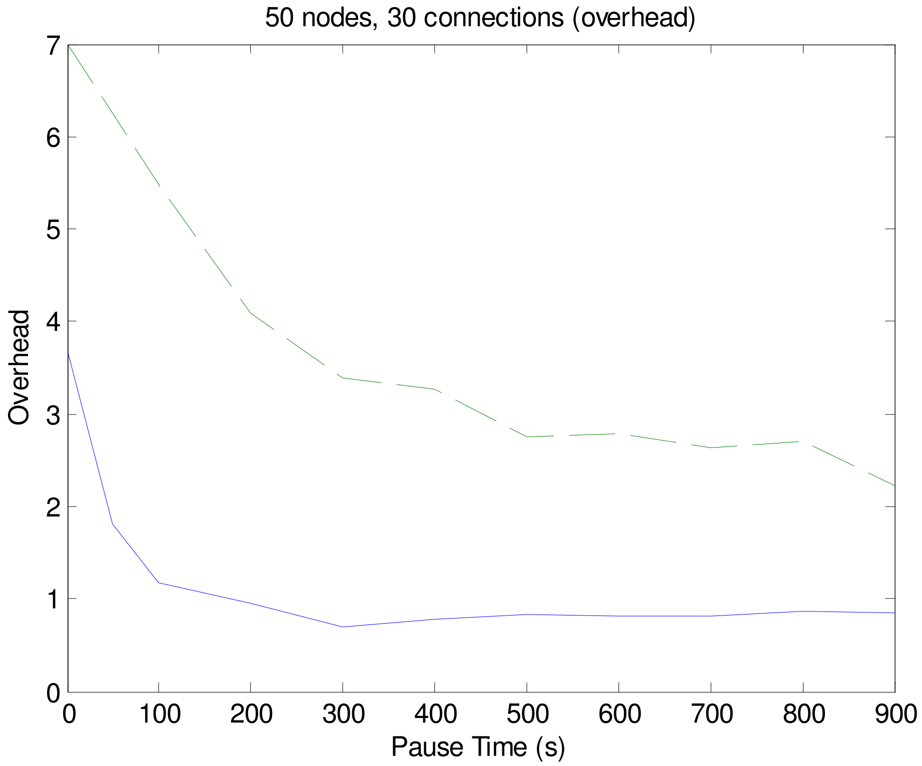


Figure 24 Packet overhead with 30 connection traffic sources

Chapter 5: Conclusion and Future Work

In this thesis, we derive an analytical formulation model about link lifetime considering the link stability in different zone. In this model, we develop a series of analytical expressions including: (1) An expected link lifetime in strong and weak zone；(2) An PDF and CDF distribution in strong and weak zone, respectively；(3) The residual link lifetime time distribution；At the same time, we design a highly efficient and adaptive routing strategy based on our zone-based link stability model.

By establishing such a zone-based link lifetime model, we can have distinct knowledge to know the mobile node is located either in strong zone or in weak zone and according to such information to determine a stabile and robust routing path and provide a protection mechanism to avoid the overhead while link failed.

By such a scheme, we can provide a stale routing path on the routing discovery stage since we establish the routing path based on strong links. Furthermore, on the route maintenance stage we can decrease the network overhead and increase the packet delivery efficiency by providing a protection mechanism: prior route update message while a node is far from the weak zone and immediately inform next packets transfer through another routing path before node leaves the transmission range according to our efficient link stability efficient monitoring mechanism before the current link really breaks.

Our results indicate that our scheme: adaptive routing based on zone-based link stability model can reduce the network overhead over 50% compared to AODV. Our ZBR can also increase packet delivery benefit efficiently (our ZBR have more than 90 % packet delivery ratio under all scenarios) since we can efficiently detect the link situation early and provide another stable routing path before link fails since decreasing the probability of packet retransmission.

Since the desirable features of routing protocols for MANETs include ability to adapt to frequent changing network conditions due to mobility and provide quality control mechanisms during the life time of a route. Hence, how to provide a suitable Quality of service (QoS) in MANETs is a challenge. In our zone-based link stability model, we can gather information about signal strength to find a more stable route during route discovery and uses this information in route choosing to provide a QoS guarantee communication depending on the desired service. In the future, we will try to design a QoS aware routing algorithm to provide a better QoS choosing metric under various QoS requirements.

Reference:

[1] P. Samar, S.B. Wicker,"On the Behavior of Communication Links of a Node in a Multi-Hop Mobile Environment," *Proceedings of The Fifth ACM International Symposium on Mobile Ad Hoc Networking and Computing (MobiHoc) 2004*, Tokyo, May 2004

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