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Research on Topology Property for Wireless Multi-hop Communication Network

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Abstract

The random movement of nodes makes the topology structure be one of the most important characteristics in wireless multi-hop communication network, which makes the description and quantization of the dynamic property the very foundation of the design, simulation and measurement for this kind of network. Wireless Ad hoc network as a typical multi-hop network will be focused on in this paper. The distributions of the link duration and the topology duration will be derived and verified by simulations. Then, the topology flapping sensing method has been put forward based on TTL. Finally, the probability model of the topology stability in the measurement time has been established and calculated based on network tomography for wireless ad hoc network in this paper. Simulating results verify the correctness and efficiency of the approach, which will provide the technique basis of research on the dynamic property and end-to-end measurement for wireless multi-hop communication network.

Keywords: *Link duration; Topology Property; Multi-hop Network; Wireless Communication*

1. Introduction

A wireless ad hoc network is a self-configuring infrastructureless network of mobile devices connected by wireless links, which is a typical multi-hop communication network. Each device in a wireless ad hoc network is free to move independently in any direction, and will therefore change its links to other devices frequently. Each must forward traffic unrelated to its own use, and therefore be a router. The primary challenge in building a wireless ad hoc network is equipping each device to continuously maintain the information require to properly route traffic, which is quite difficult since the topology keeps changing caused by nodes movement [1, 2]. Relevant studies indicate that the overall performance of wireless ad hoc network is closely related to the adaptability of the network protocol to the dynamic property. The description and quantization of the dynamic property is the foundation of design, simulation and measurement for wireless ad hoc network [3]. The topology duration is always adopted to measure the dynamic property in relevant researches [4]. [5] made analysis of four common moving model link distributed functions, and pointed out by both theoretical and simulating way that the distribution would never be described by a simple probability distributed function. With a longer route, the link duration distribution would approach to an exponential distribution, which has been verified by [6]. [7] established a relational model of route duration. The inconsistency of probability distributed function, however, appeared when the length of route is 1.

The network tomography is the science of inferring performance characteristics of the network interior by correlating sets of the end-to end measurements [8]. The strength of protocol and the forwarding nodes being independent is quite appropriate for wireless ad hoc network. Generally, the network tomography problems can be approximately described by a linear model as $Y = A\theta + \varepsilon$, where Y is the measurement vector by observation, A is the route matrix, θ is the parameter vector to be estimated, and ε is the error vector, which has often been ignored for simplification and the vector function X with respect to θ has been taken to substitute θ, so there is $Y = AX$. [9] and [10] discussed the measuring techniques for wireless Ad Hoc networks based on the network tomography. However, the researches in existence seldom take the dynamic property into account which has an impact on the adaptation of the network

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tomography. A TTL based topology flapping sensing method will be put forward in this paper, and the topology duration distribution will be derived as well. Finally, the probability model of the topology stability in the measurement time will be established and calculated for wireless multi-hop ad hoc network.

2. Mathematical Model

The network tomography is usually adopted on the premise of the fixed or already-known network topology [11, 12]. However, the nodes random movement raises new limitations for the network tomography in wireless ad hoc network [13], since the false route information $\boldsymbol{A}$ will produce errors for $\boldsymbol{X}$. There are two ways to resolve the contradiction between the dynamic topology for wireless ad hoc network and the fixed or already-known topology premise for network tomography [14, 15]: (1) to sense the topology flapping by data measurement and to make further deduce by the obtained information before or after the topology changing; (2) to shorten the measuring time to make the probability of topology flapping acceptable when the topology changing is imperceptible.

Let $\bar{\alpha}$ be the average probability of the topology flapping not being sensed in the measurement duration τ_M, and $\alpha=1-\bar{\alpha}$ be the correct rate. That is to say, given the correct rate α, the average maximum measurement duration will be τ_M, which is called the time constraint. Assume the topology flapping sensing rate is η, then the topology flapping occurring probability in τ_M will be $\gamma(\tau_M)$, and there is

$$\alpha = 1-\gamma(\tau_M)(1-\eta) \tag{1}$$

The topology flapping caused by nodes movement will be considered in this paper. Researches show that the factors which impact the measurement time constraint usually fall into one of three categories: (1) the parameters of the network dynamic property, including the nodes velocity, transmitting radius, scene area and number of nodes; (2) the parameters of the network scale, including the number of source and destination nodes; (3) the inferring accuracy of the user requirement, and the higher requirement, the less measurement time, so as to reduce the probability of the topology changing without being sensed during the measurement period. In a single measurement, the topology of wireless ad hoc network is known [16] , so a more precise computational procedure could be adopted, such as taking the length information of each path as in (2), where l_s is the length of the path s.

$$\alpha = 1-\gamma(\tau_M \mid l_s)(1-\eta(l_s)) \tag{2}$$

Mobility is one of the most important characters for wireless ad hoc network, and the movement conditions of the nodes are various. We focus the research on the velocity of 0.5m/s~2m/s which is according with the walking speed. During the performance analysis in the following parts, NS2.34 will be adopted to simulate the wireless ad hoc network with walking speed, and the related parameters settings will be as follows: the number of nodes N is 20~60; the minimum and maximum speed of the nodes is 0.5m/s and 2m/s respectively; the network scene is square with 1250m, 2500m and 5000m on the side; the pause time is 0s; the coverage radius is 250m.

3. Sensing of Topology Flapping

The impact of the dynamic property on network tomography inferring result will be alleviated effectively by sensing the topology flapping according to the hop changes of the detecting packets. The probability η of the topology flapping sensed by the detecting packets is equivalent to the probability of the path length changing when the route changes. TTL is usually adopted in Internet [17], and recent researches have indicated that 80% of the changes in end-to-end path are caused by the changes of the route length. Few studies, however, are carried out in wireless ad hoc network. η has a close relationship with the length of paths, and the probability of connections and the number of nodes. The global estimation of η will be obtained by random waypoint model [18]. Simulating results in walking speed scenes indicates that η is inversely proportional to the connection probability as in Figure 1.

That is mainly because the average path length is large with a small connection probability, and the probability of an equal route length in two successive selections will be small. Comparing with the connection probability, η is weakly correlated with the number of nodes though appearing an inverse proportion as well. Therefore, to sense the topology flapping by the TTL changes of the detecting packets is an effective way for wireless ad hoc network with a sensing rate over 50%.

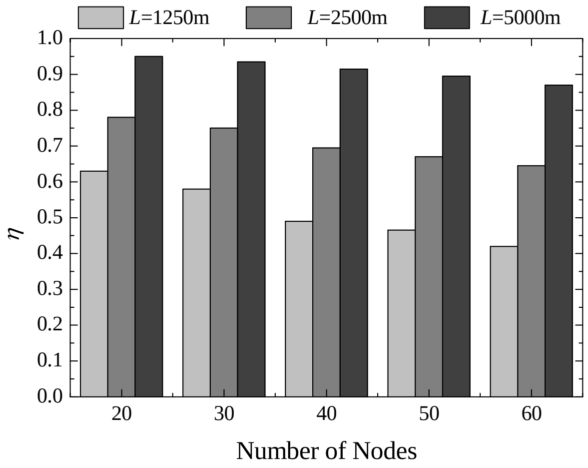

Figure 1. Topology flapping sensing rate by TTL

4. Dynamic Property of Wireless Multi-hop Communication Network

The definitions of the link and the route duration have been given out in [19] and [20], where the one lies on the connectivity graph level has been adopted in this paper. The meanings of some main parameters will be defined as follows: (1) the topology duration is the time interval between all links from each source to each destination being established and one of them being interrupted; (2) the route duration is the special case of the topology duration with the number of the source node and the destination node is 1 for both; (3) the frequency distributed function of the topology duration denoted as $F_n(t)$ is the ratio of the frequency of the topology duration being smaller than t and the big enough simulating times n; (4) the time distributed function of the topology duration denoted as $F_t(t)$ is the ratio of total time with the topology duration being smaller than t and the total duration in n times simulation.

It can be noticed that the frequency distributed function and the time distributed function are describing the probability of duration in different viewpoints and they satisfy the relationship as (3), where

$$C = \int_0^\infty x F_n'(x) \mathrm{d}x$$

is the normalization coefficient.

$$F_t(t) = \frac{1}{C}\int_0^t x F_n'(x) \mathrm{d}x \quad (3)$$

Existing researches in link duration usually take the first definition. While the time distributed function should be adopted as the distributed function of topology duration with regard to wireless ad hoc network with high dynamic property in connectivity graph level.

4.1. Link Duration

The link duration is an important parameter to measure the dynamic property of wireless multi-hop communication network. Since the link duration equals to the time taken by two nodes passing through the coverage of each other, the value only depends on the relative velocity of these two nodes and their communication radius. Accordingly, it is necessary to derive the probability distributed function of the link duration for the random waypoint model. The mobility model of wireless ad hoc network should satisfy the following assumptions: (1) the network area is much larger than the node coverage; (2) the node moving direction obeys the uniform distribution on $\left[0,2\pi\right)$, that is to say, the mobility model has no direction specificity with the pause time as 0.

The probability distribution of the link duration equals to the product of the probability distribution of the link duration λ_{12} and the velocity probability of the mobility model in the condition of any two nodes $\left(n_1,n_2\right)$ with the velocity known and the angle φ between the relative velocity directions obeying the uniform distribution on $\left[0,2\pi\right)$, as shown in (4).

$$F_t\left(t\right)=\iint F_t\left(\lambda_{12}\left|v_1,v_2,f\left(\varphi\right)=U\left(0,2\pi\right)\right.\right)f_v\left(v_1\right)f_v\left(v_2\right)\mathrm{d}v_1\mathrm{d}v_2 \quad (4)$$

Since the link duration between any two nodes in wireless multi-hop communication network is independent identical distribution, the distribution of the network link duration is the same as the distribution of any link duration. The velocity of the node n_1 and n_2 is v_1 and v_2 respectively, which are the independent identical distribution. The expression $F_t\left(\lambda_{12}\left|v_1,v_2,f\left(\varphi\right)=U\left(0,2\pi\right)\right.\right)$ will be abbreviated as $F_t\left(\lambda_{12}\left|v_1,v_2\right.\right)$ in this paper.

Assume the link has been established by n_1 and n_2 at $\left(r_0,\theta\right)$ as shown in Figure 2, and there is $\theta_v\in\left(\pi/2+\theta,3\pi/2+\theta\right)$. Since the velocity of n_1 is higher than that of n_2, the link establishment can only lie in the fore-semicircle covered by n_1. Considering the symmetry, the condition of $\theta\in\left[0,\pi/2\right)$ will only be taken into account in derivation. Since the link duration λ_{12} satisfies the relationship of $\lambda_{12}=1/v$, according to Figure 2, there will be $l=2r_{.0}\cos\left(\theta+\beta\right)$ or $l=2r_{.0}\cos\left(\theta-\beta'\right)$. The relationship between v_1, v_2 and v with $k>1$ can be seen in Figure 3.

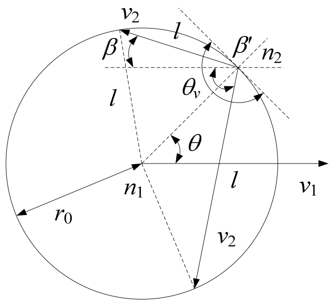

Figure 2. n_2 passing through coverage of n_1

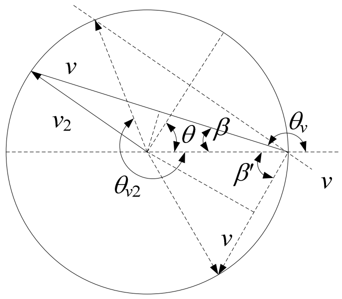

Figure 3. Relationship between v_1, v_2 and v ($k>1$)

$$\theta_v=\pi-\beta=\pi-\arcsin\frac{\sin\theta_{v_2}}{\sqrt{1-2k\cos\theta_{v_2}+k^2}} \quad (5)$$

$$v=v_2\sqrt{1-2k\cos\theta_{v_2}+k^2} \quad (6)$$

In a condition with the given value of θ, the range of the links being established is Θ, and there will be

$$\Theta = \begin{cases} [0, \theta-\alpha) \cup (\theta+\alpha, 2\pi), & k\cos\theta < 1 \\ [0, 2\pi), & k\cos\theta \ge 1 \end{cases} \tag{7}$$

where $\alpha = \arccos(k\cos\theta)$. The value range of θ_{v_2} with $\lambda_{12} < t$ is denoted as Ψ.

Assume the link between n_1 and n_2 has been established for N_{12} times during n_1 moving for T_{mov}, and the movement covering area is Q as shown in Figure 4.

n_1 will set up the connection with n_2 in the angle range of $(\theta, \theta+\Delta\theta)$, and the velocity direction will lie in $(\theta_{v_2}, \theta_{v_2}+\Delta\theta_{v_2})$ with the times of connection as Δm. Here Δm equals to the product of the area of relative movement of Δd in T_{mov} and the probability density of n_2.

$$\Delta m = \frac{\Delta\theta_{v_2}}{2\pi}\frac{S}{Q}\Bigg|_{\substack{\Delta\theta\to 0 \\ \Delta\theta_{v_2}\to 0}} = \frac{1}{2\pi Q} r_0 v T_{\text{mov}} \Delta\theta_{v_2} \Delta\theta \sin\left(\theta_v - \theta - \frac{\pi}{2}\right) \tag{8}$$

Accordingly, the distributed function of link duration will be calculated by (9).

$$F_t\left(\lambda_{12} \middle| v_1 > v_2\right) = \lim_{\substack{\Delta\theta_{v_2}\to 0 \\ \Delta\theta\to 0 \\ T_{mov}\to\infty}} \frac{1}{\sum\limits_{\theta\in\left[0,\frac{\pi}{2}\right)} \sum\limits_{\theta_{v_2}\in\Theta} \Delta m} \sum_{\theta\in\left[0,\frac{\pi}{2}\right)} \sum_{\theta_{v_2}\in\Psi} \Delta m \tag{9}$$

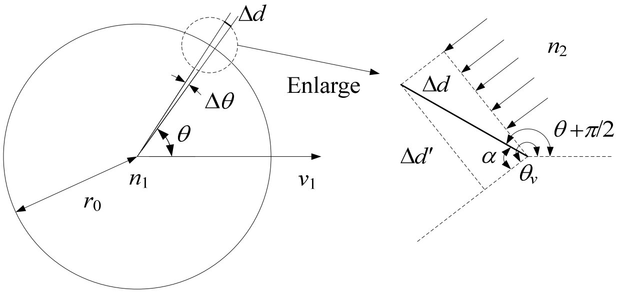

Figure 4. Calculation for connecting times for n_1 and n_2

Then the distributed function of link duration with $v_1 > v_2$ will be (10), where Θ satisfies (11). Similar with the condition above, when $v_1 < v_2$, the link establishing point may in the whole coverage circle of n_1.

$$F_t\left(\lambda_{12} \middle| v_1 > v_2\right) = \frac{\int_0^{\frac{\pi}{2}} \int_{\theta_{v_2}\in\Psi} \sqrt{1-2k\cos\theta_{v_2}+k^2}\,\sin\left(\frac{\pi}{2}-\theta-\arcsin\frac{\sin\theta_{v_2}}{\sqrt{1-2k\cos\theta_{v_2}+k^2}}\right)\mathrm{d}\theta_{v_2}\,\mathrm{d}\theta}{\int_0^{\frac{\pi}{2}} \int_{\theta_{v_2}\in\Theta} \sqrt{1-2k\cos\theta_{v_2}+k^2}\,\sin\left(\frac{\pi}{2}-\theta-\arcsin\frac{\sin\theta_{v_2}}{\sqrt{1-2k\cos\theta_{v_2}+k^2}}\right)\mathrm{d}\theta_{v_2}\,\mathrm{d}\theta} \tag{10}$$

$$\Theta=\begin{cases}\left[0,\theta-\arccos\left(k\cos\theta\right)\right)\cup\left(\theta+\arccos\left(k\cos\theta\right),2\pi\right), & k\cos\theta<1\\ \left[0,2\pi\right), & k\cos\theta\geq 1\end{cases} \quad (11)$$

In view of the symmetry, only the condition of $\theta\in\left[0,\pi\right)$ has to be considered in derivation. When there is $\theta\in\left[0,\pi/2\right)$, the value range of θ_{v_2} will be $\Theta_1=\left(\alpha+\theta,2\pi+\theta-\alpha\right)$ and $\alpha=\arccos\left(k\cos\theta\right)$. When there is $\theta\in\left[\pi/2,\pi\right)$, the value range of θ_{v_2} will be , and there will be $\alpha=\arccos\left(k\cos\left(\pi-\theta\right)\right)$.

Let Θ_{11}, Θ_{12}, Θ_{21} and Θ_{22} substitute the value range as show in (12) then there is $\Theta_1=\Theta_{11}\cup\Theta_{12}$ and $\Theta_2=\Theta_{21}\cup\Theta_{22}$.

$$\begin{aligned}\Theta_{11}&=\left(\arccos\left(k\cos\theta\right)+\theta,2\pi-\arccos k\right)\\ \Theta_{12}&=\left(2\pi-\arccos k,2\pi+\theta-\arccos\left(k\cos\theta\right)\right)\\ \Theta_{21}&=\left(0,\arccos\left(k\cos\left(\pi-\theta\right)\right)+\theta-\pi\right)\cup\left(2\pi-\arccos k,2\pi\right)\\ \Theta_{22}&=\left(\pi+\theta-\arccos\left(k\cos\left(\pi-\theta\right)\right),2\pi-\arccos k\right)\end{aligned} \quad (12)$$

Ψ_{11}, Ψ_{12}, Ψ_{21} and Ψ_{22} represents the value range of θ_{v_2} in Θ_{11}, Θ_{12}, Θ_{21} and Θ_{22} respectively with $\lambda_{12}<t$ as (13),

$$\begin{aligned}\Psi_{11}&=\left\{\theta_{v_2}\left|\Gamma_1<t,\theta_{v_2}\in\Theta_{11},\theta\in\left[0,\pi/2\right)\right.\right\}\\ \Psi_{12}&=\left\{\theta_{v_2}\left|\Gamma_2<t,\theta_{v_2}\in\Theta_{12},\theta\in\left[0,\pi/2\right)\right.\right\}\\ \Psi_{21}&=\left\{\theta_{v_2}\left|\Gamma_2<t,\theta_{v_2}\in\Theta_{21},\theta\in\left[\pi/2,\pi\right)\right.\right\}\\ \Psi_{22}&=\left\{\theta_{v_2}\left|\Gamma_1<t,\theta_{v_2}\in\Theta_{22},\theta\in\left[\pi/2,\pi\right)\right.\right\}\end{aligned} \quad (13)$$

Where

$$\begin{aligned}\Gamma_1&=2r_0\cos\left(\theta+\arcsin\left(\sin\theta_{v_2}/\Gamma\right)\right)\Big/\left(v_2\Gamma\right)\\ \Gamma_2&=2r_0\cos\left(\pi-\theta+\arcsin\left(\sin\theta_{v_2}/\Gamma\right)\right)\Big/\left(v_2\Gamma\right)\\ \Gamma&=\sqrt{1-2k\cos\theta_{v_2}+k^2}\end{aligned}$$

Then there will be (14) and (15) according to the condition with $v_1>v_2$.

$$l=\begin{cases}2r_0\cos\left(\pi-\theta+\arcsin\left(\sin\theta_{v_2}/\Gamma\right)\right), & \theta_{v_2}\in\Theta_{12}\cup\Theta_{21}\\ 2r_0\cos\left(\theta+\arcsin\left(\sin\theta_{v_2}/\Gamma\right)\right), & \theta_{v_2}\in\Theta_{11}\cup\Theta_{22}\end{cases} \quad (14)$$

$$\underset{\substack{\Delta\theta\to 0\\ \Delta\theta_{v_2}\to 0}}{\Delta m}=\begin{cases}\dfrac{1}{2\pi Q}r_0v_2T_{\mathrm{mov}}\Delta\theta_{v_2}\Delta\theta\Gamma\sin\left(\dfrac{\pi}{2}-\theta-\arcsin\left(\dfrac{\sin\theta_{v_2}}{\Gamma}\right)\right), & \theta\in\left[0,\pi\right),\theta_{v_2}\in\Theta_{11}\cup\Theta_{22}\\ \dfrac{1}{2\pi Q}r_0v_2T_{\mathrm{mov}}\Delta\theta_{v_2}\Delta\theta\Gamma\sin\left(\dfrac{3\pi}{2}-\theta+\arcsin\left(\dfrac{\sin\theta_{v_2}}{\Gamma}\right)\right), & \theta\in\left[0,\pi\right),\theta_{v_2}\in\Theta_{12}\cup\Theta_{21}\end{cases} \quad (15)$$

The distributed function of the link duration with $v_1 < v_2$ can be obtained by the integral of Δm as (16).

$$F_t\left(\lambda_{12} \middle| v_1 < v_2\right) = \left(\int_0^{\pi/2} \int_{\theta_{v_2} \in \Psi_{11}} \Gamma\Gamma_3 \mathrm{d}\theta_{v_2} \mathrm{d}\theta + \int_0^{\pi/2} \int_{\theta_{v_2} \in \Psi_{12}} \Gamma\Gamma_4 \mathrm{d}\theta_{v_2} \mathrm{d}\theta + \int_{\pi/2}^{\pi} \int_{\theta_{v_2} \in \Psi_{21}} \Gamma\Gamma_4 \mathrm{d}\theta_{v_2} \mathrm{d}\theta + \right.$$
$$\left. \int_{\pi/2}^{\pi} \int_{\theta_{v_2} \in \Psi_{22}} \Gamma\Gamma_3 \mathrm{d}\theta_{v_2} \mathrm{d}\theta \right) \Bigg/ \left(\int_0^{\pi/2} \int_{\theta_{v_2} \in \Theta_{11}} \Gamma\Gamma_3 \mathrm{d}\theta_{v_2} \mathrm{d}\theta + \int_0^{\pi/2} \int_{\theta_{v_2} \in \Theta_{12}} \Gamma\Gamma_4 \mathrm{d}\theta_{v_2} \mathrm{d}\theta + \right. \quad (16)$$
$$\left. \int_{\pi/2}^{\pi} \int_{\theta_{v_2} \in \Theta_{21}} \Gamma\Gamma_4 \mathrm{d}\theta_{v_2} \mathrm{d}\theta + \int_{\pi/2}^{\pi} \int_{\theta_{v_2} \in \Theta_{22}} \Gamma\Gamma_3 \mathrm{d}\theta_{v_2} \mathrm{d}\theta \right)$$

Though the existing researches have obtained the distribution of the link duration for many nodes velocities, the functions are quite complicated. In order to simplify the latter calculation, the distribution of the link duration will be obtained by simulation and the distributed function could be set up by means of fitting. The result shows that the average deviation and the variance of Gompertz function are small with three parameters as in (17).

$$F_d(t) = a \exp(-\exp)\frac{t_0 - t}{d} = 0.99 \exp(-\exp)\frac{146 - t}{120} \quad (17)$$

4.2. Number of Topology Links

The topology duration has a close relationship with the number of links in wireless multi-hop communication network. The more links exist, the shorter the average topology duration will be. Assume the set of source nodes is $\boldsymbol{S}$ with M elements, and the set of destination nodes is $\boldsymbol{D}$ with N elements. The path from node i to node j is $P[i,j]$. The shared path of $P[k,i]$ and $P[k,j]$ will be denoted as $P[k;i,j]$; and $P[i,j;k]$ for $P[i,k]$ and $P[j,k]$. The number of topology links being measured can be represented as (18).

$$h(G) = \sum_{i\in\mathbf{S},\, j\in\mathbf{D}} h(\mathrm{P}[i,j]) - \sum_{i\in\mathbf{S},\, j,k\in\mathbf{D}} h(\mathrm{P}[i;j,k]) - \sum_{i,j\in\mathbf{S},\, k\in\mathbf{D}} h(\mathrm{P}[i,j;k]) \quad (18)$$

When the source nodes and destination nodes are selected randomly, simulating results show that few shared paths exist for two routes in wireless ad hoc network. Then (18) can be simplified as

$$h(G) = \sum_{i\in\mathbf{S},\, j\in\mathbf{D}} h(\mathrm{P}[i,j])$$

The distributed function of topology links will be

$$F_G(h,\rho,N) = \sum_{\sum_{i\in\mathbf{S},\, j\in\mathbf{D}} h(\mathrm{P}[i,j]<h)} \prod \varphi\left(h(\mathrm{P}[i,j]),\rho,N\right)$$

where $\varphi\left(h(\mathrm{P}[i,j]),\rho,N\right)$ is the probability distribution of the path length, which can be obtained by simulation as in Figure 5 with L=2500m.

4.3. Topology Duration

Simulations based on NS2.34 have been carried out to analyze the relationship between the topology duration and the wireless ad hoc network parameters in this paper.

In walking speed scenes, the set of source nodes and destination nodes will be selected randomly with (1) M=1, N=4; (2) M=1, N=8; (3) M=3, N=4. Then the number of paths included in these topologies will be 4, 8 and 12 respectively. Simulation results of topology duration distribution can be seen in Figure 6, which shows that the more paths there are in wireless multi-hop communication network topology, the smaller the topology duration will be.

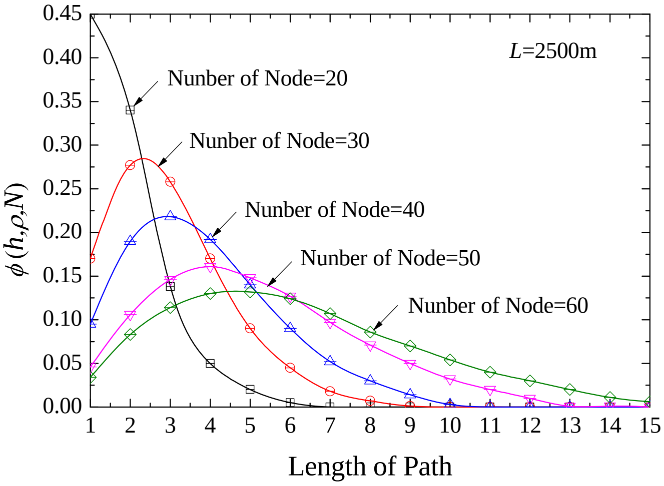

Figure 5. Probability distributed functions of the path length with L=2500m

Since the length of path depends on the number of nodes and the probability of connections, they have a direct impact on the network topology duration. Simulations will make the measurement time, the source node and destination node selected randomly in each walking speed scene, and the results can be seen in Figure 7 and Figure 8.

The topology duration equals to the smallest remaining time of all links duration after the topology being completely set up. This is because the links setting up time may be different. When the last one ξ is being established, other links may hold for some time. Therefore, the distribution of topology duration can be represented as (19).

$$P\{T<t\}=P\left\{\min_{i\in(E-\xi)}\{c_i\lambda_i,\xi\}<t\right\} \tag{19}$$

The movement of the shared node in adjacent links may have an impact on the link duration of the adjacent links, so the durations of all links in wireless multi-hop communication network are correlated with each other. Existing researches, however, show that this kind of correlation is weak. Assume the link duration and ci are mutually independent. Then (20) will be obtained accordingly.

Since the starting time of each link is independent, c_i can be assumed to obey a uniform distribution on $[0,1]$. Then (20) will be simplified as (21).

$$\begin{aligned} P\{T<t|E\}&=1-\prod_{i\in\{E-\xi\}}P\{c_i\lambda_i>t\}P\{\xi>t\}=1-\left(P\{c\lambda>t\}\right)^{|E|-1}P\{\lambda>t\}\\ &=1-\left(\int_0^1\int_{t/x}^{\infty}f_c(x)\,f_\lambda(y)\,\mathrm{d}y\mathrm{d}x\right)^{|E|-1}\left(\int_t^{\infty}f_\lambda(y)\,\mathrm{d}y\right)\end{aligned} \tag{20}$$

The path duration function will be obtained by substituting the link duration distributed function to (21) and (22).

Comparison result of the simulation and the calculation for time distributed function can be seen in Figure 9, which shows a big difference in the conditions with a large duration. That is because: (1) there are errors existing in topology duration statistics caused by limited simulating duration; (2) there is an approximate calculation in the link duration fitting function. In process of calculating the measurement time constrain, the value on small duration of the topology duration function has been mainly adopted so as hardly to produce any severe impacts.

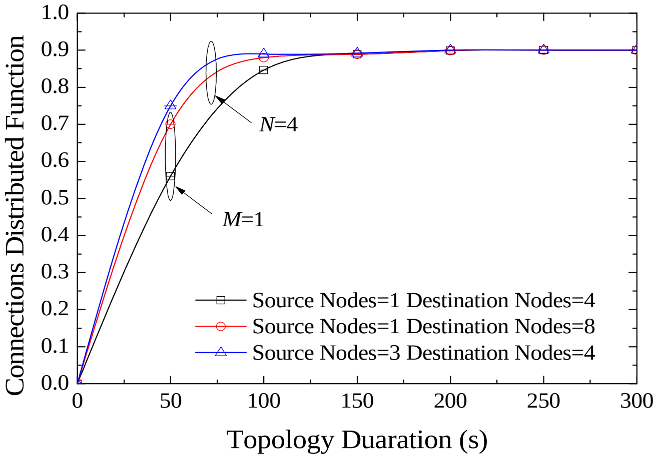

Figure 6. Continuous distributed function of topology duration

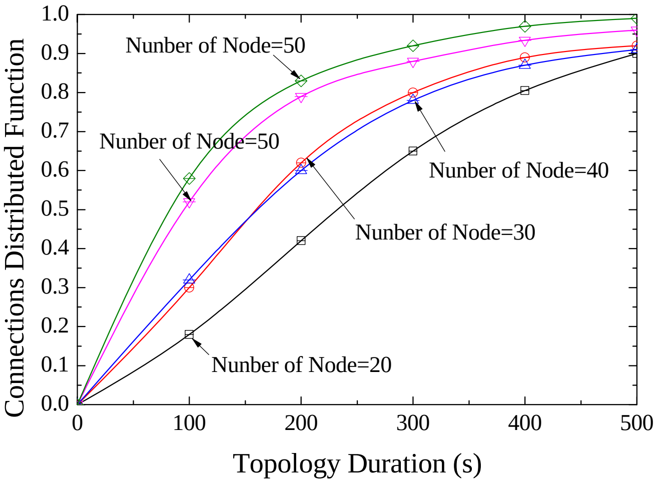

Figure 7. Comparisons with $L = 2500m$

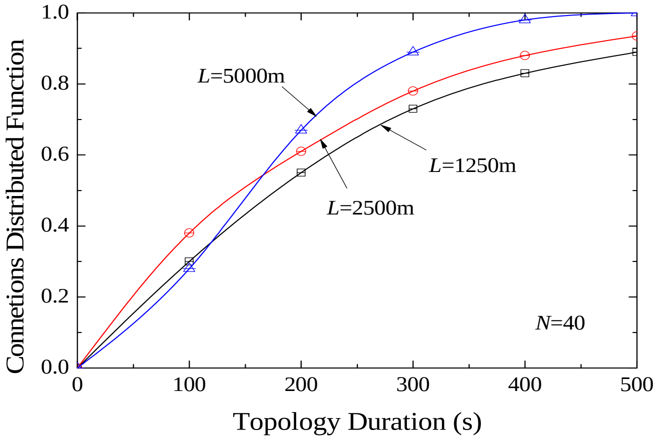

Figure 8. Comparisons with $N = 40$

$$F_n\left(t,|E|\right)=1-\left(\int_0^1\int_{t/x}^{\infty} f_\lambda\left(y\right)\mathrm{d}y\mathrm{d}x\right)^{|E|-1}\left(\int_t^{\infty} f_\lambda\left(y\right)\mathrm{d}y\right)=1-\left(\int_0^1\left(1-F_\lambda\left(\frac{t}{x}\right)\right)\mathrm{d}x\right)^{|E|-1}\left(1-F_\lambda\left(t\right)\right)$$
$$=1-\left(1-\int_0^1 F_\lambda\left(\frac{t}{x}\right)\mathrm{d}x\right)^{|E|-1}\left(1-F_\lambda\left(t\right)\right) \tag{21}$$

$$\gamma\left(t,|E|\right)=F_t\left(t,|E|\right)=\frac{1}{C}\int_0^t y\left(\left(1-\int_0^1 F_\lambda\left(\frac{y}{x}\right)\mathrm{d}x\right)^{|E|-1} f_\lambda\left(y\right)+\left(1-\int_0^1 F_\lambda\left(\frac{y}{x}\right)\mathrm{d}x\right)^{|E|-2}\right.$$
$$\left.\left(1-F_\lambda\left(y\right)\right)\int_0^1\frac{1}{x}f_\lambda\left(\frac{y}{x}\right)\mathrm{d}x\right)\mathrm{d}y \tag{22}$$

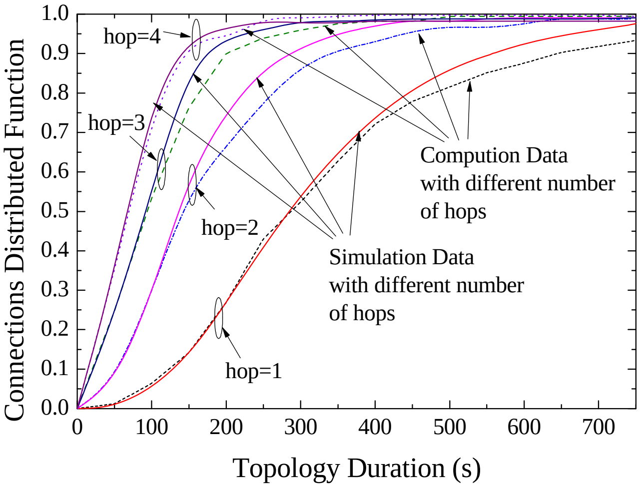

Figure 9. Continuous distributed function of the topology duration.

5. Conclusion

Wireless ad hoc network as a typical wireless multi-hop communication network, has been regarded as an important step to realize the ubiquitous communication world. The dynamic topology makes the network being organized flexibly to adapt more general environment, but will have an impact on packets transmitting performance. We have focused on the topology flapping in wireless ad hoc network to obtain the description and quantification for dynamic properties based on network tomography. Combining the theoretical derivation and simulation verification, the dynamic property has been investigated systematically on graph level, and a novel method to sense the topology flapping based on TTL has been proposed in this paper. Simulation results show a better sensing rate. Moreover, the network tomography has been introduced in wireless ad hoc network, through which the calculating model for the probability distributed function of the network topology stability has been established and simulated in wireless ad hoc network in walking speed scenes. The experimental results with both simulation and calculation demonstrated the effectiveness of the proposed model. Future work will concentrate on the algorithm universality and environment adaption.

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