Link Availability Prediction Based on Capacity Optimization in MANET

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Abstract

Mobile Ad hoc Network (MANET) is a wireless network composed of multiple wireless nodes without fixed infrastructure support, which is expected to play an important role in future commerce and military, especially in marine and aerospace communications systems. In this paper, for link failure caused by node mobility, the prediction of link availability is given according to the dynamic characteristics of the link, and transmission modes and relay nodes are selected to optimize the link capacity and reduce the interference. Simulation results show that the proposed routing metric method can select stable routing paths with less interference, and reduce routing overhead caused by node movement based on link availability analysis.

Keywords: Link availability, Mobile Ad hoc Network (MANET), Cooperative transmission, Outage capacity.

1 Introduction

The integrated satellite, sky, terrestrial and ocean networks has become the focus of state, military and aerospace scholars, due to its capability of time-space continuity, high reliability, large regional capacity and high mobility. However, the integrated network carries a variety of services, which are characterized by large time and space, long time delay, interruption, multi-track and multi-type. MANET can not only exist as an independent network, but also serve as an effective supplement to the integrated network structure based on its independence and flexibility.

MANET is a multi-hop temporary autonomous system which has no fixed base station and basic network, and all nodes in the network have the functions of host and router at the same time, and can be moved at will. Therefore, dynamic topology is one of the most remarkable characteristics of MANET. Due to the rapid topology changes, established routes can be broken frequently, which brings severe challenges to routing design. In order to reduce reroute operations, the most stable path must be chosen. In [1], the interference in large wireless networks influence on the performance in the system is analyzed. In [2], the influence of co-channel interference on the interruption rate of wireless Ad hoc network is defined. In [3], the link expiration time is predicted, assuming that the velocity and direction of the two nodes have not changed since the beginning. In [4], the current motion information of nodes (position, velocity and direction) is used to predict the respective positions of two nodes and whether they are still connected at time t. In [5], A. Bruce McDonald et al. proposed the concepts of link availability and path availability, and applied them to the design of routing protocol. In [6], proposed link models for predicting the availability, the probability that the link will last to a certain time is predicted based on the possible changes in motion. In [7], the transmission reliability is defined to measure the transmission performance of the MANET, the impact of interference is considered, and genetic algorithm is used for optimization. In [8], proposed a learning automata-based topology control method within a cognitive approach, which deals with adding cognition to entire network protocol stack to achieve stack-wide and network-wide performance goals. In [9], proposed a Bayesian pursuit algorithm, which predicts the node movement parameters by learning environment to predict the length of the link. In [10], artificial neural networks were applied to classify the set of cooperative relays under DF-relaying constraints, to maximize the achievable secrecy rates. However, above literature did not consider the dynamic change of network topology caused by mobile node, and the topology structure with more than two hops is not suitable for fast moving network. In addition, control of network topology requires acquisition of certain network state information, so it is not applicable to mobile AD hoc network without central control infrastructure. Therefore, a two-hop link model based on mobility is established, and a capacity optimization link predictive (COLP) topology control scheme with cooperative communication is proposed in this paper.

The paper is organized as follows. Section II gives a detailed description of the dynamic system model in MANET. In Section III, link availability is calculated according to the relative motion of nodes to predict the link life, and the optimal topology is selected based on network capacity and interference. In Section IV, numerical results from the model simulation are presented. Finally, conclusions are drawn in Section V.

2 System model

The prediction method in this paper is based on the modified Random Walk-based Mobility model. Due to the fast change of topology, the limited storage space and energy of nodes, it is difficult to predict the future motion state of nodes based on historical data. However, link prediction requires that the motion of nodes must conform to a certain habitant rather than be completely random. In MANET, nodes can obtain their position through some devices, such as GPS, the topology state of the network can be predicted effectively according to the motion habitant of nodes [11]. Assuming that the nodes obey the Poisson distribution and move independently, thus the links break independently, which is fits the actual scene of transportation and ship navigation.

In this model, it is assumed that the maximum radius of a mobile's radio coverage is R, if a node is within the transmission range of another node, then the link composed of them is available, and one-way communication is not considered. In wireless communication, signal attenuation occurs in the transmission process, the received signal power is $P_r = P_t \times d^{-\alpha}$. Where, P_t is the power transmitted by the antenna, P_r is the power received, d represents the distance between nodes, α is the path loss index. In a time interval, the node moved straight with the fixed speed and direction until the next epoch. The epoch lengths are identically, independently distributed with mean $1/\lambda$, the speed and the direction at each epoch change randomly and independently. The speed of nodes at each time interval follows a normal distribution with mean μ and variance σ^2, the direction of movement at each epoch uniformly distributed over $[0,2\pi]$, fluctuation range is set to be smaller than π/2. In the two-dimensional plane, the moving nodes randomly choose the initial place and destination, R^i and $R(t)$ respectively denote the displacement vector of the node in epoch i and the total time t, $\vec{R}(t)=\sum_{1}^{N(t)} \vec{R}^i$. Where, N(t) denote the number of the epoch simulated in time t. According to the random movement model, the magnitude is equal to the distance from $\left(X(t_0),Y(t_0)\right)$ to $\left(X(t_0+t),Y(t_0+t)\right)$, which is approximately Rayleigh distribution with parameters of $\alpha=\left(\frac{2t}{\lambda}\right)\times\left(\mu^2+\sigma^2\right)$. Therefore, the movement characteristics of node can be described by the parameter { λ, μ, σ^2 }.Since $x(t)$ and $y(t)$ are not correlated, the joint probability density of the node is:

$$f_{x,y}(x,y)=\frac{1}{\pi\alpha}\exp\left[-\frac{\left(x^2+y^2\right)}{\alpha}\right] \tag{1}$$

It is assumed that nodes M and N move according to movement parameters (λ_M, μ_M, σ_M^2) and (λ_N, μ_N, σ_N^2). Since the movements of the two nodes are independent and uniformly, to investigate the joint motion distribution of two nodes, assuming that node N is fixed, where the motion of node N is equivalent to the opposite motion of node M [12]. In figure 1(a), nodes M and N arrive at positions M' and N' respectively after time t, and the distance between the two nodes is D; while fig 1(b) is equivalent to figure 1(a), random mobility vector of node M with respect to node N is obtained by fixing N, which is expressed as $R_{M,N}(t)=R_M(t)-R_N(t)$, and the amplitude is approximately Rayleigh distribution with parameters of $\alpha_{M,N}=\alpha_M+\alpha_N$.

3 Methods

Capacity optimization link predictive topology control is proposed to improve the network. The broken of any link will lead to the failure of the path, so the stability of the path depends on the stability of all the links in this path. During the non-breaking time, the most stable path refers to the path with the maximum capacity and minimum interference. Transmission mode is one of the main factors affecting outage capacity, interference is another major factor affecting network capacity. Therefore, link availability and interference needs to be analyzed to improve the network reliability, and objective function needs to be given to measure the topology performance.

3.1 Link availability analysis

In order to predict network topology changes, it is necessary to analyze link availability between nodes. Link availability refers to the probability that link exists at time t_0 and still exists at time t_0+t [13]. In order to describe the link connectivity of two nodes in a time period, the motion distribution of individual nodes should be analyzed first, then according to the magnitude and the direction of one moving node relative to another, the connection probability of node is calculated, which is the influence of motion on link availability [14].

At time t, relates the distance between two nodes to the link availability. $\vec{D}_{\mathrm{M,N}}(t)$ can be expressed as the sum of random mobility vector $\vec{R}(t)$ and a constant vector $\vec{c}$. The relationships among these variables are depicted in Figure 2. The result is exactly the solution of the general problem of finding the sum of a uniformly distributed Raleigh vector and a constant, the complete derivation can be found in Reference [15]. Break down $\vec{R}(t)$ into the X and Y components of the normal distribution, add them to x_C and y_C components of the initial distance, and the probability distribution function of the link available time is given by the following expression:

$$
\begin{aligned}
f_{D_{M,N},\theta_D}(d,\theta) &= f_{x,y}(x,y)\begin{pmatrix}\cos\theta & -d\sin\theta \\ \sin\theta & d\cos\theta\end{pmatrix} = \frac{d}{\pi\alpha_{M,N}}\exp\left[-\frac{(d\cos\theta - x_C)^2 + (d\sin\theta - y_C)^2}{\alpha_{M,N}}\right] \\
&= \frac{d}{\pi\alpha_{M,N}}\exp\left[-\frac{(d^2+C^2)\text{-}2d(x_c\cos\theta + y_c\sin\theta)}{\alpha_{M,N}}\right]
\end{aligned}
\qquad (2)
$$

Where $\alpha_{M,N} = \alpha_M + \alpha_N = \left(\frac{2t}{\lambda_M}\right)\times(\mu_M^2+\sigma_M^2) + \left(\frac{2t}{\lambda_N}\right)\times(\mu_N^2+\sigma_N^2)$.

When node N moves to the limit of the communication range of node M, in the triangle, according to the law of cosines, we can figure out the angle between line M’ and N’ and the X-axis is $\theta_D = \theta_Z + \theta_{Z,D} = \theta_Z + \arcsin\left\{\frac{C}{R}\sin\left[\theta_Z + (180^{\circ}\text{-}\theta_C)\right]\right\}$. Link availability $A_{M,\mathrm{N}}$ is denoted as the average probability distribution of link connectivity between node M and N, which is the probability $P_{M,N}$ that $D_{M,\mathrm{N}}(t) \le R$, thus link availability can be expressed as:

$$A_{M,N}(t)=P_{M,N}\left[D_{M,N}(t_0+t) \le R \mid D_{M,N}(t_0) \le R\right]=\int_0^R \int_0^{2\pi} f_{D_{\mathrm{M,N}},\theta_D}(d,\theta)\, d\theta\, dd$$

$$=\frac{d}{\pi\alpha_{M,N}} \int_0^R \int_0^{2\pi} \exp\left[-\frac{\left(d^2+C^2\right)+2d\left(C\cos\theta_C \cos\theta + C\sin\theta_C \sin\theta\right)}{\alpha_{M,N}}\right] d\theta\, dd \qquad (3)$$

Where, the distance $D_{M,N}(t)$ is greater than or equal to 0. When $R \to \infty$, link availability reaches its maximum value.

3.2 Objective Function

The objective function is the capacity while network is connected. In the transmission, signal is attenuated from one terminal to another, therefore each terminal can only communicate directly with the others closed to it. If the nodes are far apart, middle terminal is required as a router to forward the information, until the destination receives the message. Thus, direct transmission, two-hop transmission and cooperative transmission modes will be considered [16], the analysis of topological properties in this paper is divided into three aspects.

1) Direct Transmission

According to the initial position, when the distance between source S and destination D is less than effective communication radius R, the two nodes become adjacent nodes. The source S is located in the center of the circular, the destination D should be located in the effective communication range of source, and traditional point-to-point direct transmission can be used. Signal-to-Noise Ratio (SNR) of the received signal is $\gamma_{S,D}(t)=\frac{P_t \times d_{S,D}^{-\alpha}(t)}{N_0}$. Outage capacity is used to reflect the link rate, which is the link capacity obtained under a small interrupt link probability ε, the outage capacity of direct transmission is [17]:

$$C_{DT}^{\varepsilon}(t)=B\log_2\left(1+\frac{1.5\varepsilon \times \gamma_{S,D}(t)}{0.2-\varepsilon}\right) \qquad (4)$$

To ensure the quality of transmission, interference of the path should be the sum of all participating nodes covered in the transmission. Since only two nodes participate in direct transmission process, the interfered nodes include the nodes covered by source and destination:

$$I_{DT}=I(S) \cup I(D) \qquad (5)$$

Due to the mobility of nodes, motion state of nodes will affect link connectivity and system stability, which will affect network capacity. The relative motion speed between source and terminal is denoted as $V_{S,D}$, which can be expressed as the effective value of vector sum of the random moving velocity vectors V_S and $-V_D$. When destination D moves to the limit of the communication range boundary of source S, according to the law of cosines, relative motion distance between nodes is $Z=R\times\frac{\sin\left[180^\circ-\theta_Z-\left(180^\circ\text{-}\theta_C\right)-\theta_{Z,D}\right]}{\sin\left[\theta_Z+\left(180^\circ\text{-}\theta_C\right)\right]}$, communication time is $T_{S,D}=\frac{Z_{S,D}}{\left|V_{S,D}\right|}$. Then the availability of a link can be extended to the path. Since the change of link connectivity is nonlinear in MANET, link is independent of each other. When the route is about to fail, other routes should be selected in advance according to link availability, $T_P=T_{S,D}\times A_{S,D}\left(t\right)$.

Link availability, rate and interference are three main factors that determine network capacity. During communication time, network capacity can be optimized by increasing link availability and rate, and reducing interference. The traffic between nodes in communication time can be obtained by integrating the outage capacity, therefore, the objective function is:

$$g_{DT}\left(t\right)=\int_0^{T_{S,D}\times A_{DT}(t)}\frac{C_{DT}^{\varepsilon}\left(t\right)}{I_{DT}}dt \tag{6}$$

2) Two-hop Transmission

Two -hop transmission attempts to improve the link quality by replacing its long distance direct transmission with two-hop transmission, it takes two time slots. In the first slot, data is transmitted from the source to the relay, in the second slot, it is transmitted to the destination, as shown in Figure 3. The SNR of the signals received by relay from the source, and by the destination from the relay are $\gamma_{S,R}\left(t\right)=\frac{P_t\times d_{S,R}^{-\alpha}\left(t\right)}{N_0}$ and $\gamma_{R,D}\left(t\right)=\frac{P_t\times d_{R,D}^{-\alpha}\left(t\right)}{N_0}$, respectively. The maximum instantaneous mutual information of the two-hop transmission link is:

$$\begin{aligned}C_{MT}^{\varepsilon}\left(t\right)&=\frac{1}{2}\min\left\{C_{S,R},C_{R,D}\right\}\\&=\frac{1}{2}\min\left\{B\log_2\left(1+\frac{1.5\varepsilon\times\gamma_{S,R}\left(t\right)}{0.2-\varepsilon}\right),B\log_2\left(1+\frac{1.5\varepsilon\times\gamma_{R,D}\left(t\right)}{0.2-\varepsilon}\right)\right\}\end{aligned} \tag{7}$$

According to the interference model, all covered nodes must remain silent while the node is transmitting the information, thus the interference of a link can be defined as the number of all the surrounding nodes covered during link transmission. Each hop of two-hop transmission has its own interference, but it occurs at different time slots, and its interference are $I_{S,R}=I(S)\cup I(R)$ and $I_{R,D}=I(R)\cup I(D)$, respectively. Since the transmission of these two hops cannot occur at the same time, the interference of two-hop link is determined by the larger one:

$$I_{MT}=\max\left(I_{S,R},I_{R,D}\right) \qquad (8)$$

The relative motion velocity between source and relay is denoted as $V_{S,R}$, the relative velocity between relay and terminal is $V_{R,D}$, the link communication time are $T_{S,R}=\frac{Z_{S,R}}{\left|V_{S,R}\right|}$ and $T_{R,D}=\frac{Z_{R,D}}{\left|V_{R,D}\right|}$ respectively. The availability of a link can be extended to the path, since path availability is related to the availability of links from source to relay and relay to destination, the predicted path communication time is $T_P=\min\left(T_{S,R}\times A_{S,R}(t),T_{R,D}\times A_{R,D}(t)\right)$.

Therefore, the objective function is:

$$g_{MT}(t)=\int_0^{T_P}\frac{C_{MT}^{\varepsilon}(t)}{I_{MT}}dt \qquad (9)$$

3) Cooperative Transmission

The traditional direct transmission only uses signals from source to destination, while cooperative transmission is able to decode the combined signals from source and relay received at destination to obtain the better SNR. The DF scheme with only one relay is adopted for cooperative transmission, that is, the relay decodes the received source signals, then recodes and transmit them to the destination. Maximum ratio combining technique (MRC) [18] could be used to decode the two signals. Its maximum instantaneous mutual information is:

$$\begin{aligned}C_{CT}^{\varepsilon}(t)&=\frac{1}{2}\min\left\{C_{S,R},C_{MRC}\right\}\\&=\frac{1}{2}\min\left\{B\log_2\left(1+\frac{1.5\varepsilon\times\gamma_{S,R}(t)}{0.2-\varepsilon}\right),B\log_2\left(1+\frac{1.5\varepsilon\times\left(\gamma_{R,D}(t)+\gamma_{R,D}(t)\right)}{0.2-\varepsilon}\right)\right\}\end{aligned} \qquad (10)$$

The interference of cooperative transmission is more complex than the other two transmission modes, to ensure the success of transmission, the interference of path should be the sum of coverage of all participating nodes [19]. In the broadcast stage, not only the neighbors covered by source, but also the neighbors covered by relay and destination need to be silent. Thus the interference of cooperative transmission may be more serious, which will reduce the number of transmission nodes and capacity. The interfered nodes include the coverage of source, relay and destination, the interference set of cooperative transmission is:

$$I_{CT}=I(S)\cup I(R)\cup I(D) \qquad (11)$$

Since cooperative transmission requires constant communication, the predicted communication time is

$T_P = \min\left(T_{S,R} \times A_{S,R}\left(t\right), T_{R,D} \times A_{R,D}\left(t\right), T_{S,D} \times A_{S,D}\left(t\right)\right)$. Therefore, the objective function is:

$$g_{CT}\left(t\right) = \int_0^{T_P} \frac{C_{CT}^{\varepsilon}\left(t\right)}{I_{CT}} dt \qquad (12)$$

This system choose the appropriate transmission mode and relay with minimal interference to optimize link capacity [20]. Cooperative transmission does not have a higher rate than direct and two-hop transmission, because the performance of transmission also depends on the relative position of relay. If there is no relay capable of achieving higher interrupt capacity, direct or two-hop transmission should be used. In MANET, the objective function of the path is:

$$g\left(j\right) = \max\left(g_{DT}, g_{MT}\left(j\right), g_{CT}\left(j\right)\right) \qquad (13)$$

Therefore, when the relay set $v_{S,D} = \{1, 2, ..., m\}$ exists within the communication range of source and destination, the objective function for each relay can be calculated, using its maximum value can determine the transmission mode and relay that can optimize network capacity. Since objective function is decomposed into multiple independent sub-targets, parallel computing can be used to speed up the computation.

$$j = \arg\max_{j \in v_j} g\left(j\right), \text{ for all } j \in v_{S,D} \qquad (14)$$

4 Results and discussion

In this section, MATLAB is used to simulate the dynamic topology reconstruction performance of random topology model. Wireless channels follow the Rayleigh distribution of slow fading, and only the effect of network topology on capacity is concerned. In the simulation, 30 nodes randomly distributed over 1000x1000 square meter area. Nodes move according to the random-walk-based mobility model, and generates a velocity for its next movement randomly. Nodes periodically exchanges information with neighbors, the effective transmission area is circle, the transmission range of each mobile node is R. Figure 4(a) shows the initial position of each nodes, Figure 4(b) is the position of nodes when time is 100s.

Figure 5 compares the topological performance of the COLP with reconstruction mechanism with that without reconstruction mechanism and direct transmission. The maximum speed of movement is 1m/s, and the path loss index is set as 3.5. Simulation results show that topology performance of COLP is higher than other systems, and performance optimization comes from the joint design of reconstruction mechanism and link prediction in topology algorithm. Simulation results show that when the coverage radius is smaller than 100m, the larger the coverage radius is, the more adjacent nodes are in the simulation area, and the larger the outage capacity is. When the coverage radius is greater than 100m, topological properties deteriorates instead with the increase of coverage radius, this is because the large coverage radius not only increase the capacity, but also increase the interference accordingly. In this case, direct and two-hop transmission perform better than cooperative schemes, and reduce the energy consumption. When the coverage is 100m, the topological performance of COLP system is better, and improved by 17% over that of direct transmission system.

Due to the mobility, the link availability is less than 1, thus there is a mismatch between the predicted curve and the practical curve, see Figure 6. Although prediction error is inevitable, they have the same change trend, which means that the prediction model can predict communication duration and capacity. Since node is not allowed to move out of the given space, in the simulation, the higher the speed, the easier the link is to break. However, low node activity can increase the accuracy of link prediction, and prediction error is smaller when angle of motion was π than when it was π/2, in the direction of motion, the larger the motion angle fluctuation is, the closer it is to the random walking movement model, and the relative motion speed of the two nodes is small, the link will connected for a long time.

Figure 7 is a comparison of the topology performance of the COLP system and the prediction under different path loss index. The loss factor also affects the optimal transmission range of nodes, as loss coefficients increase, the optimal transmission range and the prediction error becomes smaller. When path loss index is 3.5 and transmission range is 100, the communication time and topology effect are improved with the increase of the average link length, as shown in Table 1. The prediction accuracy of the communication time can reach 99%, average error of less than one second, because when there are multiple relay available in the system, it tends to choose the relay with a low speed relative to source and the destination, 7 nodes with low relative motion are selected, while only one node with high relative motion is selected, which increases the stability of the link and the accuracy of the prediction.

When the interrupt probability increases, the topological performance of the system is improved, as shown in Figure 8. When path loss index is 3.5, the optimal transmission range increases from 79m to 113m, as shown in Table 2. Due to the interference, the greater path loss index is, the difference value of optimal transmission range is smaller when the interrupt probability are 10^{-4} and 10^{-3} respectively.

Table 1. Performance versus other mobility models: 1000m×1000m, α=3.5

	R=50	R=100	R=150	R=200
communication time	58.375	92.16	90.23	94.6
$T_p \times L(T_p)$	51.06	93.08	89.66	93.8
High mobility relay	0	0	1	13
Low mobility relay	0	4	7	18
Average path length	1.5	2.2	1.825	1.88

Table 2. Coverage radius from higher topology performance for a given (ε,α) pair

	α=2.5	α=3	α=3.5	α=4
$\varepsilon = 10^{-4}$	160m	133m	79m	78m
$\varepsilon = 10^{-3}$	199m	160m	113m	101m

5 Conclusion

In MANET, random movement of nodes results in dynamic change of network topology, this paper propose a predictive topology control mechanism of capacity optimization for highly dynamic wireless self-organizing networks, and the connectivity probability of the whole route can be obtained by link availability. Theoretically, cooperative transmission can achieve higher network capacity than direct transmission, however, it does not necessarily have a higher rate than direct and two-hop transmission, because the performance of cooperative transmission also depends on the relative location of the relay. If there is no relay that can reach the higher interrupt capacity, direct transmission should be used. Interference of cooperative transmission is more serious, which will reduce the number of nodes transmitted simultaneously in the network. Therefore, the performance gain obtained in this algorithm is actually derived from the joint design of retaining optimal transmission mode, more reliable and stable relay node, and minimum interference path in topology control. This algorithm significantly reduces data storage capacity by obtaining the location information of nodes within a certain time interval, computational time and complexity are reduced to adapt to the rapidly changing network structure by abandoning the multi-hop mode and iterative algorithm, network capacity is improved by optimizing topology for mobile AD hoc networks without central fixed infrastructure, and unnecessary overhead of frequent information exchange is avoided by predicting communication time of link through the motion law and trajectory of nodes. The theory proposed in this paper not only provides a reference for MANET, but also can be used as an effective complement to the integrated satellite, sky, terrestrial and ocean network structure.

Error of this prediction model is affected by mobility and wireless communication conditions, so there is no perfect prediction technique with 100% accuracy. Although the prediction error is inevitable, this system can accurately predict the existence time and the capacity of link, generate a reliable and stable network topology, achieve higher network capacity compared with fixed topology configuration. However, due to lack of global information, this paper use interference of the initial path, learning algorithm can be used to predict the degree of interference in future research. Communication quality and network coverage will be affected by obstacles in wireless transmission path, so multi-hop topology can be extended to enhance network connectivity. Message exchange can run out of nodes' power, and a more energy-efficient topology model should be considered in the future.

List of Abbreviations

MANET: Mobile Ad hoc Network;

COLP: Capacity optimization link predictive.

MRC: Maximum ratio combining technique.

SNR: Signal-to-Noise Ratio

Declarations

Availability of data and materials

The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

CR provided the idea of algorithm, carried out the simulations, arranged the architecture and drafted the manuscript. SZ and SH supervised the work and revised the manuscript. Both authors read and approved the final manuscript.

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Publisher’s Note

Figure Legends

Figure 1 Joint mobility transformation.

(a) Joint node transformation: The adjacent nodes start at position M and N with distance C. During time t, nodes travel $R_M(t)$ and $R_N(t)$ along angles θ_M and θ_N, and then arrive at points M 'and N', respectively, the distance is D.

(b) Single node mobility transformation: Assuming that node N is fixed and is the same as endpoint N'. Move M distance $R_M(t)$ from its initial position along angle θ_M. Motion of N is equivalent to the opposite motion of M, then move M distance $-R_N(t)$ along angles $-\theta_N$, it reaches M ', and the distance is still D. Figure (b) is equivalent to (a).

Fig 2 Ad hoc link availability model (Direct Transmission).

The two nodes become adjacent nodes when the distance between source and destination is less than effective communication radius R. Fix source at the point M which is the center of circle, the destination should be located in this circular area. The initial distance of the nodes is C, and the angle is θ_C. After the destination moves $Z=\vec{R}(t)$ along angle θ_Z from N to N 'with respect to the source, it reaches the edge of the receiving distance R. The relative moving distance can be obtained by the relative moving speed and angle between the mobile nodes, and then $\vec{D}_{M,N}(t)$ can be represented as the sum of random mobility vector $\vec{R}(t)$ and the constant vector $\vec{C}$ at every moment, and the angle of is θ_D.

Fig 3. Ad hoc link availability model (Two-hop Transmission).

Two-hop transmission attempts to improve the link quality by replacing its long distance direct transmission with two hop transmission. Fix relay at the point R which is the center of circle, the source and destination should be located in this circular area. When the source moves $Z_{S,R}$ along from S to S ' or destination moves $Z_{R,D}$ along from D to D ' with respect to the relay, the path will be broken. Therefore, available communication time can be predicted with the relative moving distance obtained by the relative moving speed and angle between the two pairs of mobile nodes.

Fig 4. The position of 30 nodes in a 1000×1000m^2area. (a) t=0s. (b) t=100s.

(a) t=0s: The initial position of each nodes. In the simulation, 30 nodes randomly distributed over 1000×1000 square meter area.

(b) t=100s: The position of nodes when time is 100s. Nodes move according to the random-walk-based mobility model, at each interval, they generate velocity and angle for their next movement randomly in the range of maximum speed and angle, respectively.

Fig 5. Outage capacity performance comparison.

Outage capacity topological performance of the reconstruction COLP mechanism, system without reconstruction, and direct transmission are all influenced by communication radius. 30 nodes distributed randomly, move with the maximum speed 1m/s, and the path loss index is set as 3.5. The objective function of COLP is higher than other mechanism, and performance of cooperative schemes are not always better than direct or two-hop transmission schemes, due to the affection of interference radius.

Fig 6. Objective function versus maximum movement speed.

Objective function of the COLP mechanism is effected by maximum movement speed and motion angle. With the same motion angle, the higher the speed, the easier the link is to break. In the direction of motion, the larger the motion angle fluctuation is, the small the relative motion speed of the two nodes is, and the smaller the prediction error is. Although there is a mismatch between the predicted curve and practical curve, they have the same change trend, and they are close.

Fig 7. Objective function versus path loss index.

The topology performance of the COLP mechanism is influenced by path loss index under different communication radius, and the loss factor also affects the optimal transmission range of nodes. There are multiple relay available in the system with a large communication radius, means the system has more options and tends to choose a relay with appropriate position and low speed relative to the source and the destination, which can increases the stability of the link and the accuracy of the prediction.

Fig 8. Objective function versus interrupt probability.

The topology performance of the COLP mechanism is influenced by interrupt probability under different communication radius. The topological performance of the system is improved with the increase of interrupt probability. And predicted curve and practical curve are close to each other in both the interrupt probability are 10^{-4} and 10^{-3}.

Figures

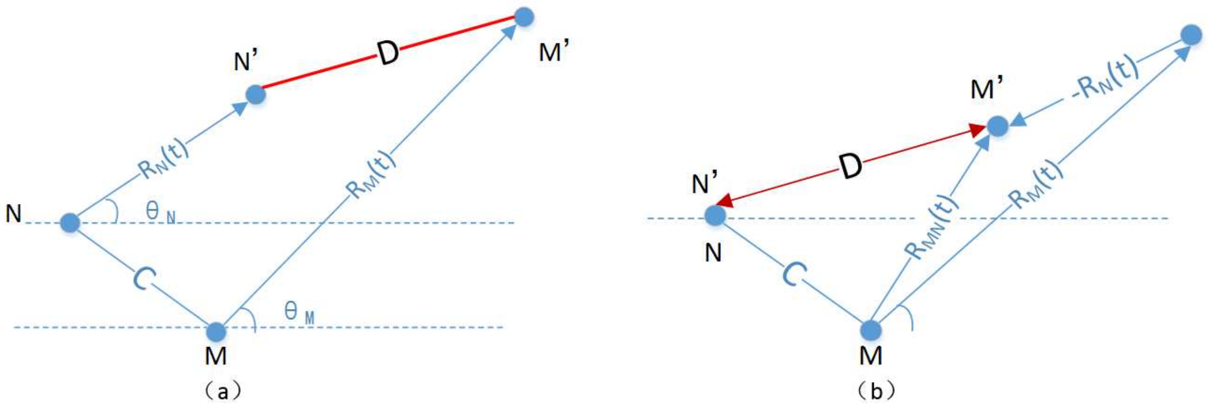


Fig 1. Joint mobility transformation. (a) Joint nodes transformation. (b) Single node mobility transformation.

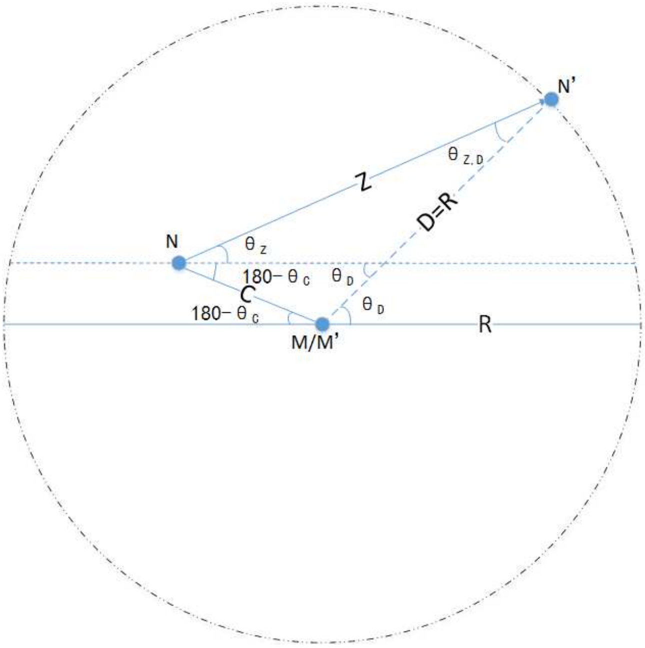


Fig 2. Ad hoc link availability model (Direct Transmission).

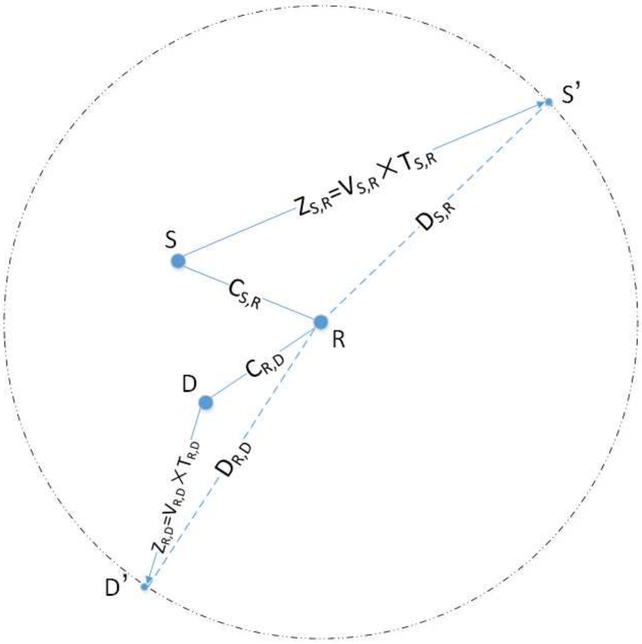
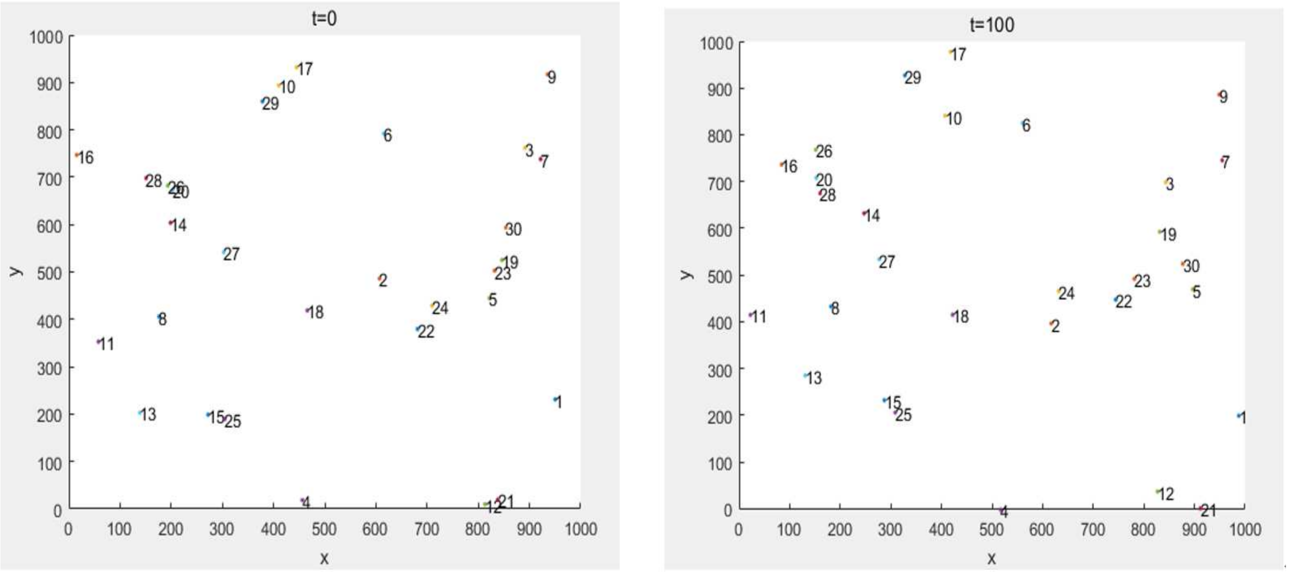


Fig 3. Ad hoc link availability model (Two-hop Transmission).



(a) (b)

Fig 4. The position of 30 nodes in a 1000×1000 m^2 area. (a) t=0s. (b) t=100s.

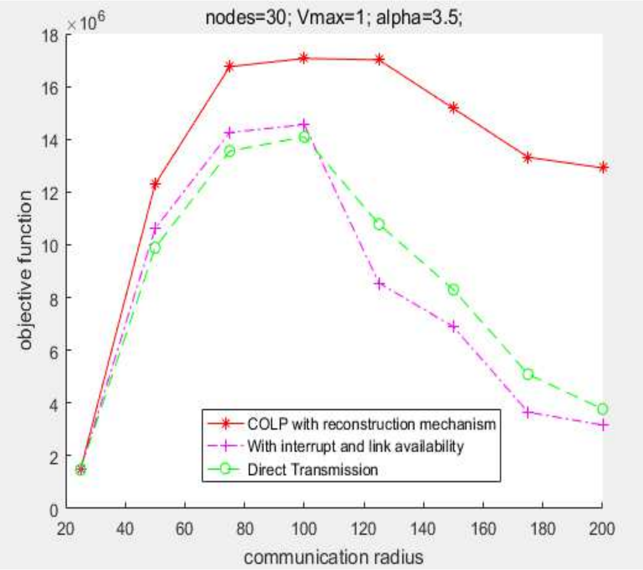


Fig 5. Outage capacity performance comparison.

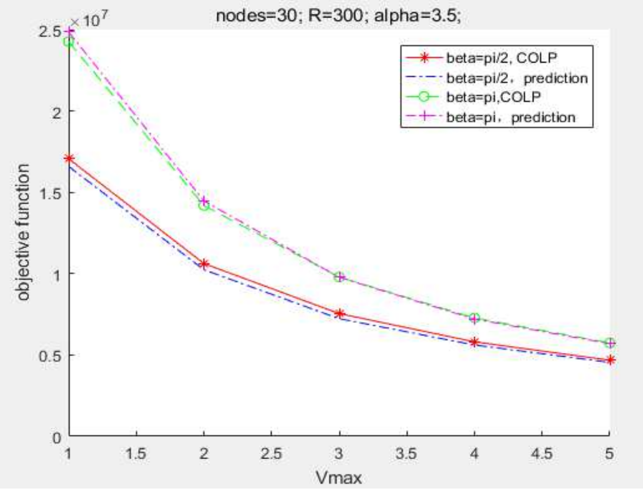


Fig 6. Objective function versus maximum movement speed.

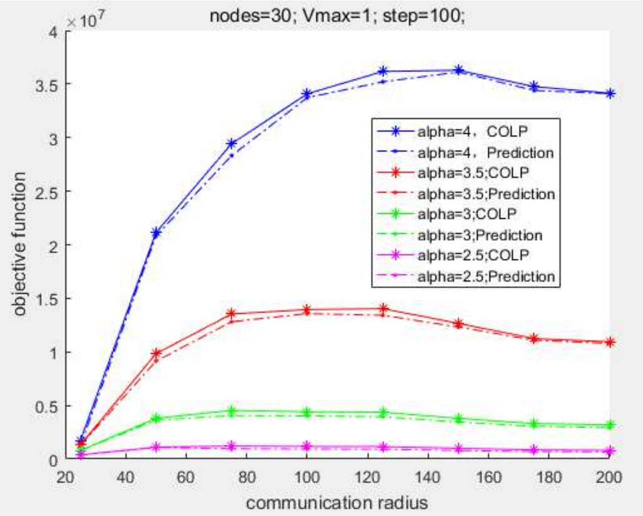


Fig 7. Objective function versus path loss index.

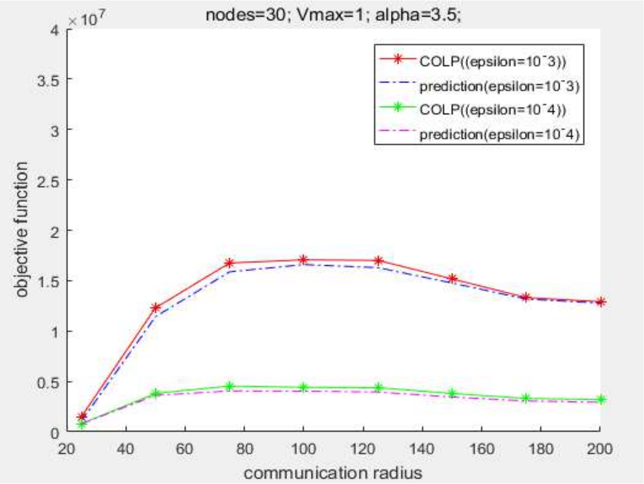


Fig 8. Objective function versus interrupt probability.

Figures

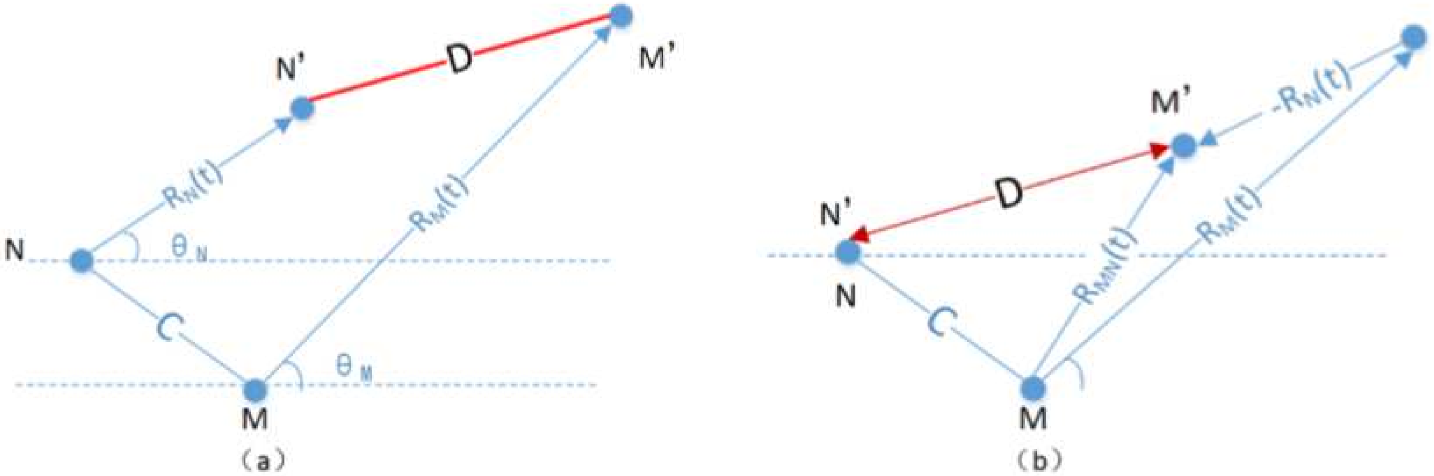


Figure 1

Joint mobility transformation. (a) Joint nodes transformation. (b) Single node mobility transformation.

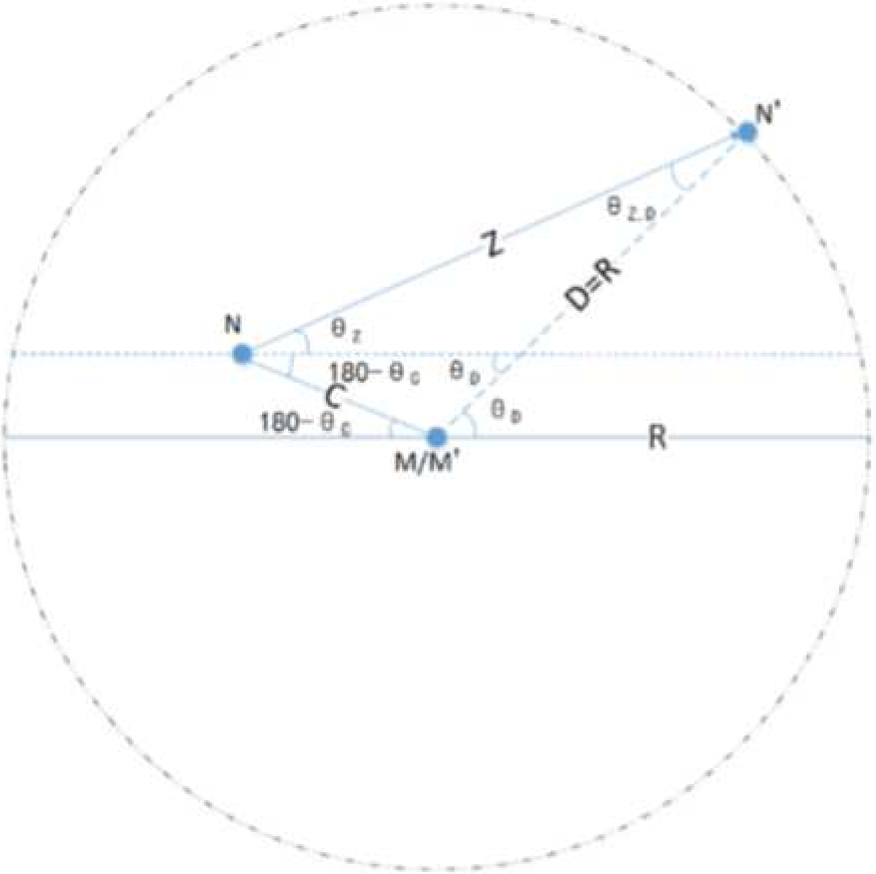


Figure 2

Ad hoc link availability model (Direct Transmission).

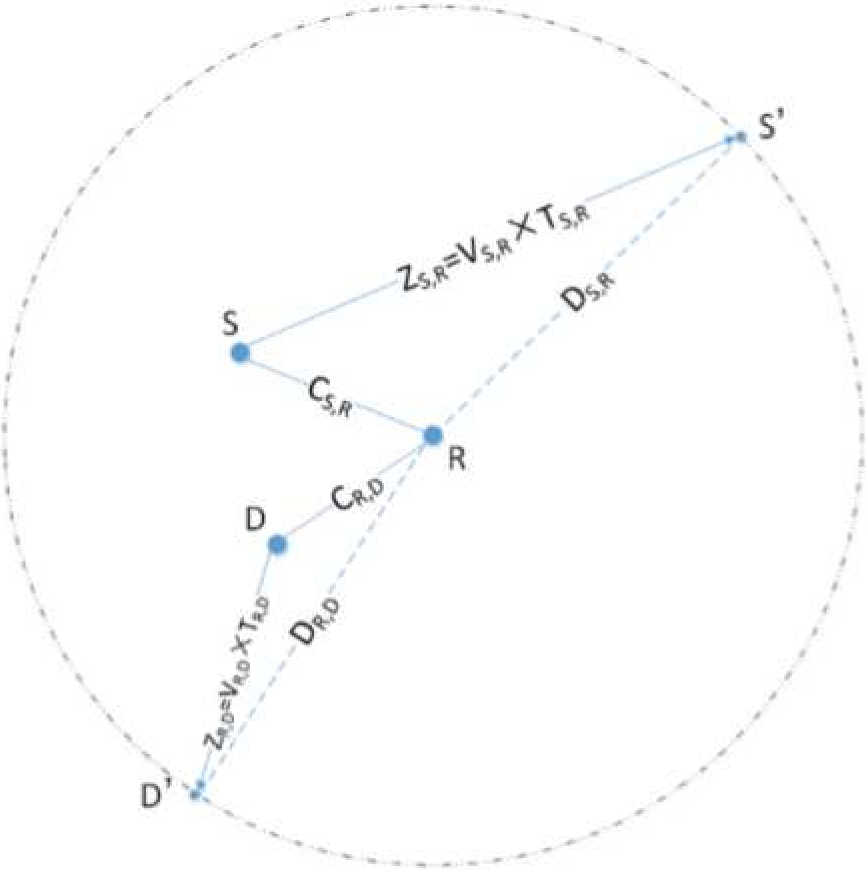
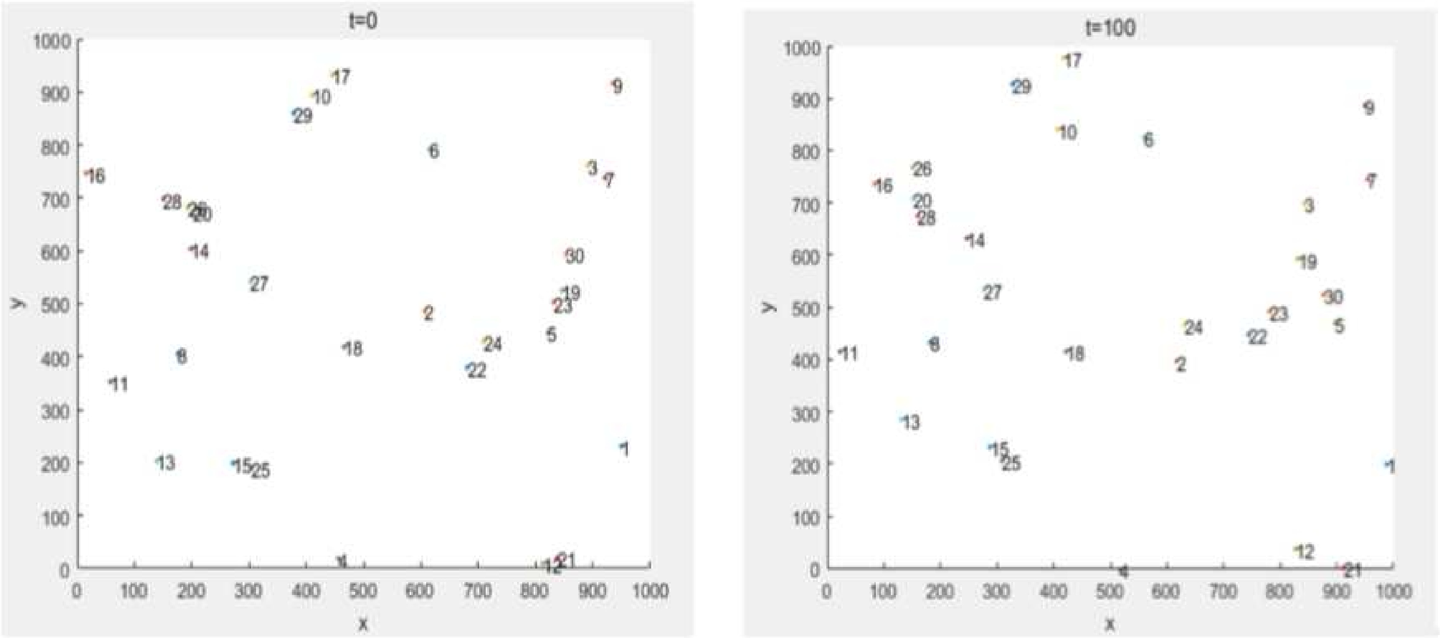


Figure 3

Ad hoc link availability model (Two-hop Transmission).



(a) (b)

Figure 4

The position of 30 nodes in a 1000×1000 □2 area. (a) t=0s. (b) t=100s.

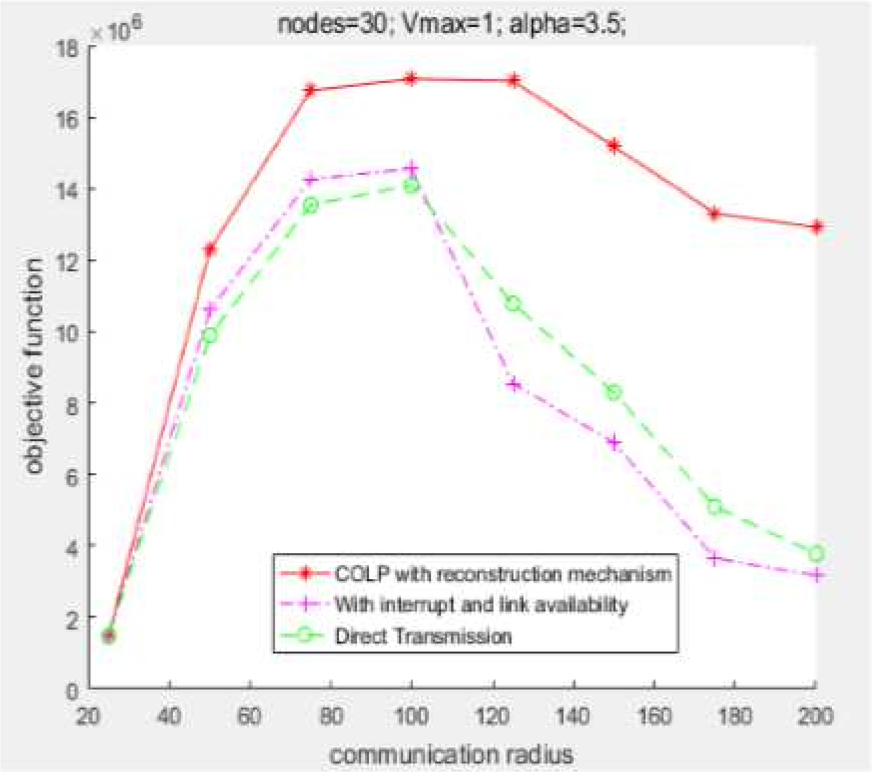


Figure 5

Outage capacity performance comparison.

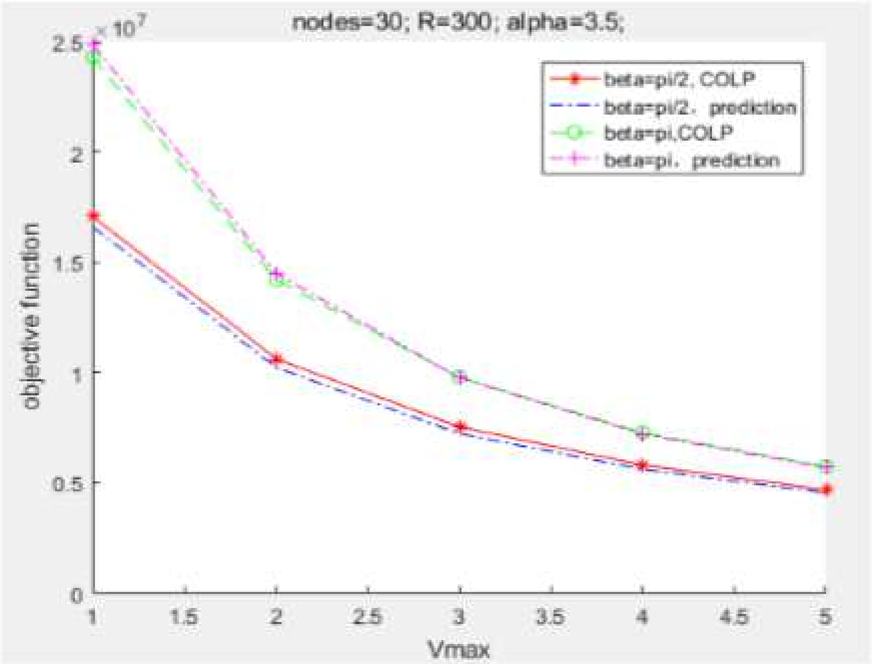


Figure 6

Objective function versus maximum movement speed.

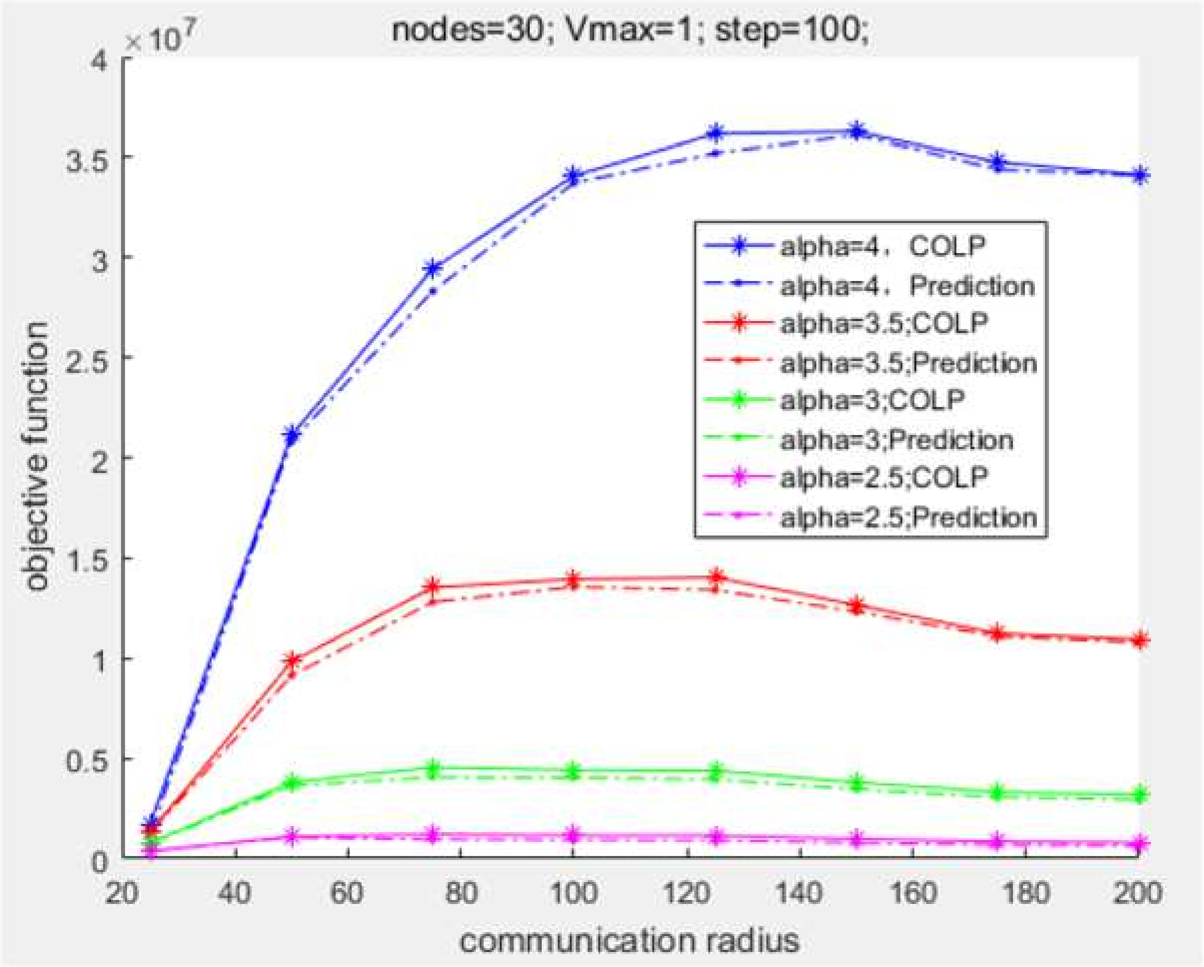


Figure 7

Objective function versus path loss index.

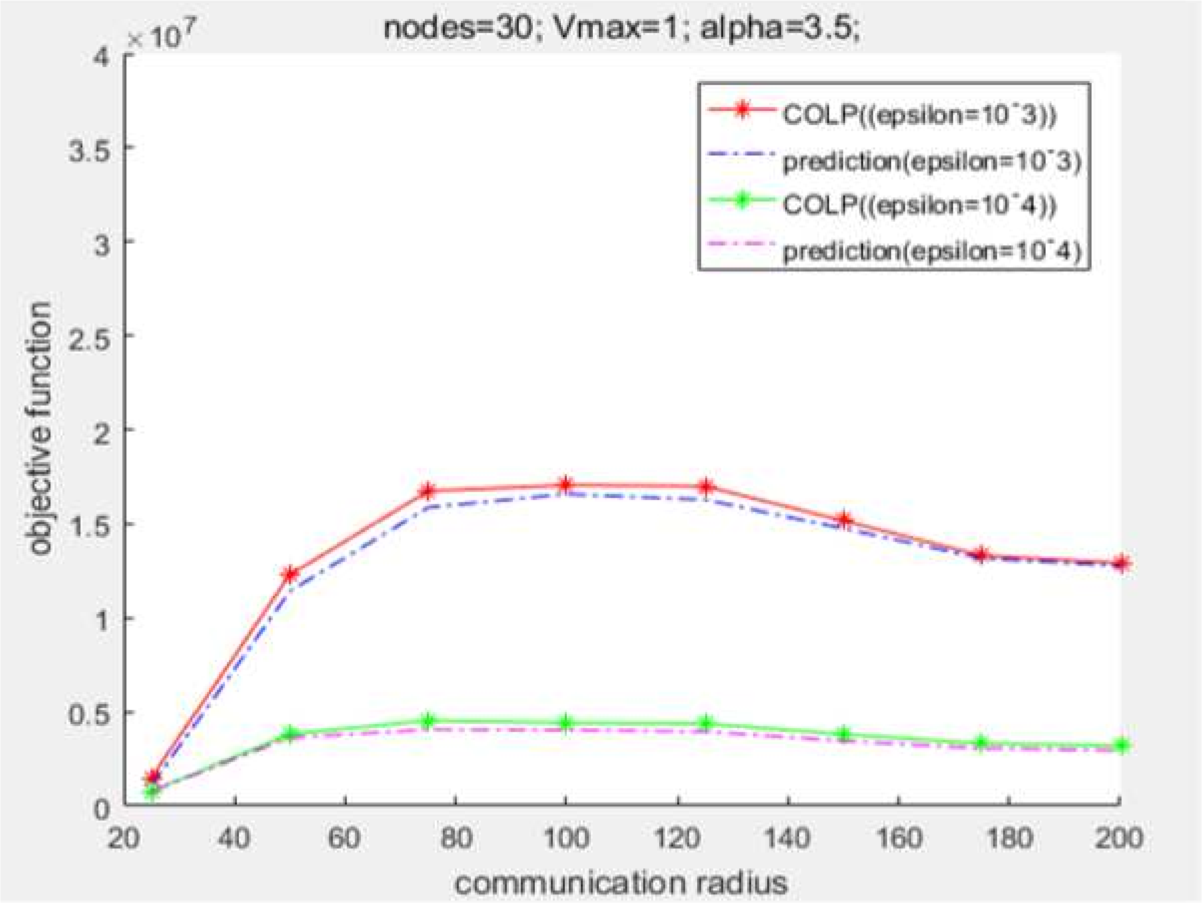


Figure 8

Objective function versus interrupt probability.