

Analysis of the Impact of Emergencies on Traffic Capacity under BA Network and the Application of the Static Local Routing Strategy

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Abstract. Emergencies in cities, which happen from time to time, greatly affect the normal operation of the traffic network, and even cause traffic congestions. Combined with the impact of the emergencies on the node transmitting capacity, a dynamic model of traffic network was established on the basis of the scale-free BA network. In the model, the impact of the emergencies on the network traffic was analyzed, and the optimal parameters under different levels of emergencies were obtained by applying the static local routing strategy to the emergency models. The simulation results showed that optimized routing strategy improved the generation rate of the network critical information packets, making the distribution of nodes more balanced, the path finding better, and the average transmission time less, so that the congestion of the node data packets was effectively solved. As a result, the impact of the emergencies on the network transportation was reduced and the traffic congestion caused by emergencies was effectively alleviated.

Keywords: Urban traffic, static local routing strategy, BA network model, emergencies.

1. Introduction

The sharp increase of the automobiles greatly intensifies the load of the traffic network. The traffic congestions can be solved by optimizing the distribution of the traffic network, increasing the traffic capacity, i.e. perfecting the three-dimensional transportation, increasing the lanes, or strengthening the construction of parking lots. However, the costs of these methods are far too high. Consequently, a model can be established to show the interior operation mechanism. Effective traffic routing strategy can be put forward through searching for the inherent law of the network. This is a more economical and timesaving way to solve the traffic congestion.

In the early 1960s, Erdos and Renyi introduced the famous ER random graph model, which established the network models by linking two nodes randomly through the probability p , and became the basic theory of the study of the complex network [1]. Watts and Strogatz, focusing on the evolution process from static network to random dynamic network, introduced the small-world model with both short average path lengths and high clustering [2]. Barabasi and Albert put forward BA model in which the degree distributions conformed with power-law distributions [3]. Its main feature is the heteroskedastic, i.e. the imbalance of degree distribution. Nodes with higher degree transmit the vast majority of data flows and play a decisive role in the network. More and more scholars study the network congestions and the phase change process on the basis of BA network. Capocci et al. simulated the structure and data transmission process by BA network [4]. Moreno et al. considered the heteroskedastic and simulated the transmission process of the traffic flows [5]. Reducing the amount of network control nodes by controlling the nodes with higher degree, Holme P et al. obtained a result which was almost equal to that of controlling all the nodes in the network, and improved the network transmission performance [6].

Whether the routing strategy is good or bad will determine the network performance. Therefore, the research on the optimization of the routing strategies to maximize the handling capacity has become a hot issue in recent years. Aiming at the cluster deficiency of the nodes in the shortest-path routing strategy, Wang Wenxu et al. put forward a routing strategy, which changed the routing strategy by setting up the parameter α , based on local information [7]. In the strategy, the data packet needs only the degree value of the adjacent node when choosing the nodes. The simulation results

showed that the strategy helped the data packets avoid the nodes with higher degree, reducing the possibility of causing network congestions. Valverdel et al. introduced a routing strategy which made the data packets acquire the local visibility of the whole network information via local information [8]. Yan Gang et al. proposed the "efficient routing" strategy which enabled the data packets to avoid the nodes with congestions in the original network [9].

At present, the urban traffic network is usually in the state of supersaturation. If emergencies happen, the traffic will be paralyzed easily. Vehicles and pedestrians will be caught in a dilemma, causing the rescue operation very difficult. As a result, research on the evacuation strategy under theoretical method can not only avoid the impact caused by the emergencies but also offer a practical guide for evacuating vehicles and pedestrians. In the research, a traffic network model was established on the basis of the unexpected communication capability decrease through BA network, and the static local routing strategy with initiative selection preference was applied in the analogue simulation

under the circumstance of emergencies to get the optimal preference parameters. The simulation results showed that the optimized static routing strategy increased effectively the generation rate of critical network information packets under different emergencies, making the data packets distribution more balanced, the transmission time less, and reducing the impact of the emergencies on the network transportation.

2. Scale-Free BA Network Model

The modeling of the network is as follows: let N be the number of the nodes of a fully-connected network, the number of the nodes increases one by one with the time step, the new nodes chooses the nodes of the original network to connect according to the probability value of Formula 1. It is observed that the connection probability of the nodes in the original network is in direct proportion to the degree of the nodes.

$$P_{l \rightarrow i} = \frac{k_i^\alpha}{\sum_j k_j^\alpha} \quad (1)$$

k_i is the degree of node i , to sum all the adjacent node of node l . Given enough evolution time, the scale-free network $\gamma = 3$ is obtained, and the degree distribution is in accordance with the power-law distribution $p(k) \sim k^{-3}$, the mean distance of the network $D \sim \ln N / \ln \ln N$, clustering coefficient $C \sim \ln 2N / N$ [10]. The network, now with the features of being scale-free and having the shortest average transmission distance, can be used to simulate the traffic network.

3. Traffic Network Modeling under Emergencies

The network modeling is as follows: with the passing of each time step, the network generates randomly R new data packets to be transmitted, the new data packets select randomly the nodes to connect to the network and choose randomly the destination nodes. Define the transmission capability as C_i , and $C_i = k_i$, k_i is the degree of node i , i.e. node i transmits at most k_i data packets to its adjacent node in a unit time with the application of FIFO strategy. With the passing of a time step, the data packets search all the adjacent nodes within the node processing capability. If there is a destination node, the node will forward the data packet to the destination node and then delete the data packet from the network. If not, the data packet will be forwarded randomly to a neighboring node. The emergencies are defined as follows: the decrease of the processing capability of the node with the highest degree of the original network, ranging in 10% decrease, 20% decrease, 30% decrease, 40% decrease, 50% decrease according to the severity of the emergencies.

R_c , the generation rate of the critical information, which is used as the evaluation indicator, is defined as follows: the maximum number of the data packets that the network allows to be connected in a time step on the premise that the total number of the data packets is in a stable state. When the newly generated data packets are less than or equal to R_c in every time step, the total number of the

data packets in the network will tend to be stable if given sufficient evolution. At this moment, the network is running in free stream. When the newly generated random data packets are greater than R_c in every time step, the total number of the data packets in the network will grow continuously. Then, the network will be jammed with the deepening of the network. The following conclusions can be drawn: when R_c is changing from free flow to congestion, the network can still use the following order parameter to describe the position the phase transformation point [10]:

$$\eta(R) = \lim_{t \rightarrow \infty} \frac{C \langle \Delta N_p \rangle}{R \Delta t} \quad (2)$$

$\Delta N_p = N_p(t + \Delta t) - N_p(t)$ indicates the variable quantity of the amount of all the data packets of the network during the time Δt . $N_p(t)$ indicates the amount of the data packets at time t . When the order parameter $\eta = 0$, the growth rate of the data packets is 0, and the network is in free flow; when $\eta > 0$, the growth rate of the data packets is greater than 0, and the network is evolving to congestion.

4. The Changing of the Network Traffic under Emergencies

In this section, simulation of the traffic network based on BA network and under emergencies is carried out. The parameters are set as follows: the node number $N = 1000$, the average degree $\langle k \rangle = 6$. When no emergencies occur, i.e. $\varepsilon = 0\%$, Fig. 1 shows that when $R \leq 32$, given sufficient evolution time, the amount of the data packets is in a stable state in the end, and no congestion happen. In this evolution process, the majority of the data packets cannot find their destination in the initial stage of the evolution because the data packets need some time to move from the starting point to the destination node, so the increment of the amount of the data packets is rather big. With the evolution going deeper, the data packets approach or have arrived at the destination node. Since those data packets that have arrived at the destination have been deleted, the increment obviously slow down. With the evolution going deeper and deeper, when the newly generated data packets in every time step are equal to those having arrived at the destination and been deleted, the total amount of the data packets in the network remains unchanged and the network processes the data packets stably.

When $R > 32$, the amount of the data packets increases rapidly in the initial stage of the evolution. With the increase of time, the increment of the amount of the data packets slow down, but different from the situation when $R \leq 32$, the number of the deleted data packets is consistently smaller than that of the newly generated data packets. Thus, the continuous growth of the total amount of the data packets and the consistent decrease of the amount of the deleted data packets over time finally causes the comprehensive congestion of the network.

From above, a conclusion can be drawn: the network transfers from free flow to congestion when $R = 32$, as a result, in the scale-free network based on BA, the generation rate of the critical information packet under the application of free path transmission routing model is 32.

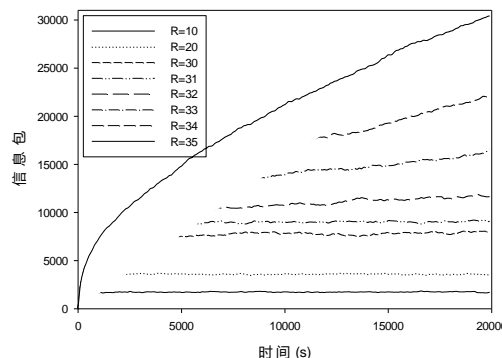


Fig 1. Curves of the changes of the total amount of the data packets over the evolution time

Fig. 2 shows that the order parameter η remains to be 0 when $R \leq 32$, and that η is greater than 0 when $R > 32$. So, $R = 32$ is the critical point of the changing of the network from free-flow to congestion, and the communication capability of the data packet of the network is 32.

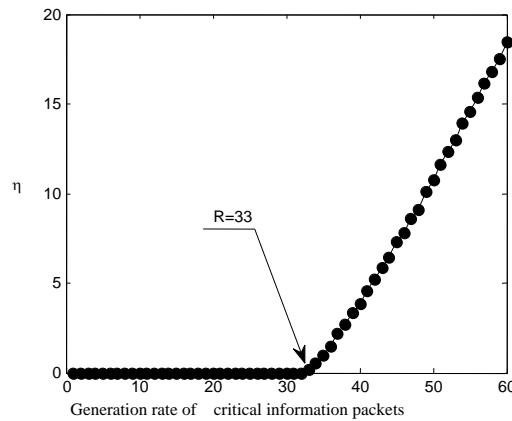


Fig 2. $\eta - R$ curve

The decrease of the processing capability of the node with the highest degree is chosen as the study object of the network emergencies. In different degrees of emergencies, the network transportation situations are simulated in sequence so as to obtain the corresponding generation rates of the critical information packets when the decrease $\varepsilon = 10\%, 20\%, 30\%, 40\%, 50\%$.

As is shown in Fig. 3, the generation rate of the critical information packets of the network drops dramatically with the decrease of the processing capability of the data packets of the node with the highest degree. The processing capability decreases by a half, and the generation rate drops nearly by a half with it. This indicates that the decrease of the processing capability greatly affects the transmission capacity of the whole network. Fig. 4 shows the variations of the generation rate of the critical information packets with the changing of the average degree. R_c increases with the increase of the average degree, but in the network with the same average degree, R_c decreases with the increase of the emergency degree. Therefore, in order to improve the transmission capability of the data packets of the whole network, the node degree should be increased as much as possible and the possibility of emergency be reduced simultaneously.

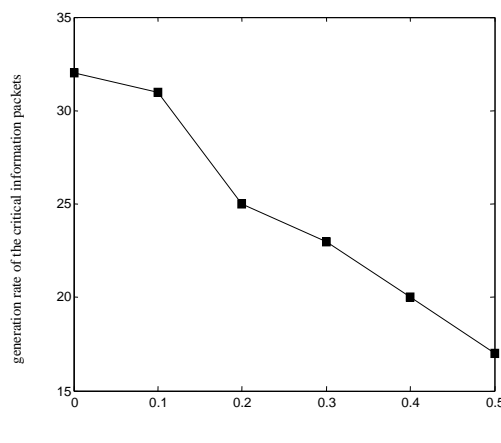


Fig 3. Variation of the generation rate of the critical information packets with the changes of the emergency degrees

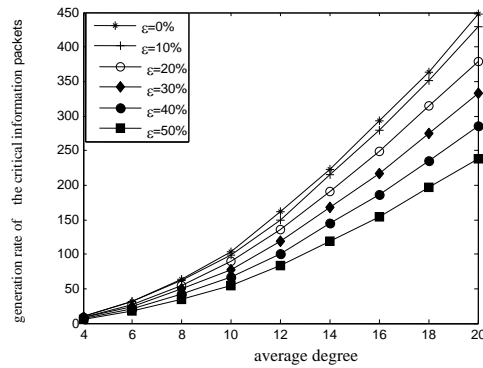


Fig 4. Variation of the generation rate of the critical information packets with the changes of the average degree

The evaluation of the transmission efficiency should take into consideration not only the maximum number of the newly added data packets in every time step but also the average transmission time of the data packets of the whole network. So, simulation is carried out to get the changing curve of the effect of the decrease of the processing capability of the node with the highest degree to the average transmission time of the data packets of the whole network. The result is shown in Fig. 5. When $R=10, R=15$, there is no obvious change in the average transmission of the data packets due to the fact that the network is in the state of free flow. The nodes in the network do not queue up, and the data packets of the node with the highest degree do not stay with the decrease of the processing capability of the node. As a result, the decrease of the processing capability of the node with the highest degree basically has no impact on the transmission time of free flow. When $R=35, R=40$, the network is in congestion. Now, there must be queuing at some nodes including the node with the highest degree. Because of the decrease of the processing capability of the node with the highest degree, the amount of the data packets transmitted to the adjacent node in unit time decreases, intensifying the queuing at the node with the highest degree, lengthening the staying time, the data transmission rate of the whole network slowing down. Consequently, when the network is in congestion, the transmission time increases with the increase of the emergency degree and the transmission efficiency drops constantly.

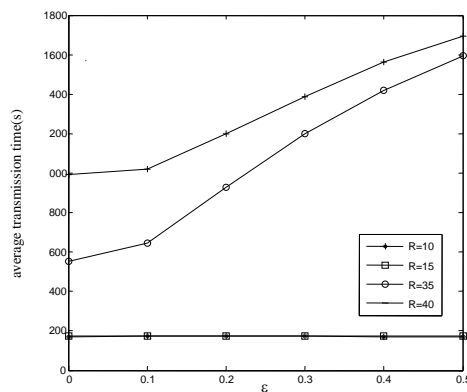


Fig 5. Average transmission time of the data packets under different emergency degrees

5. The Evacuation Strategy of the Network Traffic Congestion under Emergencies

Under emergencies, if the data packets cannot avoid unexpected situations by themselves through the original routing strategy, we adjust and optimize the random routing strategy of the original network. Every node set up its preference before determining the next transmission node by using the following routing strategy: the node searches its neighboring nodes; if the destination node of the data packet is found, the data packet will be transmitted to the destination node directly and be deleted

from the network; if not, it will be transmitted to the node chosen according to the probability P , which is defined as follows.

$$P_{l \rightarrow i} = \frac{k_i^\alpha}{\sum_j k_j^\alpha} \tag{3}$$

k_i is the degree of node i , to sum all the adjacent node of node l . Seen from (3), the bigger the value of α is, the bigger the probability of being chosen is for its neighboring node with higher degree. This gives full play to the transmission advantages of the nodes with higher degree. However, there is a limitation to the processing capability of the nodes with higher degree. If we simply choose the nodes with higher degree to transmit the data packets, the nodes with higher degree will be jammed with the evolution going deeper, lengthening the transmission processing time, causing the decrease of the transmission capability of the whole network. Therefore, if the value of α is too big, the generation rate of the critical information packets will be lowered; on the contrary, if the value of α is too small, the probability of being chosen for the nodes with higher degree will be greatly reduced, with the result of not giving full play to the transmission advantages of the nodes with higher degrees to improve the generation rate of the critical information packets. Hence, under different degrees of emergencies, α should fetch an optimal value that maximizes the generation rate of the critical information packets. Fig. 6 demonstrates the optimal values of α under different degrees of emergencies. We can see that the generation rate of the critical information packets will increase and then drop with the increment of α under different emergencies. The optimal values of α are 0, -0.1, -0.1, -0.1, -0.2, and the optimized generation rates are 31, 27, 26, 24, 22 correspondingly, with the improvement rate of 0%, 8.00%, 13.04%, 20.00%, 29.41% respectively compared with the original strategy.

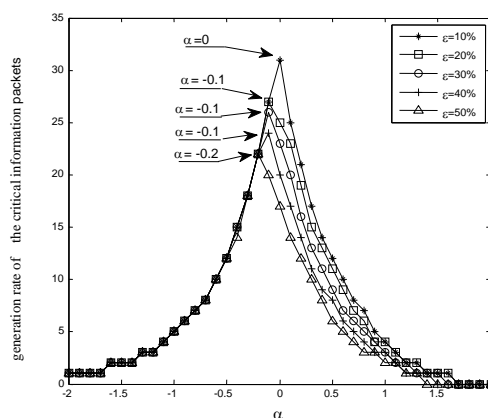


Fig 6. Optimal values of α under different degrees of emergencies

The more balanced the distribution of the data packets at the nodes are, the more difficult the congestion is. Fig. 7 and Fig. 8 simulate respectively the distribution of the information packet nodes of the network in free flow when the emergency $\epsilon = 30\%$ and $\epsilon = 50\%$. The figures indicate that the higher the degree of the node is, the more the queuing data packets are, and that the number of the average queuing data packets of the nodes with lower degree before optimization is less than that after optimization, and that the number of the average queuing data packets of the nodes with higher degree before optimization is less than that after optimization. This shows that the optimization avoids the accumulation of the data packets at some network nodes, making the distribution of the data packets more balanced.

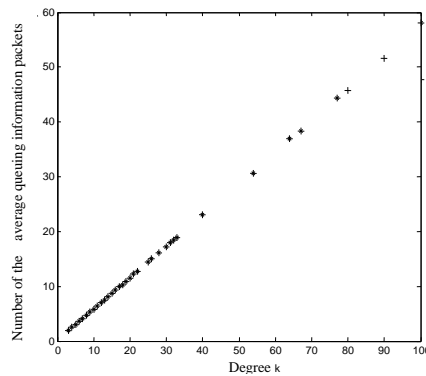


Fig 7. Situation of average queuing information packets of the nodes with different degrees
 $\varepsilon = 30\%, R = 20$

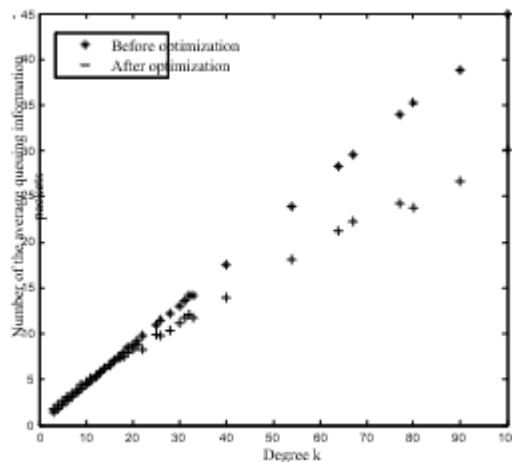


Fig 8. Situation of average queuing information packets of the nodes with different degrees
 $\varepsilon = 50\%, R = 15$

6. Conclusion

Based on BA network, the thesis set up a traffic network model by means of decreasing the data packets processing capability of the node with the highest degree to simulate the situation in which the network is under emergencies. The simulation analysis shows the impact of different degrees of emergencies on the generation rate of the critical information packets and the average transmission time of the data packets in the network. The result indicates that the generation rate of the critical information packets drops with the decrease of the data packets processing capability of the node with the highest degree, causing the network congestion, and lengthening the transmission time of the data packets. In this case, the static local routing strategy is applied to the network under emergencies. The network changes the original random routing strategy to the routing strategy with the initiative selection preference. Through simulation, the generation rate of the critical information packets under different degrees of emergencies are obtained by using the optimal preference parameters. After the optimization, the generation rate of the critical information packets improves by 0%, 8.00%, 13.04%, 20.00%, 29.41% respectively.

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