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Efficient routing method on the mobile communication networks

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Abstract—
The routing control of the packet is one of the important tasks to reduce the congestion of packets in the mobile communication networks. For this reason, various routing methods are widely proposed to exchange the data packets reliably while avoiding the congestion of the packets. As one of the efficient routing methods for the mobile communication networks, a routing method considering the memory information or the packet routing history is proposed in this paper. The obtained results show that the proposed routing method achieves to remove the congestion of the packets using the routing history effectively, realizing that the large number of the packets are transmitted to their destinations even if the number of packets increases in the communication networks.

1. Introduction

Enhancing the communication network capacity to carry a large volume of data traffic is one of the most important tasks for future communication society. One of the solutions to expand its capacity is to capture the flow dynamics of the packet transmission. For this reason, Ohira *et al.* [1] clarified the onset of phase transition behavior from free-flow state to congestion state as the packet creation rate increases. Zhao *et al.* [2] studies the dynamics of flowing packets for various network topologies, and showed that the networks with significant heterogeneous property would inhibit packet congestion.

Another solution to enhance the communication network capacity is to apply the effective routing method, realizing that the large number of packets can be transmitted to their destinations even if the flowing packets increases. For example, Echenique *et al.* [3, 4] proposed the deterministic routing strategy, which evaluates the efficient paths of sending packets by distance information and dynamic information. In addition, Kimura *et al.* proposed the routing method using memory information [5]. The routing method [5] exploits the memory information such as the amount of packets transmitted in adjacent nodes to avoid congestion substantially. Although the above routing method [5] has been examined for the wired communication networks, the performance evaluation of the routing method for the mobile communication networks is also necessity. From this view point, the routing method using the memory information is applied to the mobile communication networks in this paper. The numerical simulations show that the proposed routing method achieves higher arrival rate of the packets than that of the conventional one.

2. Mobile communication network model

We used weighted and undirected graphs $G = (V, E)$ to construct the mobile communication network model [6], where V is the set of nodes, and E is the set of links. Each node represents a mobile agent and each link represents a communication channel between two nodes. $N = |V|$ expresses the total number of nodes and these N nodes are placed within a squared-shaped cell of size L. Then, at each time step, the position and the velocity of the ith node are updated as follows:

$$\begin{aligned} x_i(t+1) &= x_i(t) + v\cos\theta_i(t), && (1)\\ y_i(t+1) &= y_i(t) + v\sin\theta_i(t), && (2)\\ \theta_i(t) &= \phi_i, && (3) \end{aligned}$$

where $x_i(t)$ and $y_i(t)$ are the coordinates of the ith node at the tth time, v is the moving speed of the mobile agent, $\theta(t)$ is the moving direction of the ith node at the tth time, and ϕ_i is the uniformly distributed random number in $[-\pi, \pi]$ intervals. Initially, the coordinates of the nodes are randomly determined using uniformly distributed random numbers. Although the moving directions of the mobile agents change as the time evolves, their moving speed are fixed in this paper. Further, if the ith mobile agent will move beyond the range of the square-shaped cell size, L, namely, $x_i(t+1) > L$ or $y_i(t+1) > L$, the position and the velocity of the ith mobile agent are again updated so as not to stay the outside of the cell.

In addition, the geographical distance between the ith node and the jth node at the tth time, $D_{ij}(t)$, is defined as

$$D_{ij}(t) = \sqrt{[x_i(t) - x_j(t)]^2 + [y_i(t) - y_j(t)]^2}. \quad (4)$$

Neighbors of the ith node are defined as the nodes within $D_{ij}(t) < C_r$, where C_r is the communication radius of the mobile agent. Then, each node transmits a packet to one of these neighbors. Further, if a packet is created at a node, the packet is stored at the tail of the buffer of the node, and a packet at the head of the buffer is transmitted to the neighbor. In other words, all the packets are transmitted to their destinations according to the first-in-first-out principle. Sources and destinations of the packets are randomly selected using uniformly distributed random numbers. In addition, if a node to which a packet will be transmitted has a full buffer, or the other nodes have already transmitted any packets to this node, movement of the packet is cancelled and the packet must wait for the next opportunity to be transmitted in the following step.

3. Packet routing method with memory information

In our routing method with the memory information, the optimal neighbor for transmitting the packet from the ith node is determined by the following equation:

$$y_{ij}(t+1) = \xi_{ij}(t+1) + \zeta_{ij}(t+1), \tag{5}$$

where

$$\xi_{ij}(t+1) = \beta\left(\frac{d_{ij}(t) + d_{jg(p_i(t))}(t)}{\sum_{k\in N_i(t)}(d_{ik}(t) + d_{kg(p_i(t))}(t))}\right), j \in N_i(t), \tag{6}$$

and,

$$\zeta_{ij}(t+1) = \alpha\sum_{\gamma=0}^{t} k_r^{\gamma} x_{ij}(t-\gamma)$$
$$= \alpha x_{ij}(t) + k_r \zeta_{ij}(t-1). \tag{7}$$

In Eqs. (6) and (7), β is a controlling parameter, $N_i(t)$ is the set of the neighbors of the ith node at the tth time, $p_i(t)$ is a packet transmitted from the ith node at the tth time, $g(p_i(t))$ is the destination of $p_i(t)$, $d_{ij}(t)$ is the dynamic distance between the ith node and the jth neighbor and $d_{jg(p_i(t))}(t)$ is the dynamic distance between the jth neighbor and $g(p_i(t))$, α is a scaling parameter of the memory information, k_r is a decay parameter, and $x_{ij}(t)$ is the packet transmission history of the jth neighbor at the tth time, i.e.,

$$x_{ij}(t) = \begin{cases} 1 & (\min(y_{ij}(t+1)), \\ 0 & (\text{otherwise}). \end{cases} \tag{8}$$

If $y_{ij}(t+1)$ of the jth neighbor takes the smallest value among all the neighbors, a packet at the ith node is transmitted to the jth neighbor. Then, the transmission history of the jth neighbor, $x_{ij}(t)$, is updated according to Eq. (8).

4. Performance Evaluation

To evaluate the performance of the proposed routing method, we compared it with the shortest path routing strategy (SP), which is commonly employed by communication networks.

Numerical simulations are conducted as follows. First, the packets were created based on randomly selected sources and destinations. Then, at every node, an optimal neighbor was selected using Eqs. (5)–(8), and the packets were transmitted to their destinations. The transmitting orders of the nodes were randomly selected at each iteration. The buffer size of each node, B, is set to 100. In addition, we set the moving speed, v, and the communication radius, C_r, to 0.01 and 0.6, and the square-shaped cell size, L, to 3.0, respectively. Further, the parameters in Eqs.(6)–(8) are set as follows: $\beta = 0.3$, $\alpha = 8.0$, and $k_r = 0.9$.

The node selection and packet transmission, I, were repeated for $I = 2,000$. We conducted 30 simulations to average the results. To evaluate the performance of the routing strategies, we used the following metrics.

1. Density of the packets (D):

$$D = p \cdot N \cdot B \tag{9}$$

$p(0 < p \leq 1)$ is the packet generating rate. If D increases, the large number of packets are generated in the mobile communication networks.

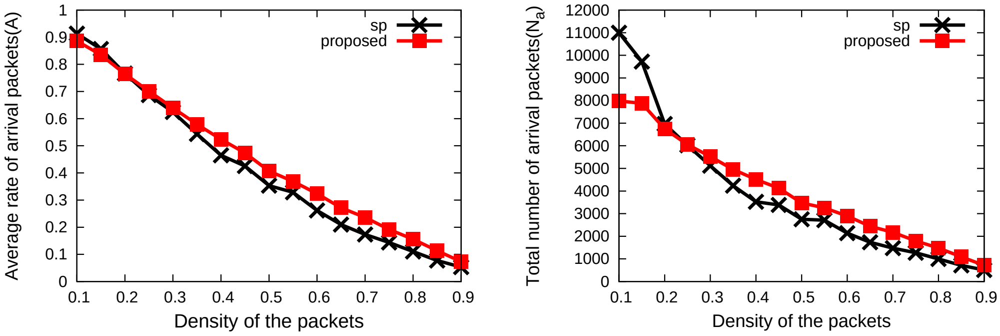
2. Average arrival rate of the packets (A):

$$A = \frac{\sum_{t=1}^{T} N_a(t)}{\sum_{t=1}^{T} D} \tag{10}$$

where $N_a(t)$ is the number of arrival packets at the tth time.

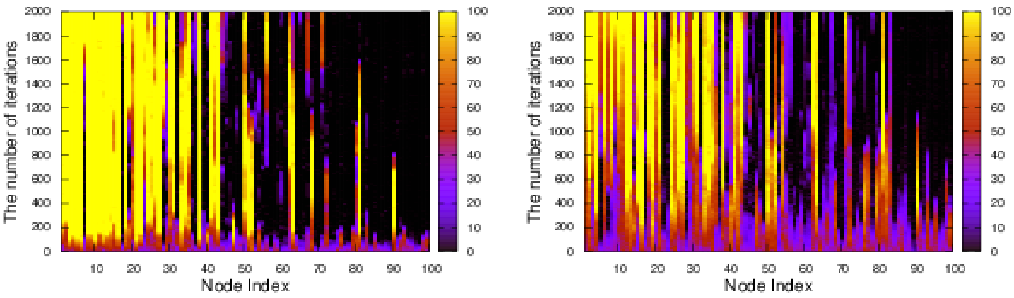
Figure 1 shows the average arrival rate of the packets and the total number of arrival packets by the shortest path method (SP) and the proposed routing method (Proposed). In Fig. 1 (a), the proposed routing method (Proposed) keeps higher average arrival rates of the packets (A) even if the density of the packets increases as compared to that of the shortest path approach (SP). In addition, in Fig. 1 (b), the Proposed transmits more packets to their destination as compared to the SP if the density of the packets is in between 0.25 and 0.9.

Figure 2 shows the congestion levels of (a) the shortest path approach (SP), and (b) the proposed routing method (Proposed). The congestion level of the ith



(a) (b)

Figure 1: Relationship between the density of the packets and (a) the average arrival rate of the packets and (b) the total number of arrival packets for the shortest path approach (SP) and the proposed routing method (Proposed).



(a) (b)

Figure 2: Congestion levels of the nodes as a function of the number of iterations (I) and the node index by (a) the shortest path approach and (b) the proposed routing method. In these figures, the density of the packets is set to 0.7

node at the tth time is evaluated by $n_i(t)/B$, where $n_i(t)$ is the number of queuing packets of the ith node at the tth time and B is the buffer size of the node.

In Figs. 2 (a) and (b), the congestion level of the SP becomes higher if the node index is in between 1 and 30. Because the node index in Figs. 2 were rearranged by the central order in the squared-shaped cell, this result indicates that the nodes close to the central coordination in the mobile communication networks are congested quickly as the time evolves. Contrary to the congestion level in the case of the SP, the Proposed inhibits them lower. Clearly, the congestion of the packets are alleviated by the proposed routing method, resulting that the packets can be transmitted to their destinations using various routes even if the large number of the packets are flowed in the mobile communication networks.

The conventional routing method [6] uses the information such as the queuing numbers of the packets at the neighbors to select the effective paths to the destinations. If these information are employed to the routing protocol, exchanging data in real time among all the nodes are needed to update them, causing that the flowing packets in the mobile communication networks much increases. On the other hand, the proposed routing method effectively selects the paths for routing the packets by the memory information which are owned by each node.

5. Conclusions

In this paper, the performance of the routing strategy with memory information was evaluated for the mobile communication networks. According to the previous study for the wired communication networks [5], obtained results in this paper lead to the conclusions that the routing control by the memory information works well not only for the wired communication networks but also for the wireless communication networks. However, the question remains why the memory information can remove the packets congestion efficiently. Thus, the further study of effectiveness of the memory information for routing packets should be conducted in the future work.

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