Abstract. Since communication networks such as the Internet, which is regarded as a complex network, have recently become a huge scale and a lot of data pass through them, the improvement of packet routing strategies for transport is one of the most significant themes in the study of computer networks. It is especially important to find routing strategies which can bear as many traffic as possible without congestion in complex networks. First, using neural networks, we introduce a strategy for packet routing on complex networks, where path lengths and queue lengths in nodes are taken into account within a framework of statistical physics. Secondly, instead of using shortest paths, we propose efficient paths which avoid hubs, nodes with a great many degrees, on scale-free networks with a weight of each node. We improve the heuristic algorithm proposed by Danila et al. which optimizes step by step routing properties on congestion by using the information of betweenness, the probability of paths passing through a node in all optimal paths which are defined according to a rule, and mitigates the congestion. We confirm the new heuristic algorithm which balances traffic on networks by achieving minimization of the maximum betweenness in much smaller number of iteration steps. Finally, We model virus spreading and data transfer on peer-to-peer (P2P) networks. Using mean-field approximation, we obtain an analytical formulation and emulate virus spreading on the network and compare the results with those of simulation. Moreover, we investigate the mitigation of information traffic congestion in the P2P networks.

1. Introduction

Since the discovery of small world and scale free networks[1,2], where average lengths of shortest paths and degree distribution with a power law, respectively, have characteristic properties, their structures and various dynamics on the networks have been investigated actively in many fields. These networks are called complex networks. Because the Internet has such properties and is regarded as a complex network, information communication on complex networks is one of the most important problems, for examples, packet routing, peer-to-peer (P2P) communication and so on. In routing strategies, hubs, which are nodes with a great many links and characteristic in scale-free networks, should be avoided for mitigation of congestion. We propose an efficient algorithm for avoidance of hubs on communication routes. On the other hand, in P2P networks, there are two notable aspects. One is that a peer searches for a file and downloads it from a “host peer”, which has the requested file. The other aspect is that peers leave and join in the network repeatedly. Thus, the topology of the network changes gradually with time and the behavior of the density of infected peers and data transfer become complicated. We appropriately simulate virus spreading and data transfer on the networks under the change of its topology by the effect of leaves and compare the results with mean field approximations. We also consider the mitigation of traffic congestion on the P2P networks.
2. Packet routing strategy using neural networks on scale-free networks

We investigate routing strategies on complex networks. Using neural networks, we introduce a routing strategy where path lengths and packet-queue lengths are taken into account within a framework of statistical physics. The performance of this strategy becomes more efficient from adjustment of parameters. At the same time, we analyze how the properties of networks influence the performance of this strategy. Moreover, we propose a routing strategy where connection weights in neural networks are adjusted by local information. We also confirm how the distance term and the properties of networks influence the performance of this adaptive strategy.[3]

In Fig. 1, the average number of packets arriving at their destinations per transmission time $A$ is depicted as functions of the average packet-queue length in a node $⟨q⟩$. Since $A$ with our strategy is smaller than that with the strategy based on shortest paths (SP), we confirm that our proposed strategy is more effective than the SP strategy.

3. Efficient packet routing strategy in complex networks

We investigate new packet routing strategies which mitigate traffic congestion on complex networks. Instead of using shortest paths, we propose efficient paths which avoid hubs on scale-free networks with the use of a weight of each node. We improve the heuristic algorithm [6] which improves step by step routing properties on congestion by using the information of the betweenness of each node in every step. We propose a new heuristic algorithm which balances traffic on networks by achieving minimization of the maximum betweenness in the much smaller number of iteration steps [4] than that in [6].

In Fig. 2, we compare the average traveling time of a packet $T_{avg}$ as functions of the packet generation rate $\lambda$ for Barabási and Albert (BA) model [2] with the total node number 500 and the average degree 8 for the shortest path strategy (SPS), the strategy proposed by Yan et. al. [5] (DEPS), the strategy proposed by Danila et. al. [6] (OPS) and our algorithm (NOPS).
Figure 2. The results with SPS (circles), DEPS (triangles), OPS (diamonds) and NOPS (squares) for $T_{\text{avg}}$ are compared as functions of $\lambda$ for the BA model.

4. Virus spreading and data transfer model in P2P networks

Recently peer-to-peer (P2P) file-sharing systems have been a new communication paradigm. P2P networks have two notable aspects. One is that a peer searches for a file and downloads it from a “host peer”, which has the requested file. To determine whether a peer has the requested file or not in modeling of the search and download process, we introduce a parameter $P_j$, which expresses the normalized amount of files stored in the peer $j$. It is assumed that the more a peer has files, the more possibly it becomes a host peer, that is, if $P_j$ is large, the peer $j$ has many files and can respond other peers’ requests with high probability. The other aspect is that peers leave and join in the network repeatedly. The topology of the network, therefore, changes gradually with time and the behavior of $\rho$ (the fraction of infected peers) becomes complicated. We propose models appropriate to P2P networks and simulate virus spreading on the networks under the change of its topology by the effect of leaves and joins. Since peers empirically seem not to leave the network randomly, the two directions of separation from the networks are examined. One is that peers randomly leave (called “RA-separation”) and the other is that the peer $j$ leaves at the rate which is proportional to $1 - P_j$ (called “F2-separation”). We devise F2-separation to take into account the existence of “file suppliers”, who hold many files and principally supply files to other peers and rarely leave the network, and “free riders”, who possess few files and hardly supply files and quite often leave the network in a moment after joining.

Moreover, using mean-field approximation, we obtain an analytical formulation and emulate virus spreading on the network and compare the results with those of simulation. In practice, an infected computer is recovered when being outside the network. Thus, we introduce an extended SIS model, where infected peers never turn to susceptible in the network, susceptible peers may turn to infected only in the network and infected peers always turn to susceptible while leaving the network. Fig.3 represents the results for two directions of separation. The fraction of infected peers $\rho$ is not zero for F2-separation even when the infection rate $\mu$ is too small, whereas for RA-separation, $\mu_c$, the epidemic threshold value of $\mu$, under which $\rho$ is 0, has a positive value. In Fig.3, dashed curves represent simulation results and solid curves represent the results from the theoretical analysis with mean field approximations. Although the simulation results of
Figure 3. The fraction of infected peers $\rho$ is plotted as a function of $\mu$ with extended SIS model for leaving rate, the fraction of leaving node, $0.2$. Dashed curves indicate simulation results and solid curves represent the theoretical results with mean-field approximation. For RA-separation, the epidemic threshold $\mu_c$, where $\rho = 0$ for theoretical analysis is smaller than that for simulation results.

the behavior of $\rho$ for F2-separation are in good agreement with the theoretical analysis, the agreement for RA-separation is not so good, especially near the epidemic thresholds $\mu_c$. The reason is that the number of peers in the network is finite in simulation, whereas mean-field approximation theory is effective for infinite systems. The theoretical results for F2-separation show that the epidemic threshold is 0 and $\rho$ is proportional to $-\mu \log \mu$ for quite small $\mu$.

We attain the fact that viruses spread on the network even for quite small infection rate when peers leave in accordance with F2-separation. In other words, the network is more vulnerable to virus in the case of F2-separation than RA-separation. We also investigate traffic congestion for file transport on the P2P network and confirm the effectiveness of the strategy propose in section 3.

5. Conclusion

We devise efficient packet routing strategies on communication networks in order to avoid traffic congestion. With neural networks and the heuristic algorithm the above purpose is achieved. On the other hand, P2P networks are modeled with their notable properties, and investigated virus spreading on them theoretically and with simulation. We also confirm that the similar strategy proposed in section 3 is effective for mitigation of congestion on the P2P network.

Our methods are also applied to treat traffic properties of other communication networks. Various characteristic properties of such networks will be investigate in near future.

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