Adaptive Routing Approaches of Controlling Traffic Congestion in Internet

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Abstract. Different routing strategies may result in different behaviors of traffic in internet. We review the routing strategies developed recently in the field of physics and show that the traffic can be significantly improved by the adaptive routing approaches. Comparing with the shortest path approach, the adaptive routing approaches can reduce the over-loading of hub nodes and thus increase the capacity of network. Especially, for the realistic situation with fluctuated traffic, the local self-adjusting traffic awareness protocol can efficiently reduce the traffic congestion. These results provide new insight in sustaining the normal function of Internet.

Keywords: traffic in internet, routing strategies, self-adjusting, traffic congestion;shortest path.

1 Introduction

The internet has become a very important tool in our daily life although its short history. The operations on the internet, such as browsing World Wide Web (WWW) pages, sending messages by email, transferring files by ftp, searching for information on a range of topics, and shopping etc., have benefited us a lot. Once we need some information, we may immediately refer ourself to Internet for searching. Therefore, sustaining its normal and efficient functioning is a basic requirement. However, it has been found that there is intermittent congestion in Internet [1]. As the Internet is continuously growing and there is no central organizer to handle it, finding better routing strategy to accelerate the delivering of packets on it becomes a hot topic recently [2,3,4,5,6,7,8,9,10,11,12,13,14,15,16]. The main aim of routing approach is to reduce the possibility for the appearance of the intermittent congestion in Internet.

At the autonomous system level, the Internet consists of nodes and links. The nodes are connected by links and the degrees of nodes satisfy a power-law, which is called scale-free (SF) [17]. The nodes can produce packets and route them to their destinations through the links, i.e., a node is taken to be both host and router. As host, node can receive packets from other hosts; and as a router, node

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can forward packets one step toward their destinations along the shortest pathes in each time step. A packet is usually assumed to take two messages: the time of creation and its destination.

The modeling of traffic in Internet is originally focused on the computer network and three different computer network models have been extensively studied [18,19,20,21,22,23,24,25,26,27,28,29,30]. The first one considers the edge nodes of network as hosts and the inner nodes as routers [23]. The second one treats all the nodes as both hosts and routers [24,27,28]. And the third one is in between these two extremes [25,29,30], i.e., part of the nodes are hosts and the remainders are routers. However, all of these models focus on the situation where the underlying network is a 2-dimensional lattice [23,24,25,29] or a Cayley tree [26,27,28]. Considering that the Internet is a scale-free network with heterogeneous topology [31,32], how to model the traffic in heterogeneous networks is currently a focus in complex networks. The aim to study this topic is to find the optimal network topologies for searching and the optimal routing strategies to reduce or control the congestion. A great progress has been achieved along this direction and the studies can be classified into three stages. The first stage takes both the creation and delivering rates of packets as uniform to every node [2,3,4,5,6,7,8,9,10,11]. That is, each node can deliver one packet and produce λ packets in each time step. The second stage takes into account the influence of the degree of a node on the delivering rate and modifies the delivering rate into $1 + \beta k_i$, i.e., proportional to the degree k_i [12]. The unit in $1+\beta k_i$ comes from the consideration that each node should handle at least one packet in each time step. The third stage considers both the creation and delivering rates as proportional to the degree k_i, i.e., the creation rate is λk_i and the delivering rate is $1 + \beta k_i$ [13,14,15,16]. This stage is more close to the real Internet where larger agent/node has more users and hence has larger creation and delivering rates. We here focus on the third stage and summarize the results obtained there.

The paper is organized as follows. Section 2 gives an economic approach to increase the capacity of Internet. Section 3 presents an efficient approach to save the delivering time. Section 4 studies the adaptive routing approach for the case of fluctuated traffic. Finally, Sec. 5 includes the discussion and the conclusions.

2 An Economic Approach

The routers have the function to find the shortest path between the origin of a packet and its destination. In the computer network models, the routing approach is the shortest path where the router routes the packet to go the path with the smallest number of links to the destination. As the Internet has the SF topology, the shortest path approach will result in some problem when it is applied to the Internet. That is, most of the shortest pathes will go through the hub nodes with heavy links and thus result in a heavy load on them. Therefore, it is very easy for the Internet to occur congestion. We here focus on the third stage, i.e., the case with the creation rate λk_i and the delivering rate $1 + \beta k_i$.

When the creation rate is small and the network is in the free phase, the shortest path approach is the most efficient approach for the delivering of packets. However, this approach has the smallest capacity to handle the communication because of the easy occurrence of congestion at the hub nodes. Once the creation rate is relatively large, the network will be in the congestion phase. A direct idea to solve this problem is to increase the capacity of each node in the Internet. As the number of nodes in Internet is typically very large and there is no central organizer to manage the development of the whole network, this idea thus does not work.

Ref. [13] suggests a way to solve this problem. The idea is based on the consideration that the hub nodes represent the larger companies and academic institutions which could increase their local capacity, i.e., the value of β, more readily. As the congestion are mainly caused by the hub nodes, we may significantly reduce the congestion by increasing the delivering rates of the hub nodes. Therefore, an economical way to control the congestion in Internet is to ask only the hub nodes to increase their β but ignore the extensive small and middle nodes. This approach is thus called *economical approach*. The detailed process is as follows: we choose a fraction of nodes with the heaviest links, f, and increase their communication capacities ($\beta > 0$) and let the other nodes stay at the status of $\beta = 0$. Correspondingly, we call the case with the same β to all the nodes as *normal approach*. Ref. [13] shows that the effect by only increasing $f = 3\%$ hub nodes in the economical approach is equivalent to that of increasing the capacity β of all the nodes in the normal approach.

Let's numerically show the equivalency between the economical approach and the normal approach in a SF network. The network is constructed by the algorithm given by Barabási and Albert (BA), i.e., the BA model with degree distribution $P(k) \sim k^{-3}$ and average degree $< k >= 6$ [33,34]. Then we use the following routing algorithm to simulate the packet delivering in Internet:

(1) At each time step, a node i has a possibility $k_i\lambda$ to create a new packet. If the node has some packets waiting to be sent, the newly created packet will be placed at the end of the queue.

(2) At each time step, a node i has an ability to forward $(1 + \beta k_i)$ packets in its queue one step towards their destinations. Noticing that βk_i may be an integer plus a fractional part, the fractional part is implemented by possibility. The packet will be removed once it reaches its destination.

(3) Once a packet is created, a destination node, different from the original one, is chosen at random in the network. The router will find a shortest path between the newly created packet and its destination and the packet will be forwarded along this path during the following time steps. If there are several shortest paths for one packet, we choose the one whose next station (selected node) has the shortest queuing length.

This procedure works for every node at the same time. According to these steps, Fig. 1 shows the difference between the normal approach and the economical approach of $f = 3\%$ at the evolution time $t = 500$ where $< n(k) >$ denotes the average number of packets on nodes with the same degree k, the lines with "asterisks" denote the case of normal approach, the lines with "circles" denote the case of economical approach, the network size is $N = 1000$, and (a) and (b) represents the cases of $\beta = 0.05$ and 0.1, respectively. The results are averaged over 100 different realizations. From Fig. 1(a) and (b) it is easy to see that the nodes with heavy links are in the congested phase in (a) but in the free phase in (b). However, from Fig. 1(a) and (b) we also see that no matter it is in the congested phase or the free phase, the "circles" is always fluctuated around the "asterisks", indicating that the effect of the economical approach is equivalent to that of the normal approach. Therefore, to increase the capacity of network it is not necessary to increase the capacities of all the nodes but only need to increase the capacities of the 3% hub nodes.

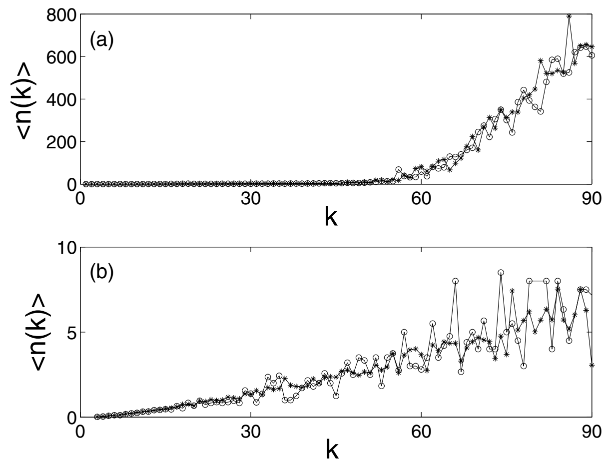

Fig. 1. $< n(k) >$ versus k for $\lambda = 0.01$, $< k >= 6$, $N = 1000$, and averaging over 100 different realizations for the same parameters, where the lines with "asterisks" denote the case of normal approach and the lines with "circles" the case of economical approach with $f = 3\%$, and (a) denotes the situation of $\beta = 0.05$ and (b) the situation of $\beta = 0.1$ when the system runs up to the time step $t = 500$

3 An Efficient Approach of the Shortest Waiting Time

The equivalency between the economical approach and the normal approach tells us that in the case of the shortest path approach, the congestion comes mainly from the hub nodes but leave the nodes with small and middle links in the free status. If we can control the congestion in the hub nodes, we can control the congestion of the network. This problem may be thought in another way: Can we transfer the accumulated packets in the hub nodes to the nodes with small and middle links to reduce or control the congestion? This problem is extremely important in the case that the hardware of all the nodes are fixed. Its solution provides the basis why we need to improve the routing algorithm.

An approach to implement the above idea is proposed by Echenique *et al.* [6,7] in which a node would choose a neighboring node to deliver a packet by considering both the shortest path from the neighboring node to the destination *and* the waiting time at the neighboring node. The waiting time depends on the number of packets in the queue at a neighboring node at the time of decision and thus corresponds to a *dynamical* or *time-dependent* information. This algorithm performs better than the shortest path approach as packets may be delivered not necessarily through the shortest path and thus the loading at the hub nodes is reduced. As a cost for the Echenique's approach to increase the capacity of network, the delivering time turns out to be much longer than that in the shortest path approach. The Echenique's approach belongs to the first stage where the delivering rate is unity for every node. In detail, the next station of a delivering packet is chosen from one of the neighbors with the minimum value of $hd_{\ell,j} + (1-h)n_\ell$, where $d_{\ell,j}$ is the shortest path length from node ℓ to j and n_ℓ is the number of packets accumulated at node ℓ. The traffic awareness parameter h is a weighing factor, which can be taken as a variational parameter and $h \approx 0.8$ is found to give the best performance. If we rewrite the Echenique's approach in the third stage, the chosen neighbor will have a minimum value of

$$\delta_\ell = hd_{\ell,j} + (1-h)\frac{n_\ell}{1+\beta k_\ell}. \tag{1}$$

The Echenique's approach considers only the waiting time at the nearest neighbors. Ref. [14] extends this idea to include all the waiting time along the delivering path. Let's call it *the efficient approach of the shortest waiting time* (EASWT). In the free phase of traffic, the EASWT becomes the shortest path approach. While in the congestion phase, the EASWT will make the packet go along a path with the shortest delivering time, instead of the shortest path, to reduce the congestion. The delivering time includes both the waiting time and path length. In detail, let's consider a packet leaving node i with destination node j. Each of the k_i neighbors of node i has a shortest path to the destination node j. The shortest path refers to the smallest number of links from a node to another. However, due to the possible accumulation of packets at each node, the number of time steps for a packet to be delivered to its destination may be different from the number of links along the shortest path. Consider a neighbor labeled ℓ of the node i. We label the shortest path from node ℓ to j by $\{SP : \ell, j\}$. Along this path, we evaluate the following quantity for the node ℓ:

$$\delta_\ell = \sum_{s\in\{SP:\ell,j\}} \frac{n_s}{1+\beta k_s}, \tag{2}$$

where the sum is over the nodes along the shortest path $\{SP : \ell, j\}$, excluding the destination. Thus, δ_ℓ is an estimate of the time that a packet would take to go from node ℓ to the destination j through the shortest path. Node i would choose a neighboring node with the minimum δ_ℓ to forward the packet, i.e., the selection is based on $min\{\delta_\ell, \ell \in \{i\}\}$, where $\{i\}$ is the set of k_i nodes consisting of the neighbors of node i. This procedure is repeated for each node and each packet in every time step.

Comparing with the Echenique's approach, the EASWT has two advantages. One is that the average waiting time of all the packets is the shortest. The other is that it does not need an adjustable parameter h whose optimal value may depend on the network topology. In practice, we need a criterion to evaluate the effect of routing approach. Considering that a better algorithm will increase the capacity of communication, we may use the critical point of congestion to evaluate the effect of a routing approach. For a fixed delivering parameter β, there is a critical creation rate λ_c. The network is in the free phase when $\lambda < \lambda_c$ and in the congestion phase when $\lambda > \lambda_c$. And for a fixed creation rate λ, there is a critical delivering parameter β_c. The network is in the free phase when $\beta > \beta_c$ and in the congestion phase when $\beta < \beta_c$. Thus one may use either λ_c or β_c to represent the capacity of communication. Ref. [14] chooses β_c to represent the capacity of communication and shows that for the discussed three routing approaches, the EASWT has the smallest β_c, the Echenique's approach has the middle β_c and the shortest path approach has the largest β_c, indicating that the EASWT has the largest capacity, the Echenique's approach has the middle capacity and the shortest path has the smallest capacity. Fig. 2 shows how β_c changes with λ where the "circles" denotes the case of the EASWT, "stars" the case of the Echenique's approach, and "squares" the case of the shortest path approach.

From Fig. 2 it is easy to see that the EASWT is better than both the Echenique's approach and the shortest path approach. Ref. [14] also presents a mean-field theory to explain the the delivering mechanism of the EASWT. The interesting readers may go to there for detail. We should point here that the shortest path approach depends entirely on geometrical information and it is thus *static*. Once the origin and destination of a packet is known, the shortest

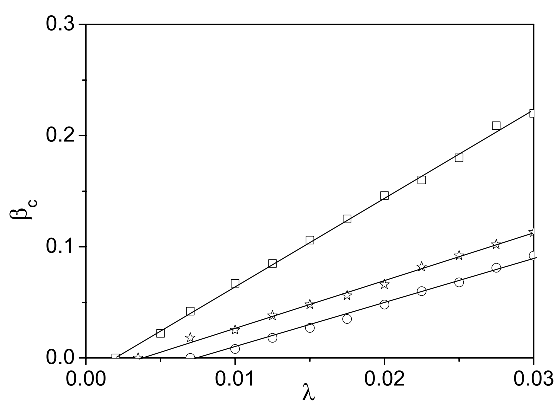

Fig. 2. The critical value $\beta_c(\lambda)$ for three different routing approaches for forwarding packets: the EASWT ("circles"), the Echenique's approach with $h = 0.8$ ("stars"), and the shortest path approach ("squares"). The lines are guidance to eye.

path is fixed. While the Echenique's approach considers both geometrical and local dynamical information. By considering the waiting time at a neighboring node, a packet from a node i to a destination j will not always follow the same path. Thus, the Echenique's approach is a strategy of *adaptive*, i.e., a decision based on the current situation. The EASWT, like the Echenique's approach, is also adaptive and makes use of *global* information in which all the waiting times along a path are taken into account. It should be, however, noted that the shortest path approach does not require update of the routing strategy. The Echenique's approach and the EASWT require continuing update of the number of packets accumulated at the nodes. Such updating plays the role of a cost, with the payoff being the better performance. Practical implementation would have to consider the balance between the cost and the payoff.

4 Adaptive Routing Approach for Fluctuated Traffic

All the above three methods and other routing algorithms are designed for the situations with fixed parameters λ and β. However, the human activities usually have some periodicity, such as the circadian and weekly cycles etc. Thus the information flow in Internet is fluctuated around an average and the amplitude of fluctuation depends on the time interval in one day and also depends on the date whether it is workdays, weekends or holidays etc. [35]. That is, the transportation of information in the Internet has rush hours. When you search or send out some information packets, it usually takes a slightly longer time in the rush hours than in other time. The reason is that more data are produced in the rush hours. Larger fluctuation means that it is possible for a higher packet generating rate at one time and a lower rate at another time. This fluctuation reduces the capacity of the network and makes the congestion easier to occur. After considering these factors, the generating rate λ should depend on time t, i.e., $\lambda(t)$. For simplicity, we may take $\lambda(t)$ as a periodic function. Ref. [16] suggests that the $\lambda(t)$ should be taken as the following form

$$\lambda(t) = \lambda_0 + A \sin \omega t, \tag{3}$$

where $A \sin \omega t$ represents the periodic fluctuation of generating rate, A and ω are the amplitude and frequency of fluctuation, respectively. Different A and ω may reflect the local fluctuations in different countries or regions.

In our framework, the produced packets by a node is $k_i \lambda(t)$ in each time step, which depends on time. If we apply the Echenique's approach to this case, an interesting question is whether there is still an optimal h? For answering this question, let's use the Echenique's approach to discuss the performance of the fluctuated generating rate (3). Fig. 3 shows the critical β_c versus h for fixed $\lambda_0 = 0.01$ and different sets of A and ω where the "squares" denote the case of $A = 0$, the "circles" the case of $A = 0.005$ and $\omega = 0.01$, the "up triangles" the case of $A = 0.005$ and $\omega = 0.005$, and the "down triangles" the case of $A = 0.01$ and $\omega = 0.01$. Obviously, the "squares" with $A = 0$ (no fluctuation in $\lambda(t)$) show its optimal capacity at around $h = 0.8$, which is consistent with Ref. [6].

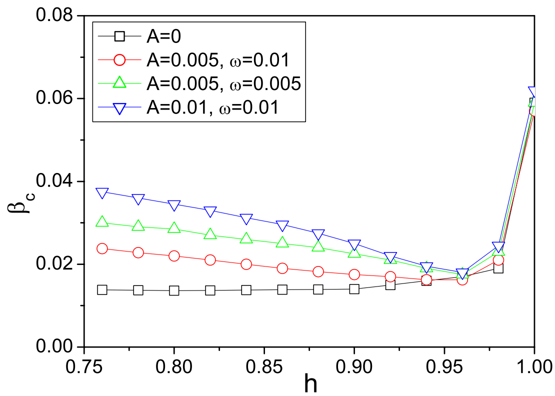

Fig. 3. (color online). The critical capacity β_c versus the traffic awareness parameter h in the Echenique's approach for fixed $\lambda_0 = 0.01$ and different sets of A and ω where the "squares" denote the case of $A = 0$, the "circles" the case of $A = 0.005$ and $\omega = 0.01$, the "up triangles" the case of $A = 0.005$ and $\omega = 0.005$, and the "down triangles" the case of $A = 0.01$ and $\omega = 0.01$.

However, the cases with fluctuation do not show the optimal capacity at around $h = 0.8$ but at $h \approx 0.96$, see the "circles", "up triangles", and "down triangles" in Fig. 3. That is, the optimal $h = 0.8$ for $A = 0$ moves to the optimal $h = 0.96$ for $A > 0$. This phenomenon can be understood as follows. The positive $A \sin \omega t$ in Eq. (3) makes $\lambda(t) > \lambda_0$ and hence its β_c should be larger than that of λ_0. While the negative $A \sin \omega t$ in Eq. (3) makes $\lambda(t) < \lambda_0$ and thus it is possible for the traffic to run in the free phase, resulting in $h = 1$. The balance between $h = 0.8$ and $h = 1$ makes the optimal h move to $h = 0.96$.

Through the above analysis we see that the optimal h for $\lambda(t) > \lambda_0$ and that for $\lambda(t) < \lambda_0$ should be different, indicating that the fixed h in the Echenique's approach is not a good approach for the case of fluctuated $\lambda(t)$. Furthermore, the optimal h should depend on $\lambda(t)$ and also be a variable of time t. We here meet a problem of how to figure out the optimal $h(t)$. For solving this problem, let's see the meaning of $h(t)$. The parameter $h(t)$ reflects in fact the weight between the shortest distance $d_{\ell,j}$ and the waiting time $n_\ell/(1 + \beta k_\ell)$ of the new arriving packets. Dividing $1 - h(t)$, Eq. (1) becomes $D^\ell_{eff} = \frac{h(t)}{1-h(t)} d_{\ell,j} + \frac{n_\ell(t)}{1+\beta k_\ell}$. Therefore, the factor $h(t)/(1 - h(t))$ reflects the traffic status of the system at time t. Ref. [16] assumes that $h(t)/(1 - h(t))$ depends on the average packets $< n(t) >$ in the system and presents the following formula

$$D^\ell_{eff} = Q < n(t) > d_{\ell,j} + \frac{n_\ell(t)}{1 + \beta k_\ell}, \tag{4}$$

to evaluate the effective distance, where Q is a number and can be determined by the optimal performance of routing. A characteristic feature of Eq. (4) is that the factor $< n(t) >$ changes with time and can reflect the fluctuated traffic or the fluctuation of $\lambda(t)$. Thus, we call Eq. (4) as the *self-adjusting traffic awareness protocol* (SATAP).

On the other hand, considering the fact that the global information of Internet is difficult to get, thus we generally do not have $< n(t) >$. What we can obtain is the local information, such as the average packets on the neighboring nodes of node i. Therefore, we modify Eq. (4) into the following form

$$D^{\ell}_{eff} = Q' < n_2(t) > d_{\ell,j} + \frac{n_\ell(t)}{1+\beta k_\ell}, \tag{5}$$

where $< n_2(t) >$ is the average packets on the nearest neighbor and next-nearest neighbor nodes and Q' is a number. For distinguishing it from the SATAP, we call Eq. (5) as the *local self-adjusting traffic awareness protocol* (LSATAP). In the following we will check the effect of SATAP and LSATAP by numerical experiments.

In numerical simulations, let's firstly figure out the optimal Q and Q' for the SATAP and LSATAP, respectively. Take $\lambda_0 = 0.01$ as an example. By choosing different sets of A and ω we find that they have a common optimal $Q \approx 2.5$ for SATAP and a common optimal $Q' \approx 1.0$ for LSATAP. Figure 4 shows the results where (a) β_c versus Q for SATAP, (b) β_c versus Q' for LSATAP, and the "squares" denote the case of $A = 0$, the "circles" the case of $A = 0.005$ and $\omega = 0.01$, the "up triangles" the case of $A = 0.01$ and $\omega = 0.01$, and the "down triangles" the case of $A = 0.005$ and $\omega = 0.005$. Comparing the curves in Fig. 4(a) it is easy to see that all the curves of β_c have the same minimum at $Q \approx 2.5$ and all the β_c for $A > 0$ is larger than the corresponding β_c for $A = 0$. Fig. 4(b) shows the similar results. Therefore, we will fix $Q = 2.5$ and $Q' = 1.0$ in this paper. Although the similar results between Fig. 4(a) and (b), there are some differences between them. For example, the shapes of their curves are different, i.e., the increasing speed of β_c in Fig. 4(a) is less than that in (b). The second difference is that the optimal β_c in Fig. 4(a) is slightly lower than that in (b), indicating the SATAP is slightly better than the LSATAP.

Then, we investigate how the parameters λ_0, A, and ω influence the critical β_c. For fixed $A = 0.005$ and $\omega = 0.01$, we let λ_0 change gradually and calculate β_c by the Echenique's approach, SATAP and LSATAP, respectively. Noticing that the cases with fluctuated $\lambda(t)$ have minimums at the same optimal $h \approx 0.96$ in Fig. 3, we here calculate two typical cases, i.e., $h = 0.8$ and 0.96, in the the Echenique's approach. Fig. 5(a) shows the results where the "squares" denote the case of the Echenique's approach with $h = 0.8$, "circles" the case of the Echenique's approach with $h = 0.96$, the "up triangles" the case of SATAP, and the "down triangles" the case of LSATAP. It is easy to see that all the β_c increase linearly with λ_0 and the case of the Echenique's approach with $h = 0.8$ is much larger than the three other cases, confirming that the previous optimal $h = 0.8$ in the Echenique's approach is not a good approach for the situation of fluctuated $\lambda(t)$. Moreover, from Fig. 5(a) we can see that the β_c in the cases of SATAP and

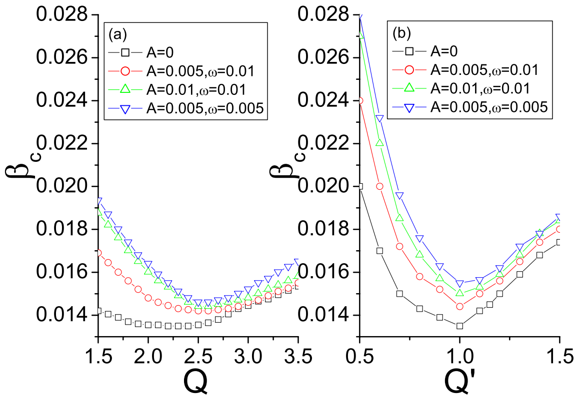

Fig. 4. (color online). (a) β_c versus Q for SATAP, (b) β_c versus Q' for LSATAP, where $\lambda = 0.01$ and the "squares" denote the case of $A = 0$, the "circles" the case of $A = 0.005$ and $\omega = 0.01$, the "up triangles" the case of $A = 0.01$ and $\omega = 0.01$, and the "down triangles" the case of $A = 0.005$ and $\omega = 0.005$.

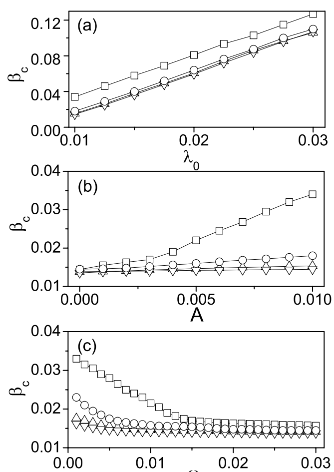

Fig. 5. The critical capacity β_c as a function of λ_0, A, and ω for three routing policies with the BA network size $L = 1000$ and average degree $< k >= 6$, where the "squares" denote the case of the Echenique's approach with $h = 0.8$, "circles" the case of the Echenique's approach with $h = 0.96$, the "up triangles" the case of SATAP, and the "down triangles" the case of LSATAP. (a) β_c versus λ_0 for fixed $A = 0.005$ and $\omega = 0.01$; (b) β_c versus A for fixed $\lambda_0 = 0.01$ and $\omega = 0.01$; and (c) β_c versus ω for fixed $\lambda_0 = 0.01$ and $A = 0.005$.

LSATAP is a little smaller than that of the Echenique's approach with $h = 0.96$, indicating the advantage of self-adjusting of routing. This advantage can be seen more clearly for larger fluctuated amplitude A. Fig. 5(b) shows the results for fixed $\lambda_0 = 0.01$ and $\omega = 0.01$ where the symbols have the same meaning with that in Fig. 5(a). It is easy to see that the β_c for both the case of the Echenique's approach with $h = 0.8$ and the case of the Echenique's approach with $h = 0.96$ increase with A but the cases of SATAP and LSATAP do not change with A, indicating that the cases of SATAP and LSATAP are the good routing approaches for the situation of fluctuated traffic. Fig. 5(c) shows the results for fixed $\lambda_0 = 0.01$ and $A = 0.005$. Obviously, the β_c of the Echenique's approach depend strongly on ω when $\omega < 0.015$ but the β_c of both SATAP and LSATAP remain approximately constant, confirming the advantage of SATAP and LSATAP again.

5 Discussion and Conclusions

The status of traffic in Internet depends on the routing strategy. For a fixed hardware of network, a better routing approach will make the network have larger capacity. To increase the communication capacity of network implies to find a better routing strategy. A common feature of all the routing approaches is that they should go back to the shortest path approach when there is no accumulation of packets in the network. This is the regime of true free phase where the delivering time equals the shortest path length. Beyond this regime, the routing approach makes the network keep the normal function but with some degree of accumulation, which makes the delivering times be larger than the shortest path length. Ref. [15] calls this regime, i.e., between the true free phase and the congestion phase, as the *buffer* phase in the sense that the delivered packets has no correlation in the free phase, has local correlation in the buffer phase, and has global correlation in the congestion phase. In the buffer phase, it is usually necessary for the packets to go a little longer path than the shortest path and waiting a while sometimes. With the decrease of β, more and more nodes have accumulated packets. When the nodes with the smallest links begin to be accumulated with packets, the congestion occurs.

In conclusions, we have reviewed three approaches to increase the communication capacity of network. The first one shows that the economical approach with $f = 3\%$ is equivalent to the normal approach. The second one takes into account all the waiting time along the path and is thus an approach with the shortest waiting time. And the third one can self-adjust its traffic awareness parameter to fit the fluctuated traffic flow. These results are based on the assumption that both the creation and delivering rates are proportional to the degree. Future work will be focused on the case where the assumption does not work or need to be modified.

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