Evaluating the Impact of Flooding Schemes on Best-effort Traffic

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Abstract

Flooding is a technique used by link state routing protocols to exchange network status information. In packet switched networks, flooding traffic competes with user traffic for the same physical medium, and a flooding scheme which has a good impact on QoS routing may degrade the performance of best-effort traffic greatly. In this paper, Lazy Flooding schemes are defined for packet-switched networks. An analytical model is proposed to study how much traffic is added by Lazy Flooding schemes and Periodic Flooding scheme in single link case. And the impact of different flooding schemes on transmission delay of best-effort traffic in whole network case is studied by simulation.

I Introduction

A routing protocol is a set of rules to collect and exchange information necessary for a routing algorithm to make routing decisions [1]. Flooding is a technique used by some link state routing protocols such as OSPF [2] to exchange network status information among the control nodes in the network. One of the main scaling problems of today's link-state protocols is that flooding consumes excessive communication resources [4]. OSPF cope with the scaling problems inherent in any link state advertisement(LSA) by organizing the network into areas connected by a backbone, but OSPF can only organize the network into two layers and the increasing number of routers in each layer still makes the flooding traffic a heavy burden. Moreover, aggregating a network into layers can result in inaccurate network information and have negative impact on routing decision [3].

There are also some work to confine LSAs to specific route in order to reduce the flooding traffic. For example, [4] proposes to selectively diffuse the link-state information based on the distributed computation of preferred paths rather than flooding of complete link-state information to all routers. Flooding problems in multicast routing protocols are studied in [9], and many schemes to reduce the message overhead such as Time To Live (TTL) protocol [6][8], Distributed Spanning Join (DSJ) protocols and Directed Reverse Path Join (DRPJ) protocol are discussed and evaluated.

Another way to reduce flooding traffic is to control the conditions of updates. Some update policies such as threshold based updates, equal class based updates and exponential class based updates have been proposed in [10]. Controlled updates can result in inaccuracy of network information, and the effects of such an inaccuracy on the performance of quality of service routing algorithms have been studied in [10]. The work in [11] studies the relation between link state information and size and connectivity of the underlying topology. The trade off relation between the quality of routing and messages overhead when flooding frequency is reduced is studied in [7].

All previous work is focused on evaluating the impact of inaccurate link state on Quality of Service routing. There is no work to study how much different flooding schemes effect the performance of best-effort traffic. In the context of QoS routing or optical network [7], it is usually not considered that flooding messages can compete with the best-effort traffic for the network resource such as link bandwidth, CPU time, buffers. In packet switched networks, LSAs share the same physical medium with the user data, a flooding scheme which has a good impact in the context of QoS routing may degrade the performance of best-effort traffic greatly. Though there is no performance guarantee requirement for best-effort traffic, too degraded quality for these traffic make the network service unacceptable.

In this paper, we formally define some Lazy Flooding schemes for packet switched networks and study the impact of the schemes on transmission delay of best-effort traffic. OSPF floods LSA messages periodically or when an interface becomes down, while in our proposal, an LSA message for a link is flooded based on the length of the queue in the buffer of a link. Periodically the queue length is checked, when the queue length satisfies the following conditions, an LSA is flooded out: (1) Queue length is below a threshold (Threshold Flooding); (2) Queue length follows a geometric sequence (Exponential Flooding); or (3)The variation of queue length is greater than a threshold (Δ Flooding).

We call the flooding scheme used in OSPF as Periodic Flooding and above three flooding schemes as Lazy Flooding. By intuition we know that less flooding will result in less LSA traffic. We build an analytical model to show how much traffic is added to a link by different flooding schemes. For the network case, we use simulation to study how different flooding schemes impact on the performance of best-effort traffic. In section 2, we gives the formal definitions of different flooding schemes, section 3 gives some mathematical analysis of these schemes and some simulation results of the flooding schemes in single link case are also given in this section, section 4 gives the simulation result of the flooding schemes in network case. The paper concludes in section 5.

II Lazy Flooding Methods

We model a link in the network which does not include flooding traffic as an M/M/1/C system, that is, the arrival of user packets to the data link conforms to Poisson distribution, the service time is exponential distribution. There are at most C packets waiting in the system.

Let $\rho = \frac{\lambda}{\mu}$, the density distribution function of service time is $f(t) = \mu e^{-ut}, t > 0$. Set $N(t)$ to be the length of queue in the buffer of link at time t, $p_n(t) = p[N(t) = n]$ is the probability that queue length is equal to n at time t. In the following, we give the definition of several flooding schemes:

Periodical Flooding: With periodic T, an LSA including the information of each link in the network is flooded.

Threshold Flooding: With periodic T, queue length n of each link is checked, if $n \geq L$, an LSA is flooded out. $L \leq C$ is a specified threshold. That is, for threshold flooding, the probability of one LSA being generated is $p_{tf} = \frac{1}{T} p[n \geq L]$.

Exponential Flooding: With periodic T, queue length n of each link is checked, if $n = 2^k, k = 0, 1, \cdots, \lfloor \log C \rfloor$, an LSA is flooded out, where $\lfloor x \rfloor$ denotes the largest integer smaller than x, set $\lfloor \log C \rfloor = K$. The flooding probability of LSA is $p_{ef} = \sum\limits_{k=0}^{K} p[n = 2^k] \frac{1}{T}$.

Δ Flooding: With periodic T, queue length of a link in the network is checked, $n_1, n_2, \cdots, n_i, n_{i+1}, \cdots$ is the queue lengths. An LSA for the link is flooded out if $|n_i - n_{i-1}| \geq \Delta$, that is,

$$p_{\Delta f} = \frac{1}{T} \sum_{i=0}^{C} (p[n = i]) \sum_{k=0}^{C-i} \Lambda_k \sum_{\substack{m=0 \\ |k-m| \geq \Delta}}^{k+i} U_m$$

Λ_k is the probability of k packets coming to the queue in periodic T, and U_m is the probability of m packets leaving the queue during T.

Traditional routing protocols are usually topology driven and no much information needs to be flooded in a short period. But with the requirements for traffic engineering increasing, getting the performance parameters of each link in time becomes important. Moreover, for different QoS purposes, many traffic engineering parameters need to be flooded such that link state advertisement packets become larger. To make link state information known instantly, the flooding period T must be decreased. When a link state has no much change, the flooded information is useless; in order to decrease the flooding traffic as well as have the link state information flooded in time when it has a change,Lazy Flooding schemes are proposed. The principle behind lazy flooding is to have a link state known when it is heavily loaded such that network traffic can avoid the much loaded links.

III Mathematical Analysis

With flooding traffic added to the link, the distribution of queue length will be changed. In the following, we study the impact of flooding schemes on network performance in terms of the queue length and flooding probabilities.

III-A Periodic Flooding

Let h be infinitesimal,denote the probability of n packets come in time interval $(t, t+h)$as $\lambda_n(t, t+h)$, the probability of n packets in the queue at time t as $p_n(t)$, the probability of n packets leaving as $\mu_n(t, t+h)$.

$$\begin{aligned} p_n(t+h) &= p_{n-1}\lambda_1(t,t+h) + p_n(t)\lambda_0(t,t+h)\mu_0(t,t+h) \\ &\quad + p_{n+1}\mu_1(t,t+h) + o(h) \end{aligned}$$

For the user packets and LSA coming to the link independently, we have:

$$\lambda_1(t,t+h) = \lambda h(1 - \frac{h}{T}) + \frac{h}{T}(1 - \lambda h) \tag{1}$$

$$= \lambda h + \frac{h}{T} + o(h) \tag{2}$$

$$\lambda_0(t,t+h) = (1 - \lambda h) \times (1 - \frac{h}{T}) \tag{3}$$

$$p_n(t+h) = \begin{cases} p_{n-1}(t)(\lambda + \frac{1}{T})h + p_n(t)(1 - \lambda h - \frac{1}{T} - \mu h) \\ +p_{n+1}(t)\mu h, \quad \text{if } 0 < n < C, \\ p_0(1 - \lambda h - \frac{h}{T}) + p_1 \mu h, \quad \text{if } n = 0, \\ p_{C-1}(\lambda + \frac{1}{T})h + p_C(1 - \mu h), \quad \text{if } n = C. \end{cases} \tag{4}$$

Set $p[N(t+h) = n]$ as $p_n(t+h)$, from above equations we get:

$$\frac{p_n(t+h) - p_n(t)}{h} = p_{n-1}(t)(\lambda + \frac{1}{T}) - p_n(t)(\lambda + \frac{1}{T} + \mu) + p_{n+1}\mu$$

We only consider the distribution of queue length at stationary state, that is set $\frac{p_n(t+h)-p_n(t)}{h} = 0$, we get

$$p_n = \begin{cases} (\frac{\lambda}{\mu} + \frac{1}{T\mu})p_0, & \text{if } n = 1, \\ (\frac{\lambda}{\mu} + \frac{1}{T\mu})p_{C-1}, & \text{if } n = C, \\ \left[p_{n-1}(\frac{\lambda}{\mu} + \frac{1}{T\mu}) + p_{n+1}\right] \frac{\mu}{\lambda + \frac{1}{T} + \mu}, & \text{otherwise.} \end{cases} \tag{5}$$

Denote $\rho' = \frac{\lambda}{\mu} + \frac{1}{T\mu}$, we get $p_n = \rho'^n p_0$ from above equations. For $\sum_{n=0}^{C} p_n = 1$, we get that

$$p_0 = \frac{1 - \rho'}{1 - \rho'^{C+1}}, p_k = \frac{(1 - \rho')\rho'^k}{1 - \rho'^{C+1}}, k = 1, \cdots, C$$

The expected value of queue length is:

$$E[n] = \sum_{n=0}^{C} np_n = \frac{(C-1)\rho'^{C+1} - C\rho'^{C+2} + \rho'}{(1-\rho'^{C+1})(1-\rho')}$$

III-B Threshold Flooding

Under threshold flooding, the probability of an LSA being generated is: $\sum_{j=L}^{C} p_j(t)\frac{h}{T}$, similar to the analysis in above subsection we have:

$$\begin{cases} p_0 = \frac{1-p'_{CL}}{1-(p'_{CL})^{C+1}} \\ p_k = (p'_L)^k p_0, 0 < k \leq C \\ p'_L = \frac{\lambda + p_{CL}}{\mu} \end{cases} \tag{6}$$

For $p_k = (p'_L)^k p_0 = \frac{(1-p'_{CL})(p'_{CL})^k}{1-(p'_{CL})^{C+1}}$, sum up $p_k, k = L, \cdots, C$, we can get:

$$(p'_{CL})^L - (p'_{CL})^{C+1} = (\mu p'_{CL} - \mu(p'_{CL})^{C+2} - \lambda + \lambda(p'_{CL})^{C+1})T$$

III-C Exponential Flooding

p_{ef} is the flooding probability of exponential flooding, similar to the analysis of the threshold flooding in last section, we get

$$\begin{cases} p_0 = \frac{1-p'_{ef}}{1-(p'_{ef})^{C+1}} \\ p_k = (p'_{ef})^k p_0, 0 < k \leq C \\ p'_{ef} = \frac{\lambda + p_{ef}}{\mu} \end{cases} \tag{7}$$

$$p_{ef} = \frac{1}{T}\sum_{k=0}^{K} p_{2^k} = p_0 \frac{1}{T}\sum_{k=0}^{K} (p'_{ef})^{2^k}$$

By further abbreviation, we get: $T(\mu p'_{ef} - \lambda)[1-(p'_{ef})^{C+1}] = (1-p'_{ef})\sum_{k=0}^{K}(p'_{ef})^{2^k}$ We can get the asymptotic solution of above equation and the flooding probability of exponential flooding p_{ef} can be get accordingly.

III-D Δ Flooding

$p_{\Delta f}$ is the flooding probability of Δ flooding, similar to previous analysis, we get:

$$Tp_{\Delta f}\left[1 - (\frac{\lambda + p_{\Delta f}}{\mu})^{C+1}\right] = (1 - \frac{\lambda + p_{\Delta f}}{\mu})\sum_{i=0}^{C}(\frac{\lambda + p_{\Delta} f}{\mu})^i \sum_{k=0}^{C-i}\Lambda_k \sum_{\substack{m=0 \\ |k-m| \geq \Delta}}^{k+i} U_m$$

Based on Burke's theorem [5], the output of an $M/M/S$ queue is poisson with the same parameter as the input. So we have $\Lambda_k = \frac{(\lambda \times T)^k}{k!}e^{-\lambda T}, U_m = \frac{(\lambda \times T)^m}{m!}e^{-\lambda T}$.

$$\begin{cases} p_0 = \frac{1-p'_{\Delta f}}{1-(p'_{\Delta f})^{C+1}} \\ p_k = (p'_{\Delta f})^k p_0, 0 < k \leq C \\ p'_{\Delta f} = \frac{\lambda + p_{\Delta f}}{\mu} \end{cases} \tag{8}$$

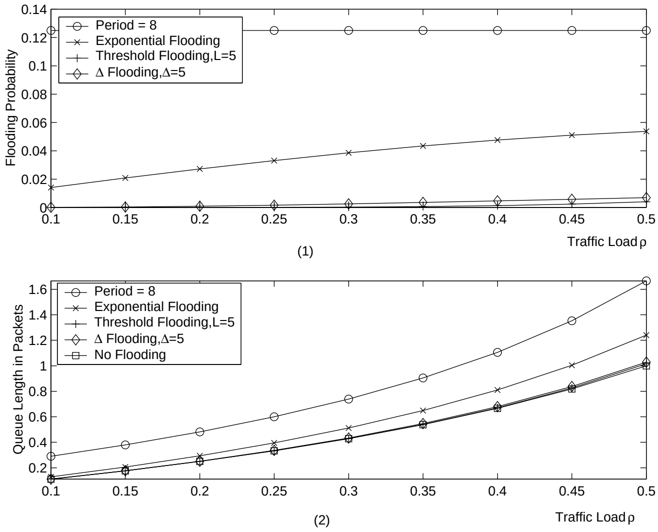

Figure 1: Calculation Result for Flooding Probabilities (1) and Average Queue Length (2)

Fig.1 gives the calculation result based on the analytical format. Fig. 1 (1) shows the comparison of flooding probability of each scheme. Fig.1 (2) gives the average queue length when different flooding scheme is adopted. The X-axis of the figures are $\rho = \frac{\lambda}{\mu}$, where λ is the mean packet arrival rate and μ is the mean network element service rate. From Fig.1, we can see that Lazy Flooding schemes can reduce the flooding probability and queue length significantly.

III-E Experiment Results for Single Link

We have analyzed the flooding probability, mean queue length of different Lazy Flooding schemes, which reflects the gain of Lazy Flooding. In this section, we conduct a discrete event simulation to validate the analytical results in the previous section.

III-E.1 Simulation Environment

We consider a single link network with traffic load ranges from 0.1 to 0.5. Packets comes to the link are generated based on a Poisson distribution, and the length of each packet conforms to an exponential distribution with average packet size being 800 bytes. The flooding period T is set to 8 seconds,the same as the value used in the case study of the theoretical calculation. For all the Lazy Flooding schemes, we set the flooding threshold to be $L = 5$,$\Delta = 5$.The queue length of the link is monitored, and LSA is flooded out if the flooding conditions are satisfied. We consider flooding probability, mean queue length to investigate the difference between analytical and experimental results. It turns out that their difference is negligible.

III-E.2 Single Link Simulation Result

Fig.2 gives the comparison of the analytical and simulation flooding probabilities for different flooding schemes. X-axis is the traffic load which varies from 0.1 to 0.5, Y-axis is the flooding probabilities. With period set to $8s$, the flooding probability

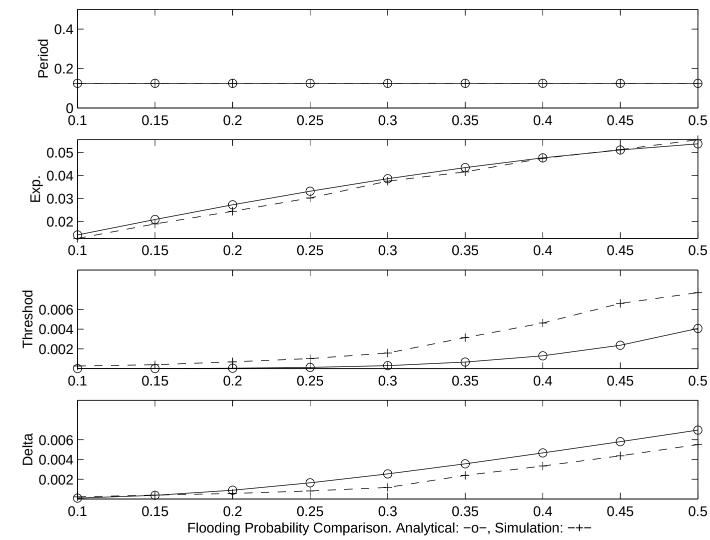

Figure 2: Flooding Probability Comparison between Analytical and Simulation Result

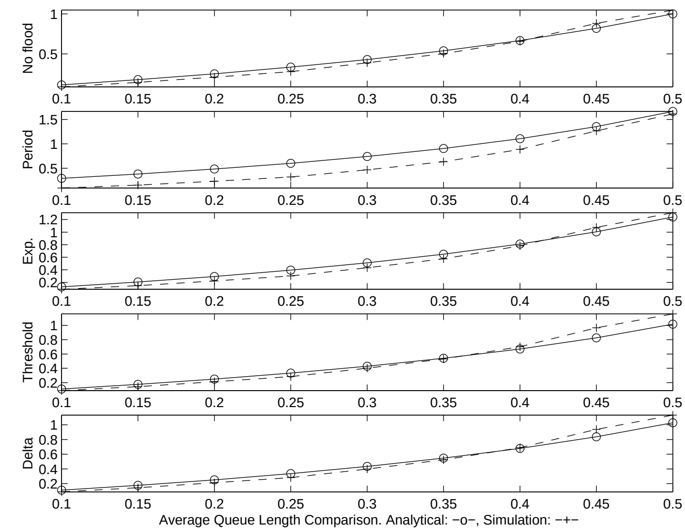

Figure 3: Average Queue Length Comparison between Analytical and Simulation Result

for Periodic Flooding is always 0.125, while the flooding probability of Threshold Flooding is from 0.0002 to 0.007, the flooding probability of Exponential Flooding is from 0.0125 to 0.055, and the flooding probability of Δ Flooding is from 0.0002 to 0.00055. The difference between theoretical and experimental result is no more than 0.002 for any flooding schemes. Fig.3 gives the comparison of the analytical and simulation queue length for different flooding schemes. X-axis is the traffic load which varies from 0.1 to 0.5, Y-axis is the number of packets in the queue. From these figures we can see that, the analytical estimation of queue length is quite accurate and the difference is no more than 0.1 packet.

IV Experiment Results for Networks

In previous section, we have given an analytical model for flooding schemes in single link scenario. It is difficult to give a close form expression for the overall network performance. In this part, we use discrete event simulation to study the impact of different flooding schemes on network performance.

IV-A Simulation Environment

The network simulation is on a 14 nodes network that has a similar topology as NSFnet in U.S.A. [7]. In this simulation, the parameters are the same as that of single link simulation.The path for each packet is calculated based on two shortest path algorithms. Their difference is the weight assignment: one is insensitive to the link load and the other is sensitive to the link load.

- **Algorithm 1:** Every link is assigned $weight = 1$, then we find a path with the least number of hops by Dijkstra shortest path algorithm.

- **Algorithm 2:** Every link is assigned $weight = (2 \times H + 1)^{\alpha}$, where $\alpha = 1 - \frac{C}{B}$ is the load of the link and H is the network diameter. C is the available bandwidth of the link. Then we find a path, in which every link weight exponentially increases with its traffic load, by Dijkstra shortest path algorithm.

For the simulated traffic from node i to node j, $average\ packet\ delay$, is calculated. With periodic T, the queue length of each link is checked. A random timer is used to control that nodes in the network do not check the link at the same time to avoid flooding storm. If the queue length satisfies the flooding condition, an LSA is flooded out, and the new information on the link resource is carried to all the other nodes in the network. The packets transmitted by the nodes should follow the path calculated based on the new resource.

IV-B Network Simulation Result

Algorithm 1 is topology driven and not sensitive to the link state.Fig.4 compares average delays between Lazy Floodings and Period Flooding when algorithm 1 is used. The X-axis of all the figures is traffic load and the Y-axis is network delay in the unit of million second. From these figures we can see that periodic flooding can increase network delay largely, while Lazy Flooding schemes have a quite little impact on the network performance.

Algorithm 2 is sensitive to the link state, that is, when bandwidth usage of a link increases, its weight also increases such that traffic in a network is routed to avoid a much loaded link. Fig.5 compares average delays between lazy floodings and period flooding when algorithm 2 is used. X-axis of these figures is traffic load and Y-axis is the network delay in unit of million second. From these figures we can see that Periodic Flooding can increase network delay greatly, Lazy Floodings have little impact on transmission delay of best-effort traffic. Comparing with algorithm 1, the packet delay is much reduced and when

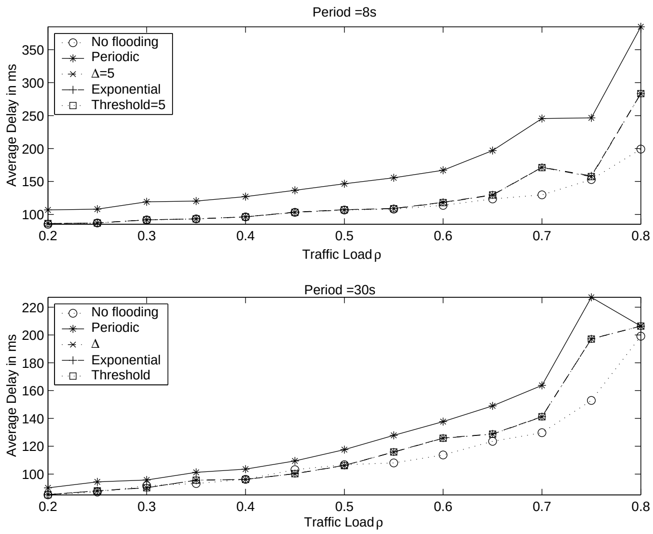

Figure 4: Algorithm 1: Average Delay Comparison

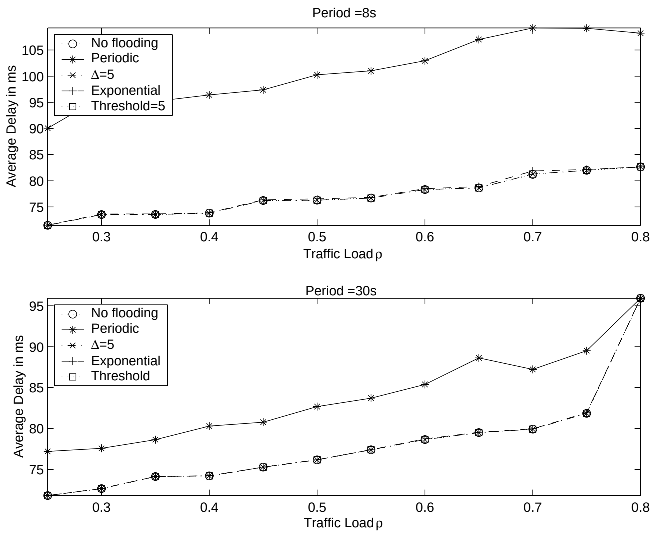

Figure 5: Algorithm 2: Average Delay Comparison.

traffic load increases, the increasing of packet delay is much slow.

V Conclusion

We have studied four flooding methods: Periodic, Threshold, Exponential, and Δ. We have shown how much traffic can be added to a link by different flooding schemes. Comparing with Periodic Flooding, Lazy Floodings significantly reduce the flooding traffic and their impact on the delay of best-effort traffic is negligible. For a whole network, when a topology driven shortest path algorithm is adopted to calculate path for best-effort traffic, less traffic results in less message delay and the Lazy Flooding schemes are certain to provide better network performance. When a load balancing routing algorithm is adopted and link utilization is considered when computing a path, more flooding can help routers to get more accurate link resource information and route packets to less loaded links such that the blocking rate for QoS routing can be reduced. But for best-effort traffic, the difference resulted by Lazy Flooding schemes is negligible. Combining our study and previous work, we believe that a good flooding scheme should consider its effect on traffic with and without QoS requirement.

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