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Prioritized Treatment of Specific OSPF Packets and Congestion Avoidance

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Abstract

This document proposes methods that are intended to improve the scalability and stability of large networks using OSPF protocol. The methods include processing OSPF Hellos and LSA Acknowledgements at a higher priority compared to other OSPF packets, and other congestion avoidance procedures. Simulation results in support of some of the proposals are given in the appendix sections.

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1. Motivation

A large network running OSPF [Ref1] or OSPF-TE [Ref2] protocol may occasionally experience the simultaneous or near-simultaneous update of a large number of link-state-advertisement messages, or LSAs. We call this event, an LSA storm and it may be initiated by an unscheduled failure or a scheduled maintenance or upgrade event. The failure may be hardware, software, or procedural in nature.

The LSA storm causes high CPU and memory utilization at the node processors causing incoming packets to be delayed or dropped. Delayed acknowledgements (beyond the retransmission timer value) results in retransmissions, and delayed Hello packets (beyond the router-dead interval) results in links being declared down. The retransmissions and additional LSA generations result in further CPU and memory usage, essentially causing a positive feedback loop, which, in the extreme case, may drive the network to an unstable state.

The default value of retransmission timer is 5 seconds and that of the router-dead interval is 40 seconds. However, recently there has been a lot of interest in significantly reducing OSPF convergence time and as part of that plan much shorter (subsecond) Hello and router-dead intervals have been proposed [Ref3]. In such a scenario it will be more likely for Hello packets to be delayed beyond the router-dead interval during a network congestion event caused by an LSA storm.

Appendix A explains in more detail LSA storm generation scenarios, its impact, and points out a few real-life examples of control-message storm generation. Appendix B presents a simulation study on this phenomenon.

In order to improve the scalability and stability of networks we propose steps for prioritizing critical OSPF packets and avoiding congestion. The details of the proposals are given in Section 2. We also do a simulation study on a subset of the proposals in Appendix B and show that they indeed improve the scalability and stability of networks using OSPF protocol.

Appendix C provides some further proposals with similar goals.

2. The Proposals

The proposals below are intended to improve the scalability and stability of large networks using OSPF protocol. During periods of network congestion they would reduce retransmissions, avoid an interface to be declared down due to Hello packets being delayed beyond the RouterDeadInterval, and take other congestion avoidance steps.

Either all, or a subset of the proposals may be implemented by a Router. It is also possible for some routers to implement them fully or partially, and others to not implement them at all.

(1) Classify all OSPF packets in two classes: a "high priority" class comprising of OSPF Hello packets and Link State Acknowledgement packets, and a "low priority" class comprising of all other packets. The classification is accomplished by examining the OSPF packet header. While receiving a packet from a neighbor and while transmitting a packet to a neighbor, try to process a "high priority" packet ahead of a "low priority" packet.

(2) Reset the Inactivity Timer for an interface whenever any OSPF packet is received over that interface (currently this is done only for the Hello packet).
So OSPF would declare the interface to be down only if no OSPF packet is received over that interface for a period equaling or exceeding the RouterDeadInterval.

(3) Use an Exponential Backoff algorithm for determining the value of the LSA retransmission interval (RxmtInterval). Let R(i) represent the RxmtInterval value used during the i-th retransmission of an LSA. Use the following algorithm to compute R(i)

```
R(1) = Rmin
R(i+1) = Min(KR(i),Rmax)  for i>=1
```

where K, Rmin and Rmax are constants and the function Min(.,.) represents the minimum value of its two arguments. Example values for K, Rmin and Rmax may be 2, 5 seconds and 40 seconds respectively.

(4) Implicit Congestion Detection and Action Based on That: If there is control message congestion at a node, its neighbors do not know about that explicitly. However, they can implicitly detect it based on the number of unacknowledged LSAs to this node. If this number exceeds a certain "high water mark" then the rate at which LSAs are sent to this node should be reduced. At a future time, if the number of unacknowledged LSAs to this node falls below a certain "low water mark" then the normal rate of sending LSAs to this node should be resumed. An example value for the "high water mark" may be 20 unacknowledged LSAs and that for the "low water mark" may be 10 unacknowledged LSAs. An example value for the rate on exceeding the "high water mark" may be 50% the normal rate.

(5) Throttling Adjacencies to be Brought Up Simultaneously: If a node tries to bring up a large number of adjacencies to its neighbors simultaneously then that may cause severe congestion due to database synchronization and LSA flooding activities. It is recommended that during such a situation no more than "n" adjacencies should be brought up simultaneously. Once a subset of adjacencies have been brought up successfully, newer adjacencies may be brought up as long as the number of simultaneous adjacencies being brought up does not exceed "n". An example value for "n" may be 4.

3. Security Considerations

This memo does not create any new security issues for the OSPF protocol. Security considerations for the base OSPF protocol are covered in [Ref1].

4. Acknowledgments

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Appendix A. LSA Storm: Causes and Impact

An LSA storm may be initiated due to many reasons. Here are some examples:

(a) one or more link failures due to fiber cuts,

(b) one or more node failures for some reason, e.g., software crash or some type of disaster (including power outage) in an office complex hosting many nodes,

(c) Link/node flapping,

(d) requirement of taking down and later bringing back many nodes during a software/hardware upgrade,

(e) near-synchronization of the once-in-30-minutes refresh instants of a subset of LSAs,

(f) refresh of all LSAs in the system during a change in software version,

(g) injecting a large number of external routes to OSPF due to
    a procedural error.

In addition to the LSAs generated as a direct result of link/node failures, there may be other indirect LSAs as well. One example in MPLS networks is traffic engineering LSAs generated at other links as a result of significant change in reserved bandwidth resulting from rerouting of Label Switched Paths (LSPs) that went down during the link/node failure.

The LSA storm causes high CPU and memory utilization at the node processors causing incoming packets to be delayed or dropped. Delayed acknowledgements (beyond the retransmission timer value) results in retransmissions, and delayed Hello packets (beyond the Router-Dead interval) results in links being declared down. A trunk-down event causes Router LSA generation by its end-point nodes. If traffic engineering LSAs are used for each link then that type of LSAs would also be generated by the end-point nodes and potentially elsewhere as well due to significant changes in reserved bandwidths at other links caused by the failure and reroute of LSPs originally using the failed trunk. Eventually, when the link recovers that would also trigger additional Router and traffic engineering LSAs.

The retransmissions and additional LSA generations result in further CPU and memory usage, essentially causing a positive feedback loop. We define the LSA storm size as the number of LSAs in the original storm and not counting any additional LSAs resulting from the feedback loop described above. If the LSA storm is too large then

the positive feedback loop mentioned above may be large enough to indefinitely sustain a large CPU and memory utilization at many network nodes, thereby driving the network to an unstable state. In the past, network
outage events have been reported in IP and ATM networks using link-state protocols such as OSPF, IS-IS, PNNI or some proprietary variants. See, for example [Ref4-Ref7]. In many of these examples, large scale flooding of LSAs or other similar control messages (either naturally or triggered by some bug or inappropriate procedure) have been partly or fully responsible for network instability and outage.

In Appendix B, we use a simulation model to show that there is a certain LSA storm
size threshold above which the network may show unstable behavior caused by large number of retransmissions, link failures due to missed Hello packets and subsequent link recoveries. We also show that the LSA storm size causing instability may be substantially increased by providing prioritized treatment to Hello and LSA

Acknowledgment packets and by using an exponential backoff algorithm for determining the LSA retransmission interval. Furthermore, if we prioritize Hello packets then even when the network operates somewhat above the stability threshold, links are not declared down due to missed Hellos. This implies that even though there is control plane congestion due to many retransmissions, the data plane stays up and no new LSAs are generated (besides the ones in the original storm and the refreshes). These observations are the basis of the first three proposals in Section 2.

One might argue that the scalability issue of large networks should be solved solely by dividing the network hierarchically into multiple areas so that flooding of LSAs remains localized within areas. However, this approach increases the network management and design complexity and may result in less optimal routing between areas. Also, ASE LSAs are flooded throughout the AS and it may be a problem if there are large numbers of them. Furthermore, a large number of summary LSAs may need to be flooded across Areas and their numbers would increase significantly if multiple Area Border Routers are employed for the purpose of reliability. Thus it is important to allow the network to grow towards as large a size as possible under a single area.

Our proposal here is synergistic with a broader set of scalability and stability improvement proposals. [Ref8, Ref9] proposes flooding overhead reduction in case more than one interface goes to the same neighbor. [Ref10] proposes a mechanism for greatly reducing LSA refreshes in stable topologies. [Ref11] proposes a wide range of congestion control and failure recovery mechanisms.

Appendix B. Simulation Study

The main motivation of this study is to show the network congestion and instability caused by large LSA storms and the improvement in stability and scalability that can be achieved by following the proposals in this memo.

Appendix B.1. The Network Under Simulation

We generate a random network over a rectangular grid using a modified version of Waxman's algorithm [Ref12] that ensures that the network is connected and has a pre-specified number of nodes, links, maximum number of neighbors per node, and maximum number of adjacencies per node. The rectangular grid resembles the continental U.S.A. with maximum one-way propagation delay of 30 ms in the East-West direction and maximum one-way propagation delay of 15 ms in the North-South direction. We consider two different network sizes as explained in Section B.2.

The network has a flat, single-area topology.

Each node is a Router and each link is a point-to-point link connecting two routers.

We assume that node CPU and memory (not the link bandwidth) is the main bottleneck in the LSA flooding process. This will typically be true for high speed links (e.g., OC3 or above) and/or links where OSPF traffic gets an adequate Quality of Service (QoS) compared to other traffic.

Different Timers:

  LSA refresh interval = 1800 seconds,
  Hello refresh interval = 10 Seconds,
  Router-Dead interval = 40 seconds,
  LSA retransmission interval: two values are considered, 10 seconds and 5 Seconds (note that a retransmission is disabled on the receipt of either an explicit acknowledgment or a duplicate LSA over the same interface that acts as an implicit acknowledgment)
  Minimum time between successive generation of the same LSA = 5 seconds,
  Minimum time between successive Dijkstra SPF calculations is 1 second.

Packing of LSAs: It is assumed that for any given node, the LSAs generated over a 1-second period are packed together to form an LSU but no more than 3 LSAs are packed in one LSU.

LSU/Ack/Hello Processing Times: All processing times are expressed in terms of the parameter T. Two values of T are considered, 1 ms and 0.5 ms.

In the case of a dedicated processor for processing OSPF packets the processing time reported represents the true processing time. If the processor does other work and only a fraction of its capacity can be dedicated to OSPF processing then we have to inflate the processing time appropriately to get the effective processing time and in that case it is assumed that the inflation factor is already taken into account as part of the reported processing time.

The fixed time to send or receive any LSU, Ack or Hello packet is T. In addition, a variable processing time is used for LSU and Ack depending on the number and types of LSAs packed. No variable processing time is used for Hello.
Variable processing time per Router LSA is (0.5 + 0.17L)T where L is the number of adjacencies advertised by the Router LSA. For other LSA types (e.g., ASE LSA or a "Link" LSA carrying traffic engineering information about a link), the variable processing time per LSA is 0.5T.

Variable processing time for an Ack is 25% that of the corresponding

LSA.

It is to be noted that if multiple LSAs are packed in a single LSU packet then the fixed processing time is needed only once but the variable processing time is needed for every component of the packet.

The processing time values we use are roughly in the same range of what has been observed in an operational network.

LSU/Ack/Hello Priority: Two non-preemptive priority levels and three priority scenarios are considered. Within each priority level processing is FIFO with new packets of lower priority being dropped when the lower priority queue is full. The higher priority packets are never dropped.

   In Priority scenario 1, all LSUs/Acks/Hellos received at a node are queued at the lower priority.

   In Priority scenario 2, Hellos received at a node are queued at the higher priority but LSUs/Acks are queued at lower priority.

   In Priority scenario 3, Hellos and Acks received at a node are queued at the higher priority but LSUs are queued at lower priority.

All packets generated internally to a node (usually triggered by a timer) are processed at the higher priority. This includes the initial LSA storm, LSA refresh, Hello refresh, LSA retransmission and new LSA generation after detection of a failure or recovery.

Buffer Size for Incoming LSUs/Acks/Hellos (lower priority): Buffer size is assumed to be 2000 packets where a packet is either an Ack, LSU, or Hello.

LSA Refresh: Each LSA is refreshed once in 1800 seconds and the refresh instants of various LSAs in the LSDB are assumed to be uniformly distributed over the 1800 seconds period, i.e., they are completely unsynchronized. If however, an LSA is generated as part of the initial LSA storm then it goes on a new refresh schedule of once in 1800 seconds starting from its generation time.

LSA Storm Generation: As defined earlier, "LSA storm" is the simultaneous or near simultaneous generation of a large number of LSAs. In the case of only Router and ASE LSAs we normally assume that the number of ASE LSAs in the storm is about 4 times that of the Router LSAs, but the ratio is allowed to change if either the Router or the ASE LSAs have reached their maximum possible value. In the case of only Router and Link LSAs (carrying traffic engineering information) we normally assume that the number of Link LSAs in the storm is about 4 times that of the Router LSAs, but the ratio is allowed to change if either the Router or the Link LSAs have reached their maximum possible value. For any given LSA storm we keep generating LSAs starting from Node index 1 and moving upwards and stop until the correct number of LSAs of each type have

been generated. The LSAs generated at any given node is assumed to
start at an instant uniformly distributed between 20 and 30 seconds

from the start of the simulation. Successive LSA generations at a node are assumed to be spaced apart by 400 ms. It is to be noted that during the period of observation there are other LSAs generated besides the ones in the storm. These include refresh of LSAs that are not part of the storm and LSAs generated due to possible link failures and subsequent possible link recoveries.

Failure/Recovery of Links: If no Hello is received over a link (due to CPU/memory congestion) for longer than Router-Dead Interval then the link is declared down. At a later time, if Hellos are received then the link would be declared up. Whenever a link is declared up or down, one Router LSA is generated by each Router on the two sides of the point-to-point link. If "Link LSAs" carrying traffic engineering information is used then it is assumed that each Router would also generate a Link LSA. In this case it is also assumed that due to rerouting of LSPs, three other links in the network (selected randomly in the simulation) would have significant change in reserved bandwidth which would result in one Link LSA being generated by the routers on the two ends of each such link.

Appendix B.2. Simulation Results

In this section we study the relative performance of the three priority scenarios defined earlier (no priority to Hello or Ack, priority to Hello only, and priority to both Hello and Ack) with a range of Network sizes, LSA retransmission timer values, LSA types, processing time values and Hello/Router-Dead-Interval values:

Network size: Two networks are considered. Network 1 has 100 nodes, 1200 links, maximum number of neighbors per node is 30 and maximum number of adjacencies per node is 50 (same neighbor may have more than one adjacencies).   Network 2 has 50 nodes, 600 links, maximum number of neighbors per node is 25 and maximum number of adjacencies per node is 48. Dijkstra SPF calculation time for Network 1 is assumed to be 100 ms and that for Network 2 is assumed to be 70 ms.

LSA Type: Each node has 1 Router LSA (Total of 100 for Network 1 and 50 for Network 2). There are no Network LSAs since all links are point-to-point links and no Summary LSAs since the network has only one area. Regarding other LSA types we consider two situations. In Situation 1 we assume that there are no ASE LSAs and each link has one "Link" LSA carrying traffic engineering information (Total of 2400 for Network 1 and 1200 for Network 2). In Situation 2 we assume that there are no "Link" LSAs and half of the nodes are ASA-Border nodes and each border node has 10 ASE LSAs (Total of 500 for Network 1 and 250 for Network 2). We identify Situation 1 as "Link LSAs" and Situation 2 as "ASE LSAs".

LSA retransmission timer value: Two values are considered, 10
seconds and 5 seconds (default value).

Processing time values: Processing times for LSUs, Acks and Hello packets have been previously expressed in terms of a common parameter T. Two values are considered for T, which are 1 ms and 0.5 ms respectively.

Hello/Router-Dead-Interval: It is assumed that Router-Dead interval is four times the Hello interval. In one case it is assumed that Hello interval is 10 seconds and Router-Dead-Interval is 40 seconds (default values), and in the other case it is assumed that Hello interval is 2 seconds and Router-Dead-Interval is 8 seconds.

Based on Network size, LSA type and processing time values we develop 6 Test cases as follows:

```
Case 1: Network 1, Link LSAs, retransmission timer = 10 sec.,
        T = 1 ms, Hello/Router-Dead-Interval = 10/40 sec.

Case 2: Network 1, ASE LSAs, retransmission timer = 10 sec.,
        T = 1 ms, Hello/Router-Dead-Interval = 10/40 sec.

Case 3: Network 1, Link LSAs, retransmission timer = 5 sec.,
        T = 1 ms, Hello/Router-Dead-Interval = 10/40 sec.

Case 4: Network 1, Link LSAs, retransmission timer = 10 sec.,
        T = 0.5 ms, Hello/Router-Dead-Interval = 10/40 sec.

Case 5: Network 1, Link LSAs, retransmission timer = 10 sec.,
        T = 1 ms, Hello/Router-Dead-Interval = 2/8 sec.

Case 6: Network 2, Link LSAs, retransmission timer = 10 sec.,
        T = 1 ms, Hello/Router-Dead-Interval = 10/40 sec.
```

For each case and for each Priority scenario we study the network stability as a function of the size of the LSA storm. The stability is determined by looking at the number of non-converged LSUs as a function of time. An example is shown in Table 1 for Case 1 and Priority scenario 1 (No priority to Hellos or Acks).

LSA STORM SIZE	Number of Non-Converged LSUs in the Network at Time(in sec)								
	10s	20s	30s	35s	40s	50s	60s	80s	100s
100 (Stable)	0	0	24	29	24	1	0	1	1
140 (Stable)	0	0	35	48	46	27	14	1	1
160 (Unstable)	0	0	38	57	55	40	26	65	203

Table 1: Network Stability Vs. LSA Storm
(Case 1, No priority to Hello/Ack)

The LSA storm starts a little after 20 seconds and so for some period of time after that the number of non-converged LSUs should stay high and then come down for a stable network.
This happens for LSA storms of sizes 100 and 140. With an LSA storm of size 160, the number of non-converged LSUs stay high indefinitely due to repeated retransmissions, link failures due to missed Hellos for more than the Router-Dead interval which generates additional LSAs and also due to subsequent link recoveries which again generate additional LSAs. We define network stability threshold as the maximum allowable LSA storm size for which the number of non-converged LSUs come down to a low level after some time. It turns out that for this example the stability threshold is 150.

The network behavior as a function of the LSA storm size can be categorized as follows:

(1) If the LSA storm is well below the stability threshold then the CPU/memory congestion lasts only for a short period and during this period there are very few retransmissions, very few dropped OSPF packets and no link failures due to missed Hellos. This type of LSA storms are observed routinely in operational networks and networks recover from them easily.

(2) If the LSA storm is just below the stability threshold then the CPU/memory congestion lasts for a longer period and during this period there may be considerable amount of retransmissions and dropped OSPF packets. If Hello packets are not given

priority then there may also be some link failures due to missed Hellos. However, the network does go back to a stable state eventually. This type of LSA storm may happen rarely in operational networks and they recover from it with some difficulty.

(3) If the LSA storm is above the stability threshold then the CPU/memory congestion may last indefinitely unless some special procedure for relieving congestion is followed. During this period there are considerable amount of retransmissions and dropped OSPF packets. If Hello packets are not given priority then there would also be link failures due to missed Hellos. This type of LSA storm may happen very rarely in operational networks and usually some manual procedure such as taking down adjacencies in heavily congested nodes is needed.

(4) If Hello packets are given priority then the network stability threshold increases, i.e., the network can withstand a larger LSA storm. Furthermore, even if the network operates at or somewhat above this higher stability threshold, Hellos are still not missed and so there are no link failures. So even if there is congestion in the control plane due to increased retransmissions requiring some special procedures for congestion reduction, the data plane remains unaffected.

(5) If both Hello and Acknowledgement packets are given priority then the stability threshold increases even further.

In Table 2 we show the network stability threshold for the five different cases and for the three different priority scenarios defined earlier.

Case Number	Maximum Allowable LSA Storm Size For		
	No Priority to Hello or Ack	Priority to Hello Only	Priority to Hello and Ack
Case 1	150	190	250
Case 2	185	215	285
Case 3	115	127	170
Case 4	320	375	580
Case 5	120	175	225
Case 6	185	224	285

Table 2: Maximum Allowable LSA Storm for a Stable Network

We also considered one more scenario with priority to Hello and Ack and with a truncated binary exponential backoff of the retransmission interval with an upper limit of 40 seconds (for the same LSA, each successive retransmission interval is doubled but not to exceed 40 seconds). The maximum allowed LSA storm size for this scenario significantly exceeded the numbers given in the third column.

Appendix B.3. Observations on Simulation Results

Table 2 shows that in all cases prioritizing Hello packets increases the network stability threshold, and in addition, prioritization of LSA Acknowledgment packets increases the stability threshold even further. The reasons for the above observations are as follows. The main sources of sustained CPU/memory congestion (or positive feedback loop) following an LSA storm are (1) LSA retransmissions and (2) links being declared down due to missed Hellos which in turn causes further LSA generation and future recovery of the link causing even more LSA generation.
Prioritizing Hello packets avoids and practically eliminates the second source of congestion. Prioritizing Acknowledgements significantly reduces the first source of congestion, i.e., LSA retransmissions. It is to be noted that retransmissions can not be completely eliminated due to the following reasons. Firstly, only the explicit Acknowledgments are prioritized but duplicate LSAs carrying implicit Acknowledgments are still served at the lower priority. Secondly, LSAs may get greatly delayed or dropped at the input queue of receivers and therefore Acknowledgments may not even get generated in which case prioritizing Acks would not help. Another factor to keep in mind is that since Hellos and Acks are prioritized, the LSAs see bigger delay and potential for dropping. However, the simulation results show that on the whole prioritizing Hello and LSA Acks are always beneficial and significantly improve the network stability threshold.

As stated in Section B.2, exponenetial backoff of LSA retransmission interval further increases the network stability threshold.

Our simulation study also showed that in each of the cases, instead of prioritizing Hello packets if we treat any packet received over a link as a surrogate for a Hello packet (an implicit Hello) then we get about the same stability threshold as obtained with prioritizing Hello packets.

Appendix C. Other Proposals

(1) Explicit Marking: In Section 2 we proposed that OSPF packets

be classified to "high" and "low" priority classes based on
examining the OSPF packet header. In some cases (particularly

in the receiver) this examination may be computationally costly. An alternative would be the use of different TOS (DSCP) bits marking for high and low priority OSPF packets respectively. The exact specification of this marking is for further study.

(2) Other High Priority OSPF Packets: Besides the packets designated as high priority in Section 2 there may be other packets with a need for high priority designation. One example is the Database Description (DBD) packet from a slave (during the database synchronization process) that is used as an acknowledgement. A second example is an LSA carrying intra-area topology change information (this may trigger SPF calculation and rerouting of Label Switched paths and so fast processing of this packet may improve OSPF/LDP convergence times).