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LTP Fragmentation
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Abstract

The Licklider Transmission Protocol (LTP) provides a reliable datagram convergence layer for the Delay/Disruption Tolerant Networking (DTN) Bundle Protocol. In common practice, LTP is often configured over UDP/IP sockets and inherits its maximum segment size from the maximum-sized UDP datagram, however when this size exceeds the maximum IP packet size for the path a service known as IP fragmentation must be employed. This document discusses LTP interactions with IP fragmentation and mitigations for managing the amount of IP fragmentation employed.

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[1.](#) Introduction

The Licklider Transmission Protocol (LTP) [[RFC5326](#)] provides a reliable datagram convergence layer for the Delay/Disruption Tolerant Networking (DTN) Bundle Protocol (BP) [[I-D.ietf-dtn-bpbis](#)]. In common practice, LTP is often configured over the User Datagram Protocol (UDP) [[RFC0768](#)] and Internet Protocol (IP) [[RFC0791](#)] using the "socket" abstraction. LTP inherits its maximum segment size from the maximum-sized UDP datagram (i.e. 2^{16} bytes minus header sizes), however when the UDP datagram size exceeds the maximum IP packet size for the path a service known as IP fragmentation must be employed.

LTP breaks BP bundles into "blocks", then further breaks these blocks into "segments". The segment size is a configurable option and represents the largest atomic block of data that LTP will require underlying layers to deliver as a single unit. The segment size is therefore also known as the "retransmission unit", since each lost segment must be retransmitted in its entirety. Experimental and operational evidence has shown that on robust networks increasing the LTP segment size (up to the maximum UDP datagram size of slightly less than 64KB) can result in substantial performance increases over smaller segment sizes. However, the performance increases must be tempered with the amount of IP fragmentation invoked as discussed below.

When LTP presents a segment to the operating system kernel (e.g., via a `sendmsg()` system call), the UDP layer prepends a UDP header to

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create a UDP datagram. The UDP layer then presents the resulting datagram to the IP layer for packet framing and transmission over a networked path. The path is further characterized by the path Maximum Transmission Unit (Path-MTU) which is a measure of the smallest link MTU (Link-MTU) among all links in the path.

When LTP presents a segment to the kernel that is larger than the Path-MTU, the resulting UDP datagram is presented to the IP layer, which in turn performs IP fragmentation to break the datagram into fragments that are no larger than the Path-MTU. For example, if the LTP segment size is 64KB and the Path-MTU is 1280 bytes IP fragmentation results in 50+ fragments that are transmitted as individual IP packets. (Note that for IPv4 [[RFC0791](#)], fragmentation may occur either in the source host or in a router in the network path, while for IPv6 [[RFC8200](#)] only the source host may perform fragmentation.)

Each IP fragment is subject to the same best-effort delivery service offered by the network according to current congestion and/or link signal quality conditions; therefore, the IP fragment size becomes known as the "loss unit". Especially when the packet loss rate is non-negligible, however, performance can suffer dramatically when the loss unit is significantly smaller than the retransmission unit. In particular, if even a single IP fragment of a fragmented LTP segment is lost then the entire LTP segment is deemed lost and must be retransmitted.

This document discusses LTP interactions with IP fragmentation and mitigations for managing the amount of IP fragmentation employed. It further discusses methods for increasing LTP performance both with and without the aid of IP fragmentation.

2. Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [BCP 14](#) [[RFC2119](#)][[RFC8174](#)] when, and only when, they appear in all capitals, as shown here.

3. IP Fragmentation Issues

IP fragmentation is a fundamental service of the Internet Protocol, yet it has long been understood that its use can be problematic in some environments. Beginning as early as 1987, "Fragmentation Considered Harmful" [[FRAG](#)] outlined multiple issues with the service including a performance-crippling condition that can occur at high data rates when the loss unit is considerably smaller than the

retransmission unit during intermittent and/or steady-state loss conditions.

Later investigations also identified the possibility for undetected data corruption at high data rates due to a condition known as "ID wraparound" when the 16-bit IP identification field (aka the "IP ID") increments such that new fragments overlap with existing fragments still alive in the network and with identical ID values [[RFC4963](#)][RFC6864]. Although this issue occurs only in the IPv4 protocol (and not in IPv6 where the IP ID is 32-bits in length), the IPv4 concerns along with the fact that IPv6 does not permit routers to perform "network fragmentation" have led many to discourage its use.

Even in the modern era, investigators have seen fit to declare "IP Fragmentation Considered Fragile" in an Internet Engineering Task Force (IETF) Best Current Practice (BCP) reference [[RFC8900](#)]. Indeed, the BCP recommendations cite the Bundle Protocol LTP convergence layer as a user of IP fragmentation that depends on some of its properties to realize greater performance. However, the BCP summarizes by saying:

"Rather than deprecating IP fragmentation, this document recommends that upper-layer protocols address the problem of fragmentation at their layer, reducing their reliance on IP fragmentation to the greatest degree possible."

While the performance implications are considerable and have serious implications for real-world applications, our goal in this document is neither to condemn nor embrace IP fragmentation as it pertains to the Bundle Protocol LTP convergence layer operating over UDP/IP sockets. Instead, we examine ways in which the benefits of IP fragmentation can be realized while avoiding the pitfalls. We therefore next discuss our systematic approach to LTP fragmentation.

[4.](#) LTP Fragmentation

In common LTP implementations over UDP/IP (e.g., the Interplanetary Overlay Network (ION)), performance is greatly dependent on the LTP segment size. This is due to the fact that a larger segment presented to UDP/IP as a single unit incurs only a single system call and a single data copy from application to kernel space via the `sendmsg()` system call. Once inside the kernel, the segment incurs UDP/IP encapsulation and IP fragmentation which again results in a loss unit smaller than the retransmission unit. However, during fragmentation, each fragment is transmitted immediately following the previous without delay so that the fragments appear as a "burst" of consecutive packets over the network path resulting in high network

utilization during the burst period. Additionally, the use of IP fragmentation with a larger segment size conserves header framing bytes since the LTP layer headers only appear in the first IP fragment as opposed to appearing in all IP packets.

In order to avoid retransmission congestion (i.e., especially when the loss probability is non-negligible), the natural choice would be to set the LTP segment size to a size that is no larger than the Path-MTU. Assuming the minimum IPv4 MTU of 576 bytes, however, transmission of 64KB of data using a 576B segment size would require well over 100 independent `sendmsg()` system calls and data copies as opposed to just one when the largest segment size is used. This greatly reduces the bandwidth advantage offered by IP fragmentation bursts. Therefore, a means for providing the best aspects of both large segment fragment bursting and small segment retransmission efficiency is needed.

Common operating systems such as linux provide the `sendmmsg()` ("send multiple messages") system call that allows the LTP application to present the kernel with a vector of up to 1024 segments instead of just a single segment. This affords the bursting behavior of IP fragmentation coupled with the retransmission efficiency of employing small segment sizes. (Note that LTP receivers can also use the `recvmmsg()` ("receive multiple messages") system call to receive a vector of segments from the kernel in case multiple recent packet arrivals can be combined.)

This work therefore recommends implementations of LTP to employ a large block size, a conservative segment size and a new configuration option known as the "Burst-Limit" which determines the number of segments that can be presented in a single `sendmmsg()` system call. When the implementation receives an LTP block, it carves Burst-Limit-many segments from the block and presents the vector of segments to `sendmmsg()`. The kernel will prepare each segment as an independent UDP/IP packet and transmit them into the network as a burst in a fashion that parallels IP fragmentation. The loss unit and retransmission unit will be the same, therefore loss of a single segment does not result in a retransmission congestion event.

It should be noted that the Burst-Limit is bounded only by the LTP block size and not by the maximum UDP datagram size. Therefore, each burst can in practice convey significantly more data than a single IP fragmentation event. It should also be noted that the segment size can still be made larger than the Path-MTU in low-loss environments without danger of triggering retransmission storms due to loss of IP fragments. This would result in combined UDP message and IP fragment bursting for increased network utilization in more robust environments. Finally, both the Burst-Limit and UDP message sizes

need not be static values, and can be tuned to adaptively increase or decrease according to time varying network conditions.

5. Beyond "sendmmsg()"

Implementation experience with the ION DTN distribution along with two recent studies have demonstrated performance increases for employing sendmmsg() for transmission over UDP/IP sockets. A first study used sendmmsg() as part of an integrated solution to produce 1M packets per second assuming only raw data transmission conditions [MPPS], while a second study focused on performance improvements for the QUIC reliable transport service [QUIC]. In both studies, the use of sendmmsg() alone produced observable increases but complimentary enhancements were identified that (when combined with sendmmsg()) produced considerable additional increases.

In [MPPS], additional enhancements such as using recvmmsg() and configuring multiple receive queues at the receiver were introduced in an attempt to achieve greater parallelism and engage multiple processors and threads. However, the system was still limited to a single thread until multiple receiving processes were introduced using the "SO_REUSEPORT" socket option. By having multiple receiving processes (each with its own socket buffer), the performance advantages of parallel processing were employed to achieve the 1M packets per second goal.

In [QUIC], a new feature available in recent linux kernel versions was employed. The feature, known as "Generic Segmentation Offload (GSO) / Generic Receive Offload (GRO)" allows an application to provide the kernel with a "super-buffer" containing up to 64 separate QUIC/UDP segments. When the application presents the super-buffer to the kernel, GSO segmentation then sends 64 separate UDP/IP packets in a burst. If each packet is larger than the Path-MTU, then IP fragmentation will be invoked for each packet leading to high network utilization (at the risk of IP fragment loss and retransmission storms). The GSO facility can be invoked by either sendmsg() (i.e., a single super-buffer) or sendmmsg() (i.e., multiple super-buffers), and the study showed a substantial performance increase over using just sendmsg() and sendmmsg() alone.

For LTP fragmentation, our ongoing efforts explore using these techniques in a manner that parallels the effort undertaken for QUIC. Using these higher-layer segmentation management facilities is consistent with the guidance in "IP Fragmentation Considered Fragile" that states:

"Rather than deprecating IP fragmentation, this document recommends that upper-layer protocols address the problem of

fragmentation at their layer, reducing their reliance on IP fragmentation to the greatest degree possible."

By addressing fragmentation at their layer, the LTP/UDP functions can then be tuned to minimize IP fragmentation in environments where it may be problematic or to adaptively engage IP fragmentation in environments where performance gains can be realized without risking data corruption.

6. Implementation Status

Supporting code for invoking the `sendmsg()` facility is included in the official ION source code distribution, beginning with release `ion-4.0.1`.

7. IANA Considerations

This document introduces no IANA considerations.

8. Security Considerations

Communications networking security is necessary to preserve confidentiality, integrity and availability.

9. Acknowledgements

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