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Tunneling Compressing and Multiplexing (TCM) Traffic Flows. Reference  
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## Abstract

Tunneling, Compressing and Multiplexing (TCM) is a method for improving the bandwidth utilization of network segments that carry multiple small-packet flows in parallel sharing a common path. The method combines different protocols for header compression, multiplexing, and tunneling over a network path for the purpose of reducing the bandwidth consumption. The amount of packets per second can be reduced at the same time.

This document describes the TCM framework and the different options which can be used for each of the three layers (header compression, multiplexing and tunneling).

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## 1. Introduction

This document describes a way to combine different protocols for header compression, multiplexing and tunneling to save bandwidth for applications that generate long-term flows of small packets.

### 1.1. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

### 1.2. Bandwidth efficiency of flows sending small packets

The interactivity demands of some real-time services (VoIP, videoconferencing, telemedicine, video surveillance, online gaming, etc.) make the applications generate a traffic profile consisting of high rates of small packets, which are necessary in order to transmit frequent updates between the two extremes of the communication. These services also demand low network delays. In addition, some other services also use small packets, although they are not delay-sensitive (e.g., instant messaging, M2M packets sending collected data in sensor networks or IoT scenarios using wireless or satellite links). For both the delay-sensitive and delay-insensitive applications, their small data payloads incur significant overhead.

When a number of flows based on small packets (small-packet flows) share the same path, their traffic can be optimized by multiplexing packets belonging to different flows. As a consequence, bandwidth can be saved and the amount of packets per second can be reduced. If a number of small packets are waiting in the buffer, they can be multiplexed and transmitted together. In addition, if a transmission queue has not already been formed but multiplexing is desired, it is necessary to add a delay in order to gather a number of packets. This delay has to be maintained under some threshold if the service presents tight delay requirements. It is a believed fact that this delay and jitter can be of the same order of magnitude or less than other common sources of delay and jitter currently present on the Internet without causing harm to flows that employ congestion control based on delay.

#### 1.2.1. Real-time applications using RTP

The first design of the Internet did not include any mechanism capable of guaranteeing an upper bound for delivery delay, taking into account that the first deployed services were e-mail, file

transfer, etc., in which delay is not critical. RTP [RTP] was first defined in 1996 in order to permit the delivery of real-time contents. Nowadays, although a variety of protocols are used for signaling real-time flows (SIP [SIP], H.323 [H.323], etc.), RTP has become the standard par excellence for the delivery of real-time content.

RTP was designed to work over UDP datagrams. This implies that an IPv4 packet carrying real-time information has to include (at least) 40 bytes of headers: 20 for the IPv4 header, 8 for UDP, and 12 for RTP. This overhead is significant, taking into account that many real-time services send very small payloads. It becomes even more significant with IPv6 packets, as the basic IPv6 header is twice the size of the IPv4 header. Table 1 illustrates the overhead problem of VoIP for two different codecs.

IPv4	IPv6
IPv4+UDP+RTP: 40 bytes header	IPv6+UDP+RTP: 60 bytes header
G.711 at 20 ms packetization: 25% header overhead	G.711 at 20 ms packetization: 37.5% header overhead
G.729 at 20 ms packetization: 200% header overhead	G.729 at 20 ms packetization: 300% header overhead

Table 1: Efficiency of different voice codecs

#### 1.2.2. Real-time applications not using RTP

At the same time, there are many real-time applications that do not use RTP. Some of them send UDP (but not RTP) packets, e.g., First Person Shooter (FPS) online games [First-person], for which latency is very critical. The quickness and the movements of the players are important, and can decide the result of the game. In addition to latency, these applications may be sensitive to jitter and, to a lesser extent, to packet loss, since they implement mechanisms for packet loss concealment [Gamers].

#### 1.2.3. Other applications generating small packets

Other applications without delay constraints are also becoming popular. Some examples are instant messaging, M2M packets sending collected data in sensor networks using wireless or satellite links, IoT traffic generated in Constrained RESTful Environments, where UDP packets are employed [RFC7252]. The number of wireless M2M (machine-to-machine) connections is steady growing since a few years, and a share of these is being used for delay-intolerant applications, e.g.,

industrial SCADA (Supervisory Control And Data Acquisition), power plant monitoring, smart grids, asset tracking.

#### 1.2.4. Optimization of small-packet flows

In the moments or places where network capacity gets scarce, allocating more bandwidth is a possible solution, but it implies a recurring cost. However, including optimization techniques between a pair of network nodes (able to reduce bandwidth and packets per second) when/where required is a one-time investment.

In scenarios including a bottleneck with a single Layer-3 hop, header compression standard algorithms [cRTP], [ECRTP], [IPHC], [ROHC] can be used for reducing the overhead of each flow, at the cost of additional processing.

However, if header compression is to be deployed in a network path including several Layer-3 hops, tunneling can be used at the same time in order to allow the header-compressed packets to travel end-to-end, thus avoiding the need to compress and decompress at each intermediate node. In these cases, compressed packets belonging to different flows can be multiplexed together, in order to share the tunnel overhead. In this case, a small multiplexing delay will be required as a counterpart, in order to join a number of packets to be sent together. This delay has to be maintained under a threshold in order to grant the delay requirements.

A series of recommendations about delay limits have been summarized in [I-D.suznjevic-dispatch-delay-limits], in order to maintain this additional delay and jitter in the same order of magnitude than other sources of jitter currently present on the Internet.

A demultiplexer and a decompressor are necessary at the end of the common path, so as to rebuild the packets as they were originally sent, making traffic optimization a transparent process for the origin and destination of the flow.

If only one stream is tunneled and compressed, then little bandwidth savings will be obtained. In contrast, multiplexing is helpful to amortize the overhead of the tunnel header over many payloads. The obtained savings grow with the number of flows optimized together [VoIP\_opt], [FPS\_opt].

All in all, the combined use of header compression and multiplexing provides a trade-off: bandwidth can be exchanged by processing capacity (mainly required for header compression and decompression) and a small additional delay (required for gathering a number of packets to be multiplexed together).

The processing delay can be kept really low. It has been shown that the additional delay can be in the order of 250 microseconds for commodity hardware [Simplemux\_CIT].

#### 1.2.5. Energy consumption considerations

As an additional benefit, the reduction of the sent information, and especially the reduction of the amount of packets per second to be managed by the intermediate routers, can be translated into a reduction of the overall energy consumption of network equipment. According to [Efficiency] internal packet processing engines and switching fabric require 60% and 18% of the power consumption of high-end routers respectively. Thus, reducing the number of packets to be managed and switched will reduce the overall energy consumption. The measurements deployed in [Power] on commercial routers corroborate this: a study using different packet sizes was presented, and the tests with big packets showed a reduction of the energy consumption, since a certain amount of energy is associated to header processing tasks, and not only to the sending of the packet itself.

All in all, another trade-off appears: on the one hand, energy consumption is increased in the two extremes due to header compression processing; on the other hand, energy consumption is reduced in the intermediate nodes because of the reduction of the number of packets transmitted. This tradeoff should be explored more deeply.

#### 1.3. Terminology

This document uses a number of terms to refer to the roles played by the entities using TCM.

- o native packet

A packet sent by an application, belonging to a flow that can be optimized by means of TCM.

- o native flow

A flow of native packets. It can be considered a "small-packet flow" when the vast majority of the generated packets present a low payload-to-header ratio.

- o TCM packet

A packet including a number of multiplexed and header-compressed native ones, and also a tunneling header.

- o TCM flow

A flow of TCM packets, each one including a number of multiplexed header-compressed packets.

- o TCM optimizer

The host where TCM optimization is deployed. It corresponds to both the ingress and the egress of the tunnel transporting the compressed and multiplexed packets.

If the optimizer compresses headers, multiplexes packets and creates the tunnel, it behaves as a "TCM-Ingress Optimizer", or "TCM-IO". It takes native packets or flows and "optimizes" them.

If it extracts packets from the tunnel, demultiplexes packets and decompresses headers, it behaves as a "TCM-Egress Optimizer", or "TCM-EO". The TCM-Egress Optimizer takes a TCM flow and "rebuilds" the native packets as they were originally sent.

- o TCM session

The relationship between a pair of TCM optimizers exchanging TCM packets.

- o policy manager

A network entity which makes the decisions about TCM optimization parameters (e.g., multiplexing period to be used, flows to be optimized together), depending on their IP addresses, ports, etc. It is connected with a number of TCM optimizers, and orchestrates the optimization that takes place between them.

#### 1.4. Scenarios of application

Different scenarios of application can be considered for the Tunneling, Compressing and Multiplexing solution. They can be classified according to the domains involved in the optimization:

##### 1.4.1. Multidomain scenario

In this scenario, the TCM tunnel goes all the way from one network edge (the place where users are attached to the ISP) to another, and therefore it can cross several domains. As shown in Figure 1, the optimization is performed before the packets leave the domain of an ISP; the traffic crosses the Internet tunnelized, and the packets are rebuilt in the second domain.

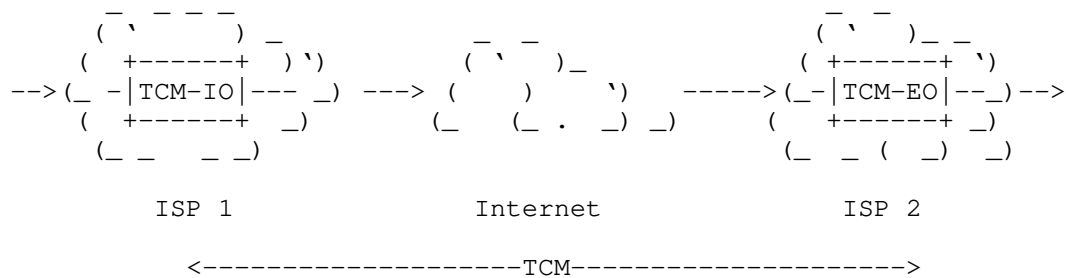


Figure 1

Note that this is not from border to border (where ISPs connect to the Internet, which could be covered with specialized links) but from an ISP to another (e.g., managing all traffic from individual users arriving at a Game Provider, regardless users' location).

Some examples of this could be:

- o An ISP may place a TCM optimizer in its aggregation network, in order to tunnel all the packets belonging to a certain service, sending them to the application provider, who will rebuild the packets before forwarding them to the application server. This will result in savings for both actors.
- o A service provider (e.g., an online gaming company) can be allowed to place a TCM optimizer in the aggregation network of an ISP, being able to optimize all the flows of a service (e.g., VoIP, an online game). Another TCM optimizer will rebuild these packets once they arrive to the network of the provider.

#### 1.4.2. Single domain

In this case, TCM is only activated inside an ISP, from the edge to border, inside the network operator. The geographical scope and network depth of TCM activation could be on demand, according to traffic conditions.

If we consider the residential users of real-time interactive applications (e.g., VoIP, online games generating small packets) in a town or a district, a TCM optimizing module can be included in some network devices, in order to group packets with the same destination. As shown in Figure 2, depending on the number of users of the application, the packets can be grouped at different levels in DSL fixed network scenarios, at gateway level in LTE mobile network scenarios or even in other ISP edge routers. TCM may also be applied



for fiber residential accesses, and in mobile networks. This would reduce bandwidth requirements in the provider aggregation network.

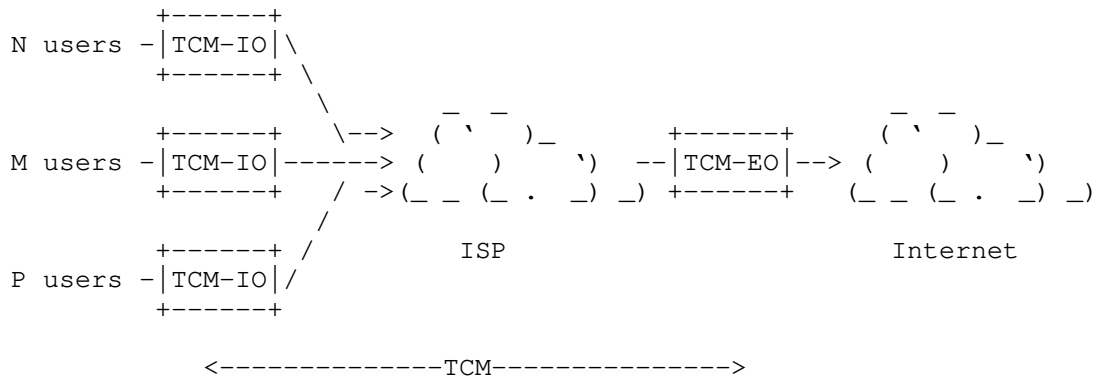


Figure 2

At the same time, the ISP may implement TCM capabilities within its own MPLS network in order to optimize internal network resources: optimizing modules can be embedded in the Label Edge Routers of the network. In that scenario MPLS will act as the "tunneling" layer, being the tunnels the paths defined by the MPLS labels and avoiding the use of additional tunneling protocols.

Finally, some networks use cRTP [cRTP] in order to obtain bandwidth savings on the access link, but as a counterpart considerable CPU resources are required on the aggregation router. In these cases, by means of TCM, instead of only saving bandwidth on the access link, it could also be saved across the ISP network, thus avoiding the impact on the CPU of the aggregation router.

### 1.4.3. Private solutions

End users can also optimize traffic end-to-end from network borders. TCM is used to connect private networks geographically apart (e.g., corporation headquarters and subsidiaries), without the ISP being aware (or having to manage) those flows, as shown in Figure 3, where two different locations are connected through a tunnel traversing the Internet or another network.

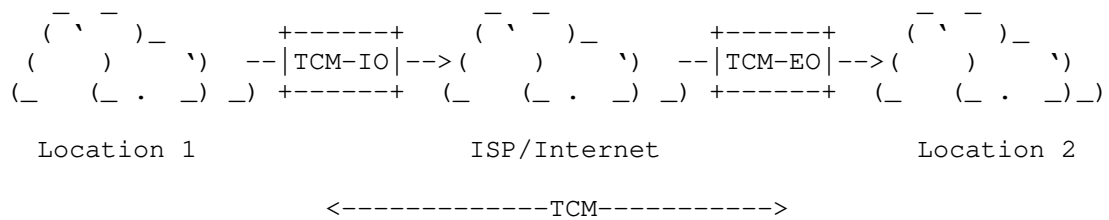


Figure 3

Some examples of these scenarios are:

- o The case of an enterprise with a number of distributed central offices, in which an appliance can be placed next to the access router, being able to optimize traffic flows with a shared origin and destination. Thus, a number of remote desktop sessions to the same server can be optimized, or a number of VoIP calls between two offices will also require less bandwidth and fewer packets per second. In many cases, a tunnel is already included for security reasons, so the additional overhead of TCM is lower.
- o An Internet cafe, which is suitable of having many users of the same application (e.g., VoIP, online games) sharing the same access link. Internet cafes are very popular in countries with relatively low access speeds in households, where home computer penetration is usually low as well. In many of these countries, bandwidth can become a serious limitation for this kind of businesses, so TCM savings may become interesting for their viability.
- o Alternative Networks [topology\_CNs], [I-D.irtf-gaia-alternative-network-deployments] (typically deployed in rural areas and/or in developing countries), in which a number of people in the same geographical place share their connections in a cooperative way. The structure of these networks is not designed from the beginning, but they grow organically as new users join. As a result, a number of wireless hops are usually required in order to reach a router connected to the Internet.
- o Satellite communication links that often manage the bandwidth by limiting the transmission rate, measured in packets per second (pps), to and from the satellite. Applications like VoIP that generate a large number of small packets can easily fill the maximum number of pps slots, limiting the throughput across such links. As an example, a G.729a voice call generates 50 pps at 20 ms packetization time. If the satellite transmission allows 1,500

pps, the number of simultaneous voice calls is limited to 30. This results in poor utilization of the satellite link's bandwidth as well as places a low bound on the number of voice calls that can utilize the link simultaneously. TCM optimization of small packets into one packet for transmission will improve the efficiency.

- o In a M2M/SCADA (Supervisory Control And Data Acquisition) context, TCM optimization can be applied when a satellite link is used for collecting the data of a number of sensors. M2M terminals are normally equipped with sensing devices which can interface to proximity sensor networks through wireless connections. The terminal can send the collected sensing data using a satellite link connecting to a satellite gateway, which in turn will forward the M2M/SCADA data to the to the processing and control center through the Internet. The size of a typical M2M application transaction depends on the specific service and it may vary from a minimum of 20 bytes (e.g., tracking and metering in private security) to about 1,000 bytes (e.g., video-surveillance). In this context, TCM concepts can be also applied to allow a more efficient use of the available satellite link capacity, matching the requirements demanded by some M2M services. If the case of large sensor deployments is considered, where proximity sensor networks transmit data through different satellite terminals, the use of compression algorithms already available in current satellite systems to reduce the overhead introduced by UDP and IPv6 protocols is certainly desirable. In addition to this, tunneling and multiplexing functions available from TCM allows extending compression functionality throughout the rest the network, to eventually reach the processing and control centers.
- o Desktop or application sharing where the traffic from the server to the client typically consists of the delta of screen updates. Also, the standard for remote desktop sharing emerging for WebRTC in the RTCWEB Working Group is: {something}/SCTP/UDP (Stream Control Transmission Protocol [SCTP]). In this scenario, SCTP/UDP can be used in other cases: chatting, file sharing and applications related to WebRTC peers. There can be hundreds of clients at a site talking to a server located at a datacenter over a WAN. Compressing, multiplexing and tunneling this traffic could save WAN bandwidth and potentially improve latency.

#### 1.4.4. Mixed scenarios

Different combinations of the previous scenarios can be considered. Agreements between different companies can be established in order to save bandwidth and to reduce packets per second. As an example, Figure 4 shows a game provider that wants to TCM-optimize its

connections by establishing associations between different TCM-IO/EOs placed near the game server and several TCM-IO/EOs placed in the networks of different ISPs (agreements between the game provider and each ISP will be necessary). In every ISP, the TCM-IO/EO would be placed in the most adequate point (actually several TCM-IO/EOs could exist per ISP) in order to aggregate enough number of users.

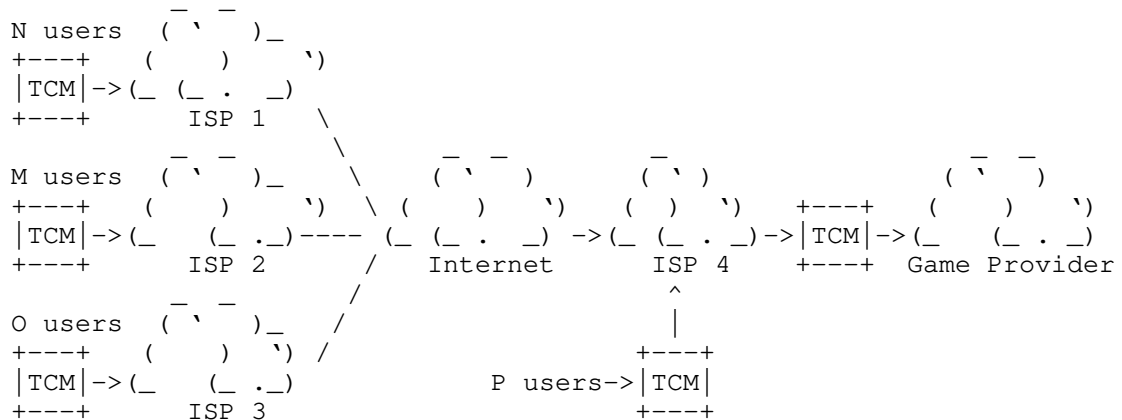


Figure 4

#### 1.5. Potential beneficiaries of TCM optimization

In conclusion, a standard way to compress headers, multiplex a number of packets and send them together using a tunnel, can benefit various stakeholders:

- o network operators can compress traffic flows sharing a common network segment;
- o ISPs;
- o developers of VoIP systems can include this option in their solutions;
- o service providers, who can achieve bandwidth savings in their supporting infrastructures;
- o users of Alternative Networks, who may be able to save significant bandwidth amounts, and to reduce the number of packets per second in their networks.

Other fact that has to be taken into account is that the technique not only saves bandwidth but also reduces the number of packets per

second, which sometimes can be a bottleneck for a satellite link or even for a network router [Online].

#### 1.6. Current Standard for VoIP

The current standard [TCRTP] defines a way to reduce bandwidth and pps of RTP traffic, by combining three different standard protocols:

- o Regarding compression, [ECRTP] is the selected option.
- o Multiplexing is accomplished using PPP Multiplexing [PPP-MUX]
- o Tunneling is accomplished by using L2TP (Layer 2 Tunneling Protocol [L2TPv3]).

The three layers are combined as shown in the Figure 5:

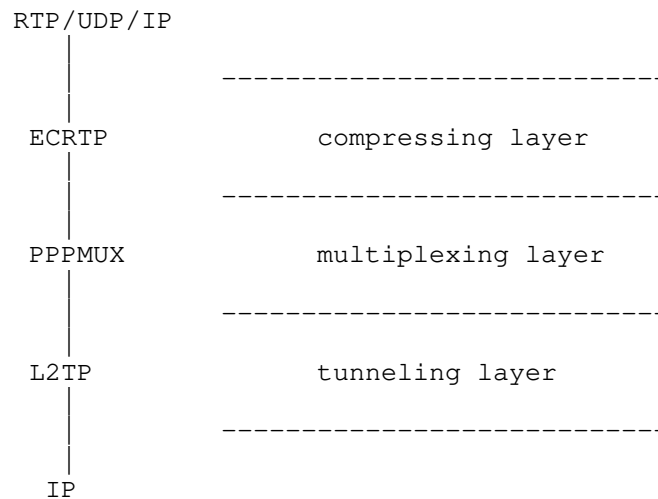


Figure 5

#### 1.7. Current Proposal

In contrast to the current standard [TCRTP], TCM allows other header compression protocols in addition to RTP/UDP, since services based on small packets also use by bare UDP, as shown in Figure 6:

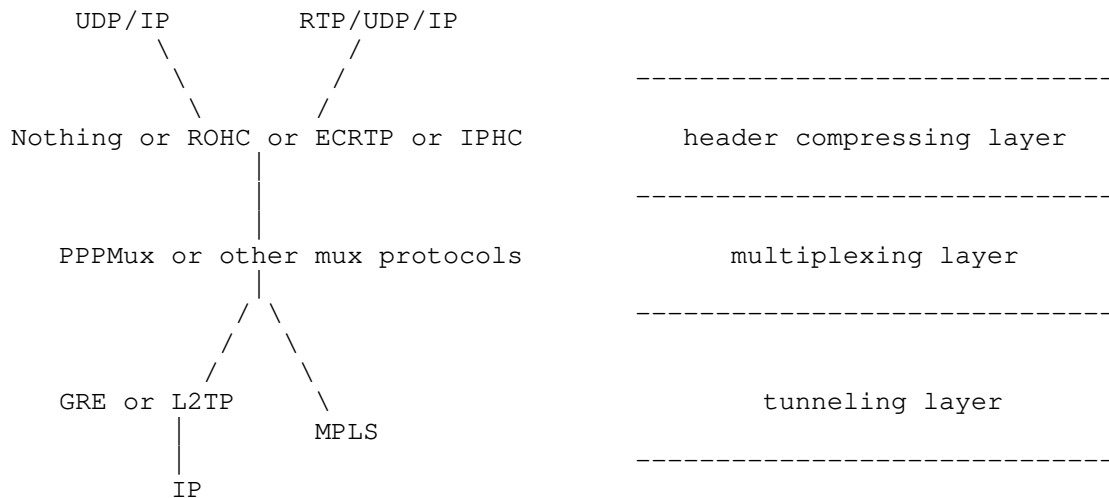


Figure 6

Each of the three layers is considered as independent of the other two, i.e., different combinations of protocols can be implemented according to the new proposal:

- o Regarding compression, a number of options can be considered: as different standards are able to compress different headers ([cRTP], [ECRTP], [IPHC], [ROHC]). The one to be used can be selected depending on the protocols used by the traffic to compress and the concrete scenario (packet loss percentage, delay, etc.). It also exists the possibility of having a null header compression, in the case of wanting to avoid traffic compression, taking into account the need of storing a context for every flow and the problems of context desynchronization in certain scenarios. Although not shown in Figure 6, ESP (Encapsulating Security Payload [ESP]) headers can also be compressed.
- o Multiplexing can be accomplished using PPP Multiplexing (PPPMux) [PPP-MUX]. However, PPPMux introduces an additional complexity, since it requires the use of PPP, and a protocol for tunneling layer 2 frames. For this reason, other multiplexing protocols can also be considered, as the one proposed in [I-D.saldana-tsvwg-simplemux].
- o Tunneling is accomplished by using L2TP (Layer 2 Tunneling Protocol [L2TPv3]) over IP, GRE (Generic Routing Encapsulation [GRE]) over IP, or MPLS (Multiprotocol Label Switching Architecture [MPLS]).

It can be observed that TCRTCP [TCRTCP] is included as an option in TCM, combining [ECRTCP], [PPP-MUX] and [L2TPv3], so backwards compatibility with TCRTCP is provided. If a TCM optimizer implements ECRTCP, PPPMux and L2TPv3, compatibility with RFC4170 MUST be granted.

If a single link is being optimized a tunnel is unnecessary. In that case, both optimizers MAY perform header compression between them. Multiplexing may still be useful, since it reduces packets per second, which is interesting in some environments (e.g., satellite). Another reason for that is the desire of reducing energy consumption. Although no tunnel is employed, this can still be considered as TCM optimization, so TCM signaling protocols will be employed here in order to negotiate the compression and multiplexing parameters to be employed.

Payload compression schemes may also be used, but they are not the aim of this document.

## 2. Protocol Operation

This section describes how to combine protocols belonging to three layers (compressing, multiplexing, and tunneling), in order to save bandwidth for the considered flows.

### 2.1. Models of implementation

TCM can be implemented in different ways. The most straightforward is to implement it in the devices terminating the flows (these devices can be e.g., voice gateways, or proxies grouping a number of flows):

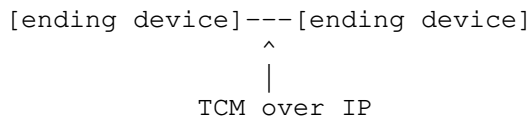


Figure 7

Another way TCM can be implemented is with an external optimizer. This device can be placed at strategic places in the network and can dynamically create and destroy TCM sessions without the participation of the endpoints that generate the flows (Figure 8).

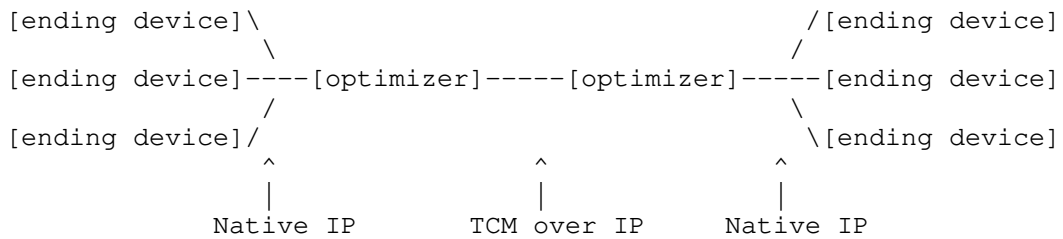


Figure 8

A number of already compressed flows can also be merged in a tunnel using an optimizer in order to increase the number of flows in a tunnel (Figure 9):

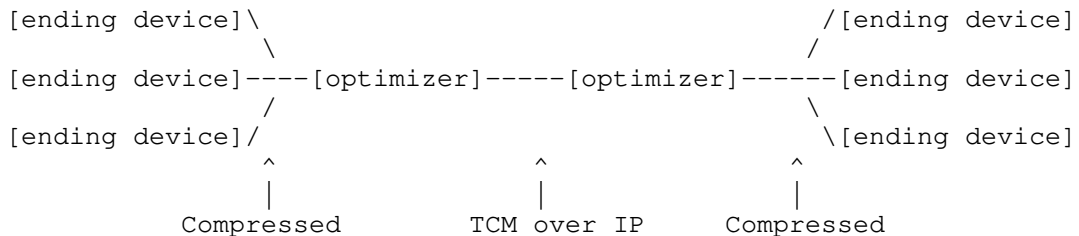


Figure 9

## 2.2. Choice of the compressing protocol

There are different protocols that can be used for compressing IP flows:

- o IPHC (IP Header Compression [IPHC]) permits the compression of UDP/IP and ESP/IP headers. It has a low implementation complexity. On the other hand, the resynchronization of the context can be slow over long RTT links. It should be used in scenarios presenting very low packet loss percentage.
- o cRTP (compressed RTP [cRTP]) works the same way as IPHC, but is also able to compress RTP headers. The link layer transport is not specified, but typically PPP is used. For cRTP to compress headers, it must be implemented on each PPP link. A lot of context is required to successfully run cRTP, and memory and processing requirements are high, especially if multiple hops must implement cRTP to save bandwidth on each of the hops. At higher line rates, cRTP's processor consumption becomes prohibitively expensive. cRTP is not suitable over long-delay WAN links commonly used when tunneling, as proposed by this document. To avoid the per-hop expense of cRTP, a simplistic solution is to use cRTP with



L2TP to achieve end-to-end cRTP. However, cRTP is only suitable for links with low delay and low loss. Thus, if multiple router hops are involved, cRTP's expectation of low delay and low loss can no longer be met. Furthermore, packets can arrive out of order.

- o ECRTTP (Enhanced Compressed RTP [ECRTTP]) is an extension of cRTP [cRTP] that provides tolerance to packet loss and packet reordering between compressor and decompressor. Thus, ECRTTP should be used instead of cRTP when possible (e.g., the two TCM optimizers implementing ECRTTP).
- o ROHC (RObust Header Compression [ROHC]) is able to compress UDP/IP, ESP/IP and RTP/UDP/IP headers. It is a robust scheme developed for header compression over links with high bit error rate, such as wireless ones. It incorporates mechanisms for quick resynchronization of the context. It includes an improved encoding scheme for compressing the header fields that change dynamically. Its main drawback is that it requires significantly more processing and memory resources than the ones necessary for IPHC or ECRTTP.

The present document does not determine which of the existing protocols has to be used for the compressing layer. The decision will depend on the scenario and the service being optimized. It will also be determined by the packet loss probability, RTT, jitter, and the availability of memory and processing resources. The standard is also suitable to include other compressing schemes that may be further developed.

#### 2.2.1. Context Synchronization in ECRTTP

When the compressor receives an RTP packet that has an unpredicted change in the RTP header, the compressor should send a COMPRESSED\_UDP packet (described in [ECRTTP]) to synchronize the ECRTTP decompressor state. The COMPRESSED\_UDP packet updates the RTP context in the decompressor.

To ensure delivery of updates of context variables, COMPRESSED\_UDP packets should be delivered using the robust operation described in [ECRTTP].

Because the "twice" algorithm described in [ECRTTP] relies on UDP checksums, the IP stack on the RTP transmitter should transmit UDP checksums. If UDP checksums are not used, the ECRTTP compressor should use the cRTP Header checksum described in [ECRTTP].

### 2.2.2. Context Synchronization in ROHC

ROHC [ROHC] includes a more complex mechanism in order to maintain context synchronization. It has different operation modes and defines compressor states which change depending on link behavior.

### 2.3. Multiplexing

Header compressing algorithms require a layer two protocol that allows identifying different protocols. PPP [PPP] is suited for this, although other multiplexing protocols can also be used for this layer of TCM. For example, Simplemux [I-D.saldana-tsvwg-simplemux] can be employed as a light multiplexing protocol which is able to carry packets belonging to different protocols.

When header compression is used inside a tunnel, it reduces the size of the headers of the IP packets carried in the tunnel. However, the tunnel itself has overhead due to its IP header and the tunnel header (the information necessary to identify the tunneled payload).

By multiplexing a number of small payloads in a single tunneled packet, reasonable bandwidth efficiency can be achieved, since the tunnel overhead is shared by multiple packets belonging to the flows active between the source and destination of an L2TP tunnel. The packet size of the flows has to be small in order to permit good bandwidth savings.

If the source and destination of the tunnel are the same as the source and destination of the compressing protocol sessions, then the source and destination must have multiple active small-packet flows to get any benefit from multiplexing.

Because of this, TCM is mostly useful for applications where many small-packet flows run between a pair of hosts. The number of simultaneous sessions required to reduce the header overhead to the desired level depends on the average payload size, and also on the size of the tunnel header. A smaller tunnel header will result in fewer simultaneous sessions being required to produce adequate bandwidth efficiencies.

When multiplexing, a limit in the packet size has to be established in order to avoid problems related to MTU. This document does not establish any rule about this, but it is strongly recommended that some method as Packetization Layer Path MTU Discovery is used before multiplexing packets[RFC4821].

## 2.4. Tunneling

Different tunneling schemes can be used for sending end to end the compressed payloads.

### 2.4.1. Tunneling schemes over IP: L2TP and GRE

L2TP tunnels should be used to tunnel the compressed payloads end to end. L2TP includes methods for tunneling messages used in PPP session establishment, such as NCP (Network Control Protocol). This allows [IPCP-HC] to negotiate EC RTP compression/decompression parameters.

Other tunneling schemes, such as GRE [GRE] may also be used to implement the tunneling layer of TCM.

### 2.4.2. MPLS tunneling

In some scenarios, mainly in operator's core networks, the use of MPLS is widely deployed as data transport method. The adoption of MPLS as tunneling layer in this proposal intends to natively adapt TCM to those transport networks.

In the same way that layer 3 tunnels, MPLS paths, identified by MPLS labels, established between Label Edge Routers (LSRs), could be used to transport the compressed payloads within an MPLS network. This way, multiplexing layer must be placed over MPLS layer. Note that, in this case, layer 3 tunnel headers do not have to be used, with the consequent data efficiency improvement.

## 2.5. Encapsulation Formats

The packet format for a packet compressed is:

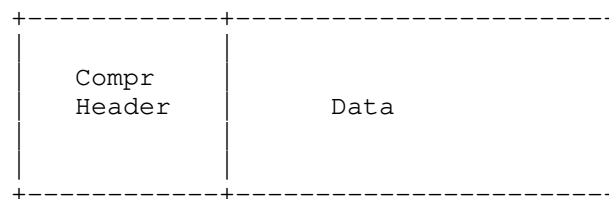


Figure 10

The packet format of a multiplexed PPP packet as defined by [PPP-MUX] is:

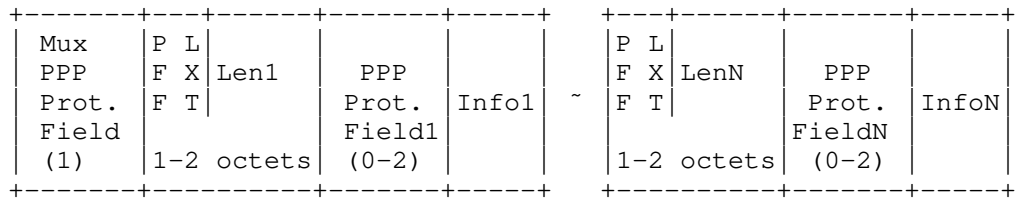


Figure 11

The combined format used for TCM with a single payload is all of the above packets concatenated. Here is an example with one payload, using L2TP or GRE tunneling:

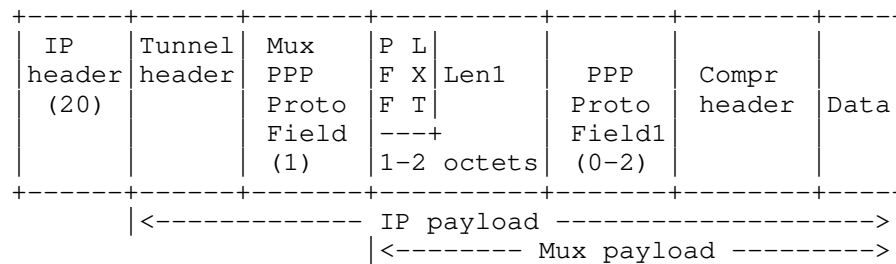


Figure 12

If the tunneling technology is MPLS, then the scheme would be:

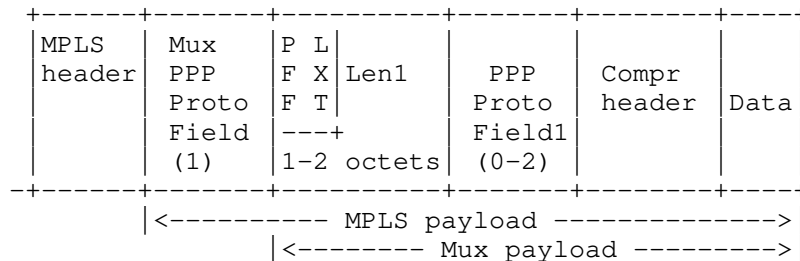


Figure 13

If the tunnel contains multiplexed traffic, multiple "PPPMux payload"s are transmitted in one IP packet.

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#### 5. IANA Considerations

This memo includes no request to IANA.

#### 6. Security Considerations

The most straightforward option for securing a number of non-secured flows sharing a path is by the use of IPsec [IPsec], when TCM using an IP tunnel is employed. Instead of adding a security header to the packets of each native flow, and then compressing and multiplexing them, a single IPsec tunnel can be used in order to secure all the flows together, thus achieving a higher efficiency. This use of IPsec protects the packets only within the transport network between tunnel ingress and egress and therefore does not provide end-to-end authentication or encryption.

When a number of already secured flows including ESP [ESP] headers are optimized by means of TCM, and the addition of further security is not necessary, their ESP/IP headers can still be compressed using suitable algorithms [RFC5225], in order to improve the efficiency. This header compression does not change the end-to-end security model.

The resilience of TCM to denial of service, and the use of TCM to deny service to other parts of the network infrastructure, is for future study.

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Delay Limits and Multiplexing Policies to be employed with Tunneling  
Compressing and Multiplexing Traffic Flows  
draft-suznjevic-tsvwg-mtd-tcmtf-05

Abstract

This document contains recommendations to be taken into account when using methods which optimize bandwidth utilization through Tunneling Compressing and Multiplexing (TCM) traffic flows over a network path. Different multiplexing policies and implementation issues which are service and link specific are discussed. Additionally, this document describes policies which can be used for detecting, classifying, and choosing the network flows suitable for optimization by using TCM. Finally, recommendations of maximum tolerable delays to be added by optimization techniques are reported. Recommendations are presented only for network services for which such bandwidth optimization techniques are applicable (i.e., services with low payload to header size ratio, which will also be denoted as "small-packet flows").

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## 1. Introduction

This document extends the draft [TCM] with a set of recommendations regarding the processes of traffic optimization, which may include compressing, multiplexing, and/or tunneling a number of packets. These recommendations are needed because these traffic optimization techniques, while saving bandwidth and reducing overhead, may cause network impairments if packets are delayed before being sent together. These techniques are also proposed at layer 2. For example, in [IEEE.802-11N.2009], a number of Protocol Data Units can be grouped and transmitted together.

Network delay is one of the main factors which can degrade the Quality of Experience (QoE) of real-time network services RFC 6390

[RFC6390] [TGPP\_TR26.944]. In order to prevent the perceived quality degradation of the services when using TCM, a policy defining a multiplexing period can be employed.

First, the document describes different multiplexing policies which can be employed for defining which native packets are multiplexed together. A policy combining a multiplexing period and a packet size limit is proposed in order to put an upper bound on the added delay.

Additionally, this document describes the policies that can be employed for detecting, classifying, and choosing the network flows suitable for TCM optimization.

Finally, values for maximum tolerable delays presented here from the base of the proposed multiplexing policy. The recommendations are presented for both real-time and non real-time network services in which TCM bandwidth optimization is applicable (i.e., services which have low payload-to-header-size ratio, which results in high protocol overhead, which will also be denoted as small-packet flows).

## 1.1. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

## 2. Terminology

This document uses a number of terms to refer to the roles played by participants in, and objects of, the TCM sessions.

TCM optimizer

The host where TCM optimization is deployed. If that hosts corresponds to the ingress of the tunnel where native packets are included it is called TCM-ingress optimizer (TCM-IO).

The host where TCM multiplexed packets are received and rebuilt to their native form is called TCM-egress optimizer (TCM-IO). It corresponds to the tunnel egress.

policy manager

A network entity which makes the decisions about TCM parameters: multiplexing period; flows to be multiplexed together, depending on their IP addresses, ports, etc. It is connected with a number of TCM optimizers, and orchestrates the optimization that takes place between them.

native packet

A packet sent by an application, belonging to a flow that can be optimized by means of TCM.

TCM-optimized packet

A packet including a number of multiplexed and header-compressed native ones, and also a tunneling header shared by all the packets, as detailed by TCM.

### 3. Considered services

The services considered suitable for being optimized by TCM are those that generate long-term flows of small packets, with a low payload to header size ratio. Some real-time and some non real-time services are suitable for optimization by means of TCM.

#### 3.1. Real-time services

Under the term "real-time network services" we consider both conversational and streaming service classes as defined in [TGPP\_TS]. Interactive and background services are considered non real-time. Fundamental requirements of real-time network services include conversational pattern (stringent and low delay) and preservation of the time relation (variation) between the information entities of the stream.

We identify the following real-time network services with low payload to header size ratio as candidates for the bandwidth optimization techniques presented in TCM:

- o Voice over IP
- o Online games
- o Remote desktop services

While video services are considered real-time, they are not suitable for bandwidth optimization techniques proposed in [TCM], due to their high payload to header size ratio. Due to the same reason, we do not take into account cloud gaming services. In such gaming services all the calculations of the game state are deployed at the server and a real-time video stream is sent to the client. In these cases, TCM optimization is neither interesting nor applicable.

### 3.2. Non real-time services

On the other hand, TCM can be applied for some non real-time services such as streaming audio, and instant messaging. These applications are suitable for TCM in terms of payload to header size ratio, but different studies have shown that acceptable delays for these services are up to several seconds [ITU-T\_G.1010]. Also, some types of machine to machine (M2M) traffic (e.g., metering messages from various sensors) may have traffic properties suitable for TCM. Acceptable delays for these services can be go up to an hour [Liu\_M2M]. We list limitations for these services as well, although in the practical application TCM should not introduce delays which would be noticeable in comparison with delays of such magnitude (i.e., seconds and more).

### 4. Multiplexing policies in TCM

A multiplexing policy defines the decision process for determining which native packet goes in which multiplexed packet. The policies proposed for TCM are:

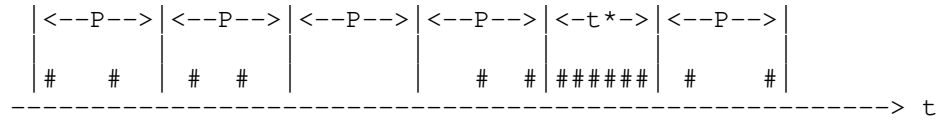
- o Fixed number of packets - once a fixed number of packets (N) has arrived, a multiplexed packet is created and sent.
- o Size limit - once a size limit is reached (e.g., next to the MTU of the underlying network), a multiplexed packet is sent.
- o Period - a multiplexed packet is sent every time period T.
- o Timeout - sends a multiplexed packet if a native one arrives and the time since the last multiplexed packet departure is above a defined timeout value.

Only the two latter policies are able to control the additional delay introduced by multiplexing. In addition, different policies can be combined.

In this document we focus on the combination of "size limit" and "period" policies, as shown in Figure 1. A multiplexed packet is sent at the end of each "period". However, if the size limit is reached, then a multiplexed packet is sent immediately, and the period is "reset". Thus, the added delay is for the worst case scenario equal to the defined period.



native traffic:



multiplexed traffic:



\* period reset ( $t < P$ ) because size limit is reached

Combined "period" and "size limit" policies

Figure 1

It should be noted that the number of aggregated flows and their packet rate will have an influence on the average multiplexing delay added. If the number of flows is high, then the MTU size will be reached before the end of the period in most cases, so the additional delay will be smaller than the period. The recommendations presented in this document present the maximum period values to be used as a limit, in order to avoid delays which could impair the quality of the service.

## 5. Detecting, classifying, and choosing network flows to be optimized

Three basic issues need to be solved in order to employ TCM optimization. First, the flows which are candidates for optimization need to be detected from the overall traffic mix. Secondly, the flows need to be classified into one of the defined categories so an adequate multiplexing period can be assigned. Finally, the decision whether a specific flow will be optimized or not using TCM needs to be made.

### 5.1. Optimization within an administrative domain

Several scenarios can be considered for the use of TCM. If the optimization is deployed within an administrative domain, then all the data of the end hosts, the service class, etc., are known by the TCM optimizers.

Two examples of this are 1) the end-to-end optimization and aggregation of a number of flows between two offices of the same

company and 2) the agreement between a network operator and a game provider in order to multiplex all the packets generated in an aggregation network with destination on a game server. In these cases, the detection and classification of the desired flows will be straightforward, since the TCM optimizer can simply inspect the destination IP address and port, and apply the traffic category according to the kind of service.

## 5.2. Optimization based on statistics

If the optimization is not performed within an administrative domain, then the detection and classification of the flows, and the decision about multiplexing them, will have to be based on statistics of the traffic and heuristics. The intelligence of the flow identification method can be improved according to the statistics of already classified flows. E.g., if a number of small-packet flows sharing the same IP destination address are found, then this destination host can be classified as a frequent receiver of small-packet flows, and a tunnel including all the packets addressed to it can be set within a common network path.

In addition, statistics can be enriched by the assignment of the traffic class, taking into account that some services, in addition to well-known ports, also have well-known IP addresses. E.g., the traffic travelling to the IP address of a popular online game server, can be associated with the proper traffic class; or the ports corresponding to certain services can also be identified and used in order to improve the classification.

The detection of the flows candidates for TCM optimization should be done based on flow characteristics, primarily on the packet payload to header ratio and on the packet rate. As these properties cannot be established from statistics of just one packet, it is needed to gather a certain number of packets for each new flow arriving at the TCM optimizer, and to use some heuristics in order to decide whether to multiplex a certain flow or not.

The classification method employed for the TCM needs to identify only the flows which are candidates for the TCM optimization. Therefore, the classification problem is significantly simplified by removal of peer to peer (P2P) downloading applications, video streaming, data transfer, and all other services which in general, utilize large packets. This is especially important as P2P applications are known to use various non assigned ports which may greatly ruin the performance of simple traffic classification methods. For the purposes of TCM optimization there is no need to identify a particular application, only the delay sensitive class in which that application falls. Also, the traffic classification methods employed

by TCM need to be able to assign flows to respective delay sensitive classes in real time. Current network traffic classification methods can be grouped into [Nguyen\_TCSurvey]:

- o Port based - through lookup of port numbers of endpoints in the Internet Assigned Numbers Authority (IANA)'s list of registered ports.
- o Payload based - through stateful reconstruction of session and application information from each packet's content.
- o Statistical - through comparison of the statistical properties of the traffic at the network layer.

While payload inspection does give the best results, and is often used as ground truth in classification of network traffic, it is demanding computation wise. Also, these techniques may be interpreted as a violation of privacy. For the purposes of TCM we recommend using a combination of port based classification (which can yield very good results for games based on a client-server architecture and remote desktop services), and inspection of statistical properties of the flows. One such algorithm has been employed for classification of different types of game flows and showed good results [Han\_GameClassification]. TCM should use metadata information regarding the traffic class of particular flow where such information is available as that significantly simplifies the detection and classification problem.

The decision whether the flow should be optimized with TCM can be made based on the following policies (configurations of the multiplexing node):

- o A static configuration - predefined rule set for each new occurring flow, so the TCM optimizer makes a decision.
- o A policy manager which dynamically enforces the rule set.
- o The TCM optimizer demands instructions for each new flow from the policy manager.

## 6. Delay recommendations

The three normally considered network impairments in the studies related to subjective quality in real-time interactive games are:

- o delay - can be reported as one-way-delay (OWD) [RFC2679] and two-way-delay (Round Trip Time) [RFC2681]. In this document, under the term latency, one way end-to-end delay is considered.

- o delay variation - which is a statistical variance of the data packet inter-arrival time, in other words the variation of the delay as defined in RFC 3393 [RFC3393].
- o packet loss - more important for certain applications, while other include very good algorithms for concealing it (e.g., some game genres).

In this document we give recommendations for overall tolerable delays to be taken into account when optimizing network services by means of TCM. In an interactive service, the total delay is composed by the addition of delays as defined in 3GPP TR 26.944 [TGPP\_TR26.944].

- o Transfer delay - from Host1 to Host2 at time T is defined by the statement: Host1 sent the first bit of a unit data to Host2 at wire-time T and that Host2 received the last bit of that packet at wire-time T+dT. Thus, it includes the transmission delay (the amount of time Host1 requires to push all of the packet's bits into the wire) and the propagation delay in the network (the amount of time it takes for the head of the packet to travel from Host1 to Host2).
- o Transaction delay - the sum of the time for a data packet to wait in queue and receive the service during the server transaction.

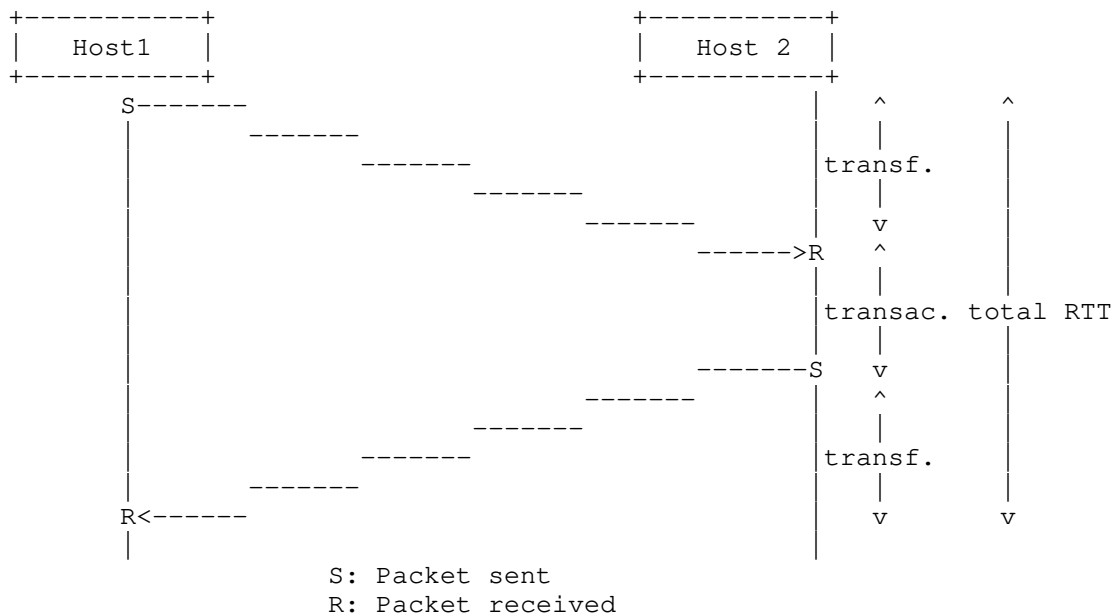


Figure 2

Figure 2 illustrates these delays. The labeled times (S and R) designate the times in which the packet is sent and received, respectively, by the network card interface.

The use of TCM requires the addition of TCM optimizers in the scenario. A number of flows are multiplexed together before being sent through the network. The packets are demultiplexed and rebuilt before being forwarded to the application server. A scheme of TCM is included in Figure 3:

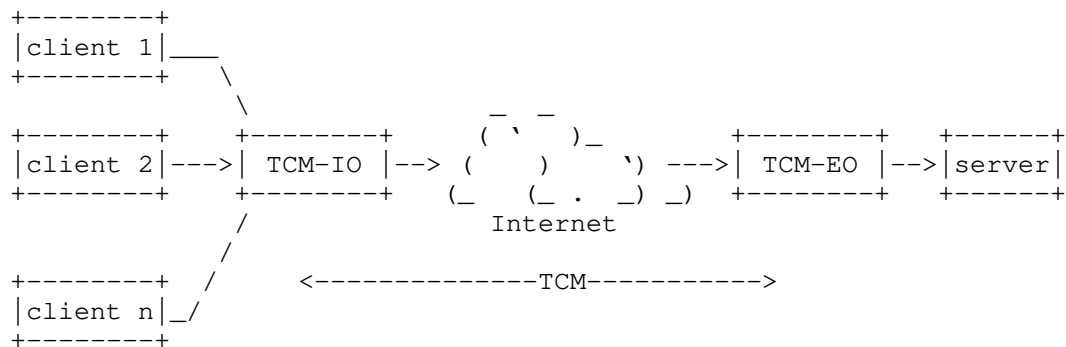


Figure 3

This technique groups packets in order to build a multiplexed one. As previously stated, the focus of this document is on "multiplexing period" policy for creating the multiplexed packet combined with size limit policy. Multiplexing period is a time frame in which the TCM optimizer waits for native packets to arrive in order to send them as one multiplexed packet. If the multiplexed packet size limit is reached before the multiplexing period has run out (i.e., if enough native packets arrive to fill the limit), the multiplexed packet is sent right away. In this way a certain amount of delay caused by the TCM optimization is added in the communication. It is important to emphasize that multiplexing delay can't exceed the multiplexing period, and that it will only reach the value of multiplexing period on a link with a low traffic load. Multiplexing delay can be classified as caused by the middlebox presence as defined in RFC 6390 RFC 6390 [RFC6390]. The delay in the TCM-IO includes the time during which the packets are retained until the bundled packet is sent, plus processing time. In the TCM-EO however, the packets are not retained, so only the processing time is considered.

Figure 4 shows the total delay, when a TCM optimizers are added. It should be noted that multiplexing can be deployed independently in both directions, or only in one of them.

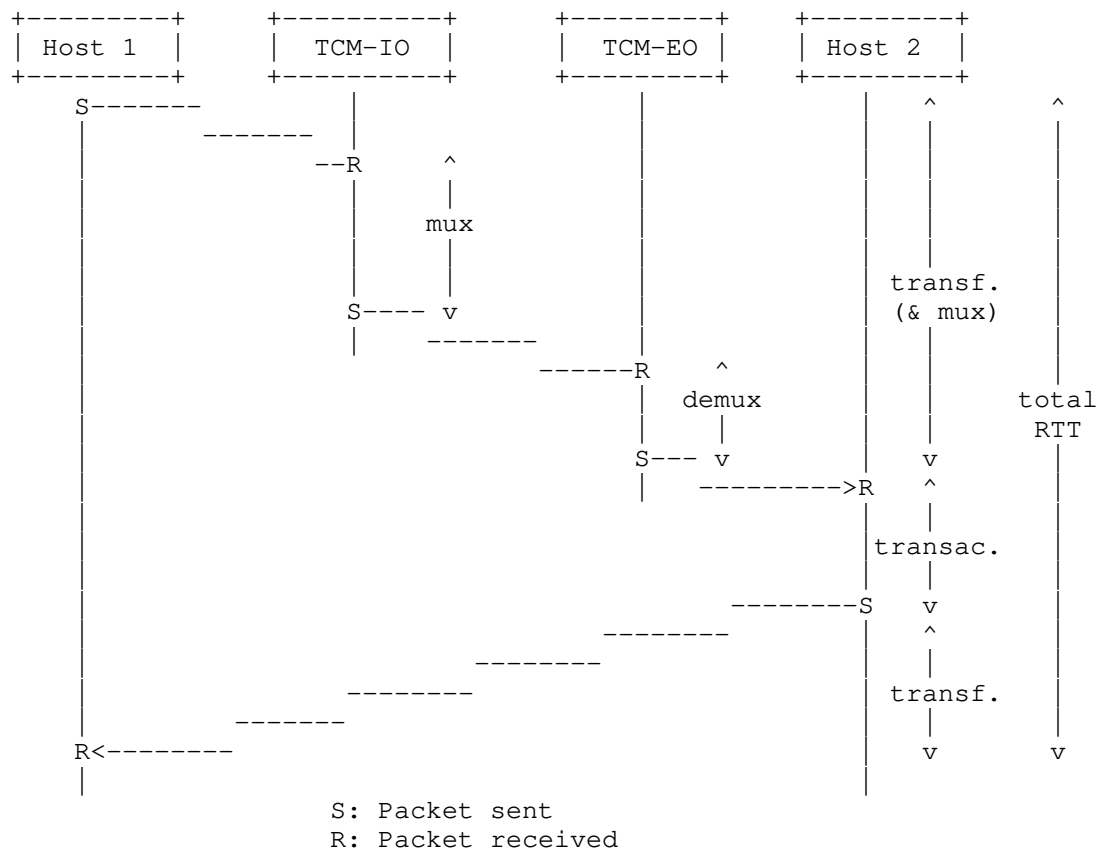


Figure 4

With respect to efficiency in terms of use of the bandwidth, a tradeoff appears: the longer the multiplexing period, the higher the number of packets which can be grouped, thus obtaining better bandwidth savings. So in order to calculate the maximum multiplexing period, the rest of the delays have to be considered: if the sum of transaction, and transfer delays is under the maximum tolerable delay, then multiplexing will be possible without harming the user experience. The overall delay may be calculated according to the ITU-T Y.1541 recommendation [ITU-T\_Y.1541]. Subtracting propagation, processing, and transmission delay from the tolerable delay for specific service results in the maximum value of the multiplexing period.

Next, we will report the maximum tolerable latency for the previously listed real-time network services.

### 6.1. VoIP

For conversational audio, the International Telecommunication Union recommends [ITU-T\_G.114] less than 150 millisecond one-way end-to-end delay for high-quality real time traffic, but delays between 150 ms and 400 ms are acceptable. When considering conversational audio it should be noted that this delay limits include jitter buffers and codec processing. For streaming audio, delay constraints are much looser, the delay should be less than 10 s [ITU-T\_G.1010]. Tunneling Multiplexed Compressed RTP (TCRTP) [RFC4170] already considers tunneling, compressing and multiplexing VoIP packets.

### 6.2. Online games

Online games comprise game genres which have different latency requirements. This draft focuses on real-time online games and endorses the general game categorization proposed in [Claypool\_Latency] in which online games have been divided into:

- o Omnipresent, with the threshold of acceptable latency (i.e., latency in which performance is above 75% of the unimpaired performance) of 1000 ms. The most representative genre of omnipresent games are Real-Time Strategies.
- o Third Person Avatar, with the threshold of acceptable latency of 500 ms. These games include Role Playing Games (RPG) and Massively Multiplayer Online Role-Playing Games (MMORPG).
- o First Person Avatar, in which threshold of acceptable latency is 100 ms. The most popular subgenre of them are First Person Shooters, such as "Call of Duty" or "Halo" series.

As remarked in [Bernier\_Latency] and [Oliveira\_online], different methods can be employed to combat delay in online games. The so-called "client-side prediction" has been largely used in First Person Shooters. It can be divided into "input prediction" and "dead reckoning," where input prediction hides the latency for the client-controlled actions while dead reckoning hides the latency of other participating players.

The study [Claypool\_Latency] evaluated players' performance in certain tasks, while increasing latency, and reported values at which the performance dropped below 75% of the performance under unimpaired network conditions. While measuring objective performance metrics, this method highly underestimates the impact of delays on players' QoE. Further studies accessing a particular game genre reported much lower latency thresholds for unimpaired gameplay.

Other approach some studies have taken is to perform "objective measurements" [Kaiser\_objective] a number of identical "bots", i.e. virtual avatars controlled by Artificial Intelligence, are placed in the same virtual scenario and a number of parties between them are performed. If the number of parties is high enough, then the score will be the same for all the bots. Then, different network impairments (latency, jitter, packet loss) are added to one of the bots, and another set of tests is performed. The performance degradation of the network-impaired bot can then be statistically characterized.

A survey using a large number of First Person Shooter games has been carried out in [Dick\_Analysis]. They state that latency about 80 ms could be considered as acceptable, since the games have been rated as "unimpaired". Besides service QoE, it has been shown that delay has great impact on the user's decision to join a game, but significantly less on the decision to leave the game [Henderson\_QoS].

A study on Mean Opinion Score (MOS) evaluation, based on variation of delay and jitter for MMORPGs, suggested that MOS drops below 4 for delays greater than 120 ms [Ries\_QoEMMORPG]. The MOS score of 5 indicates excellent quality, while MOS score of 1 indicates bad quality. Another study focused on extracting the duration of play sessions for MMORPGs from the network traffic traces showed that the session durations start to decline sharply when round trip time is between 150 ms and 200 ms [Chen\_HowSensitive].

While original classification work [Claypool\_Latency] states that latency up to 1 second is tolerated by omnipresent games, other studies argued that only latency up to 200 ms is tolerated by players of RTS games [Cajada\_RTS].

### 6.3. Remote desktop access

For the remote computer access services, the delays are dependent on the task performed through the remote desktop. Tasks may include operations with audio, video and data (e.g., reading, web browsing, document creation). A QoE study indicates that for audio latency below 225 ms and for data latency below 200 ms is tolerated [Dusi\_Thin].

### 6.4. Non real-time service

Traffic flows of several types of non real-time services can be optimized using TCM. Under this category we include services for M2M metering information, streaming audio, and instant messaging. M2M metering services are suitable for TCM optimization not only due to their very loose delay requirements, but also because of the one way



nature of the communication (i.e., most information travels from sensors to the central server) [Liu\_M2M]. The signalling information related to M2M can also be optimized. Internet of Things application layer protocols such as CoAP RFC 7252 [RFC7252], used in Constrained RESTful Environments (CoRE) [RFC6690], work over UDP and send small packets. The ACK\_TIMEOUT period in CoAP is set to 2 seconds. Instant messaging (despite "instant" in its name) has been categorized as data service by the ITU-T, and it has been designated with acceptable delays of up to a few seconds [ITU-T\_G.1010].

## 6.5. Summary

We group all the results in the Table 1 indicating the maximum allowed latency and proposed multiplexing periods. Proposed multiplexing periods are guidelines, since the exact values are dependant of the existing delay in the network. It should be noted that reported tolerable latency is based on values of preferred delays, and delays in which QoE estimation is not significantly degraded. Multiplexing periods of about 1 second can be considered as sufficient for non real-time services (e.g., streaming audio).

Service	Tolerable latency (OWD)	Mux. period
Voice communication	< 150ms	< 30ms
Omnipresent games	< 200ms	< 40ms
First person avatar games	< 80ms	< 15ms
Third person avatar games	< 120ms	< 25ms
Remote desktop	< 200ms	< 40ms
Instant messaging	< 5s	< 1s
M2M (metering)	< 1hour	< 1s

Table 1: Final recommendations

## 7. Acknowledgements

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## 8. IANA Considerations

This memo includes no request to IANA.

## 9. Security Considerations

No relevant security considerations have been identified

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