Inter-Path OOS Packets Differentiation Based Congestion Control for Simultaneous Multipath Transmission

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Abstract: *An increase in the popularity and usage of Multimode's devices for ubiquitous network access creates thrust for utilization of simultaneous network connections. Unfortunately, the standard transport layer protocols used single homed congestion control mechanism for multipath transmission. One major challenge in such multipath transmission is related to the Receiver Buffer (RBuf) blocking that hinders higher aggregation ratio of multiple paths. This study proposed Simultaneous Multipath Transmission (SMT) scheme to avoid the RBuf blocking problem. Realistic simulation scenarios were designed such as intermediate nodes, cross traffic, scalability or mix of them to thoroughly analyses SMT performance. The results revealed that SMT has overcome RBuf blocking with improvement in aggregate throughput up to 95.3 % of the total bandwidth.*

Keywords: *Multipath transmission, RBuf blocking, out-of-sequence arrival, throughput, congestion window.*

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1. Introduction

The multihoming is utilization of more than one interface for communication. Now-a-days, the communication devices with multiple interfaces are growing in numbers. These multi interface devices called MultiHomed (MH) provide comparatively more reliability and load balancing as compared to single interface devices. The multihoming can be more useful, if these multiple interfaces are simultaneously used for single data stream transmission. In this way, we can aggregate the bandwidth of multiple interfaces to have a higher aggregated throughput; is a challenge.

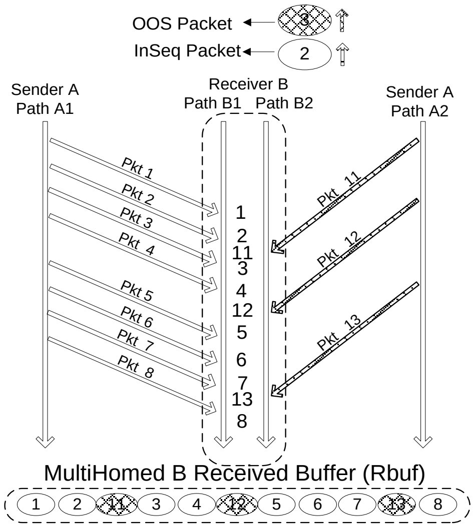
This challenge becomes more severe due to Out Of Sequence (OOS) arrival of the packets at the receiver side, where packets received out of order due to multiplepaths effects. In such a scenario, the standard transport layer protocols (Transmission Control Protocol (TCP) and Stream Control Transmission Protocol (SCTP)) trigger packets fast retransmission and shrink the Congestion Window (CWnd) with the intention that reordering is an indication of congestion in the network [2]. Single path transport layer protocol does not prevent congestion by moving traffic away from congested paths. They only spread out its traffic over time on the same path. The availability of multiple paths will make it possible to shift traffic load from congested path to non-congested path.

Traditionally, single homed Congestion Control (CC) mechanism infers OOS packet arrival as network congestion. This sense of congestion detection in network creates confusion for MH devices while transmitting single data stream overmultiple paths (as pictorially explained in Figure 1).

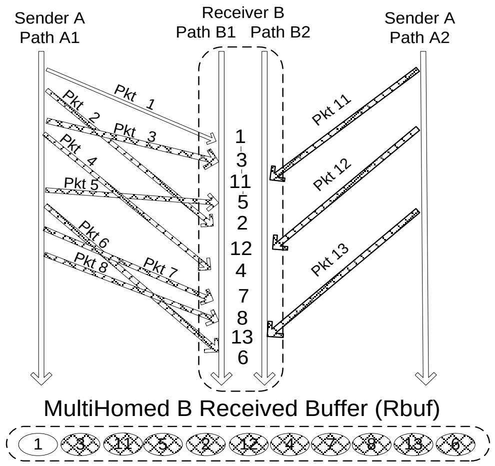
MH sender used paths A1 and A2 to communicate with MH receiver using paths B1 and B2 respectively. MH sender has to schedule packet 1-10 on 1st path (A1-B1) and 11-13 on 2nd path (A2-B2). Here MH receiver was assumed to have limited single Receiver Buffer (RBuf) for all paths.

In the first section (a) of Figure 1, packets arrived in sequence within same path confirmed no congestion in the network. Still MH receiver experiences OOS packets due to a heterogeneous multipath effect called interpath OOS packets as shown by packet 11, 12 and 14. The single homed CC mechanism was unaware of interpath OOS packets, resulted into RBuf blocking problem. RBuf blocking problem is a phenomena where the sender transmission was restricted to lowest possible limit due to advertisement of zero RBuf space [14]. The probability of inter-path OOS packets increases with an increase in bandwidth and end to end delay disparities of multiple paths.

On the other hand, the RBuf blocking is more severe if there are traditional packets reordering within same path called intra-path OOS as indicated by packet 3, 5, 7 and 8. Intra-path OOS is a sign of congestion in the network. The probability of intra-path OOS increases with increase in congestion in the network, which triggered CC mechanism immediately to cope with network congestion. The sub categorization of OOS packets into inters and intra-path is proposed by Inter-path Out of sequence Packets Differentiation (IOPD) algorithm as given in Algorithm 1.



a) Packet reordering pattern of Inter-path OOS packet.



b) Packet reordering pattern of Intra-path OOS packet.

Figure 1. Packet reordering pattern.

In addition to this, a number of issues arise in the Simultaneous Multipath Transmission (SMT) using the traditional transport layer protocol to have a higher aggregate throughput such as unnecessary fast retransmissions, crippled congestion widow growth, superfluous network traffic, and RBuf blocking [13].

In this paper, we studied the flaws of single homed CC mechanism by transmitting a single data stream over multiple paths concurrently and proposed MultiHomed Congestion Control (MCC) mechanism to handle these issues. The proposed mechanism was implemented in SCTP due to mature multihoming. SCTP was configured with general transport layer features (such as using single stream of data instead of multistreaming). This will support us to incorporate MH-awareness related issues and algorithms developed in this research work in other transport protocols [19]. The rest of the paper is organized as follows. Section II discusses some state-of-the-art schemes proposed to-date for multipath transmission. Section III describes the proposed SMT schemes. The simulation results of the proposed MCC mechanism are compared and analyzed in a variety of scenarios with the other existing schemes in Section IV. We conclude in Section V.

2. Related Works

The idea of SMT was first suggested by [11] using TCP. Later on, this basic idea was reinvented multiple times in various forms using the Internet Engineering Task Force (IETF) standard transport protocols [22, 23, 24, 25, 26, 27, 28].

Hacker *et al.* [7] proposed parallel TCP (pTCP) that stripped the data across multiple TCP connections. Multipath Transmission Control Protocol (M/TCP) added multipath capability by distinguishing congestion on various paths using the route ID sent in a TCP option [30]. In [4], the author has proposed concurrent Transmission Control Protocol (cTCP). cTCP avoid retransmission of the lost segment of one path to another path. This weakens the backup support of cTCP. In addition to this, Arrival-Time Load Balancing (ATLB) [9] focus in order arrival of packets at the receiver using multiple path end to end delay disparity base schedulers [24].

The MultiPath TCP (MPTCP) concept was initiated by the IETF in 2009 and defined in [6, 7, 8]. The CC algorithms were proposed for MPTCP such as fully coupled [28], Linked Increases Algorithm (LIA) [27], semi coupled CC [33], Dynamic Window Coupling (DWC) [10] and recently Opportunistic Linked Increases Algorithm (OLIA) [18]. Yang *et al.* [35] focus on importance of scheduler for MPTCP. Systematic Coding-MultiPath TCP (SC-MPTCP) work on improvement of aggregate throughput in presences of minimum RBuf [20].

AppStrip [20] used multiple User Datagram Protocol (UDP) connections to manage path failures, round robin scheduling and reordering of packets. Similarly Multi-Flow Real-Time Transport Protocol (MRTP) [23] creates multiple connections using UDP. MRTP forms a layer on top of the transport protocol. MRTP has to communicate the status between the sender and receiver using redundant packets which increases overhead. The author of SCTP Concurrent Multipath Transfer (CMT) [12, 15, 16] proposes three algorithms to solve the reordering side effect with the assumption of infinite buffer.One of them is the Split Fast Retransmission (SFR) algorithm, which ignores the fast retransmission of OOS packets and hence improved CMT performance. In realistic limited RBuf size, the SFR quickly consumed the RBuf space by buffering OOS packet. This effect CMT performance in limited RBuf space by degrading aggregating throughput. Most of the research work in CMT focuses on retransmission judgment [12, 25], throughput estimation [19, 26, 31] and RBuf optimization [32] or its joint solution. The SCTP CMT is still in developing phase related to load sharing and CC mechanism [5].

In short, there is a need for a MCC mechanism that has in-depth knowledge of bandwidth and delay disparity of each interface along path based OOS packets differentiation while transmitting single stream over multiple paths in real time communication [17, 27].

3. Proposed IOPD and MCC Mechanism

The proposed IOPD algorithm is used to split the network congestion effect from the multipath effect while MCC is used to trigger specific congestion mechanism with respect to causes of congestion. In this solution, only the sender side modification is required while receiver remains unaffected. MCC is used to apply fast retransmission per destination basis.The MH sender differentiates OOS packets into inter and intra–path using information conveyed from Selective Acknowledgement (SACK) [3]. SACK is a gap report, sent from receiver to inform sender about missing packets. Let MH devices maintains following variables for each destination (D_i).

- *Transmission Sequence Number* (*TSN*): represented by Ta, is a unique sequence number assigned to data packets transmitted between MH sender and receiver.
- *Highest_in_sack_for_dest* ( ): is highest TSN acked per destination using the SACK
- *Saw_new_ack* ( ): is used to stores the boolean status of each destination interface to find out the causative TSNs: Causative TSNs for a SACK are those TSNs which caused the SACK to be sent.
- *Low_TSN* ( ) *and High_TSN*( ): These variables maintained a pointer for lowest and highest TSN in a sender queue for each destination.
- $Count_{IP}$ *and* $Count_{IAP}$: Fast retransmit threshold for inter and intra-path OOS packets respectively.

Algorithm 1: Inter-path OOS packet differentiation (IOPD)

Input: $\{S_{NAck\ i}, T_a, D_n, H_D, Count_{IP}, Count_{IAP}, High_{D_m}, Low_{D_m}\}$

Output: $\{Count_{IP}, Count_{IAP}\}$

$\forall$ D_i, *initialize* S_{NAck_i} = *False*

$\exists T_a$ *being acked that has not been acked in any previous SACK*

Let D_n *be the destination to which* T_a *was sent*

S_{NAck_i} = *True;*

$\forall D_n$, *Set* H_{D_n} *to the highest TSN being newly acked on* D_n .

To determine whether missing report count for a TSN should be incremented for inter OR for intra-path OOS.

Let D_m *be the destination to which* T_m *was sent*

If (S_{NAck_m} = = *True*) && ($High_{D_m} > T_m$) && (($T_m \leq High_{D_m}$)||($T_m > Low_{D_m}$))

Then $Count_{IAP}$ ++

else $Count_{IP}$ ++

If packet's TSN reported by SACK is a new acked packet, which is less than highest TSN acked on this destination and also take place between Low_{D_m} and $High_{D_m}$ then this TSN is treated as intra-path OOS packets otherwise it is reported as inter-path OOS packets. The IOPD algorithm increment $Count_{IAP}$ or $Count_{IP}$ based upon OOS packet classification. The next phase is the activation of MCC mechanism with respect to inter and intra-path threshold counter.

3.1. MultiHomed Congestion Control (MCC) Mechanism

In reliable transport protocols, like TCP and SCTP, dup_acks are sent every time an OOS segment arrives. The sender, on receiving these dup_acks decides their retransmission strategies. One such approach is named as a fast retransmit strategy that dictates retransmission of the segment whose three dup_acks are received, without lapse of retransmission timeout. The underlying assumption in such retransmission is that the segment may have been lost due to congestion as the later three segments have already reached, as indicated by three consecutive dup_acks. This approach saves some time for retransmission as we do not need to wait for the retransmission timeout event. One major consequence of such approach is the readjustment of CWnd of the stream that may be slashed down according to different proposed algorithms. The IOPD maintains a separate fast retransmission counter for inter and intra-path OOS as pictorially presented in the Figure 2.

The MCC triggers fast retransmit event for Intra-path OOS packets by retransmitting the missing packets on fast link and halve CWnd due to indication of real congestion in network as shown in Figure 2. The inter-path OOS packets are generated due multipath effect. MCC fast retransmit inter-path OOS packets on fast link without cutting half CWnd.

The sender can minimize OOS packet by using optimized scheduler, but still there is a chance of OOS packet arrives at the receiver due to the dynamic nature of Internet traffic and changing network topology. The excessive retransmission of duplicate packet on fast link diminishes the SMT benefit of bandwidth aggregation by resending slow link traffic on fast link. But once RBuf blocking occurred at the receiver side, then IOPD and MCC mechanism is the last hope to get rid of this chaotic situation.

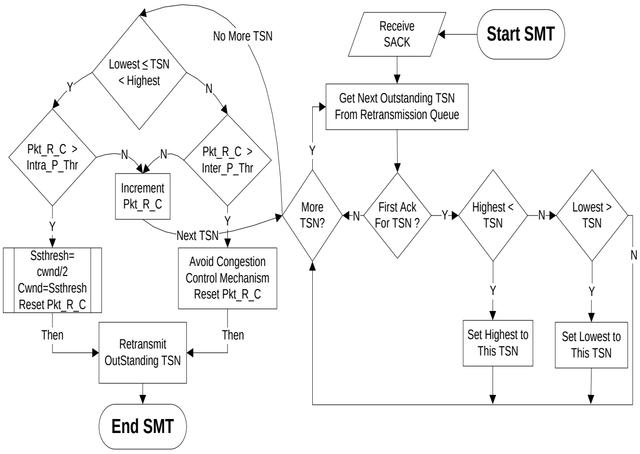
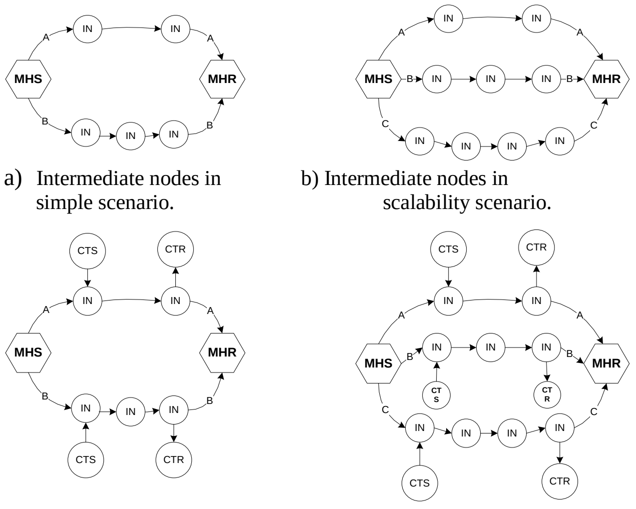


Figure 2. SMT Scheme (MCC and IOPD).



a) Intermediate nodes in simple scenario.

b) Intermediate nodes in scalability scenario.

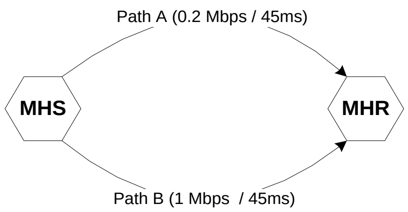
c) intermediate nodes and cross traffic in simple scenario.

d) intermediate nodes and cross traffic in scalability scenario.

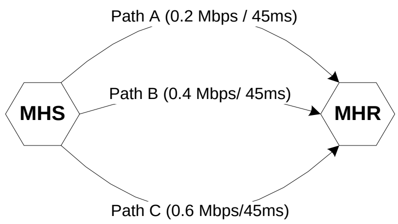
Figure 4. MH topology having intermediate nodes and cross traffic in simple scenario and scalability scenario.

4. Results and Discussion

Throughput enhancement of IOPD and MCC mechanism is verified using a large set of topologies, incorporating simple to complex scenarios with multiple paths and intermediate nodes using network simulator-2 (Ns-2). The simple scenario has two paths A and B, having bandwidth 0.2 and 1Mbps respectively as shown in Figure 3-a. Here we focused on bandwidth disparities of multiple paths therefore delay was kept same (45ms) for both paths (A and B).



a) MH topological configurations of simple scenario.



b) MH topological configuration of scalability scenario.

Figure 3. MH topological configuration

Scalability scenario is designed to find the effect of increasing multiple paths on the performance of multipath transmission. This scenario has three paths A, B and C with bandwidth 0.2, 0.4 and 0.6 Mbps respectively. Further sub scenarios of simple and scalability topologies are also designed with varying number of intermediate nodes and introducing cross traffic of UDP as shown in Figure 4.

Table 1. Simulation configuration parameters.

Parameters	Values
Traffic source	FTP
Stream (single stream)	1
Transport protocol	SMT / CMT
Packet size	1500 Bytes
RWnd	65536 Bytes
Simulation time	50 Seconds
Cross traffic	Constant Bit Rate (CBR)

The detail NS-2 parameters configuration is mentioned in Table 1.The MH device splits single stream of data over multiple connection to download a file from remote server using File Transfer Protocol (FTP), supported by CMT and SMT transport layer protocols. The MH sender has limited RBuf size of 65536 bytes that is large enough for a 100Mbps transport layer connection and easily available in most MH devices such as a smart phone. Standard transport layer packet size of 1500 bytes is used to avoid fragmentation complexities at lower layer [1]. The simulation time of 50 seconds was long enough to thoroughly analysis the performance of average transport layer connections that exist on the Internet. Normalized Receiver Window (RWnd), CWnd and throughput are used for performance analysis of multipath transmission as shown in Equation (1).

$$z_i = \frac{x_i - x_{\min}}{x_{\max} - x_{\min}} \tag{1}$$

Where as x_i=(x_1, x_2, x_3,.,.,x_n) represents i^{th} data point i.
x_{min} = the smallest value among all the data.
x_{max}= the largest value among all the data and z_i is the i^{th} normalized data of RWnd, CWnd and throughput [34].
The RWnd is a receiver side limit on the amount of outstanding segments. The CWnd is sender-side limitation on the amount of data sender can transmit

into the network without receiving an ACK. Both the RWnd and CWnd are used to regulate the data flow using flow control and CC mechanism as shown in Equation (2).

$$Send\_window = \min(rwnd, cwnd) \quad (2)$$

Throughput refers to quantity of error free data received at the receiver side per unit of time. The path's throughput is limited by RWnd and Round Trip Time (RTT).

$$Throughput \le {}^{rwnd}\!/_{RTT} \quad (3)$$

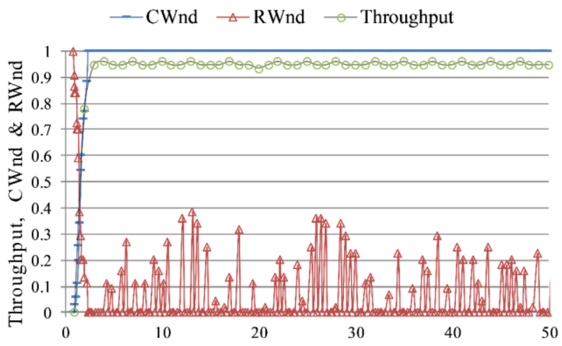


Figure 5. SMT path B's CWnd, RWnd and throughput.

Even if there is no segment loss, the throughput cannot be increased more than (RWnd/RTT) at any time. SMT performance was compared with CMT which is one of the most referenced multipath transmission schemes in literature (cited by 533 papers) [3, 29]. SMT has persistent CWnd, high aggregate throughput and enough RWnd as shown in Figure 5. SMT avoids the CC mechanism for Interpath OOS packet arrival. This avoids unnecessary CWnd collapse. The delayed packets are quickly retransmitted through fast link, so that in sequenced packets are handled to the application layer. This increase RWnd space and helped in curing RBuf blocking problem. Extensive simulations were carried out to thoroughly analysis the SMT performance gain in various topological configurations as shown in Figures 4-a and 4-b. The SMT has improved aggregate throughput with range from 95.3% to 10% in the worst scenario (Figure 7).

The OOS packet arrival is unavoidable phenomena in multipath transmission. SMT scheme improves the efficiency of any multipath scheme in handling OOS packets. The only limitation of SMT scheme is the duplicate transmission of delayed packets on the alternate fast path. In the worst scenario, all packets on slow link will be transmitted over a fast link. This problem will be solved by adaptive MCC scheme where the adaptive threshold for fast retransmission of redundant delayed packet will be used with respect to space advertise by RWnd. In this way, SMT helped fast link to be fully utilized without affecting its performance due to slow link.

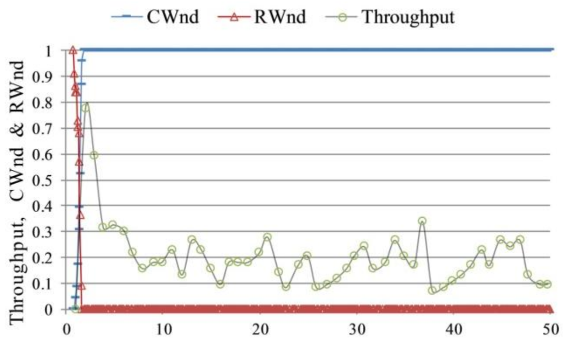


Figure 6. CMT path B's CWnd, RWnd and throughput.

On the other hand, the CMT observed throughput degradation due to RBuf blocking as shown in Figure 6. The intention of CMT is to ignore the spurious fast retransmission; triggered due to multiple paths effect. The CMT's CWnd status remained high, but its RWnd drop to lowest level throughout transmission, which becomes a reason for its throughput degradation. The delayed OOS packet makes buffer overflow, which advertise minimum RWnd. The S_{wnd} limits the sending rate up to space advertises as RWnd which resulted in to poor CMT throughput performance.SMT focus on efficient detection of Inter and Intera path OOS delayed packets with the help of IOPD algorithm. IOPD discriminate OOS packet's causes into network congestion and multiple path effects. In case of multipath effect, delayed packet was fast retransmitted without shrinking CWnd. The fast retransmission of delayed packet helped in freeing RBuf space for further incoming packets. The persistent CWnd size and increased in RBuf space, helped SMT in gaining comparatively high throughput with respect to CMT.

Figure 7 shows the performance comparison of SMT, CMT and Sender-based Multipath Out-of-order Scheduling (SMOS) [21] in number of simulation scenarios. The complexity of scenarios varies due to the presence or absence of intermediate nodes and cross traffic. SMT has comparatively high bandwidth utilization efficiency in all scenarios. The scalability effects SMT throughput which demands for fair scheduler is also part of future work. The scheduler should be optimized enough that can schedule packet on multiple paths according to dynamic Internet parameters such as bandwidth, delay and loss rate.

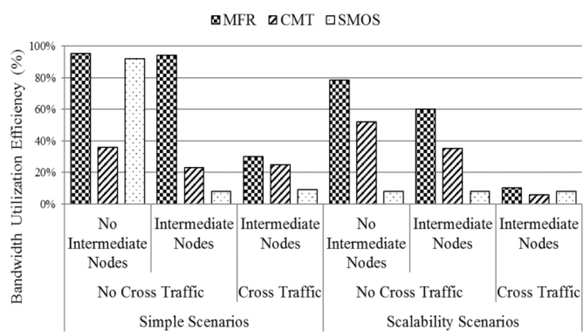


Figure 7. Aggregate bandwidth utilization of SMT,CMT and SMOS.

5. Conclusions and Future Work

The multipath transmission is one of the emerging transport scenarios with significant potential of performance boost, particularly in resource scare wireless networks. In this paper we argued that present transport layer protocols are immature for concurrent multipath transmission of single stream over multiple interfaces. They have by default single path specialized CC mechanism. These protocols undergo throughput degradation, duplicate packets abnormal fast retransmission, frequently CWnd collapses and RBuf blocking while transmitting on multipath concurrently.

We have introduced two distinct interpretations of multi-path transport, according to the OOS packet arrival at receiver side based on belonging to the same path or dissimilar path. This work proposed SMT scheme which is composed of MCC mechanism and IOPD. The extensive network simulation results supported that the proposed SMT has overcome RBuf blocking and improves throughput with range from 95.3% to 10% in worst scenario.

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