ADAPTIVE FAST RETRANSMISSION WITH RESPECT TO RECEIVER BUFFER (RBUF) SPACE IN SIMULTANEOUS MULTIPATH TRANSMISSION (SMT)

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ABSTRACT

Simultaneous Multipath Transmission has inherited problem of out-of-order packet reception. This causes receiver buffer (Rbuf) blocking, which degrades the aggregated throughput and restricts the efficiency of fastest path to its slowest companion path. This research proposed SMT-Adaptive Fast Retransmit mechanism that uses fast retransmission threshold, adapts to the size of Rbuf in order to encounter Rbuf blocking problem. In bandwidth and packet loss based disparity scenarios, SMT-AFR achieved the highest aggregated throughput and remained unaffected with respect to various Rbuf sizes. In delay based disparity scenarios, the performance of SMT-AFR affected with a decrease in Rbuf size. Simulation results revealed that SMT-AFR has solved the Rbuf blocking problem in bandwidth and packet loss disparity scenarios. There is a need for the multipath disparity aware scheduler to improve SMT-AFR performance in delay based disparity.

Keywords: Multipath transmission, Simultaneous multipath transmission (SMT), Receiver buffer blocking, Multipath disparities, Adaptive fast retransmit on multipath

1.0 INTRODUCTION

An emerging trend of multihomed devices like smartphones and tablets, can be used to fulfill bandwidth demand of many applications by the simultaneous usage of more than one path. Stream control transmission protocol (SCTP) based Concurrent Multipath Transmission (SCTP-CMT) [1- 4] provides an opportunity to exploit the additional transport layer resources by enabling multihomed devices. SCTP-CMT aggregates multiple path resources for a single transport layer session with unrealistic assumptions of infinite receive buffer (Rbuf). The aggregated performance diminishes with limited Rbuf, variations in round trip times (RTT) and disparities in the bandwidth of multiple paths [5]. This causes Rbuf blocking and reduction of aggregated throughput to the slowest path. In Simultaneous Multipath Transmission (SMT), a single stream of data is being transmitted on multiple paths concurrently with the assumption that the receiver buffer size (Rbuf) is finite.

In this paper, we propose a fast retransmission mechanism, which adapts to available Rbuf space in order to handle the Rbuf blocking problem in the presence of bandwidth and delay disparities of multiple paths. Packet reordering is an unavoidable event during multipath transmission. The traditional fast retransmit mechanism cannot handle multipath out of order packets. There is a need for another mechanism, which can analyse the disparity of multipath features in order to efficiently handle out of order packet arrival in limited Rbuf size. Adaptive fast retransmission is used to solve this issue by efficiently utilizing available Rbuf space. Here, the “Rbuf size” is used to mention the total capacity of Rbuf, while the “Rbuf space” is used for the availability of empty space in a Rbuf.

The rest of the paper is structured as follows: Section 2 gives a brief literature review on the multipath congestion window management, schedulers, Rbuf blocking and cross-layer approaches for multipath transmission. Section 3 presents our proposed adaptive fast retransmission whose implementation and performance modification is illustrated in section 4. Finally, section 5 concludes the work and recommends future direction.

2.0 LITERATURE REVIEW

Ubiquitous connectivity, reliability and bandwidth aggregation are vital features that helped concurrent multipath communication in gaining extensive research attention. Researchers have proposed a number of solutions to handle the shortcoming of multipath transmissions, such as receiver buffer blocking, naive scheduling, packet reordering and abnormal congestion window mechanism. All the solutions aimed at solving these problems by addressing either the flow control with managing the receiver buffer or by congestion control with managing the congestion window (cwnd) on the sender side.

A number of congestion window management policies (Cwnd-MPs) are introduced in the last decade, mostly designed for end-to-end communication over a single path [6]. The Cwnd-MPs introduced multihomed cwnd management schemes for efficient bandwidth aggregation of multiple paths. The Cwnd-MPs have a lack of support for multipath disparity aware scheduler, which cause packet reordering at the receiver side. This degraded the performance of Cwnd-MPs in concurrent multipath transmission. Wallace et al introduced On-Demand Scheduler (ODS) for SCTP-CMT where the cwnd size of a path is limited to its bandwidth delay product (BDP) [7]. This helped in preventing abnormal cwnd growth and restricted the destination to its fair share of resources. The ODS considered the scheduling decision based on each path reception index. The reception index is calculated using path features, such as the ratio of the current size of schedule data and unacknowledged data in flight (cwnd) to estimate bandwidth. The processing delay involved in recursive search of a suitable packet in sending buffer (Sbuf) rises with increasing in a number of destinations and size of Sbuf. This makes ODS be very expensive for smartphones having small battery power. ODS created another inefficiencies by sending data to a destination having lowest RTT and larger cwnd size. This will allow one destination to have a high proportion of shared resources.
OSI communication follows the waterfall model with virtually strict boundaries between the layers. On the other hand, the cross-layer solutions provide flexibility of getting feedback from any layer with the incentive of performance optimization. Cao et al presented a cross-layer approach for QoS-aware adaptive CMT (CMT-CQA) in which slowest trouble maker path is removed from multipath transmission to avoid aggregated bandwidth degradation [8]. The choices of best paths are made using cross layer paths history and medium access control (MAC) layer quality of service (QoS) information. The bandwidth of inactive path is estimated before including into multipath transmission to avoid slow start and jitters in delay. A local optimization technique is used in QoS-aware adaptive CMT (CMT-CQA) to allow cwnd growth of a destination having high bandwidth potential as compared to low bandwidth destinations. In SCTP-CMT, the naïve scheduling is the round-robin transmission of packets to multiple paths [9]. The naïve scheduling creates packet reordering which is an inherited issue during concurrent multipath transmission. The packet reordering generates further issues, i.e. an abnormal fast retransmission, frequent cwnd collapses, increases in packet losses and finally demolish the aggregated throughput. This situation becomes worse with the increase in disparity of multiple path features such as bandwidth and propagation delay. The researchers used intelligent, optimized multipath scheduler to minimize the packet reordering using various parameters such as Rbuf space, cwnd, slow start threshold (SSThresh), path losses and bandwidth delay product (BDP) of each destination. In addition to this, various scheduling policies are used for scheduling of retransmitted packets on more than one path. The drawback of such mechanisms is that the complexity of multipath scheduler increases with the rise in the number of parameters.

The receiver buffer (Rbuf) blocking is a phenomenon in which very early packet blocks the buffer by making it wait for a delayed packet to an extent that the entire buffer is consumed by incoming packets. This makes the receiver to advertise very low Rbuf by decreasing the sending rate to the very low rate at the sender side. This Rbuf blocking issue is notified by Iyengar et al. and proposed five retransmission policies to overcome it [11]. The intention of these five policies is to quickly retransmit the packet to a destination using receiver side congestion management features such as cwnd, slow start threshold (SSThresh) or loss rate. In Multipath State Aware Concurrent Multipath Transfer (MSACMT-RT), the packets are scheduled on different paths based on path priority [10]. The path priority is decided on the basis of lowest RTT, largest cwnd and largest SSThresh. In this scheduler, the last weakest path is selected as a redundant path to second last weakest for transmission of redundant data. MSACMT-RT scheduler has no solution to a situation where both paths (weaker path and redundant path) became failed. This resulted in performance degradation of MSACMT-RT in multipath transmission.

Some studies focus on using various retransmission schemes and buffer management techniques to effectively overcome the Rbuf blocking problem. The compound parameters retransmission policy is one of these schemes that used a combination of larger SSThresh, open cwnd and low loss rate in the selection of retransmission path [12]. If all destinations have same features than the random retransmission path is selected. The CMT-RTTA proposed buffer splitting technique on the basis of RTT [13]. The path having less RTT will occupy more Rbuf space as compared to longer RTT. This technique reported 14% aggregated throughput improvement as compared to SCTP-CMT. According to Precise Receive Buffer Assignment Method (PAM), the space of Rbuf is utilized with respect to an RTT of each path [14]. This avoided the Rbuf blocking by limiting each destination in its own Rbuf space and increased aggregated throughput. On the other hand, the Sbuf observed blocking effect by keeping the copies of received out of order packets. Non-renegable Selective acknowledgment (NR-SACK) is used to remove this packet for a non-renegable receiver [15]. In this way, NR-SACK created free space in Sbuf for new transmission. The efficiency of Rbuf decreased with an increase in the number of paths [16]. Range based path selection (RPS) method is proposed for the selection of new path with the motivation of efficient utilization of Rbuf space.

Hence, the related work concluded that Rbuf blocking can be solved using efficient Rbuf management techniques. The Rbuf space should be efficiently utilized with respect to out of order packet arrival in order to enhance the aggregate throughput in multipath transmission. At the same time, there is a need for effective retransmission technique, which will regulate the retransmission of missing packets with respect to the size of Rbuf. The retransmission techniques have the ability to retransmit the missing packet just before the occurrence of Rbuf blocking in order to reduce the redundant packet transmission in multipath transmission.

3.0 PROPOSED ADAPTIVE FAST RETRANSMISSION (SMT-AFR) MECHANISM

This is an observation that concurrent multipath communication is adversely affected when there is a difference between delay and bandwidth characteristics of multiple paths. In such situation, Rbuf blocking occurs which decreases the aggregated throughput from its theoretical maximum. Rbuf blocking can be minimized by quick retransmission of the delayed packet. Traditional congestion window management has static fast retransmit threshold which triggers a fast retransmission on the reception of three duplicate acknowledgments (Dup Acks) that worked well for single path transmission. In case of multipath transmission, there is a need for an adaptive fast retransmission mechanism, which changes the Dup Acks threshold according to the size of Rbuf.

The proposed scheme categorized Rbuf into four zones. In order to decide about classification of Rbuf, we perform some experiments. First, we will explain these experiments and their findings which helped us in formulating of SMT-AFR scheme. Then we will discuss our proposed SMT-AFR scheme. In these experiments, various test cases are simulated in network simulator-2 [18]. In these test cases, multihomed sender and receiver used two multiple paths A and B for simultaneous data transmission as shown in Fig. 1. The path error rate of 0.1% is introduced in path A.

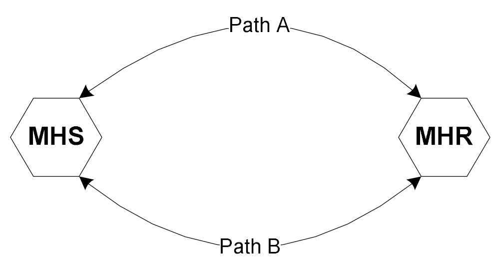

Fig. 1: Multipath transmission between Multihomed Sender (MHS) and Receiver (MHR).

In these simulation scenarios, the total Rbuf space is classified into multiple pivot points, i.e. 10, 20,.,., 100 in terms of percentage. Each pivot point in a scenario indicates the available Rbuf space in that case. Various fast retransmit thresholds (FRT (m|n) values are used for each pivot point where “m” and “n” are the values of fast retransmit threshold (FRT), used before and after that pivot point. This means that the missing packet will be retransmitted on receiving “m” duplicates Acks if the available Rbuf space is less than pivot point and “n” duplicate Acks if the available Rbuf space is greater than or equal to pivot point as shown in Fig. 2.

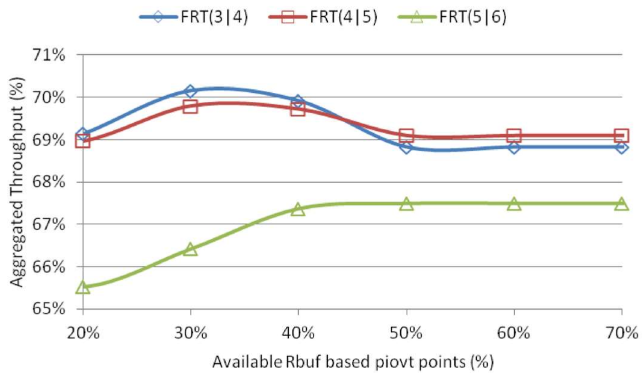

Fig. 2: Aggregated throughput of multiple paths (A & B), having bandwidth and delay based disparities

At least 20 percent Rbuf space is essential for SMT-AFR scheme to buffer at least more than 3 missing packets to generate 3 duplicate Acks. Fig. 2 shows the relativity between the available Rbuf spaces and fast retransmit threshold policies. This enables us to derive the following analysis, which helped us in presenting the SMT-AFR scheme of the multihomed congestion control mechanism.

- FRT (3) helped in high aggregated throughput when the multihomed receiver has minimum available Rbuf size (less than 40%).
- FRT (5) is more effective when Multimode receiver has a maximum available Rbuf size (greater than 80%).
- FRT (4) should be used in the middle of the transaction between the two fast retransmit policies, i.e. FRT (3) and FRT (5).

The choices of a specific fast retransmit policy become complicated with the increase in bandwidth and delay disparities of multiple paths. There is a need for an adaptive strategy where the fast retransmit threshold jumps from one policy to another with respect to available Rbuf space and previous history.

These recommendations can be useful in categorizing Rbuf size into four performance risk zones: critical, substantial, moderate and Tolerable/Minimal risk, as described in Fig.3. Critical zone starts with 0 while Tolerable/minimal risk zone end with 1. There are three dynamic pivot points, i.e. P1, P2 and P3 which are used to mark the starting point of substantial, moderate and tolerable/minimal risk zone, respectively. The initial location of these pivot points is selected based on 150 test cases. These pivot points move forward or backward depend upon the SMT-AFR schemes; designed for avoiding Rbuf blocking and aggregated throughput enhancement.

Fig. 3: Space wise categorization of Rbuf with respect to performance risk [17]

One of the most important parts of this algorithm is the fact that same available Rbuf space is advertised to all destinations according to standards. Therefore, SMT-AFR algorithm has to consider advertised Rbuf space irrespective of a specific destination.

Algorithm: SMT-AFR (Rbuf, $^{C}P_{S}$, $^{S}P_{M}$, $^{M}P_{T}$, $^{O}T_{D}$).

Input: available Rbuf size of destination D; Three Pivots ($^{C}P_{S}$, $^{S}P_{M}$, $^{M}P_{T}$) that act as boundary lines among critical, substantial, moderate and tolerate zones. Occurrence threshold ($^{O}T_{D}$) that adjust three pivots in the management of four zones.

Output: Fast Retransmit Threshold (FastRtx_Threshold) value that efficiently manages the waiting time for retransmission of out of order packet at specific destination D.

Normalized receiver buffer space into four zones i.e. critical, substantial, and moderate and tolerate zone separated by $^{C}P_{S}$, $^{S}P_{M}$, $^{M}P_{T}$ respectively. Let buffer space space advertised to receiver is Rbuf and occurrence threshold value is $^{O}T_{D.}$

If (Rbuf < $^{C}P_{S)}$ { // Critical zone
  FastRtx_Threshold = 3;
  Initialized, $^{C}P_{S}$, $^{S}P_{M}$, $^{M}P_{T}$ to by default values
}
else if (Rbuf >= $^{C}P_{S}$ && Rbuf < $^{S}P_{M}$) {// Substantial zone
  FastRtx_Threshold = 4;
  Moderate_count ++;
    if (Moderate_count >= $^{O}T_{D}$) {
     $^{S}P_{M}$ = Rbuf - 0.001;
     Moderate_count=0;
    }
}
else if (Rbuf >= $^{S}P_{M}$ && Rbuf <= $^{M}P_{T}$) { // Moderate zone
  FastRtx_Threshold =5;
  Tolerate_count++;
    If (Tolerate_count >= $^{O}T_{D}$) {
     $^{M}P_{T}$ = Rbuf -0.001;
     Tolerate_count=0;
}
}
else if (Rbuf >= $^{M}P_{T}$ && Rbuf <= 1.0) { // Tolerate Zone
  FastRtx_Threshold =6;
}

Fig. 4: SMT-Adaptive Fast Retransmit (AFR) Scheme

To elaborate the functionality of SMT-AFR scheme, Fig. 5 represents the data flow diagrams of the scheme.

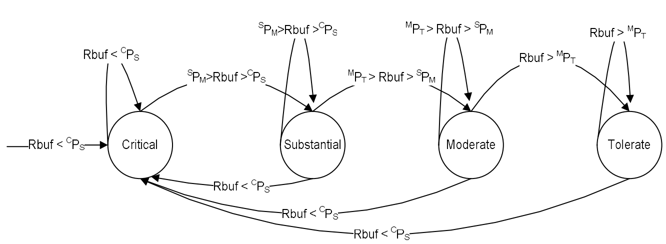

Fig. 5: Data flow diagram of SMT-Adaptive Fast Retransmission (SMT-AFR)

4.0 PERFORMANCE EVALUATION

Disparity found in bandwidth and delay of multiple paths greatly affects the performance of the simultaneous multipath transmission. The situation gets worse with packet losses occurs in transmission. The proposed SMT-AFR is compared with Naïve and Concurrent multipath transmission (SCTP-CMT). Two multiple paths P_A and P_B are used in network topology to represent frequently used realistic simulation scenarios of smartphones where a user can access the Internet using Wi-Fi and cellular interface. Throughput refers to the instantaneous rate of data packets received in a path. In case of data transmission for long duration, the Average Throughput (T_{Aver}) is used which can be defined for a path as the average amount of data packets successfully transmitted per unit time and it is typically measured in bits per Second (bps). Mathematically, Average Throughput (T_{Aver}) is calculated using the following formula.

$$T_{Aver} = \frac{\sum_{i=1}^{n} \text{Pkt\_count}_i \times \text{Packet\_size}}{\text{Total\_Time}(T_N)} \quad (1)$$

Whereas, data packets have the same size. In case of SMT, where more than one path is used for data transmission, the averaged throughput for multiple paths are combined using aggregated throughput (T_{Ag}) as given below.

$$T_{Ag} = \sum_{j=1}^{m} T_{Aver_j} \quad (2)$$

On the other hand, capacity (C) of a path can be defined as the maximum data packet transmission ability of a path per unit time and typically measured in bits per second (bps) as mentioned below:

$$C = \text{Max}(T) \quad (3)$$

T stand for instantaneous throughput. In case of multipath transmission, the capacity of multiple paths is combined using a parameter called aggregated capacity (C_{Ag}) . Mathematically, an aggregated capacity is represented by equation 4.

$$C_{Ag} = \sum_{j=1}^{m} C_j \quad (4)$$

In order to determine throughput with respect to available path capacity, the aggregated bandwidth utilization (BwU_{Ag}) is proposed and is measured in terms of percentage as mentioned mathematically in equation 5.

$$BwU_{Ag} = \left({T_{Ag}}/{C_{Ag}} \right) \times 100 \quad (5)$$

For more realistic scenario, bandwidth, delay, and packet loss based disparity are simulated in Path "A". Rbuf size variation (32 to 512 kilobytes) is used on the basis of a range of memory size,which can be found in smartphones. SCTP module of network simulator-2 (NS-2) is modified for implementation of SMT-AFR, Naïve-CMT and SCTP-CMT to get fair results. Detailed parameter configuration is mentioned in table 1. The file transfer protocol (FTP) is used in application layer where a single stream of data is transmitted by splitting among multiple connections in order to support the single sequence number concept. The SMT-AFR, Naïve-CMT and SCTP-CMT are used at the transport layer with a packet size of 1500 bytes. The probability of packet loss of 0.01 is configured on path A.

Three fast retransmit schemes (FRT (m | n)) are used with respect to four zones of Rbuf and "m" and "n" are the two different fast retransmit threshold values.

Table 1: General scenario parameters configuration

Parameters	Values
Traffic Source	File Transfer Protocol
Number of Streams/Flows	1
Transport Protocol	SMT-AFR / Naïve-CMT / SCTP-CMT
Packet Size	1500 Bytes
Probabilistic Packet Losses in Path A	0.01
Fast retransmit Thresholds (FRT (m | n))	FRT (3 | 4), FRT (4 | 5), FRT (5 | 6)

4.1 Bandwidth Based Disparity

The proposed SMT-AFR mechanism is evaluated along with Naive-CMT and SCTP-CMT in bandwidth based disparity scenarios. In bandwidth based disparity scenarios, the bandwidth of Path B is fixed (1 Mb/Sec) while path A bandwidth is kept varying (from 0.1 to 1 Mb/Sec) as mentioned in table 2. In addition to this, the delay of both paths is kept same in order to analyze the effect of bandwidth disparity on multipath transmission. Bandwidth based disparity scenarios are simulated with different Rbuf size as shown in Fig. 6. In 32 kilobytes Rbuf scenario, SMT-AFR has comparatively outperformed the other multipath transmission schemes. SMT-AFR performance is not considerably affected by bandwidth disparity. In 64-128 kilobytes Rbuf size scenarios, the SCTP-CMT faced huge aggregated bandwidth utilization collapse due to frequent Rbuf blocking problems, which are successfully solved by SMT-AFR. SMT-AFR maintains its high aggregated bandwidth utilization using large Rbuf size 256 and 512 kilobytes. These results discovered that SMT-AFR outperformed in approximately all bandwidth disparity scenarios with respect to different Rbuf sizes ranging from 32 to 512 kilobytes.

Table 2: Bandwidth based disparity scenario parameters.

Parameters	Values
Bandwidth & Delay of Path A	0.1, 0.2, 0.3,.,.,., 1.0 Mbps & 45 milliseconds
Bandwidth & Delay of Path B	1 Mbps & 45 milliseconds
Sizes of Receiver window (rwnd)	32, 64, 128, 256, 512 Kilobytes

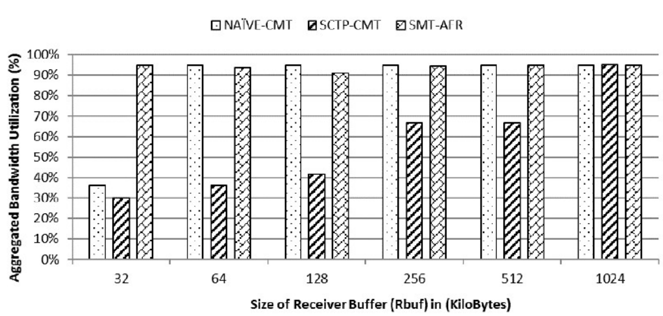

Fig. 6: Bandwidth based disparity: summarized results of aggregated bandwidth utilization with respect to varied Rbuf sizes (32 -512 Kilobytes).

4.2 Delay based Disparity

Same set of multipath transmission schemes (SMT-AFR, NAIVE-CMT, SCTP-CMT) is evaluated in delay based disparity scenarios, each having different Rbuf sizes (32 kilobytes to 512 kilobytes) as shown in Fig. 7. In these scenarios, the delay of path "B" is kept same (45 milliseconds) while the delay of a path "A" is varied (from 10 to 90 milliseconds) to find the effect of delay variation in multipath transmission as mentioned in table 3. Other path features such as bandwidth (1Mb/Sec) and loss rate, are configured same for both paths. The results of these scenarios revealed that SMT-AFR is sensitive to delay based disparity, especially when Rbuf size is kept low from 32-64 kilobytes. For best performance, the data in flight (i.e. Bandwidth delay product) must be less or same to the size of Rbuf. This diminishes the aggregated bandwidth utilization of SMT-AFR and SCTP-CMT. In rest of scenarios, where Rbuf size is larger than 64 kilobytes, the aggregated bandwidth utilization of SMT-AFR is high and remaining unaffected by delay based disparity for the rest of simulations. Fig. 7 gives a summary of aggregated bandwidth utilization results with respect to varied Rbuf sizes revealed that SMT-AFR is less immune to delay based disparity with low rub size. This can be addressed by designing delay aware multipath scheduler, which will be our future work.

Table 3: Delay based disparity scenario parameters

Parameters	**Values**
Bandwidth & Delay of Path A	1 Mbps & 10, 20,.,.,.,90 milliseconds
Bandwidth & Delay of Path B	1 Mbps & 45 milliseconds
Sizes of Receiver window (rwnd)	32, 64, 128, 246, 512 Kilobytes

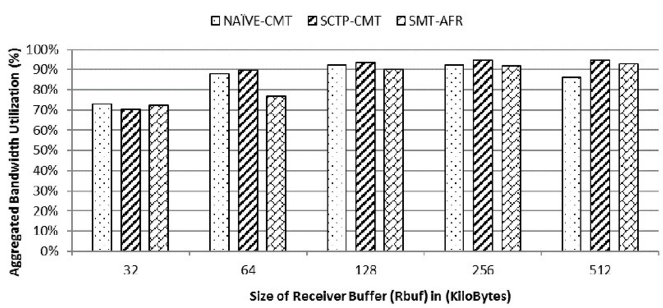

Fig. 7: Delay based disparity: summarized Results of aggregated bandwidth utilization with respect to varied Rbuf sizes (32,64,128,256,512 KiloBytes).

4.3 Probability of Packet Loss

The packet is considered to be a loss when it fails to reach the destination within limited time. In a communication data network, the packet gets lost either due to network congestion, network or packet corruption indicated by failing header checksum verification.It is a common phenomenon which badly affects network performance. The proposed SMT-AFR mechanism is evaluated under different probability of packet loss in path "A" ranged from 0.01 to 0.1 as shown in table. 4. The packet loss probability of 0.01 indicates that one packet out of hundred packets gets failed to reach its destination. This probabilistic packet loss increases in the worst scenario up to 0.1 where one packet gets lost out of 10 packets. The probabilistic packet loss scenario is simulated in path "A" with five different Rbuf sizes (32-512 kilobytes) as shown in Fig.8. Other path features such as bandwidth and delay are configured same for both paths A and B. Results revealed that SMT-AFR has shown comparatively high aggregated bandwidth utilized in almost all scenarios, especially when Rbuf size is 32 kilobytes. SMT-AFR has the ability to wait enough for the delayed packet. At the same time, SMT-AFR takes quick action by retransmitting missing packets in critical zone where the fast retransmission threshold is reduced to the low limit. This enables SMT-AFR to have a comparatively high aggregated bandwidth utilization with respect to Rbuf sizes ranges from 32 to 512 kilobytes.

Table 4: Probabilistic packet loss scenario parameters

Parameters	Values
Bandwidth & Delay of Path A	0.5 Mbps & 45 milliseconds
Bandwidth & Delay of Path B	1 Mbps & 45 milliseconds
Probability of packet losses in Path A	0.01, 0.02, 0.03,.,.,., 0.1
Receiver window (rwnd)	32, 64, 128, 256, 512 Kilobytes

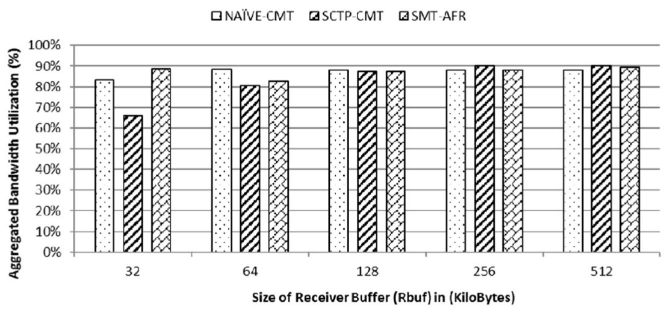

Fig. 8: Loss -based disparity: summarized results of aggregated bandwidth utilization with respect to varied Rbuf sizes (32 -512 Kilobytes).

5.0 CONCLUSION AND FUTURE RECOMMENDATION

In this paper, we proposed SMT-AFR to handle the receiver buffer (Rbuf) blocking problem, which minimizes the effect of a slow link on fast link in a multipath transmission. SMT-AFR categorizes Rbuf space into four zones i.e. critical, substantial, moderate and tolerable zones, on the basis of performance risk affected due to arrival of out of order packets in multipath transmission. These zones are classified using three dynamics pivots (P1, P2, P3). These pivots have by default placement on the basis of our experiments. These pivots move to increase or decrease specific zone space is a tradeoff between Rbuf space occupations and fast retransmit threshold, in order to avoid Rbuf blocking problems. SMT-AFR maintains a high throughput gain in presence of minimum Rbuf size along with bandwidth and loss based disparities. This enables SMT-AFR to be useful in smartphone having limited Rbuf size. In addition to avoidance of the Rbuf blocking problem, SMT-AFR is found to be successful in avoiding the throughput degradation of the fast link due to slow link. There is a need of an efficient multipath disparity aware scheduler to handle the performance degradation of SMT-AFR in delay based disparity scenario. The scheduler should be optimized to handle the scalability issues when the number of companion paths increases. In addition to these issues, the seamless connectivity and best companion path selection among multiple available paths will be addressed in future work.

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