Unequal Importance Multipath Video Streaming for Wireless Networks

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ABSTRACT: *Video streaming is a traditional network traffic application with high bandwidth and delay requirements. Optimizing the network infrastructure for video streaming traffic is an ongoing challenge. In this paper, we consider the case of unicast live video streaming over parallel channels with different reliability and bandwidth, for example, wireless channels. While video streaming over parallel channels was proposed before, each frame in the video data was considered to be equally important. As a result, important frames could be sent over less noisy channels, which impacts perceived video quality at the receiver.*

We show that by using a protocol such as the Stream Control Transmission Protocol (SCTP), we can identify higher reliability channels in a set of potential channels between the video source and consumer. To maximise the experienced video quality at the receiver, we then identify more important data in the video stream and send it over the better channels. We simulate the proposed solution and demonstrate the effectiveness of our proposed framework for concurrent multipath video streaming and the performance gain of concurrent multipath transmission in wireless networks.

Keywords: Concurrent, Multi-path, Video Streaming, Wireless, Networks.

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1. Introduction

In the era of the Internet-of-Things (IoT), most gadgets use wireless communication as the primary communication infrastructure for Internet connectivity. Different applications, from simple electronic devices to complicated industrial systems, exclusively rely on a wireless communication to access the Internet. Wireless connections provide an important and attractive feature: mobility for devices inside the network coverage. Unfortunately, guaranteeing high definition video streaming on mobile devices remains a challenge which needs to be considered when designing video broadcasting systems. To improve the quality of video streaming on different wireless channels, the main limitations related to the wireless networks should be taken into account when designing the transmission protocols [1].

In this work, we consider the case of unicast live video streaming over parallel channels with different reliability and bandwidth, for example wireless channels. While video streaming over CMT has been proposed before, each frame in the video data was considered to be equally important. As result, important frames could be sent over noisy channels, which impacts perceived video quality at the receiver.

The Stream Control Transmission Protocol (SCTP) has been conceived to provide and make use of redundant communication links to mitigate link failure effects while enhancing connectivity. Due to the rising popularity of video streaming, SCTP now includes new features such as support for Concurrent Multi-path Transfer (CMT). CMT offers bandwidth aggregation

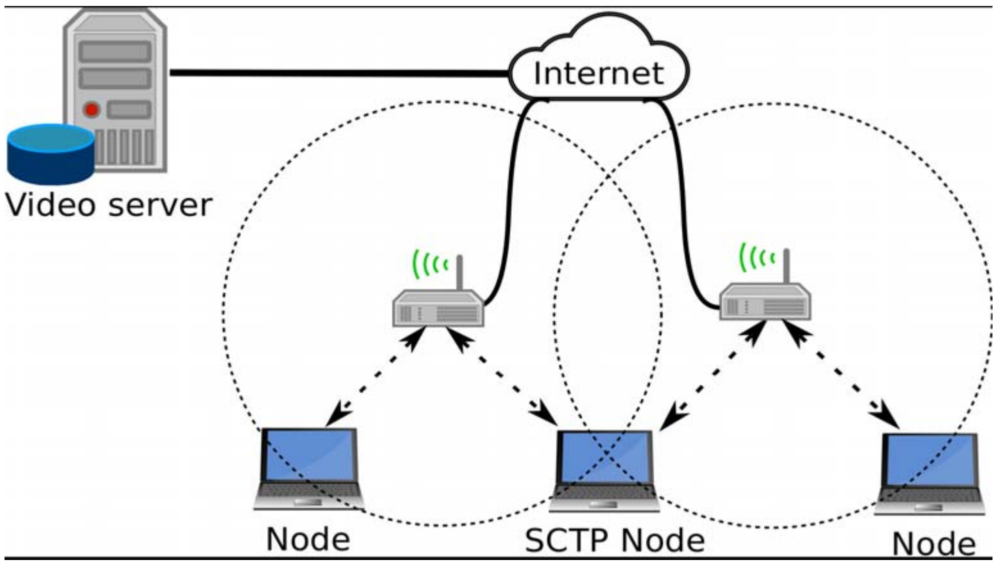

Figure 1. An example of SCTP multi-path transmission in wireless networks

wireless infrastructures [2]. Figure 1 shows an example of SCTP multi-path transmission in wireless networks, in which the SCTP node could use two wireless paths concurrently for streaming video traffic.

In homogeneous wireless network, where SCTP nodes use the same wireless standard and capacity, such CMT transmission of video chunks might provide better performance than single path video streaming. However, in settings with heterogeneous channels, the CMT transmission of video chunks may in fact decrease the video quality perceived by the receiver, as important frames might be lost over lossy channels used in the CMT.

We show that by using a protocol such as the Stream Control Transmission Protocol (SCTP), we can identify higher reliability channels in a set of potential channels between the video source and consumer. To maximise the experienced video quality at the receiver, we then identify more important data in the video stream, and send it over the better channels. We simulate the proposed solution, and demonstrate the effectiveness of our proposed framework for concurrent multipath video streaming and the performance gain of concurrent multi-path transmission in wireless networks.

We summarize our contributions as follows:

- We simulate a wireless multipath video streaming in OMNeT ++. The source codes are available at [3]
- We perform an unequal importance traffic distribution based on the path quality
- We demonstrate the effectiveness of the proposed system by a set of experiments

The rest of this paper is organized as follows. Section 2 discusses on the related works. Section 3 introduces and explains the proposed method. Simulation settings and result discussion are presented in Section 4. Finally, the paper is concluded in Section 5.

2. Related Works

Concurrent multi-path transfer is one of the promising features of the Stream Control Transmission Protocol's (SCTP) which enables bandwidth aggregation in a multi-homed SCTP association. Video streaming over wireless network is challenging due to massive traffic consuming behaviour of this kind of traffic. In this section first we will address some related works about SCTP. Then we will address some related works about video streaming over wireless networks.

2.1 SCTP

SCTP is a transport protocol which provides aggregation of communication links to decrease the link loss effects while enhancing connectivity. SCTP fail-over techniques choose one qualified link between all qualified redundant links[1][4]. Concurrent multi-path transfer is the newer implementation of SCTP which is capable of using one or more communication links concurrently which might provides better communication performance. High-quality video streaming may benefit from this additional feature as satisfying quality of service (QoS) requirements at the receiver is still an open concept.

Authors in [5] reviewed some general concepts related to SCTP transport protocol and addressed some issues regarding the performance and security of SCTP. On the other hand, the authors in [6] outline several challenges in multi-path communication aggregation and they propose a new multipath congestion control scheme. Also in [7] three challenges of concurrent multi-path transfer have been addressed. The identified limitations are:

1) fast retransmissions;

2) acknowledgement traffic;

3) congestion window (cwnd) growth.

There is another extension to TCP which adds multi-path to TCP (MPTCP). The main feature of MPTCP is the compatibility with most of current Internet devices in which the Internet application could choose between both simple TCP or MPTCP [8]. This means that MPTCP utilizes a single standard TCP socket at application layer [9] and at the lower layers different TCP connection might be used. So the Internet application will use only one MPTCP connection and migration from basic TCP to MPTCP becomes easy.

Alternatively, the authors in [10] propose a quality-aware adaptive CMT (CMT-QA) which estimates the quality of a path and distribute data basing on this estimation. In CMTQA the main focus is on the path status that is the main factor of scheduling policy. Nevertheless, application QoS requirements are important too and they should be consider in concurrent multi-path transmission. The authors in [11] propose CMT-DA, which differs from the CMT-QA by taking the video distortion as parameter in the decision process. They also employ path status estimation, flow rate allocation and retransmission control.

Althougth there exist several solutions relaying on multipath transfer, it is important to note that multi-path transfer might have a negative impact in real-world scenarios with heterogeneous wireless networks (like mobile broadband and wireless LAN networks) as stated in [1].

Figure 2. An example of GOP structure

2.2 Video streaming over wireless networks

Packet loss is very common in wireless networks due to many issues like interferences, power sources and mobility [12], [4]. First of all, interferences among wireless nodes and shared medium of wireless communication are two majorissues in wireless communication design. Power source is also another important challenge in wireless devices, which needs to be considered by the designed wireless communication protocols when deciding the transmission.

One of the main aspects of QoS in wireless networks that need to be improved is the bandwidth utilization [13]. In most video coding standards such as the H.264/MPEG there are some techniques to improve the bandwidth utilization. In MPEG-4 standard, each group-of-pictures (GOP) consists of different video frame types including I (Intra-frame), P (Predicted-frame) and B (Bi-predicted-frame) [14]. The reference frame is the Frame I and can be decoded independently without having prior knowledge of the other video frames. Due to frame dependency of frames, decoding P frames depends on the successful decoding of the previous I and P frames. Also for successfully decoding frames B, it is required to decode both previous and next I and P frames [15]. Figure 2 shows the frame dependencies in a GOP of 12 frames with 2 B frames between I or P frames. Due to these established dependencies, errors in high importance video frames will cause hierarchical error propagation into dependent video frames along the decoding mechanism [16]. Taking into account this behaviour, our proposed method sends the most important frames through the most stable links whereas lower importance frames will be send through other links concurrently.

3. Multipath Video Streaming for Wireless Networks

We now present our proposed method, based on concurrent multipath video streaming for heterogeneous wireless networks. In particular, we distribute the video traffic based on their importance inside the GOP. Then, based on the wireless link quality we send the traffic concurrently to the receiver. The rest of this section describes the details of the proposed method.

3.1 Problem Statement

We consider the case of unicast live video streaming from a server to a client node over parallel channels. In particular, the parallel channels have different reliability and bandwidth, for example because they have different channels in heterogeneous wireless networks. The problems that we are facing in concurrent multipath video streaming for heterogeneous wireless networks are:

- Heterogeneity of different wireless paths reduce the quality of service
- The link loss at the receiver is close to the highest link loss of wireless multipath
- The packet importance did not considered in current proposed methods

In the proposed method for concurrent multipath video streaming for heterogeneous wireless networks, different aspects of a high quality concurrent multipath video streaming are evaluated and an efficient and effective traffic distribution for heterogeneous wireless networks proposed. The main features of the proposed method are:

- In contrast to other proposed methods, we offer a concurrent unequal importance video distribution
- Our video distributor applied heterogeneity consideration of the multipath links, in particular, the wireless networks
- Our video distributor implementation is scalable and could distribute in large scale wireless networks
- Our proposed method make a balance between link quality and amount of video traffic
- Our proposed method consider the importance of video packets

3.2 Unequal Importance Multipath Video Streaming for Wireless Networks

In homogeneous wireless network, where SCTP node uses the same wireless standard and capacity, concurrent multipath transmission of video chunks might provides good performance. However, this condition does not always hold in real scenarios where communication links present different features. Under these circumstances, concurrent multi-path transmission of video chunks may increase the overall packet loss of video streaming [1]. Thus, additional mechanisms are required to cope with realistic scenarios.

Taking into account that wireless links present different quality features, our proposal employs those with higher quality to send the most important frames for video streaming so that the complete transmission will experiment lower propagation losses. Thus, in the proposed method the highest importance packets of a GOP will be sent through the most reliable path and the other video packets will be sent through the less reliable path. Figure 3 shows the schematic of the proposed method. As Figure 3 illustrates, the SCTP node can access to the Internet through Path1 and Path2. Particularly, Path1 has been identified as the most stable one so that I and P frames are forwarded through this link. Conversely, B frames are transmitted through Path2. As shown in Figure 2, B-frames are dependent to I- and P-frames. Hence any loss in I- or Pframes will imply losses to its dependent B-frames whereas any loss in B-frames have no loss propagation effect to the other video frames. This is the main idea of the proposed method that send B-frames through redundant paths and send I- and P-frames through the most qualified path. One important issue of our method is how to choose the path basing on the packet importance. Towards this goal, we chose the path based on the estimation of the path good-put basing on the probability of loss.

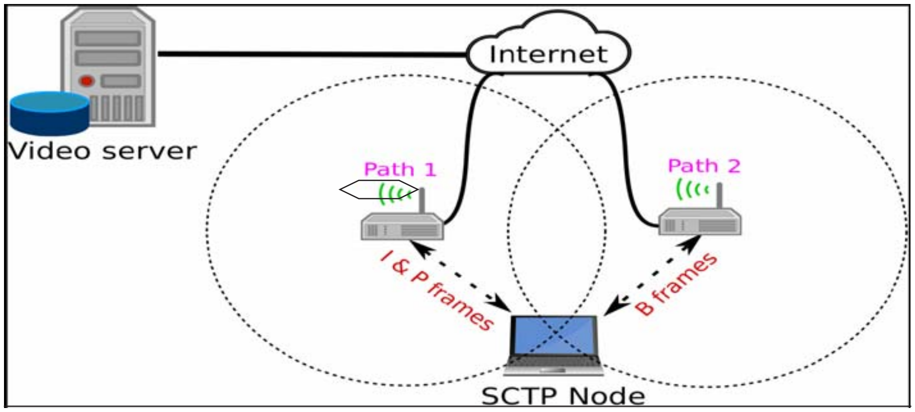

Figure 3. Overview of proposed SCTP multi-path video streaming in a multihomed wireless network

3.3 Mathematical modelling

First, considering two paths from the source to destination and each link is characterized by a loss probability of $p_1$and p_2, respectively. The probability of receiving a correct packet from path 1 can be shown as follows:

$$p\text{ (correct packet)} = (1 - p_1) \qquad (1)$$

Also, the probability of receiving a correct packet from path 2 can be shown as follows:

$$p\text{ (correct packet)} = (1 - p_2) \qquad (2)$$

Then, the probability of receiving a correct packet from one of these two paths, with the same probability of packet distribution in each path, can be shown as follows if link losses are not correlated:

$$p\text{ (correct packet)} = (1\text{-}p_{eq}) = \left(1\text{-} \left(\frac{p_1 + p_2}{2}\right)\right) \qquad (3)$$

We define N_I , N_P and N_B as average number of packets of I, P and B frames, respectively. By considering the frame dependency, the decoding probability of the I-frame in a GOP, which all of the packets of this I frame received from the path *n* will be:

$$p\text{ (}\mathbf{I}\text{ frame)} = (1\text{-}p_n)^{N_I} \qquad (4)$$

Then, the decoding probability of the I-frame in a GOP, which the packets of this I frame received distributed equally in both paths will be:

$$p\text{ (}\mathbf{I}\text{ frame)} = (1\text{-}p_{eq})^{N_I} \qquad (5)$$

Suppose that L is the number of packets of a GOP, that is:

$$L = N_B(N_I + N_P) \qquad (6)$$

As P-frames are dependent on previous I or P frames, the decoding probability of P-frames in a GOP from the path n is expressed as follows:

$$p\text{ (}\mathbf{P}\text{ frame)} = (1\text{-}p_n)^{kNp + N_I} \qquad (7)$$

$$k \in (0, \ldots, \frac{L}{3})$$

Then, the decoding probability of the P-frame in a GOP,which the packets of all packets are distributed equally in both paths will be:

$$p\,(\mathbf{P}\text{ frame}) = (p_{eq})^{kN_P + N_I} \quad (8)$$

$$k \in (0, \ldots, \frac{L}{3})$$

Also the decoding probability of B-frames in a GOP, except N_B and N_B - 1 (the last B frames in a GOP which are dependent on the next I-frame in the next GOP), is:

$$p\,(\mathbf{B}\text{ frame}) = (1 - p_n)^{kN_P + N_I + N_B} \quad (9)$$

$$k \in (0, \ldots, \frac{L}{3})\,;\; i = 3k - 1 \text{ or } 3k - 2$$

Then, the decoding probability of the B-frame in a GOP, which the packets of all packets are distributed equally in both paths will be:

$$p\,(\text{B frame}) = (1 - p_{eq})^{kN_P + N_I + N_B} \quad (10)$$

$$k \in (0, \ldots, \frac{L}{3})\,;\; i = 3k - 1 \text{ or } 3k - 2$$

And for the last B-frames in a GOP which are dependent on the next I-frame in the next GOP will be:

$$p\,(\text{final B frame}) = (1 - p_n)^{\left(\frac{L}{3} - 1\right) N_P + 2N_I + N_B}$$

Then, the decoding probability of the last B-frames in a GOP, which the packets f all packets are distributed equally in both paths will be:

$$p\,(\text{final B frame}) = (1 - p_{eq})^{\left(\frac{L}{3} - 1\right) N_P + 2N_I + N_B}$$

As we can see in Figure 2, a GOP (12, 2) consist of 12 frames including one I, three P-frames and other B-frames. For each frame we can define a random variable X_i as follows:

$$X_i = \begin{cases} 0 & \text{frame } i \text{ is not decodable} \\ 1 & \text{frame } i \text{ is decodable} \end{cases}$$

Then, the expected value of X_i in path n will be:

Parameters	I-frame	P-frame	B-frame
Average number of packets	3.64755	2.13549	1.61958

Table 1. Average Number of Packet Based on Frame Type

$$E_n(X_i) = \sum_{j=0}^{1} j p_n (X_i = j) = p_n (X_i = 1)$$

Now we define the random variable S_h as the number of decodable frames in a GOP at path n. The expected value of S_h is:

$$S_h = \sum_{i=0}^{L-1} X_i$$

$$En(S_h) = \sum_{i=0}^{L-1} E_n(X_i) = \sum_{i=0}^{L-1} p_n(X_i = 1)$$

$$E_n(S_h) = (1-p_n)^{N_I} + \sum_{i=1}^{L/3-1} (1-p_n)^{iN_P + N_I} + 2\sum_{i=1}^{L/3-1} (1-p_n)^{iN_P + N_I + N_B} \quad (11)$$

$$+2\left[(1-p_n)^{\left(\frac{L}{3}-1\right) N_P + 2N_I + N_B}\right]$$

Then, the expected value of X_i, with the same probability of packet distribution in each path, can be shown as follows:

$$E_{eq}(S_h) = (1-p_{eq})^{N_I} + \sum_{i=1}^{L/3-1} (1-p_{eq})^{iN_P + N_I} + 2\sum_{i=1}^{L/3-1} (1-p_{eq})^{iN_P + N_I + N_B} \quad (12)$$

$$+2\left[(1-p_{eq})^{(L/3-1)N_P + 2N_I + N_B}\right]$$

In the proposed method, our aim is to maintain the traffic load balanced while we are considering the dependency between video frames. Hence, we will send I and P frames through the most reliable path and B frames through the other path. Without loss of generality, consider that $p_1 < p_2$. This means that the first path provide better link quality comparing to the second path. Then, the expected value of X_i of the proposed method, can be shown as follows:

$$E_{proposed}(S_h) = (1-p_1)^{N_I} + \sum_{i=1}^{L/3-1} (1-p_1)^{iN_P + N_I} + 2\sum_{i=1}^{L/3-1} (1-p_1)^{iN_P + N_I} (1-p_2)^{N_B}$$

$$+2\left[(1-p_1)^{\left(\frac{L}{3}-1\right) N_P + 2N_I} (1-p_2)^{N_B}\right]$$

Parameters	$p_1 = 0{:}01$	$p_1 = 0{:}01$	$p_1 = 0{:}01$
	$p_2 = 0{:}01$	$p_2 = 0{:}05$	$p_2 = 0{:}1$
CMT	10.9019	9.0030	7.0954
Proposed	10.9019	10.4388	9.8767

Table 2. Expected Number of Packet Based on Frame Type

The video used used in this paper is the “The Silence of the Lambs”, 1991. Table 1 shows the average number of packets of I, P and B frames in the MPEG codec of this video. Table 2 shows the mathematical modelling of expected number of decodable frames in current CMT and proposed method, which means that while we have a concurrent multipath transmission of video packets we could reach to a higher expectations of number of decodable frames by using the proposed method. In the next section we will show the correctness of the proposed method by a set of experiments.

4. Experiments

We validated the performance of our proposal through mathematical modelling, and now we present the experimental simulation and results. In particular, we used the the OMNeT ++ tool for the simulations. Our scenario consists of 10,20 and 30 TCP nodes which access to the Internet through one of those two access points. Also we have one CMT node which uses SCTP for video streaming through both access points. The SCTP node are provided with two wireless interfaces, but the wireless channels are different as we have a set of burst TCP nodes around the access points in order to generate some interferences and packet losses. We have varied the number of nodes holding active TCP connections in order to evaluate how our proposal copes with different traffic conditions. Figure 4 illustrates a simulation scenario in OMNeT ++. Table 3 shows the simulation parameters used in the simulation of concurrent multi-path MPEG video streaming in wireless networks.

In order to have a comprehensive performance evaluation of the proposed method, three different mechanisms have been studied. These mechanisms are:

• Fail-over, in which the best communication path will be used for video streaming and other communication paths will remain as a backup paths.

• CMT, in which two communication paths are used concurrently for video streaming without differentiating among the importance of video frames.

• Proposed method, in which both wireless links are used concurrently but considering the importance of the packets as presented in Section 3.

The performance evaluation of the SCTP video streaming over wireless networks has been performed with different network sizes of 10, 20 and 30 burst TCP wireless nodes. Figure 5 shows the simulation results of the received bytes in both wireless paths. As we could see in the simulation results by using the concurrent multi-path transfer technique, in comparison with fail-over technique, we could reach higher received bytes through the secondary path. Also we could see that received bytes

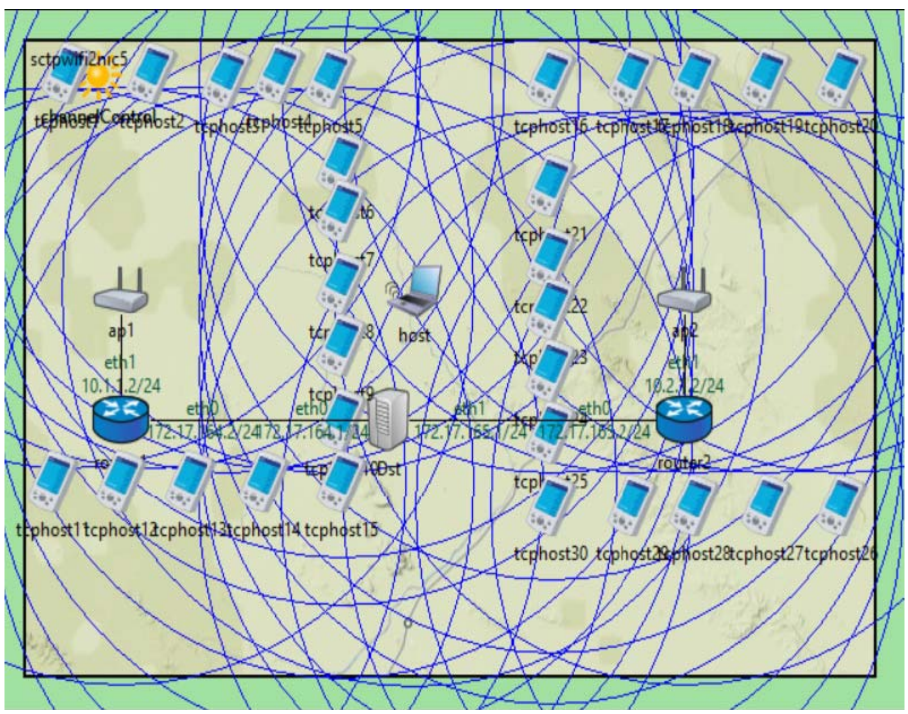

Figure 4. Implemented SCTP multi-path transmission in OMNeT++

in concurrent multi-path transfer technique and proposed method are close to each other. As it can be seen, CMT and the proposed method receive higher throughput when they use both wireless paths, concurrently. CMT and our proposed method have comparable performance in terms of overall received Bytes (our proposal ensures that more important Bytes are received), and both perform better than the the fail-over technique.

Figure 6 show the simulation results of average end-to-end delay on both paths. As we could see the proposed method suffers less than the other methods according to this parameter due to less backward recovery processes required by the data packets. Thus, the use of concurrent paths is more efficient in our proposal.

Parameters	value
Number of TCP nodes	10,20,30
Number of SCTP nodes	1
Maximum packet size	1500 Bytes
Video codec	MPEG4
Video Frame/Second	25
Number of frames in GOP	12 frames
Length of video	30 minutes
Average video bit rate	512 Kbps
Chunk size	1 frame
Simulation duration	1000 second
Number of access points	2
Number of TCP nodes per access points	5,10,15

Table 3. Simulation Parameters

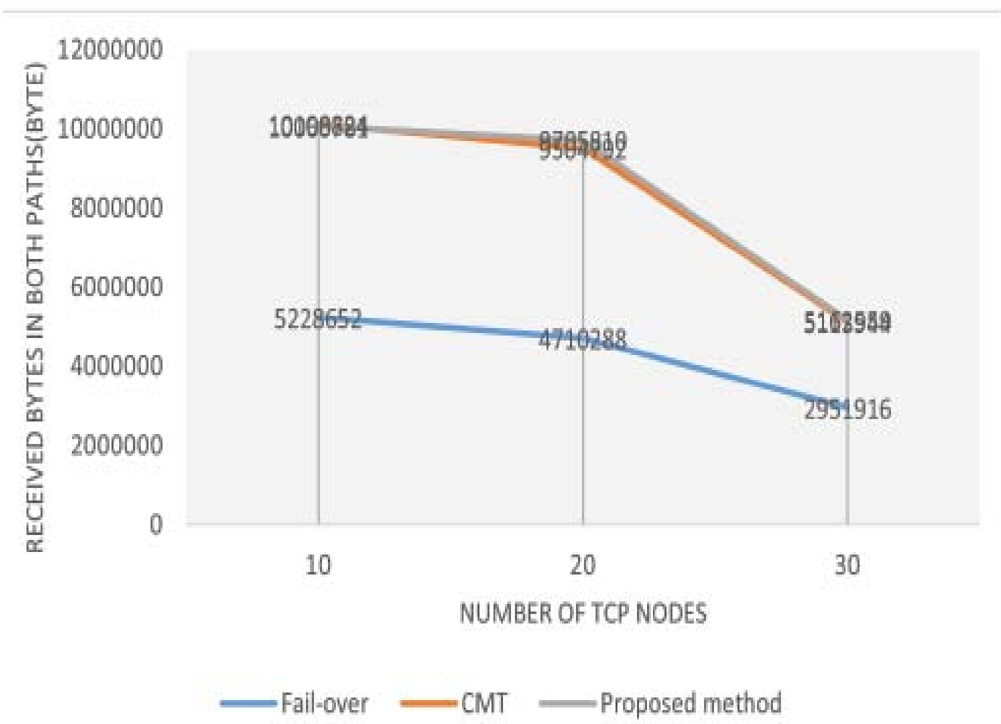

Figure 5. Received bytes in both paths

Figure 7 show the simulation results of the number of decodable video frames for those three mechanism. As we could see, the proposed method outperforms other video streaming techniques in term of number of decodable frames and efficiently use concurrent multi-path transfer to reduce the decoding error propagation to the video stream.

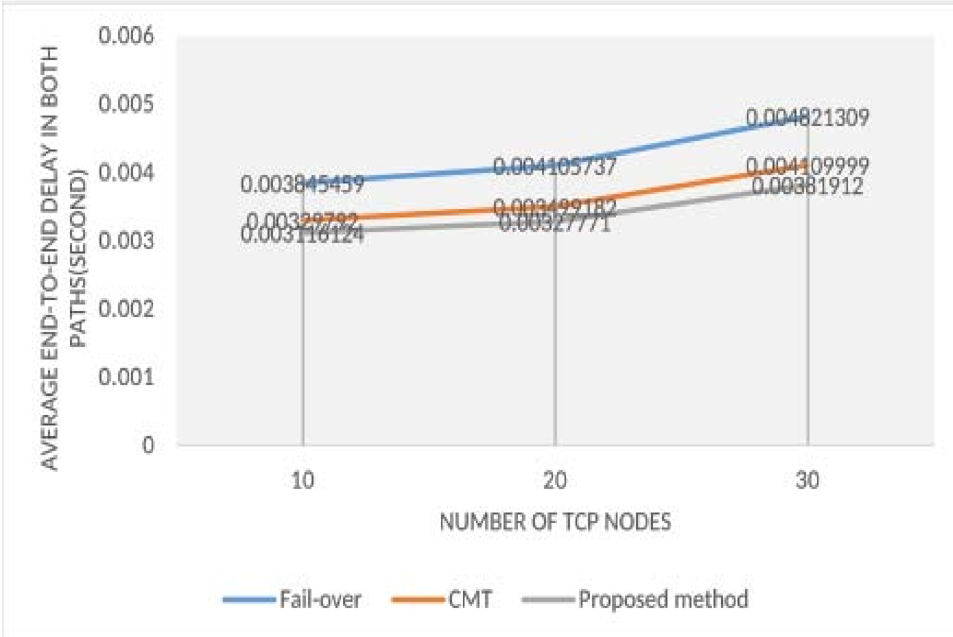

Figure 6. Average end-to-end delay on both paths

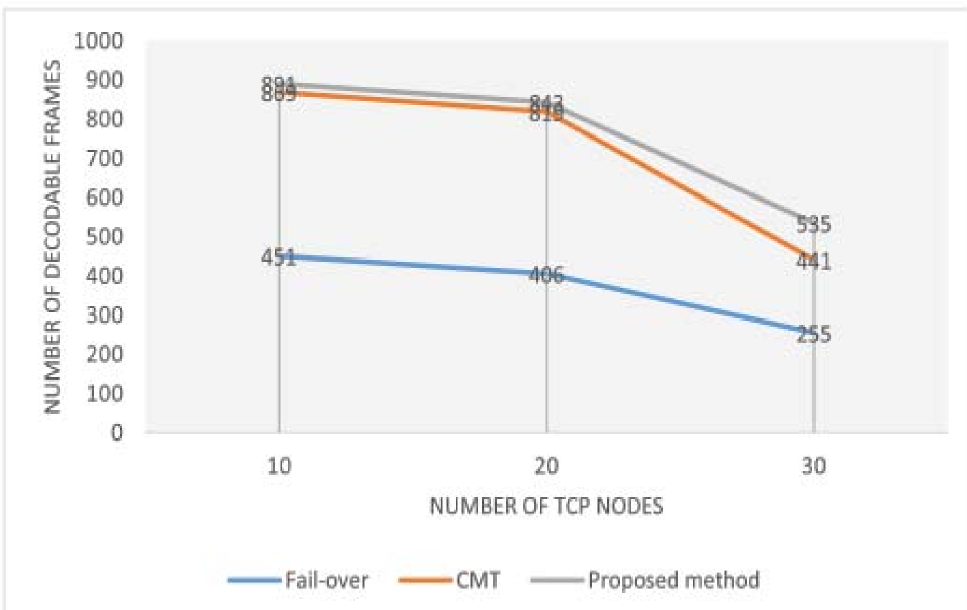

Figure 7. Number of decodable frames in three simulation scenarios

5. Conclusion

In this paper we proposed an unequal importance concurrent multipath video streaming for multipath wireless networks. Particularly, the proposed algorithm chooses the best qualified path for streaming high importance video packets. Based on the obtained results, it could be concluded that our proposed method works conveniently on different network conditions.

Moreover, the proposed method for concurrent multi-path video streaming between sender and receiver nodes can improves the overall video decoding performance and efficiently mitigates the distortion and end-to-end delay. We showed analytically that if the second path has 10 times higher loss ratio, our scheme has 39 percent better performance than CMT.

In addition, by using OMNET++ simulations, we show that our proposed method significantly outperforms other proposed methods in terms of the number of decodable frames and endto-end delay in different scenarios of wireless network size. In particular, we show that for 30 nearby TCP nodes, our scheme's performance was 21 percent better performance than CMT.

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