Optimizing Packet Transmission Mechanism with Multipath Technologies

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Abstract – **Using multipath technologies allow to aggregate bandwidth of multiple communication channels, and thus the data transfer speed can be higher than with the usage of a single channel. In order to improve the quality of service, it is needed to minimize time for packet transmission over the multiple paths. The purpose of present paper is to propose an approach to optimize waiting time of packets for multipath technologies, and to investigate its corresponding packet transmission mechanism.**

Keywords – **Optimization, Packet Transmission Mechanism MPT-GRE, MPTCP, Multipath Technology.**

I. INTRODUCTION

Nowadays for packet transmission through Internet it is used a single communication channel between the sender and the receiver, which reduces the throughput and/or quality of service that can be achieved between these hosts.

Multipath technologies allow to aggregate bandwidth of multiple communication channels, and thus the data transfer speed can be higher than with the usage of a single channel. Unfortunately, TCP and UDP protocols support only a single-path and suffer efficiency problems. These transport protocols do not take advantage of applications that provide multiple interfaces because they use a single path for transmission and also do not take advantage of the additional bandwidth.

Quality of services (QoS) is related with time delay for packet transmission from source to destination as well as variation of this delay. Keeping in mind all above, single-path leads to a reduced quality of service and throughput.

An approach to solve quality of service problems is to aggregate bandwidth in multiple communication channels, and thus data transfer speed can be higher than with the usage of a single communication channel.

In addition, multiple path technologies increase throughput but to improve the QoS [1], [2], [3], [4], it is needed to minimize time for packet transmission over these multiple communication channels.

The present paper aims at proposing an approach to optimize waiting time of packets for multipath technologies, and to investigate its corresponding packet transmission mechanism. The section below discusses some multipath protocols including MPT- GRE, MPTCP, and etc. In the third section it is proposed an approach to optimize packet transmission with multiple network channels and first numerical results are given. Finally, in order to verify optimization of the proposed mechanism a numerical example is conducted using MS Excel's Solver as a genetic algorithm calculator.

II. MULTI PATH TECHNOLOGIES

MPT-GRE [5] uses General Routing Encapsulation (GRE) over User Datagram Protocol to encapsulate data packets from one routing protocol within packets from another.

The MPT- GRE library [5] works at the network level, based on GRE tunnel in UDP (fig. 1). A MPT-GRE application uses the logical interface (multipath technologies tunnel).

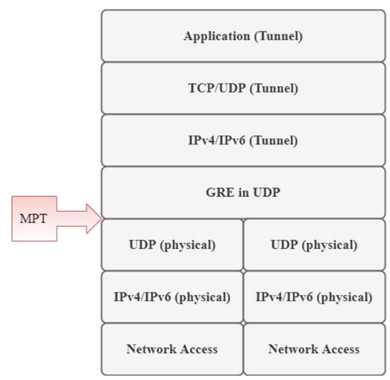

Fig. 1. MPT-GRE architecture

The case is different from MPTCP and Huawei's GRE Tunnel Bonding because it does not need to re-send and ensure the arrival of packets and control the flow within the tunnel interface [5].

Multipath TCP (MPTCP) provides the advantage of utilizing multiple communication channels between source and destination simultaneously. The application services that MPTCP provides are the same as the plain TCP/IP (fig. 2).

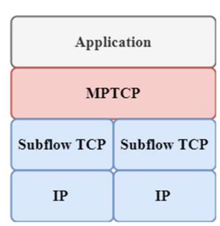

Fig. 2 MPTCP architecture

On fig.2 is depicted that the transport layer is divided into two sub-layers. The functions of communication management are related with establishing communication and rearranging packets. The former are combined in the upper part of the layer.

As mentioned above MPTCP is a multipath mechanism that operates at the transport layer. In mobile environment it creates secondary backup paths for quick handovers. Therefore, it is not needed to adjust for compatibility.

In [5 and its references] a few different multipath protocols including MPT GRE-in-UDP, MPTCP, AOMDV. and multiple path routing in VANET are analyzed. Also, a comparison of MPT, MPTCP, MMPTCP, AOMVD, OAOMDV, ODLBMP and OLiMPS with their pros and cons are given in Table 1 in [5].

In [10] is proposed a solution of a Korean Telecom company which aims to aggregate the bandwidth needed by the smartphone technologies. The theoretical bandwidths obtained from two heterogeneous communication channels with about 3 times difference in speeds - LTE with 300 Mbps and Wi-Fi with 867 Mbps results about 1.2 Gbps.

Therefore, multipath packet transmission is considered as a promising solution for solving the problems mentioned above about throughput (speed) and quality of service (waiting time of packets).

The next section of the paper is dedicated to propose an approach to optimize packet transmission with multiple network channels.

III. AN APPROACH TO OPTIMIZE PACKET TRANSMISSION WITH MULTIPLE PATHS

The multipath technologies create multiple paths (virtual channels - VC) for protocol data units from source to the destination.

Here is proposed an approach to optimize packet transmission with multiple paths to deliver traffic between two communication points (hosts) and dynamically observe and adapt the traffic load allocated to each VC.

The approach should not require intensive calculations, because of the hosts' processor performance limitations.

In fig. 3 is depicted the proposed system for traffic allocation over numerous heterogeneous communication channels. Protocol Data Units (PDUs) are sequentially encapsulated into packets and frames. As can be seen in fig. 3, the system input stream D = {dk}, k ϵ (1, 2... ∞) has intensity λ. Each PDU has length l_k, k ϵ (1, 2... ∞). Mean length of PDU is denoted with l. The system controls N virtual channels C = (c1, c2... c_N).

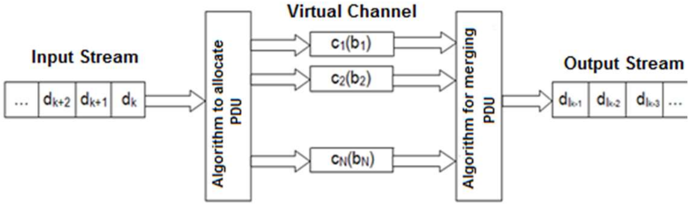

Fig. 3 Transfer of packets

For each VC, denoted by c_i, i ϵ (1, 2... N), a maximum bandwidth is b_i, in bps.

The input packet stream is allocated to each VC with intensity λ_i, respectively, with probability $p_i=\lambda_i/\lambda$, i ϵ {1,2,.. N}. Moreover $\sum\lambda_i=\lambda$, i ϵ {1, 2 … N}.

The proposed approach for the traffic allocation aims to minimize the waiting time of packets in hosts network facilities for heterogeneous VCs using the method of Lagrange with undetermined coefficients and the well-known formula for the waiting time in the M/M/1 queuing system [11]:

$$t_i = \frac{1}{\mu_i-\lambda_i}$$

where μ_i - the transmission speed of the packets and λ_i - the intensity of arrival of packets in VC c_i, i ϵ {1, 2… N} and $\mu_i>\lambda_i$.

The mechanism for traffic forwarding allocates PDUs, Vd_k, k ϵ (1,2 ,..., ∞) for each VC that is available, c_i ϵ C , with probability p_i, so as to minimize the waiting time of packets:

(1) $\sum\lambda_i t_i$ -> min.

For this purpose, the method of Lagrange is used:

$$(2)\quad \begin{cases} \frac{\partial \sum_{i=1}^{N}\lambda_i t_i}{\partial \lambda_1} + \lambda\xi = 0 \\ \frac{\partial \sum_{i=1}^{N}\lambda_i t_i}{\partial \lambda_2} + \lambda\xi = 0 \\ \dots \\ \frac{\partial \sum_{i=1}^{N}\lambda_i t_i}{\partial \lambda_i} + \lambda\xi = 0 \\ \dots \\ \sum_{i=1}^{N}\lambda_i = \lambda, i\epsilon\{1,2,..N\} \end{cases}$$

Or

$$(3)\quad \begin{cases} \frac{\partial \sum_{i=1}^{N}\frac{\lambda_i}{\mu_i-\lambda_i}}{\partial \lambda_1} + \lambda\xi = 0 \\ \frac{\partial \sum_{i=1}^{N}\frac{\lambda_i}{\mu_i-\lambda_i}}{\partial \lambda_2} + \lambda\xi = 0 \\ \dots \\ \frac{\partial \sum_{i=1}^{N}\frac{\lambda_i}{\mu_i-\lambda_i}}{\partial \lambda_i} + \lambda\xi = 0 \\ \dots \\ \sum_{i=1}^{N}\lambda_i = \lambda, i\epsilon\{1,2,..N\} \end{cases}$$

Whence for λ_i:

(4) $\frac{\mu_i}{(\mu_i-\lambda_i)^2} + \lambda\xi = 0$

Or

(5) $\mu_i + \lambda\xi(\mu_i-\lambda_i)^2 = 0$

The desired intensity-λ_i is obtained by solving (5):

(6) $\lambda_i = \mu_i - \left(\sum_{j=1}^{N}\mu_j - \lambda\right)\frac{\sqrt{\mu_i}}{\sum_{j=1}^{N}\sqrt{\mu_j}}$

Note that $\mu_i=b_i/l$, in packets per second. The intensity λ_i is obtained:

(7) $\lambda_i = \frac{b_i}{l} - \left(\sum_{j=1}^{N}\frac{b_j}{l} - \lambda\right)\frac{\sqrt{b_i}}{\sum_{j=1}^{N}\sqrt{b_j}}$

In case λ_i<0, then it should be equated to 0 and the above task have to be resolved, with the constraint λ_i=0.

Proposed mechanism allocates the protocol data units to the i-th VC with probability $p_i=\lambda_i/\lambda$, i.e.:

$$(8) \quad p_i = \frac{b_i}{\lambda l} + \left(1 - \frac{1}{\lambda l}\sum_{j=1}^{N} b_j\right)\frac{\sqrt{b_i}}{\sum_{j=1}^{N}\sqrt{b_j}}$$

Finally, allocating algorithm using these optimal probabilities p_i $i \in \{1, 2\ldots N\}$ allocates the protocol data units to each VC in a Round-robin manner.

Numerical Experiment

Below it is given a numerical experiment. The experiment is conducted with the following (see [10]) factors:

- Number of VCs is N=2;
- The bandwidth of the first VC is four times lower than the bandwidth of the second one (b_1=300Mbps and b_2=1200Mbps);
- Packets length is 1500 bytes;
- Intensity of packet arrival λ varies between 150, 450, 750, 1050, and 1350 Mbps, i.e. it is 0.1, 0.3, 0.5, 0.7, and 0.9 from the total bandwidth of the VCs b_1+ b_2=1500Mbps

For the proposed forwarding mechanism with two channels b_1 and b_2, by (7) for the set of intensities λ={150, 450, 750, 1050, and 1350 Mbps} are calculated optimal values of intensities λ_1, and λ_2 (Table 1).

TABLE 1. FIRST RESULTS FOR THE OPTIMAL INTENSITIES BY (8)

λ	150	450	750	1050	1350
λ_1	-150	-50	50	150	250
λ_2	300	500	700	900	1100

As it can be seen from column 2 and column 3 of Table 1, the optimal intensity λ_1 are negative. As it was discussed above in both these cases (when λ_1=-150 and λ_1=-50 Mbps), then λ_1 should be equated to 0 (λ_1=0) and the task have to be resolved. In both these cases λ_1=0, therefore $\lambda_2 = \lambda - \lambda_1 = \lambda$. In Table 2 are given the thus obtained values of the optimal intensities.

TABLE 2. FINAL NUMERICAL RESULTS FOR THE OPTIMAL INTENSITIES

λ	150	450	750	1050	1350
λ_1	0	0	50	150	250
λ_2	150	450	700	900	1100

Mean waiting time of allocated packets to VCs is determined by using the well-known formula from queuing system [11]:

$$(9) \qquad T=\sum p_i t_i \ ,$$

where the probability p_i is calculated using equation (8) and t_i are mean delays for the M/M/1 queuing system.

The obtained in this manner numerical results for mean delays vs. different intensities of arrival of packets are shown in Table 3. Intensity of packet arrival is chosen to be 0.1, 0.3, 0.5, 0.7, and 0.9 of the aggregated channel bandwidth (b1+ b2=1500Mbps). The optimal values for the delays (in microseconds) for MPT mechanism (see the second column), Optimized Packet Transmission Mechanism- OPTM (third column), as well as, waiting times reduction (the last column titled delay reduction) are shown in Table 3.

As the name suggests, in MPT, packets are forwarded to each VC (with constant probabilities p_1=0.2 and p_2=0.8), so that their load is the same, i.e. in this case the MPT packet transmission mechanism will forward to the second VC four times more packets than to the first one.

TABLE 3. WAITING TIMES OF PROTOCOL DATA UNITS

ρ	MPT	OPTM	Delay reduction
0.1	0.00444	0.00286	0.357
0.3	0.00571	0.004	0.3
0.5	0.008	0.0064	0.2
0.7	0.01333	0.01142	0.143
0.9	0.04	0.03555	0.111

The mean waiting time of packets in case of heterogeneous communication channels for both packet transmission mechanisms are calculated by (9).

Note that the reduction of waiting times (the last column values) is calculated by:

$$(10) \qquad Delay\ reduction = (T_{MPT}-T_{OPTM})/T_{MPT}$$

where T_{MPT}- mean waiting time of packets for MPT and T_{OPMT}- waiting time of packets for OPTM mechanism.

For OPTM as well as for MPT mechanisms the mean waiting times of packets increase with the increasing of ρ, which is expected according the queuing theory.

By comparing the results (in last column of Table 3) for MPT and OPTM mechanisms it can be concluded, that the proposed here packet transmission mechanism's mean waiting times for OPTM are smaller than these for MPT.

Moreover, OPTM mechanism permits reduction of the packet waiting time between 11.1% and 35.7% for different intensities of packets arrival.

IV. VERIFICATION BY EVOLUTIONARY MODEL

A numerical example using MS Excel's Solver as a genetic algorithm calculator [6], [7], [8] is given below. The numerical experiment is conducted with the same input data (See above for Korean Telecom's MPT solution).

The bandwidth of the virtual channels, both b1 and b2 are constants, so they cannot be chosen to be chromosomes. They are defined in two cells into the MS Excel table.

The probabilities of forwarding packets through these two channels are respectively p1 and p2. These probabilities are chosen to be chromosomes, as they vary between 0 and 1 and determine the intensities that will be respectively λ_1=p1*ro*b and λ_2=p2*ro*b. Thus, the probabilities determine the packet waiting time. The optimization problem is to minimize the packet waiting time by obtaining optimal values of pi i ϵ {1, 2… N}

$$(11) \qquad \frac{p1}{b1-(p1*ro*b)} + \frac{p2}{b2-(p2*ro*b)} \rightarrow \text{MIN}$$

The genetic algorithm works by comparing the best values of the neighboring generations of the population. The objective function is represented by a formula in the I14 cell of the MS Excel table and calculates the waiting time (see formula (9)). Note that the objective function returns the waiting time with the following constraints:

1) each of the addends in (11) must be non-negative and

2) the total probability must be 1: (∑pi=1), 0< pi<1.

In MS Excel the Solver is used for creation of the proposed GA model. Screenshots are not given here due to restriction of paper size. The MS Excel table is online available in [12]. The cell for the objective function is I14. This cell is a sum of N14 and M14 cells. N14 and M14 are the addends in (11), and their values must be non-negative (See constraint 1 above)).

In the Solver parameters window, evolutionary is chosen as a Solving Method. In the next window for the Solver, titled Options the following parameters are set: Convergence = 0.000001, Maximum rate = 0.075, Population size = 200, Random seed = 1, Maximum Time without improvement = 30 and the checkbox “Require Bounds on Variables” is not checked.

Below are given characteristics of the PC used to conduct this numerical experiment: 11th Gen Intel(R) Core(TM) i7-11800H @ 2.30GHz; 16.0 GB RAM; 500GB NVMe SSD; Windows 10 Professional, Version 21H1; Microsoft Office Professional Plus 2016 with installed Solver.

The results obtained with the Solver GA calculator for the mean waiting time for OPTM are shown in Table 4.

The mean waiting times increase as the system load increases, which is logical considering the queueing systems theory.

The obtained results from Genetic Algorithm Solver calculator for the waiting times are compared to the numerical results obtained earlier (using the method of Lagrange) for the same optimized load balancing mechanism with the same input data.

TABLE 4. NUMERICAL RESULTS FOR OPTIMAL PROBABILITIES

ro	p1	p2	Delay, ms	Difference
0,1	0	1	0.0028571	0
0,3	0	1	0.004	0
0,5	0.0666667	0.93333325	0.0064	1.66E-13
0,7	0.1428589	0.85714107	0.0114285	1.17E-10
0,9	0.1851616	0.81483837	0.0355555	2.28E-7

The results obtained using the genetic algorithm calculator and those using the method of Lagrange are almost identical as it can be seen from the table above. In the first column ro is given, the second and third column contain optimal probabilities p_i, mean waiting times of packets are given in the fourth column in microseconds and the last column contains the difference between calculated mean waiting times for OPTM (table 3, column 3) and mean waiting times generated by the Solver. As it can be seen from Table 4 for ro = {0,1;0,3} mean waiting times are equal (Difference = 0). For ro = {0,5;0,7} the difference is respectively $1,66*10^{-13}$ and $1.17*10^{-10}$. The biggest difference $2.28\ 10^{-7}$ is observed at a system load of 0.9, which confirms the correctness of the proposed method for modeling packet forwarding mechanisms.

V. CONCLUSION

In present paper a modified mechanism for traffic allocation over numerous heterogeneous communication channels (Optimized Packet Transmission with Multipaths - OPTM) is proposed, which allows minimizing waiting time of packets for different Multipath technologies. For this purpose, an analysis of different Multipath technologies has been made as well as numerical experiment has been conducted for the proposed mechanism with input data for MPT from a Korean Telecom commercial solution. By comparing the obtained results for MPT and OPTM one can conclude that the proposed here packet transmission mechanism is better, because the mean waiting times for OPTM are better than these for MPT by 11-36%. In MS Excel the Solver is used for creation of the corresponding GA model and for verification of the proposed OPTM mechanism.

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