A Novel Solution for Network Flexibility Problem in Mobile Multi-hop Tunneling Networks

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A NOVEL SOLUTION FOR NETWORK FLEXIBILITY PROBLEM IN MOBILE MULTI-HOP TUNNELING NETWORKS

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Abstract. Since the network throughput performance is always limited by the currently available technology limits, there are too many number of attempts in the literature to improve the network throughput performance by modifications on the running routing algorithms on the third layer of OSI (open systems interconnection) reference model. Although application of the tunneling on IP networks provide reserved paths for the higher priority packet streams and succeeds in providing faster communication performances, it is also determined in the literature that, the greatest up to date problem of tunneling networks, the flexibility problem, causes the difficulty of keeping the delay at lowest levels in case of instantly changing network conditions when there are congestions or node failures on the network.

In this work, an alternative high performance solution, considering the locations of the nodes in addition to their traffic loads, has been proposed for network flexibility problem of mobile multi-hop tunneling networks. And it is shown that, it is succeeded to carry the throughput of the highly loaded traffic network back to 48.6 Mbps from 36.9 Mbps by about 31.7 % performance improvement for which we could have improved it from 36.9 Mbps up to 45.9 Mbps by 24.3 % using the proposed ACN (Avoid Congested Node) algorithm in our previous work. As a result, we have succeeded in having about 7.4 % more improvement on throughput performance with respect to previously proposed ACN algorithm.

Key Words: Flexibility, Throughput, Mobile**,** Tunneling

1. INTRODUCTION

In tunneling networks, the route must completely be determined before starting the transmission of the first packet. But during the decision of the complete route, only the available network traffic condition information at that instant and the experienced traffic conditions until that instant can be considered. Due to many number of users and many number of internet based applications, since the instant changes on traffic load occurs, the traffic load can suddenly arrive to unexpected rates which dominates to reduce the network performance.

In [1], the challenges that the service providers experience during the migration to MPLS-TP are addressed. A service provider strategy in long term which is based on SDN and NFV is proposed for controlling the overall network in a centralized way.

In [2], the MPLS and also IP MPLS-TE network performances are compared on a Wide Area Network (WAN) for their provided packet loss and latency amounts. Finally, they had concluded that, MPLS-TE had almost no packet loss and had the minimum latency rate among all. However, in that work, there are no methods proposed to solve the network flexibility problem of faced in tunneling networks.

Since it is very obvious that, in order to meet the needs of high speed connection demands for real time applications, network flexibility must be provided for tunneling networks even in case of instantly changing traffic conditions.

One of the most recent reviews in the literature concludes that, "*Although MPLS is still a promising technology for future networks, there are challenges to overcome with regards to security and network flexibility, especially as far as migration to MPLS-TP (Transport Profile) is concerned*" [3].

To solve this problem, we had proposed a novel method called Avoid Congested Nodes (ACN) as a solution of network flexibility problem and implemented it on an MPLS (Multi-Protocol Label Switching) MATLAB simulation. [4]. By the ACN method proposed there, the flexibility problem [1,2,3] of the tunneling networks in case of high traffic load, is tried to adaptively be solved by switching the most congested node of the tunnel route to a node which has less traffic load. Then, it has been shown that, the proposed algorithm succeeded in, carrying the throughput of the highly loaded traffic network back to 94% (4.59 Mbps) of its best possible performance (4.89 Mbps), from the evaluated 3.69 Mbps (75.5% of its best possible performance) performance, by switching the tunnel route to an adaptively determined alternative route which has less traffic load. However, even the delay amounts caused by high traffic loads were taken into consideration for tunnel route updates, the locations of the replaced mobile nodes in the route, which have great effect on updated route, number of hops and total delay were not considered there.

In this work, an alternative high performance solution called LB-ACN (Location Based-Avoid congested node), considering also the locations of the nodes in addition to their traffic loads, has been proposed for network flexibility problem of mobile multi-hop tunneling networks.

Initially, observing the effects of different gamma (γ) values in the range of 0 and 1 with steps of 0.1, used to determine the weights of locations and traffic loads for the nodes experiencing congestions, the optimum γ value has been determined. Then, using the evaluated γ value for weighting the effects of; node locations and traffic loads for route update decision, it is shown that, by using the novel proposed LB-ACN algorithm, we have succeeded in carrying the throughput of the highly loaded traffic network back to xxx Mbps from 3.69 Mbps, which provides also a better improvement than previously evaluated 4.59 Mbps throughput performance.

This manuscript is designed in five sections. The simulation parameters and the principles of the proposed algorithm are given in Section 2. For confirmation purpose, the theoretical calculations for expected results of LB_ACN are given in Section 3. The matching results of the simulation program and the theoretical calculations are presented in Section 4. Finally, the conclusion and future works are included in Section 5.

2. IMPLEMENTATION OF NOVEL PROPOSED LB–ACN ALGORITHM ON THE MPLS MATLAB SIMULATION

a. MPLS Network Simulation Structure

In the previous work [4], the parameter values given in Table 1 were used for the MATLAB implementation of MPLS tunneling network simulation. For consistency and fair comparison, the simulation parameters are used with the same values also in this work too. In the simulation, each of the running nodes moves from its own initial random location to its random destination. During these movements the necessary statistical information such as the total numbers of;

- generated packets,
- transmitted packets,
- lost packets,
- link failures
- packets in the buffers,
- the packets successfully arrived to the destination

and the average values of;

- hop count (HC) and
- throughput

are collected by the simulation.

Simultaneously, the possible route combinations and the extra time required because of the traffic ($Time_{Trf}$) at each node, are also dynamically calculated and taken into consideration for finding the best of all possible routes.

The running algorithm of the simulation program to implement the MPLS network is given in Figure 1 [4], where the location of the block that includes the used OPR algorithm is highlighted. The previously proposed ACN algorithm and the novel proposed LB-ACN algorithm are implemented on this simulation to compare their throughput performances while Optimum Path routing algorithm [4] is used in both cases.

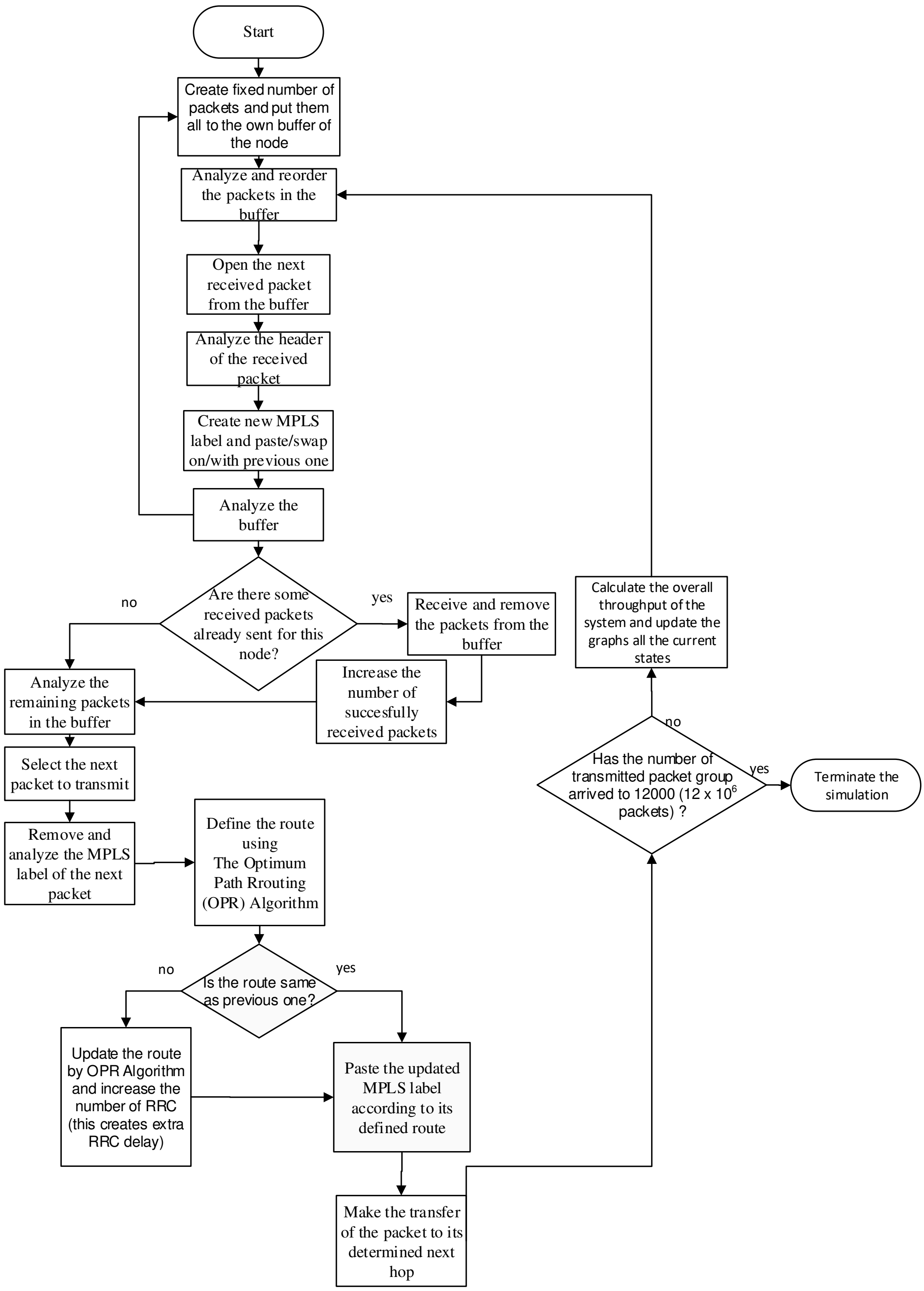

Figure 1: The algorithm that the nodes in the MPLS simulation use [4].

Table 1: Parameter values used in simulation program and calculations [4]

Number of nodes (N)	*6 nodes*
Movement Area (x, y)	*(100 pixel x 20m/pixel) x (100 pixel x 20m/pixel)* =4km^2
Relative Velocity Interval of the nodes	*Between 5 km/h -30 km/h (random but fixed)*

Mobility model used	*Random way point mobility model [5]*
Packet size (PS)	*1 Kbyte [6]*
Transmission medium	*Free Space (α=2)*
Transmission power (P)	*1 W*
Noise power (P_N)	*1mW*
Signal Frequency (f)	*1GHz*
Transmitter Antenna Gain (G_t)	*1*
Receiver Antenna Gain (G_r)	*1*
RRC time cost	*50 ms/RRC using Fast Reroute (FRR) [7]*
Speed of light (c)	*$3x10^8$ m/secs*
Number of Iterations (NOI)	*2000 iterations*
Simulation Step Period (SSP)	*30 seconds/iteration[8]*
Route update interval (RUI)	*At each iteration (30 seconds)[8]*
Simulation Run Time (SRT)	*2000 iterations x 30 seconds each = 16,66 hrs.*
Packets per Packet Groups (PPG)	*1000 packets per packet group*
Number of total transmitted packets (TP)	*6 nodes x 2000 packet groups/node x PPG Packets/ Packet group*

b. The novel proposed LB-ACN (Location Based - Avoid Congested Nodes) as a solution to network flexibility problem

While each of the nodes in the network continuously generates and transmits its packets to its randomly defined destination point via a predefined tunnel route, it dynamically uses the novel proposed LB-ACN algorithm.

By LB-ACN algorithm, the nodes also analyze the current traffic states of all the nodes in their packets routes and they look for better available node choices among all others to replace the determined congested node with. At each iteration, after the current sender in the tunnel route analysis the traffic condition of its next node, it decides either to replace or not to replace it with the decided alternative node. Of course, every route switching operation will cause an extra RRC delay and cause the throughput to decrease, during this attempt to fasten the system by reducing congestion based delay amount. Because of this trade-off, the critical decision of replacing the next node must be taken carefully in order to see a positive effect on the system throughput results. Note that, activating the proposed LB-ACN algorithm in case of node failure in the tunnel route, will also prevent the system from a reduced throughput performance. The activation criteria of the LB-ACN algorithm (highlighted) used by each of nodes in the overall route update mechanism.

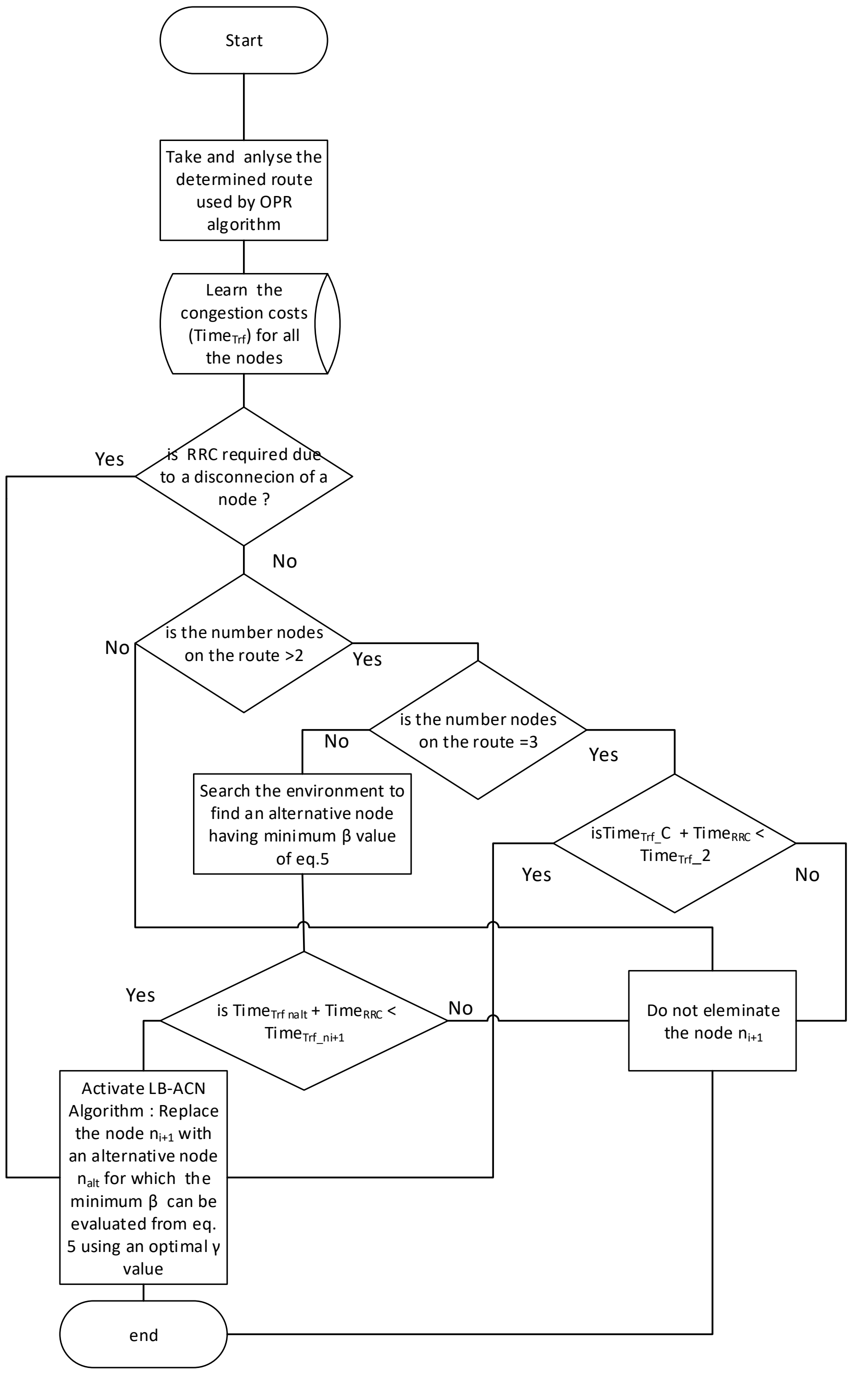

Figure 2: Activation case of the LB-ACN algorithm (highlighted) used by each of nodes in the overall route update mechanism [4].

Using LB-ACN algorithm, every time a node attempts to transfer a packet to its next node on the route, it finds the most congested node in the remaining part of the route, and replaces it by the node for which the minimum β value among all for eq .5 can be evaluated using the γ weighting value at that instant. In eq. 5 it is aimed to find the best of the alternative nodes to be replaced by the congested node (n_{i+1}), by which the access to n_{i+2} can be provided with minimum possible sum of distance from the current node (n_i) to node n_{i+2} (dist (n_i, n_{alt}) +dist (n_{alt}, n_i +2). During this, it is also desired to choose the closest n_{alt} to the one (n_{i+1}) which is subject to be eliminated because of its high traffic load. For this purpose, the distance between n_{alt} and (n_{i+1}) is also considered by also requesting the minimum sum of dist (n_i, n_{alt}), dist (n_{alt}, n_i +2) and dist (n_{i+1}, n_{alt}). Using right side part of the eq. 5 ($Time_{Trfnalt}$ x (1-γ)) the traffic load of n_{alt} is also considered, and this n_{alt} will be taken into evaluation if and only if it has less traffic load than the eliminated node (n_{i+1}).

$$\beta = \left[\underbrace{dist(n_i, n_{alt}) + dist(n_{alt}, n_{i+2}) + dist(n_{i+1}, n_{alt})}_{\substack{\text{Consideration of minimum total distance of } n_{alt} \text{ to the eleminated node} \\ (n_{i+1}) \text{, its left hand node} (n_i) \text{ and right hand node} (n_{i+2})}} \right] \times \gamma + \left[\underbrace{(Time_{Trf_{n_{alt}}})}_{\text{Consideration of the traffic load of } n_{alt}} \right] \times (1-\gamma) \quad (5)$$

Where; "$Time_{Trf}$" stands for the amount of extra time caused by congestion at the node, dist(n_i,n_{i+1}) stands for the distance between node i and node (i+1) and n_{alt} stands for the alternative node that is currently subject to be replaced by the congested node. Here, γ is the weighting function used to adjust the effects of the node location and the traffic load of each alternative node on our decision. The working principle of the proposed LB-ACN algorithm is given on figure 3 and the illustration of replacement of the congested node (n_{i+1}) with an alternative node (n_{alt}) that yields the minimum β value is given on Figure 4.

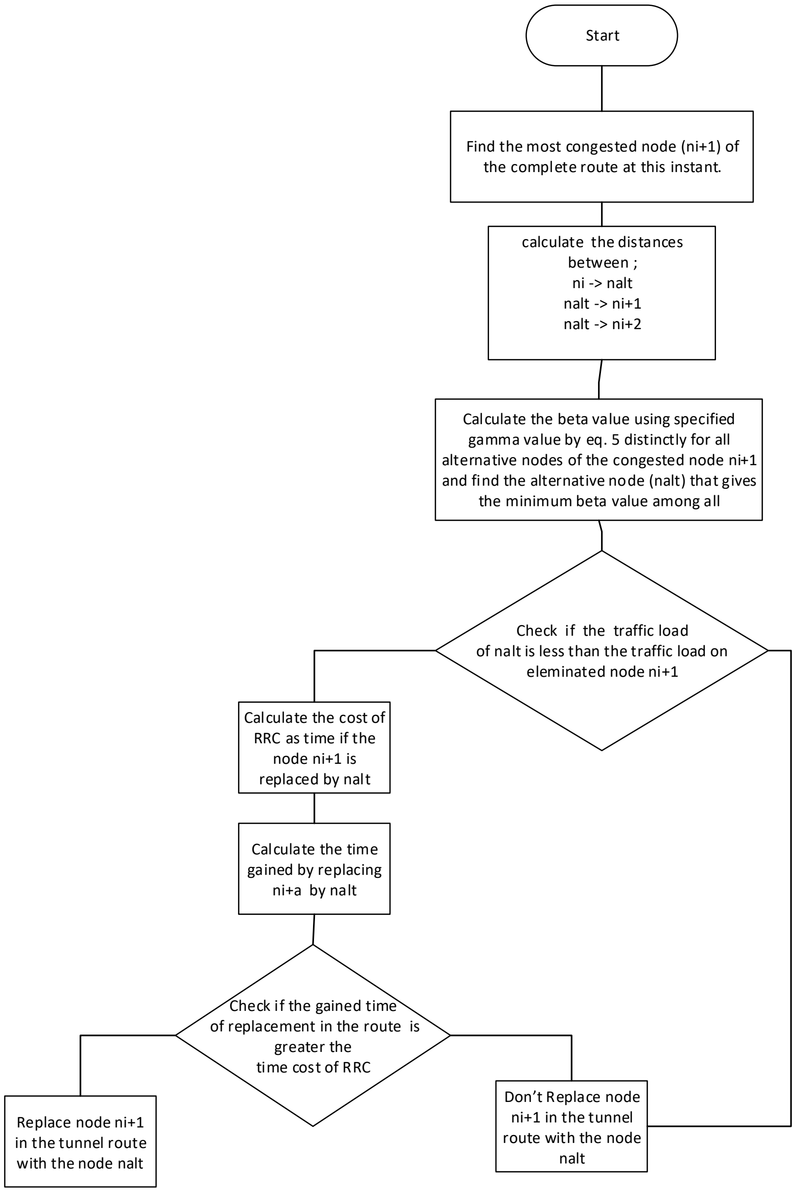

Figure 3: The working principle of the novel proposed LB-ACN algorithm

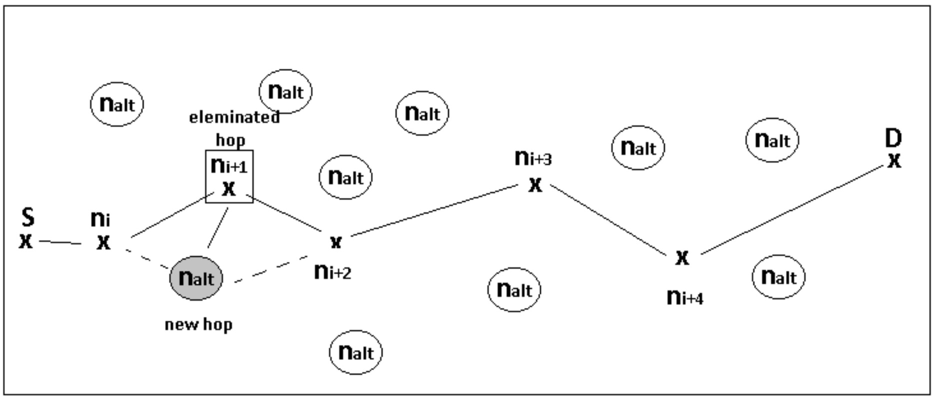

Figure 4 : Replacement of the congested node (n_{i+1}) with an alternative node (n_{alt}) that yields the minimum β value, in use of LB-ACN algorithm.

In figure 5, the how LB-ACN algorithm is embedded into OPR algorithm is given as a flow chart. Where; "$Time_{RRC}$" is the delay amount caused by route reconstruction, and "$Time_{Trfalt}$" is the delay amount caused by the alternative node which is subject to be replaced by the eliminated one.

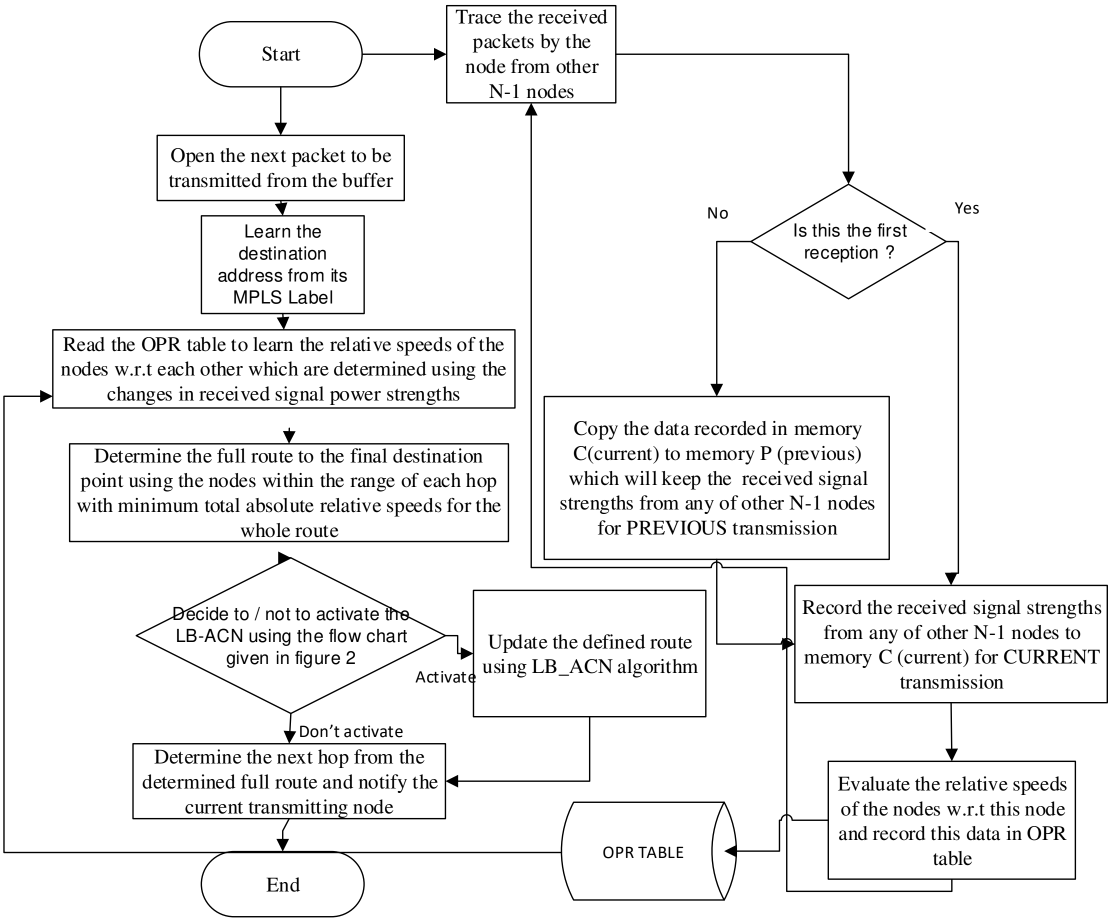

Figure 5 : The location of LB-ACN algorithm in the complete OPR algorithm[4]

3. THEORETICAL EXPECTATIONS

The expected throughput values with traffic load

As it is given in eqs. 6 and 7 we evaluated in [4] there is a close relation between the throughput and the total system capacity where they will be equal in ideal case with no packet loss and Route Reconstructions (RCC) and no traffic in the network.

$$C = Thr_{With\_Traffic\_and\_RRC} \times \underbrace{\frac{TR}{S}}_{\substack{\text{The rate of numbers of}\\ \text{Trasmitted packets}\\ \text{to the Successfully}\\ \text{arrived packets}}} \times \underbrace{\frac{\left(T + \overbrace{\left(\frac{Tr-S}{NC}\right)}^{\substack{\text{extra delay amount}\\ \text{required for retarnsmission}\\ \text{of the lost packets}}} + \overbrace{\left(\underbrace{T \times \frac{SSP}{RUI}}_{\substack{\text{Number of Route Updates}\\ \text{in the simulation time}}} \times \underbrace{\frac{Time_{RRC}/NOI}{NC}}_{\substack{\text{Average extra ,}\\ \text{RRC delay per unit}\\ \text{of time per node}}} \right)}^{\substack{\text{Total extra delay amount}\\ \text{required for Route}\\ \text{Recunstructions}}} + \overbrace{\left(T \times \Big(\overbrace{\frac{SSP \times Time_{Trf}/NOI}{NC}}^{\substack{\text{Average extra ,}\\ \text{delay caused by traffic}\\ \text{and congestions per node}\\ \text{in the simulation time}}} \Big) \right)}^{\substack{\text{Total extra ,}\\ \text{delay caused by traffic}\\ \text{and congestions per node}}} \right)}{\left[T + \left(\frac{Tr-S}{NC}\right) \right]}}_{\text{The rate of delay with traffic and RRC, to the rate of delay without traffic and RRC}} \quad (6)$$

Where;

T : simulation run time,

TR : number of transmitted packets,

S : number of successfully sent packets,

RRC : number of route reconstructions,

$Thr_{with\_traffic\_and\_RRC}$: throughput value in case of having Traffic and RRC,

SSP : simulation step period,

RUI : route update interval,

NC : number of running nodes (node count),

$Time_{RRC}$: the delay amount caused by extra route reconstructions

For the best case assumption without any packet loss (Tr/S=1 and S=Tr), no RRC ($Time_{RRC}$ =0) and no traffic delay ($Time_{Trf}$ =0), it is obvious that the throughput will be exactly equal to the overall Capacity calculated by eq. 6 and shown in eq. 7.

$$C = Thr_{Without\_Traffic\_and\_RRC} \times \underbrace{\frac{Tr}{Tr} \times \frac{\left(T + \left(\frac{Tr-Tr}{NC}\right) + \left(T \times \frac{SSP}{RUI} \times \frac{0}{NC} \right) + \left(T \times \left(\frac{SSP \times 0}{NC}\right) \right) \right)}{\left(T + \left(\frac{Tr-Tr}{NC}\right) \right)}}_{1} \quad (7)$$

Having the ideal case with no packet loss, no $Time_{Trf}$ and no $Time_{RRC}$ the maximum throughput which will be equal to capacity (C) can be calculated applying the values given in table 1 (*S*=*TP*=NC x NOI=12000, *PS* =1 kB, *SSP*=30 seconds/iteration, *PPG* = 1000 packets per group, RUI= 30 seconds, NOI= 2000 iterations, NC= 6 nodes) on eq.8 [4] and can be evaluated as in eq. 9 where $Time_{Trf}$ and $Time_{RRC}$ values are set to zero.

$$C = \frac{(S\ groups) \times PS\ bits\ /\ packet \times \text{SSP seconds} \times \text{PPG packets/group}}{(\text{RUI seconds} \times (\text{NOI}\ iterations + \frac{Time_{Trf}}{NOI}\ \text{seconds}) + \frac{Time_{RRC}}{NOI}\ \text{seconds})} \quad (8)$$

$$
\begin{aligned}
C = Thr_{\max} &= \frac{(12000\,groups)\times(1024\times 8\,bits\,/\,packet)\times(30\text{ seconds})\times(1000\text{ packets/group})}{\left((30\text{ seconds})*(2000\text{ iterations}+0)+0)\right)} \\
C = Thr_{\max} &= 49152000\,groups \times bits\,/\,packet \times seconds \times packets\,/\,group\,/\,seconds\,/\,iterations \\
C = Thr_{\max} &= 49152000\,bits\,/\,iteration
\end{aligned} \tag{9}
$$

Thus, using eq. 10 [4] which is derived by fetching $Thr_{With\_Traffic\_and\_RRC}$ from eq.6 the evaluated $Thr_{With\_Traffic\_and\_RRC}$ value can be calculated.

$$
Thr_{With\_Traffic\_and\_RRC} = \frac{C \times \left[T + \left(\dfrac{Tr - S}{NC}\right)\right]}{\dfrac{Tr}{S} \times \left(T + \left(\dfrac{Tr - S}{NC}\right) + \left(T \times \dfrac{SSP}{RUI} \times \dfrac{Time_{RRC}/NOI}{NC}\right) + \left(T \times \left(\dfrac{SSP \times Time_{Trf}/NOI}{NC}\right)\right)\right)} \tag{10}
$$

Using $Time_{Trf}$ = -0.019 seconds and $Time_{RRC}$ = 0.19 seconds, S=11976 packets, from our simulation results, C=49152000 bps from eq. 9 in addition to the parameter values given in table 1 as; T=2000*30 seconds, Tr=6*2000 packets, NC=6 nodes, SSP=30 seconds/iteration, RUI= 30, seconds, TimeRRC=0.19 seconds, TimeTrf=0.012 seconds, NOI= 2000 iterations, the Throughput value that we expect t have from the simulation can be calculated as;

$$
\begin{aligned}
Thr_{With\_Traffic\_and\_RRC} &= \frac{49152000\text{ bps} \times \left[2000\times 30\text{ sec} + \left(\dfrac{6\times 2000\text{-}11976\text{ pkts}}{6\text{ nodes}}\right)\right]}{\dfrac{12000\text{ pkts}}{11976\text{ pkts}} \times \left(2000\times 30\text{ sec} + \left(\dfrac{6\times 2000\text{ -}11976\text{ packets}}{6\text{ nodes}}\right) + \left(2000\times 30\text{ sec} \times \dfrac{30\text{ seconds/iter.}}{30\text{ sec}} \times \dfrac{0.19\text{ sec}/2000\text{ iter.}}{6\text{ nodes}}\right) + \left(2000\times 30\text{ sec}\times\left(\dfrac{30\text{ sec/iter.}\times\text{-}0.19\text{ sec}/2000\text{ iter.}}{6\text{ nodes}}\right)\right)\right)} \\
Thr_{With\_Traffic\_and\_RRC} &= 49054389\,bps = 49.05\,Mbps
\end{aligned} \tag{11}
$$

4. EXPERIMENTAL RESULTS AND DISCUSSION

In the design of our MATLAB simulation, six mobile nodes using Random Way Mobility Model [5] are simulated in a 2 km x 2 km area which generate and transmit packets towards the generated destinations. While the simulation is running, the data statistics of link failures, sent packets, lost packets and packets in the buffers for each of the nodes and number of route reconstructions (RRC) are all tracked which are used to determine the system throughput of the system. As the routing algorithm the OPR (Optimum Path Routing) is used in order to determine the OPR route.

The proposed LB-ACN algorithm given on figure 3, uses the decision mechanism given on figure 2 and it is embedded into the OPR routing algorithm given on figure 5, where OPR is already embedded into the MPLS simulation given on figure 1.

The simulation program that we run with the parameter set given in Table 1, traces the results of number of transmitted Packets, sent packets, total lost packets because of link failures or buffer fullness states, remaining packets in the buffers of each node, extra time cost caused by RRC, extra time cost caused by Traffic load on each node and finally the instant throughput value of the system for which we attempt to increase by minimizing the time amount consumed by Traffic loads and RCC.

Table 2 The simulation results evaluated by use of LB-ACN for γ between 0 and 1

γ value	Number of transmitted Packets	Number of sent Packets	Number of lost Packets	Number of link Failures	Number of packets in the buffers	Extra time caused by RRC (ms)	Extra time per iteration gained by LB-ACN (ms)	Average Hop count	Throughput (Mbps)	Experimental result / maximum capacity	Experimental result / Theoretical result
0	12000	11976	8	8	16	0,18	-0,09	1,96	46,8	95,22%	95,41%
0.1	12000	11961	25	11	14	0,19	-0,011	1,98	47,9	97,46%	97,66%
0.2	12000	11974	15	15	11	0,19	-0,011	1,98	47,6	96,85%	97,04%
0.3	12000	11975	11	11	14	0,19	-0,009	1,98	48	97,66%	97,86%
0.4	12000	11967	21	21	12	0,19	-0,009	1,98	47,7	97,05%	97,25%
0.5	12000	11975	14	14	11	0,19	-0,009	1,98	48	97,66%	97,86%
0.6	12000	11975	14	14	11	0,19	-0,009	1,98	48	97,66%	97,86%
0.7	**12000**	**11976**	**12**	**12**	**12**	**0,18**	**-0,014**	**1,98**	**48,6**	**98,88%**	**99,08%**
0.8	12000	11975	12	12	13	0,18	-0,012	1,98	47,9	97,46%	97,66%
0.9	12000	11979	9	9	12	0,18	-0,006	1,98	47,5	96,64%	96,84%
1	12000	11979	9	9	12	0,19	-0,01	1,98	47,3	96,24%	96,43%

It was calculated that the maximum theoretical limit of throughput with no loss, no traffic load and no RRC is 49.15 Mbps (eq. 9) and we expect to have 49.05 Mbps throughput (eq. 11) theoretically. Although when the traffic load, RRC, packet losses were considered the throughput performance was improved from 36.9 Mbps to 45.9 Mbps by about 24,4 % in [4]. In this work, when we apply the novel proposed LB-ACN algorithm using **γ** =0.7 on the system with the same parameter set used in [4], the throughput performance is carried from 3.69 to 48.6 Mbps which provides about 31.7 % throughput improvement against the increased traffic load. It is observed that the evaluated throughput value is 98.88 % close to the maximum possible capacity of 49.15 Mbps (eq. 9) and 99.08 % close to the expected throughput value of 49.05 Mbps (eq.11). The simulation results evaluated by use of LB-ACN by varying values of γ between 0 and 1 by steps of 0.1 are given in Table 2. It is observed the maximum time gained by traffic management of LB-ACN (by -0.014 ms per iteration) and the maximum throughput (48,6 Mbps) is evaluated when **γ** =0.7 which provides the best of the improvement rates.

All the theoretical and experimental results evaluated and the improvement provided by this work are as summarized in the figure 6

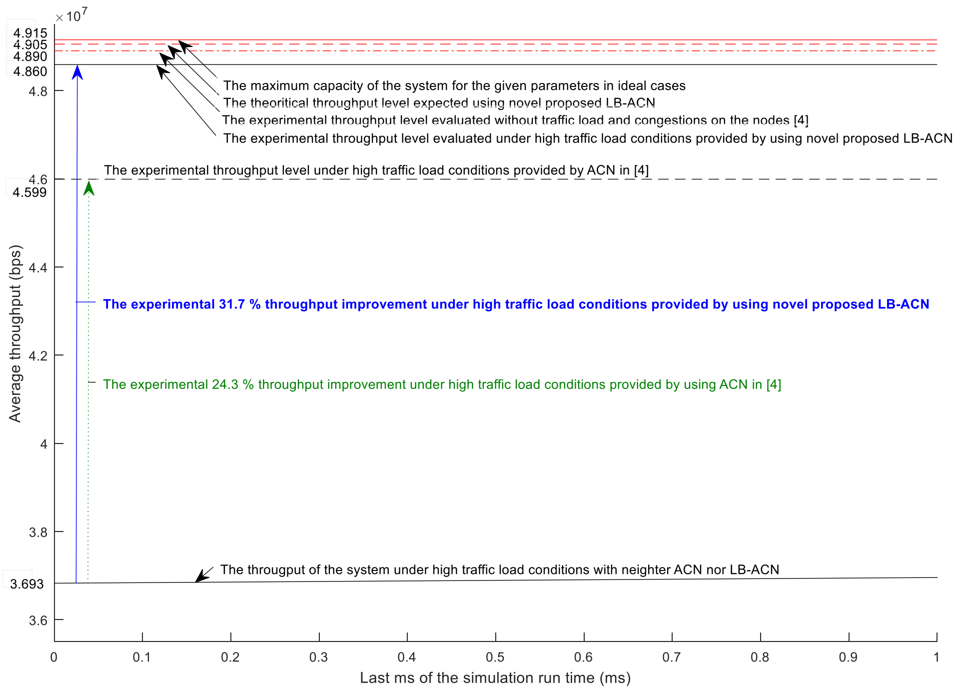

Figure 6 : The summary of the evaluated results and provided throughput improvement rate

5. CONCLUSION AND FUTURE WORK

In this work, we have proposed a novel traffic management algorithm called Location Based Avoid Congested Node (LB-ACN) that solves the network flexibility problem in occurrence of high traffic load on a node before that node starts to lose even single packet. The proposed algorithm is implemented on a tunneling network (MPLS is chosen in this work) simulation developed in MATLAB. At the end, it is shown that, the system throughput which was decreased from $4.8902x10^7$ bps to $3.693x10^7$ bps by a rate of 32.4% due to the traffic load and the congestions on the nodes and could only be carried back to $4.599x10^7$ by 24.3 % improvement using ACN algorithm in the literature, is now compensated by about 31.7 % using the proposed LB-ACN algorithm and carried back from $3.693x10^7$ bps to $4.86\ x10^7$ bps for which about 98.88 % of the maximum system capacity ($4.915\ x10^7$) is recovered.

In the future, the extra challenges that could be experienced in case of using MPLS-TP (Transport Profile) can be tried to overcome.

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Statements & Declarations

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Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Author Contributions

The author contributed to the study conception and design. Material preparation, data collection and analysis were performed by Barbaros Preveze. The first draft of the manuscript was written by Barbaros Preveze. I, Barbaros Preveze read and approved the final manuscript.

Data Availability

The datasets generated during and/or analyzed during the current study are available in the Barbaros Preveze repository, and the codes of the simulation program by which the results are evaluated, can be sent if requested