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A Novel Analytical Method for Throughput Calculation of Wireless Ad-Hoc Networks Running Different Routing Algorithms

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Abstract: *Because of the increasing number of internet related applications, the role of total router transmission delay became much more important for the service quality. For this purpose, the tunneling techniques have been widely used especially for real time multimedia transmission to have less number of route constructions and to be able to forward each packet at each router without the need of reaching the upper OSI (Open Systems Interconnection) layers. But, in mobile networks, since the network experience with more changes in traffic conditions and node locations, tunnels will be reconstructed for many times and some extra delay will occur to reconstruct these tunnels.*

In this work, the place of the tunneling algorithm is taken by the well-known MPLS (Multi-Protocol Label Switching) protocol and for confirmation the throughput calculations are made by considering two different routing algorithms, one of which is AEABR algorithm proposed in [1] (shown in [2] that it improves the system throughput w.r.t Fastest path Routing algorithm [3] for various vehicular velocities), and the other one is Fastest Path routing algorithm [3]. In this work a novel analytical method for throughput calculation of wireless ad-hoc networks running aforementioned routing algorithms is proposed including the effects of extra delay caused by extra Route Reconstructions (RRC).

Keywords: *Throughput, Calculation, AEABR, Fastest Path, Long life Routing, Mobile, Multi-hop, MPLS.*

1. Introduction

During the transmission in multi-hop networks, most of the time is consumed by decisions regarding switching through the determined path in the core part of the network. So the best route with minimum route reconstruction delay and transmission delay between source and the destination must be predicted and established in order to satisfy the requirements of especially real-time applications such as gaming, video applications and voice applications.

For this reason, a novel routing algorithm called AEABR (Alternative Enhancement on Associativity Based Routing) has been developed [1] that provides longer route life times with fewer route reconstruction delays. In [2], AEABR algorithm was suggested to be used in IEEE 802.16j network, and it was shown that AEABR algorithm always had better results in terms of overhead, connectivity and throughput than Fastest Path [3], Ant Colony [4] and other well-known long life routing algorithms such as ABR [5] and EABR [6].

The study in [3] investigates the fastest packet transmission in wireless networks. It is shown that the end-to-end packet delay depends on the locations of the relay nodes where it has more importance in mobile networks. A novel routing algorithm is proposed to find the fastest path for minimum delay. Where, the nodes are assumed as fixed nodes in the assumed scenario of [3]. But the route life time and the effects of RRC delay are not considered here.

In [7], the throughput performances of Ant Colony, Fastest Path and Shortest Path routing algorithms are compared on an MPLS network and it was also shown for N=6 that the Fastest Path algorithm gives the best throughput results among all. However, the MPLS network simulated in this work is considered as a fixed MPLS network and the route life time and the effects of RRC delay are also not considered here.

In [8], the throughput performances of Ant Colony and Fastest Path algorithms are compared on an IEEE 802.16j network and it was shown that the Fastest Path algorithm gives better throughput results than the Ant Colony algorithm for an IEEE 802.16j network.

In [9], a comparative analysis of long life routing algorithms in mobile networks has been done for an IEEE 802.16j network and it is shown that AEABR always provides longer life times than other long life routing algorithms for an IEEE 802.16j network.

In [10], a novel high performance routing algorithm Optimum Path Routing (OPR) is proposed to improve the throughout performance of mobile multi-hop tunneling networks compared to Fastest Path routing algorithm without additional message overhead and it is confirmed with the calculation results that the novel proposed routing algorithm has improved the system performance.

However, none of the aforementioned works has calculated the throughput of an MPLS network without need of the node relative velocities considering the effects of route life time and delay amount caused by RRC.

In this work, the long life AEABR algorithm and the well-known Fastest Path algorithm (which was the winner at [7] and [8]), are both implemented on a mobile MPLS network, considering the effects of route life time and delay amount caused by RRC for more accurate results. Then their effects on throughput performance on a mobile MPLS network are investigated. The evaluated calculation results are also confirmed by the results evaluated by the simulation using MATLAB which also consider the RRC delay.

The organization of this paper includes five sections, where Section 2 gives a brief explanation of the MATLAB implementation of AEABR and Fastest Path routing algorithms on mobile MPLS networks from the simulation point of view. Section 3 gives the experimental performance results of the simulation program for Fastest path [10] and AEABR algorithms, where the effects of the extra RRC delay are also considered. Section 4 gives a novel proposed theoretical calculation method for the "throughput" using the same parameter set used in the simulation and also taking the "expected RRC delay" into account either when using the Fastest Path or AEABR algorithms. And the conclusion is given in Section 5.

2. Implementation of Routing Algorithms on an MPLS Network

For a detailed simulation design of an MPLS Network, the MPLS network functions such as labeling (attaching, detaching ,encapsulation, de-capsulation...) and forwarding (transmission between the nodes, packet losses, link/node failures...) are implemented with the ability of using any desired routing algorithms with the system. From the user point of view, it is known that the system throughput performance is the major factor determining the Quality of Service (QoS) of the network and it is shown in Figure 1 that, the throughput performance has direct relations with two main factors determined by the routing algorithms, which are hop count and route life time. The expected effects of route life time on the total throughput performance of the network for equal average hop count values are highlighted in Figure 1.

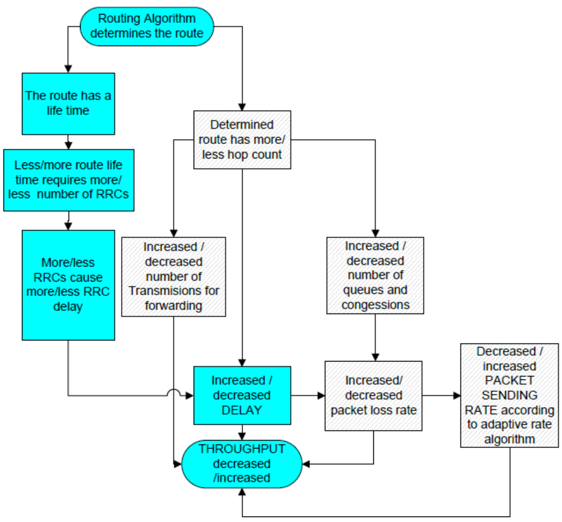

Figure1. *Illustration of the effects of route life time on the network total throughput*

In the simulation scenario there are six mobile nodes using the random way point mobility model [11] in a 2 km x 2 km area with random and different but fixed speeds from 36 km/h to 72 km/h. The nodes transmit their 1024 byte packets [12] over the free space with 1W transmission power [13] (automatically increased only if no relay is available in the range) where the noise power is considered to be 1 mW. The nodes continuously update the routes once each second to continue transmission over the determined best available path. At the ingress and egress points of the MPLS network, the Label Edge Routers (LERs) take the packets from the IP network, create the MPLS labels and paste/swap them to each of the packets according to the destination address read from the IP header of the IP packet and forward it to its determined next hop [12]. Next time, each Label Switching Router (LSR) that receives this packet extracts the previous label, analyses it and swaps with an updated MPLS label according to the updated forwarding requirements [12]. The parameters used in the simulation and in the calculations are listed in Table 1.

Table1. *Parameter values used in MPLS simulation program and calculations [10]*

Number of nodes (N)	Six nodes
Movement Area (x, y)	(100 pixel x 20m/pixel) x (100 pixel x 20m/pixel) =4 km^2
Speed Range of the nodes	Between 36 km/h - 72 km/h (random but fixed)
Mobility model	Random way point mobility model[11]
Packet size (PS)	1 kB [12]
Transmission medium	Free Space (α=2)
Transmission power (P)	1 W
Noise power (P_N)	1mW
Route update interval (RUI)	1 second
RRC extra time	50 ms/RRC using Fast Reroute (FRR) [13]
Simulation run time (SRT)	16,6 hours 2000 iterations (30 seconds each)
Simulation Step Period (SSP)	30 seconds
Number of transmitted packets (TPG)	Six nodes x 2000 groups/sec x 30 secs x 1000 Packets/group
Average Hop Count for Fastest Path	1.72 hops (evaluated from the simulation results in figure 5(a))
Average Hop Count for AEABR	1.68 hops (evaluated from the simulation results figure 5(b))

The overall algorithm running on each node simultaneously in the MPLS network either when the Fastest Path routing algorithm or the AEABR routing algorithm is being used is given in Figure 2.

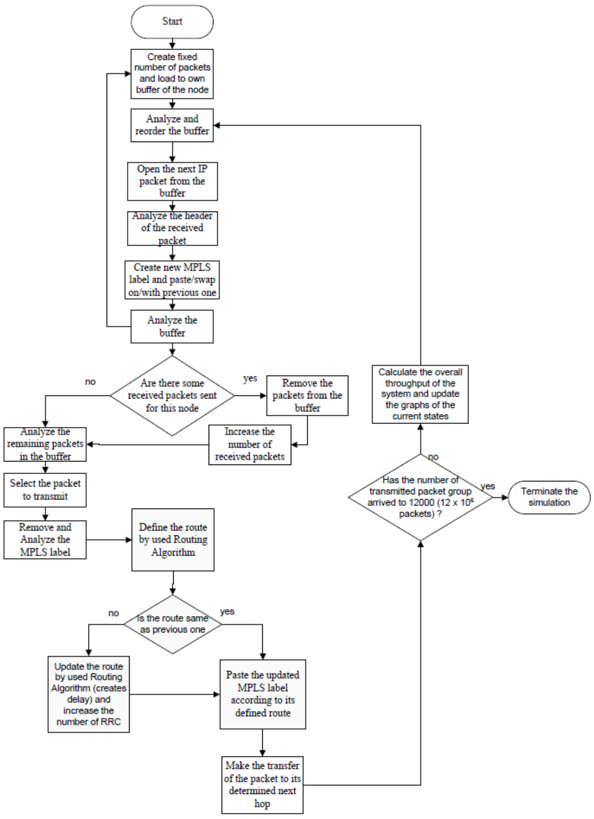

Figure2. *The overall algorithm running on each node in the MPLS network [10]*

3. Experimental Results

Using the MATLAB simulation program in [10], where the mobile nodes use the algorithm given in figure 2 [10] and continuously generate data, video and voice packets, and deciding a tunnel route for transmission either using AEABR or Fastest path routing algorithms to the number of successfully transmitted packets during the simulation run time are counted and the throughput value is observed.

The generated throughput of the system generated for both the Fastest Path algorithm and the AEABR algorithm are given in Figure 3 and Figure 4.

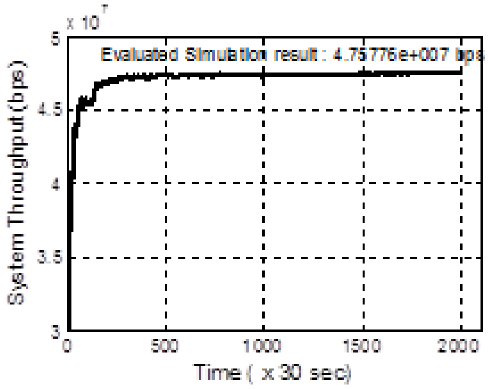

Figure3. *Throughput simulation results of MPLS when AEABR Algorithm is used [10].*

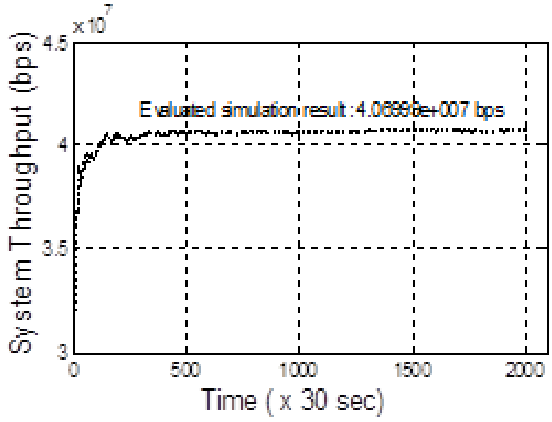

Figure4. *Throughput simulation results of MPLS when Fastest Path algorithm is used*

It can be read from Figure 3 and Figure 4 that the simulation throughput results are evaluated as; 47.57 Mbps for AEABR and 40.7 for Fastest Path routing algorithm. So, for confirmation, it is expected that the calculations for expected throughput must be close to the results given by the simulation.

4. Proposed Analytical Calculations For Expected Throughput

4.1. Calculation of Probability of RRC for Fastest Path and AEABR Algorithms ($P_{RRC\_FASTEST}$ and P_{RRC_AEABR})

The throughput of an MPLS network can be calculated for any desired number of nodes by considering the number of total packets sent, packet size and total transmission time including the time spent for RRCs. The basic form of throughput calculation is given in eq.1.

$$Throughput = \frac{N \times Packet\ Size \times Number\ of\ Packets\ sent}{Total\ Transmission\ Time + Total\ extra\ RRC\ delay} \quad (1)$$

The critical parameter here that cannot be set to a predefined value and not given in Table 1 is the "Total extra RRC delay" caused by the "RRC rates". But, the Total extra RRC delay can be determined by calculation of probability of route RRC for used routing algorithm. Since the Fastest Path and the AEABR algorithms are used in this work, the $P_{RRC\_FASTEST}$ and the P_{RRC_AEABR} values are calculated to evaluate the resultant throughput.

Figures 5 and 6 are given in order to visually illustrate the calculation methods of $P_{RRC\_FASTEST}$ and P_{RRC_AEABR} for a node that is transmitting its packets via two hops using 1W transmission power on free space (α=2) where it has a range of 12.5 unit x 20 m/unit from eq.2 [3].

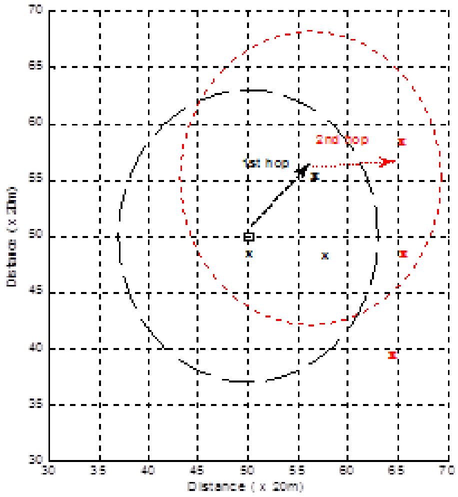

Figure5. *Illustration of determined two hops route, using the Fastest Path algorithm*

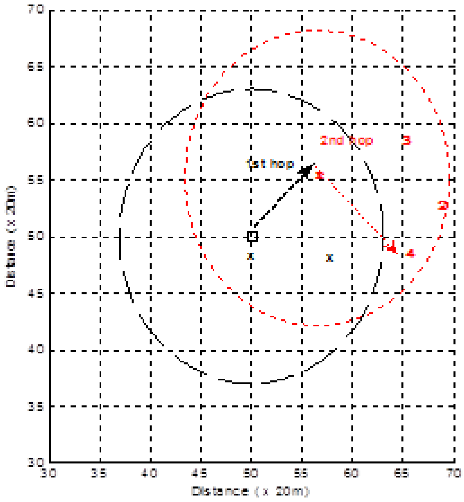

Figure6. *Illustration of determined the two hops route, using the AEABR algorithm*

$$Range_{T_x} = \left[\left(\frac{P}{N_P \times \left(e^{\alpha} - 1\right)} \right)^{\frac{1}{\alpha}} \right]^2 \qquad (2)$$

In Figure 5, all the nodes are shown by “x” while in Figure 4 the nodes in the range of current transmission (2nd hop) are shown by their Associativity Tick (AT) numbers **[1]**. Note that the nodes that are also in the range of 1st hop and so ignored during 2nd hop are shown as crosses in Figure 6.

For the calculation of “$P_{RRC\_FASTEST}$ and P_{RRC_AEABR} (probability of not choosing the same route next time, either in hop 1 or hop 2)”, it is initially formulated for two hops route for both considered routing algorithms (as illustrated in Figures 5 and 6), but then it is generalized for any desired hop count value in the formulations in eq. 11 and eq. 12.

For the calculations of $P_{RRC\_FASTEST}$ and P_{RRC_AEABR} given in eq.3 [10] and eq.4, respectively, the number of nodes in the range of the transmitter, including the transmitter itself, is abbreviated as “n” (n=3 for Figures 5 and 6), where there are “N” nodes in the whole area (N=6 for Figures 3 and 4). Therefore “N-n” gives the total number of nodes in the whole simulation area but outside the range of the current transmitter.

$$P_{RRC_{FASTEST\_2\_Hops}} = \underbrace{1-\underbrace{\sum_{n=2}^{N-1} \mathrm{P}_{\text{srfh1\_FASTEST}} \times \mathrm{P}_{\text{srfh2\_FASTEST}}}_{\text{prabability of not changing any of the relays}}}_{\text{prabability of changing at least one of the relays through the path for 2 hops}} \tag{3}$$

$$P_{RRC_{AEABR\_2\_Hops}} = \underbrace{1-\underbrace{\sum_{n=2}^{N-1} \mathrm{P}_{\text{srfh1\_AEABR}} \times \mathrm{P}_{\text{srfh2\_AEABR}}}_{\text{prabability of not changing any of the relays}}}_{\text{prabability of changing at least one of the relays through the path for 2 hops}} \tag{4}$$

Where,

- $\mathrm{P}_{\text{srfh1\_FASTEST}}$ is the "Probability of Selecting the Same Relay for Hop 1 using Fastest Path",
- $\mathrm{P}_{\text{srfh2\_FASTEST}}$ is the "Probability of Selecting the Same Relay for Hop 2 using Fastest Path",
- $\mathrm{P}_{\text{srfh1\_AEABR}}$ is the "Probability of Selecting the Same Relay for Hop 1 using AEABR",
- $\mathrm{P}_{\text{srfh2\_AEABR}}$ is the "Probability of Selecting the Same Relay for Hop 2 using AEABR".

The accumulations in eq.3 and eq.4 start from minimum possible n value (n_{min}) and they go up to maximum possible n value (n_{max}).

For possible two hop communications there must be at least one node inside the range of the transmitter (n_{min} =2, including the transmitter itself) for the first hop and there must be at least one node outside the range of the transmitter (n_{max}=N-1) for a possible second hop.

It is seen in Figures 5 and 6 in which the nodes are positioned at exactly the same locations in both cases that the routing algorithms can select different routes because of the used AT numbers in AEABR.

To be able to calculate $\mathrm{P}_{\text{srfh1\_FASTEST}}$, $\mathrm{P}_{\text{srfh2\_FASTEST}}$, $\mathrm{P}_{\text{srfh1\_AEABR}}$ and $\mathrm{P}_{\text{srfh2\_AEABR}}$ that are needed in calculations of eq.3 and eq.4, first the "Probability of a node to be located in the range of the transmitting node (P_{LRN})" can be calculated using eq.5 [10] using eq.2 [3].

$$\mathrm{P}_{LRN} = \frac{\overbrace{\pi \times \left[\left(\frac{P}{N \times e^{\alpha} - 1} \right)^{\frac{1}{\alpha}} \right]^2}^{\text{range of the transmitting node}}}{\underbrace{x \times y}_{\text{Total area}}} \tag{5}$$

For the second hop, the "probability of the next node for the second hop (which cannot be selected in the first hop) being out of the range of the previous transmitter ($\mathrm{P}_{OUT\_of\_RANGE}$)" can be calculated as in eq.6.

$$\mathrm{P}_{OUT\_of\_RANGE} = 1 - \mathrm{P}_{LRN} \tag{6}$$

Calculations of $\mathrm{P}_{\text{srfh1\_FASTEST}}$ and the $\mathrm{P}_{\text{srfh2\_FASTEST}}$ are given in eq.7 and eq.8 respectively with their explanations where the relative velocity information of the nodes are not required as in [10].

$$\mathrm{P}_{\text{srfh1\_FASTEST}} = \underbrace{\left(\frac{(N-1)!}{(n-1)! \times [(N-1)-(n-1)]!} \right)}_{\substack{\text{Combination of selecting different} \\ (n-1)\text{ nodes among } N-1 \text{ nodes} \\ \text{to be inside the range of the transmitter}}} \times \underbrace{(\mathrm{P}_{LRN})^{(n-1)}}_{\substack{\text{Probability of having all these} \\ (n\text{-}1)\text{ nodes in the range of} \\ \text{transmitting node}}} \times \underbrace{\frac{n-1}{N-1}}_{\substack{\text{Probability of having} \\ \text{the first hop node previously} \\ \text{selected being in same } n-1 \\ \text{of } N-1 \text{ nodes}}} \tag{7}$$

$$\mathrm{P}_{\mathrm{srfh2\_FASTEST}} = \underbrace{\left(\frac{(N)!}{(N-n)!\times[(N)-(N-n)]!}\right)}_{\substack{\text{Combination of selecting } (N-n) \text{ nodes outside}\\ \text{the range of the transmitter among all } N \text{ nodes}}} \times \underbrace{(1-\mathrm{P}_{LRN})^{(N-n)}}_{\substack{\text{probability of having this } (N-n) \text{ nodes}\\ \text{located out of the range of transmitter node}\\ \text{for the second hop}}} \times \underbrace{\frac{N-n}{N-1}}_{\substack{\text{Probability of having}\\ \text{the second hop node previously}\\ \text{selected, being in the}\\ \text{same } N-n \text{ nodes of}\\ N-1 \text{ nodes}}} \tag{8}$$

Note that, with AEABR algorithm, all the nodes keep the accessibility information of all their neighbors and they select the routes according to their AT numbers, which opens the ways of extending the route life time [1].

But since the AT numbers are used in AEABR, the calculations of $\mathrm{P}_{\mathrm{srfh1\_AEABR}}$ and $\mathrm{P}_{\mathrm{srfh2\_AEABR}}$ differ from the case where Fastest Path is used. The calculation methods of $\mathrm{P}_{\mathrm{srfh1\_AEABR}}$ *and* $\mathrm{P}_{\mathrm{srfh1\_AEABR}}$ are also given in eq.9 and eq.10 with their explanations.

$$\mathrm{P}_{\mathrm{srfh1\_AEABR}} = \underbrace{\left(\frac{(N-1)!}{(n-1)!\times[(N-1)-(n-1)]!}\right)}_{\substack{\text{Combination of selecting}\\ \text{(n-1) nodes among N-1nodes}\\ \text{inside the range of the transmitter}}} \times \underbrace{(\mathrm{P}_{LRN})^{(n-1)}}_{\substack{\text{Probability of having this}\\ \text{(n-1) nodes in the range of}\\ \text{the transmitter}}} \times \underbrace{\frac{\left(\sum_{j=n}^{N-1} AT(j)\right) + \overbrace{1}^{\substack{\text{increased AT number}\\ \text{because of the}\\ \text{connection establishment}\\ \text{of 1st hop}}}}{\left(\sum_{k=1}^{N-1} AT(j)\right) + \underbrace{1}_{\substack{\text{increased AT number}\\ \text{because of the}\\ \text{connection establishment of}\\ \text{1st hop}}}}}_{\substack{\text{Probability of selecting same next hop for the first}\\ \text{hop by still having the greatest AT number among the}\\ \text{nodes inside the range of first hop}}} \tag{9}$$

$$\mathrm{P}_{\mathrm{srfh2\_AEABR}} = \underbrace{\left(\frac{(N)!}{(N-n)!\times[(N)-(N-n)]!}\right)}_{\substack{\text{Combination of selecting (N-n) nodes outside}\\ \text{the range of the transmitter among all N nodes}}} \times \underbrace{(1-\mathrm{P}_{LRN})^{(N-n)}}_{\substack{\text{probability of having this (N-n) nodes}\\ \text{located in the range of the node}}} \times \underbrace{\frac{\left(\sum_{j=n}^{N-1} AT(j)\right) + \overbrace{1}^{\substack{\text{increased AT number}\\ \text{because of the}\\ \text{connection establishment of 2nd hop}}}}{\left(\sum_{k=1}^{N-1} AT(j)\right) + \underbrace{2}_{\substack{\text{increased AT number}\\ \text{because of the}\\ \text{connection establishment}\\ \text{of 1st and 2nd hops}}}}}_{\substack{\text{Probability of selecting same next hop for the second}\\ \text{hop (assuming the first hop is already same) by still having the}\\ \text{greatest AT number among the nodes outside the range}\\ \text{of the first hop.}}} \tag{10}$$

Since eq.3 or eq.4 repeat themselves for the 3rd, 4th, … hops, not only for the initially assumed two hops but also it is possible to calculate the probability of RRC for any number of hops (hc), by first calculating the square root of eq.3 to normalize the calculation from two hops to a single hop, then calculating its hc$^{\text{th}}$ power of it to normalize it for 'hc' count, as in eq.11 and eq.12.

$$P_{RRC_{Fastest\ Path\_hc\_Hops}} = \underbrace{\left(\overbrace{\sqrt{\underbrace{1-\underbrace{\sum_{n=2}^{N-1} \mathrm{P}_{\mathrm{srfh1\_FASTEST}} \times \mathrm{P}_{\mathrm{srfh2\_FASTEST}}}_{\text{probability of not changing any of the relays}}}_{\text{probability of changing any of the relays}}}}^{\text{normalised result for single hop}}\right)^{(hc)}}_{\text{normalised result for 'hc' hops}} \tag{11}$$

$$P_{RRC_{AEABR\_hc\_Hops}} = \underbrace{\left(\overbrace{\sqrt{\underbrace{1-\underbrace{\sum_{n=2}^{N-1} \mathrm{P}_{\mathrm{srfh1\_AEABR}} \times \mathrm{P}_{\mathrm{srfh2\_AEABR}}}_{\text{prabability of not changing any of the relays}}}_{\text{prabability of changing any of the relays}}}}^{\text{normalised result for single hop}}\right)^{(hc)}}_{\text{normalised result for 'hc' hops}} \tag{12}$$

At this point, the evaluated results of eq.7 and eq.8 can be replaced in eq.11 to evaluate the $P_{RRC_{FASTEST\_hc\_Hops}}$ value and the evaluated results of eq.9 and eq.10 can be replaced in eq.12 to evaluate the $P_{RRC_{AEABR\_hc\_Hops}}$ value for any given average hop count value.

The results evaluated from eq. 11 and eq.12 are respectively used for the calculation of expected RRC delays and expected throughput values in case of using either Fastest Path ($THR_{FASTEST}$) or AEABR ($THR_{FASTEST}$) algorithms. Applying the parameter set given in Table 1 in eq. 11 and eq.12, the expected $P_{RRC_{hc\_Hops}}$ values can easily be calculated as;

$P_{RRC_{Fastest\ Path\_hc\_Hops}}$ = 36.51 % and $P_{RRC_{AEABR\_hc\_Hops}}$ = 8.35 %.

4.2. Calculation of Expected RRC Delays and Throughput Values for Fastest Path and AEABR Algorithms

For calculation of expected throughput values, first the expected time delay caused by RRCs

($Time_{RRC}$) during the given length of run time (SRT) must be calculated. This calculation can be done using the $P_{RRC_{hc\_Hops}}$ value evaluated in eq.13 [10].

$$P_{RRC_{hc\_Hops}} = \frac{\left.\dfrac{\left.\dfrac{Time_{RRC}}{RRC_{\text{time\_cost}}}\right\} \text{number of RRC}}{N}\right\} \text{number of RRC per node}}{\underbrace{\dfrac{\dfrac{Time_{RRC}}{RRC_{\text{time\_cost}}}}{N} + \dfrac{SRT}{RUI}}_{\text{number of RRC per node + number of totally used routes used per node in each iteration}}} \tag{13}$$

Then, the $Time_{RRC}$ value can be calculated as in eq.14 [10] by directly fetching $Time_{RRC}$ from eq.13.

$$Time_{RRC} = \frac{\left(RRC_{\text{time\_cost}} \times N \times P_{RRC_{hc\_Hops}} \times \dfrac{SRT}{RUI}\right)}{1 - P_{RRC_{hc\_Hops}}} \tag{14}$$

That means, when the $P_{RRC_{Fastest\ Path\_hc\_Hops}}$ or $P_{RRC_{AEABR\_hc\_Hops}}$ values are calculated, they can be used to find the $Time_{RRC\_FASTEST}$ and $Time_{RRC\_AEABR}$ values by substituting them with $P_{RRC_{hc\_Hops}}$ given in eq.14.

Substituting the results evaluated before for $P_{RRC_{Fastest\ Path\_hc\_Hops}}$ and $P_{RRC_{AEABR\_hc\_Hops}}$ respectively as 36.51 % and 8.35 % in eq.14, $Time_{RRC\_FASTEST}$ and $Time_{RRC\_AEABR}$ values can be calculated as;

$$Time_{RRC\_FASTEST} = \frac{(0.05 \times 6 \times 0.3651 \times 2000)}{1 - 0.3651} = 345.03 \text{ seconds} \tag{15}$$

$$Time_{RRC\_AEABR} = \frac{(0.05 \times 6 \times 0.0835 \times 2000)}{1 - 0.0835} = 54.66 \text{ seconds} \tag{16}$$

Finally, the expected throughput values for both algorithms (Thr_{hc_Hops}) can be generalized and the evaluated $Time_{RRC}$ values in eq.15 and eq.16 can be used in eq. 17.

$$Thr_{hc\_Hops} = \frac{TPG \times PS \times \overbrace{8 \times 1024}^{kilobits}}{\left(\underbrace{(SRT \times SSP)}_{SRT\ iterations\ (SSP\ seconds\ each)} + \left(\underbrace{\frac{SSP}{RUI}}_{\substack{\text{number of route updates} \\ \text{(at each RUI seconds} \\ \text{of SSP seconds)}}} \times Time_{RRC} \right) \right)} \quad (17)$$

Where other parameter values in eq.17 are already given in Table 1 as N=6, TPG=6 nodes x 2000 groups/sec x 30 secs x 1000 packets/group, PS=1kB, SRT=2000 iterations SSP=30 seconds, RUI=1 second. At the end, using the $Time_{RRC\_FASTEST}$ and $Time_{RRC\_AEABR}$ evaluated in eqs.15-16, the expected $Thr_{FASTEST\_hc\_Hops}$ and $Thr_{AEABR\_hc\_Hops}$ are calculated using eq.17 as,

$$Thr_{FASTEST\_hc\_Hops} = \frac{6 \times 2000 \times 30 \times 1000 \times 1024 \times 8}{\left((2000 \times 30) + \left(\frac{30}{1} \times 345.03 \right) \right)} = 41.92\, Mb/s \quad (18)$$

$$Thr_{AEABR\_hc\_Hops} = \frac{6 \times 2000 \times 30 \times 1000 \times 1024 \times 8}{\left((2000 \times 30) + \left(\frac{30}{1} \times 54.66 \right) \right)} = 47.84\, Mb/s \quad (19)$$

Note that, the calculation results evaluated for Fastest Path routing algorithm, also match with the calculations made in [10] where a different calculation method that needs the relative velocities of the nodes is used, and the calculation results are also confirmed by the simulation results evaluated in section 3.

5. Conclusion

In this work, an analytical method is proposed to calculate the expected throughput performance of an MPLS network without the need of relative velocities of the nodes and it is shown that the results evaluated by the proposed method also match with the results of the simulation for both considered routing algorithms in this work. By use of this novel proposed analytical method, the expected performance of any tunneling network can be calculated easier for any given parameter set. So, the optimum parameter set can be evaluated for the networks and cheaper tunneling network designs can be made with higher throughput performances.

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