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Traffic Engineering in Computer Networks: A New Dynamic Destination Nodes Management Approach

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Abstract: Managing the number of destination nodes for multicasting services is an important challenge in communication networks. When a Multicast Multichannel Path (MMCP) transmits packets from a source node to a group of destination nodes it might be possible the number of destination nodes change. This means that during a multicast data transmission session, either removing some current destination nodes or adding some new destination nodes can be happen. Removing a current destination node loses packets which are being transmitted to that node. Therefore, increasing or decreasing the number of destination nodes causes that the router compulsorily changes or re-computes the current multicast paths. Adding or removing the destination nodes must be done by a dynamic routing algorithms because static routing algorithms do not support dynamic changes in network topology. Re-computing multicasting path must be dynamically done because static computations may disconnect multicasting path and halt data transmission. When a current path is replaced with another new path, some packets cannot be forwarded to their destinations and they will be lost. This affair removes packets and then wastes bandwidth. In this study, we will present a new Dynamic Routing Algorithm, Optimal Dy-namic Multicast Multichannel Routing (ODMMR) which prevents from losing packets and wasting network resources. Our new algorithm is based on the multichannel constraint-based routing (a traffic engineering approach) and supports Quality of Services (QoS). Computational results and simulation analysis will show that our new algorithm is more efficient than other available routing algorithms.

Key words: Traffic engineering, dynamic routing, multicasting, multichannel path, quality of services, optimization, post optimality computations

INTRODUCTION

Nowadays, various types of data transmissions such as dynamic multicast communications are widely used in telecommunication systems and computer networks (Abdel-Kader, 2011; Lee *et al*., 2011; Sun *et al*., 2011; Wang *et al*., 2014). A multicast session transfers packets of applications such as video, voice and email protocols from a source node to a group of destination nodes. Sometimes we must change the number of destination nodes which receive packets.

It is very important that how we can join or eliminate some current nodes from the group of destination nodes which are receiving packets from the source node. Dynamic routing means that both joining and eliminating some destination nodes from the group of destination nodes and traffic management must be continuously done (Paillassa *et al*., 2011; Tekbiyik and Uysal-Biyikoglu, 2011; Randhawa and Sohal, 2010; Khamayseh *et al*., 2011; Yin *et al*., 2014). In this study, we present Optimal Dynamic Multicast Multichannel Routing (ODMMR) algorithm which performs both changing destination nodes and shaping traffic continuously and optimally.

The main idea of the paper: We can see a multicast data transmission session in Fig. 1. Source node S is black and destination nodes A, B and C are red. Intermediate nodes are blue and form a subnet which transmits packet from source node S to destination nodes. Note that in our samples we suppose that intermediate nodes only can duplicate packets and only destination nodes can be removed or added. We can see that the subnet consists of some multichannel paths.

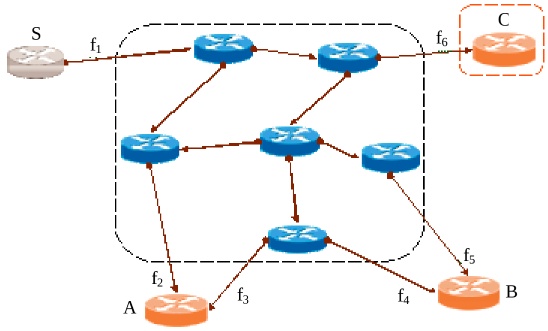

Fig. 1: A multicast session consisting of source node S and 3 destination nodes A, B and C

It is clear that a multichannel path contains one or more than one loop (Isazadeh and Heydarian, 2008, 2010). In this figure, f_1 is in-put flow and we have: $f_1 = f_6$, $f_1 = f_4+f_5$, $f_1 = f_2+f_3$. This means that the subnet triples each packet which go outs from source node S and each duplicated packet is received with a destination node. Packet duplication is done by inter-mediate nodes. Suppose that size of the message that to be transmit-ted from source node S to destina-tion nodes is $\sigma>0$ and also sup-pose that this transmission takes $\tau>0$ time units.

Suppose that during the message transmission a destination node for example node C is removed. In this case some packets which have been dispatched to node C will be lost because these packets are not received by node C and will be wasted. In this case, the Routing algorithm compulsorily will halt data transmission and will re-compute all paths and will resend the packets to nodes A and B through the new path.

Note that after failing node C, bandwidth of going out flow f6 will be released and can be used by destination nodes A and B. Therefore, f_1 and going out flows f_2, f_3, f_4 and f_5 can be increased. In this study, we will present a new Routing algorithm which can vanish f_6 and can increase f_2, f_3, f_4 and f_5 dynamically and optimally. Dynamic Routing algorithm also can replace node C with another node. In this situation, the dynamic algorithm will do two following tasks synchronously: changing flows and paths; holds data transmission. In fact our algorithm will prevent from halting data transmission and also can replace intermediate links and nodes without disconnecting transmission.

Our new algorithm supports Quality of Services (QoS) and multichannel routing. Our algorithm is based on the Linear Programming Formulation (LPF) (Bistarelli *et al*., 2007; Khadivi *et al*., 2008; Ebrahim and Razmi, 2009; Deep *et al*., 2011). The algorithm uses post-optimality to reduce computations when it vanishes f_6 and increases other flows continuously and dynamically (Yuksel *et al*., 2011; Rao and Wang, 2011; Idzikowski *et al*., 2011).

In Linear Programming (LP), a technique for determining how the optimal solution to a linear programming problem changes if the problem data such as objective function coefficients or right-hand side values change; also called post-optimality analysis. To an alert accountant, the optimal solution not only provides answers-given assumptions about resources, capacities and prices in the problem formulation-but should raise questions about what would happen if conditions should change. Some of these changes might be imposed by the environment such as changes in resource costs and market conditions. Some, however, represent changes that the manager can initiate such as enlarging capacities or adding new activities.

In solving a multicast routing problem with traffic engineering, we can formulate resources and network topology as a LP formulation. When some destination nodes are removed or added this LP formulation will changes and we can solve the LP problem using post-optimality computations. This means that we can study measuring the effect of a change in a variable (such as bandwidth and delay) on the removing or adding nodes in network topology.

Informal definition of the problem: Note that our new algorithm can reconstruct multicast session dynamically and optimally when one or more than one destination nodes are added/removed to/from current destination nodes. In fact our algorithm holds the current multicasting path and changes the number of destination nodes continuously, optimally and dynamically.

LITERATURE REVIEW

Problem: When a MMCP is established, some nodes are multicast nodes and duplicate data units and these duplicated data units will be delivered to destination nodes. Multicast nodes may be removed from MMCP and this can waste data units that must be duplicated. Therefore, lost rate will be increased and then data rate is reduced.

For removing this problem we can present a new version of OMMR algorithm which can replace the removed maulticast node with other nodes. In fact new OMMR can improve MMCP and can prevent from lost rate. For generating new OMMR we must use simplex method and post optimality computations. We leave to construct new OMMR as a new project for the future.

REVIEW OF EXISTENCE MULTICAST ROUTING ALGORITHMS

Some algorithms such as Optimal multicast Multichannel Routing (OMMR) (Isazadeh and Heydarian, 2008), Distributed Optimal Multicast Multichannel Routing Algorithm (DOMMR) (Isazadeh and Heydarian, 2010) and Nodes Links Distributed-Multicast Multichannel Routing (NLD-MMR) (Isazadeh and Heydarian, 2012) do not support dynamic routing and cannot support changing the number of destinations nodes during data transmission. These algorithms are based on the Linear Programming Formulation (LPF)

(Eusebio and Figueira, 2009; Cao and Yuan, 2011; Masip-Bruin *et al.*, 2006) and support QoS and multicast multichannel paths. On the other hands, some algorithms such as Multicast Open Shortest Path First (MOSPF) (Chen and Somr, 2008; Wang and Wu, 2012; Kim *et al.*, 2013) is dynamic but does not support traffic engineering and QoS.

Internet multicast protocols (IGMP and MOSPF): The Internet Group Management Protocol (IGMP) (Pinto and Ricardo, 2011; Islam and Atwood, 2010; Farzinvash and Dehghan, 2014) is a communications protocol used by hosts and adjacent routers on IP networks to establish multicast group member-ships. IGMP is an integral part of the IP multicast specification. It is analogous to ICMP for unicast connections. IGMP can be used for online streaming video and gaming and allows more efficient use of resources when supporting these types of applications. IGMP is used on IPv4 networks. Multicast management on IPv6 networks is handled by Multicast Listener Discovery (MLD) which uses ICMPv6 messaging contrary to IGMP's bare IP encapsulation. IGMP is bases on the datagram routing such as Minimum Spanning Tree and cannot support dynamic routing optimally.

IP multicasting is the transmission of an IP datagram to a "Ahost group" a set of zero or more hosts identified by a single IP destination address. A multicast datagram is delivered to all members of its destination host group with the same "best-efforts" reliability as regular unicast IP datagrams, i.e., the datagram is not guaranteed to arrive intact at all members of the destination group or in the same order relative to other datagrams.

The membership of a host group is dynamic that is hosts may join and leave groups at any time. There is no restriction on the location or number of members in a host group. A host may be a member of more than one group at a time. A host need not be a member of a group to send datagrams to it.

MOSPF is an enhancement of OSPF V2, enabling the routing of IP multicast datagrams. OSPF is a link-state (unicast) routing protocol, providing a database describing the Autonomous System's topology. IP multicast is an extension of LAN multicasting to a TCP/IP Internet. IP multicast permits an IP host to send a single datagram (called an IP multicast datagram) that will be delivered to multiple destinations. IP multicast datagrams are identified as those packets whose destinations are class D IP addresses (i.e., addresses whose first byte lies in the range 224-239 inclusive). Each class D address defines a multicast group.

The extensions required of an IP host to participate in IP multicasting are specified in "host extensions for IP multicasting". That document defines a protocol, the Internet Group Management Protocol (IGMP) that enables hosts to dynamically join and leave multicast groups.

Multicast Open Shortest Path First (MOSPF) (Lee *et al.*, 2012: Cheng *et al.*, 2011) routers use the IGMP protocol to monitor multicast group membership on local LANs through the sending of IGMP host membership queries and the reception of IGMP host membership reports. A MOSPF router then distributes this group location information throughout the routing domain by flooding a new type of OSPF link state advertisement, the group-membership-LSA (type 6). This in turn enables the MOSPF routers to most efficiently forward a multicast datagram to its multiple destinations: each router calculates the path of the multicast datagram as a shortest-path tree whose root is the datagram source and whose terminal branches are LANs containing group members.

A separate tree is built for each (source network, multicast destination) combination. To ease the computational demand on the routers these trees are built "on demand", i.e., the first time a datagram having a particular combination of source network and multicast destination is received. The results of these "on demand" tree calculations are then cached for later use by subsequent matching datagrams. MOSPF, ICMP and IGMP do not support multichannel paths and optimal transmission.

Graph based protocols (multicast routing trees): In graph based Routing algorithm, the network topology is modeled by a graph and routing computation of the network is associated with graph computations. Today the graph based Routing algorithms are widely used in communication networks.

There are some graph and mathematical algorithms such as Dijkstra's algorithm, Spanning tree protocol (used in switched networks), Prim's algorithm, Kruskal's algorithm and Steiner tree which are widely used for routing in communication networks. There are various types of routing mechanisms such as OSPF and Routing Information Protocol (RIP) which is based on these algorithms. MOSPF uses MST algorithm for constructing multicast paths. Given a connected, undirected graph, a spanning tree of that graph is a sub graph that is a tree and connects all the vertices together. A single graph can have many different spanning trees. We can also assign a weight to each edge which is a number representing how unfavorable it is and use this to assign a weight to a spanning tree by computing the sum of the weights of the edges in that spanning tree. A Minimum Spanning Tree (MST) or minimum weight spanning tree is then a spanning tree with weight less than or equal to the weight of every other spanning tree. Spanning trees do not support multichannel routing and optimal mathematical modelling for routing.

Optimal routing (optimal multicast multichannel routing): In this study, we use OMMR to construct new dynamic multicasting Routing algorithm and we will show that our algorithm is more efficient than other available algorithms.

Concepts, definitions and terminology: We now start by an introduction to the terminologies used. We use graphs to show the topology of the sample networks. Graphs in this study are considered to be directed and weighted including loops. A computer network is modelled by N = (V, E, b, p, q) where G = (V, E) is a directed simple graph with vertex set V, edge set E and integer weighting functions $b(\cdot)$, $p(\cdot)$ and $q(\cdot)$: $b(u, v)\geq 0$ and $p(u, v)>0$ are the bandwidth and propagation delay for a (directed) edge $e = (u, v)\in E$ and $q(u)\geq 0$ is the queuing delay at a vertex $u\in V$. Let node s be a source vertex and t a destination vertex, unicast algorithms are interested in routing a message of size σ from s to t as fast as possible while satisfying certain delay constraints.

Definition 1: A v_1-v_k path in graph G can be shown as $\pi = <v_1, v_2, ..., v_k>$ and is called as a single path. For each single path π the path delay is:

$$D(\pi) = \Sigma_{1<j\leq k}\, p(v_{j-1}, v_j) + q(v_j) \tag{1}$$

The maximum usable bandwidth of a path π is:

$$B(\pi) = \min_{1<j\leq k} b(v_{j-1}, v_j) \tag{2}$$

The time required to route a massage of σ>0 along path π using a bandwidth of $b\leq B(\pi)$ Is:

$$T(\pi, b, \delta) = D(\pi) + \left\lceil \frac{\delta}{b} \right\rceil - 1 \tag{3}$$

Suppose $\lambda = \lceil \delta/b \rceil > 1$ shows that message σ must be divided into λ fragments which must be sent out from source v_1 to destination v_k one by one. The first fragment arrives at node v_k at time unit D(π). Note that the time gap between two sequential fragments is equal to 1 time unit. In other words, each fragment as compared to former fragment arrives at node v_k after 1 time unit. Therefore, the second fragment arrives at v_k at time unit D(π)+1. It can be verified the last fragment (λ-2)th fragment, arrives at node v_k at time unit $D(\pi)+1+\lambda-2 = D(\pi)+|\delta/b|-1$.

If we are seeking the fastest transmission of a message from s to t using a single path, we have a single channel routing problem. If we are seeking the fastest transmission of a message from s to t using all available links, we have a multichannel routing problem. Xue (2003) has formally formulated multichannel routing problem as follows:

Definition 2: Let σ>0 be the size of the message to be transmitted from s to t. The single channel routing problem seeks for an s-t path π to minimize T (π, B (π), σ). The multichannel routing problem seeks for a positive integer decomposition of σ:

$$\delta = \Sigma_{1<i\leq k}\, \delta_i,\ k \text{ is a positive integere} \tag{4}$$

A corresponding non-negative integer decomposition of the bandwidth for every edge $(u, v)\in E$:

$$b(u, v) = \Sigma_{1<i\leq k}\, b_i(u, v),\ b_i(u, v) \geq 0,\ i = 1, 2, ..., k \tag{5}$$

and k number of s-t paths $\pi_1, \pi_2, ..., \pi_k$ to minimize $\max_{1\leq l\leq k} T(\pi_i, B_i(\pi_i), \sigma_i)$ where:

$$B_i(\pi_i) = \min_{1<j\leq k} b_i(u, v),\ i = 1, 2, ..., k \tag{6}$$

In 1958, Ford Jr. and Fulkerson (1958a, b) studied the following problem:

Definition 3: Maximal dynamic flow problem: given the network G(V, E, b, d) with source s and sink t, determine the maximum amount of data that can be transmitted from s to t in a specified number of time period (Ford Jr. and Fulkerson, 1958a, b).

Ford and Fulkerson proved that the maximal dynamic flow problem has a linear programming formulation and can be solved as a minimum cost flow problem (Ford Jr. and Fulkerson, 1958a, b). They proved that the multichannel routing decision problem can be solved by solving a corresponding maximal dynamic flow problem.

Definition 4: The multichannel routing decision problem (Ford Jr. and Fulkerson, 1958a, b; Xue, 2003): let σ be the size of the message to be transmitted from s to t. Let τ be a positive integer. The multichannel routing decision problem asks the existence of a decomposition of σ as in Eq. 4, a corresponding decomposition of the bandwidth for every edge $(u, v)\in E$ as in Eq. 5 and k s-t paths $\pi_1, \pi_2, ..., \pi_k$ such that $\max_{1\le i\le k} T(\pi_i, B_i(\pi_i), \sigma_i)\le\tau$ where $B_i(\pi_i)$ $(i = 1, 2, ..., k)$ are defined in Eq. 6.

In theorem 1, Ford Jr. and Fulkerson (1958a, b) proved that there is always an optimal solution to the maximal dynamic flow problem which can be decomposed into a set of s-t arc chain flows.

Theorem 1: The maximal dynamic flow problem for τ periods, MDF(τ) can be computed by solving the following minimum cost static flow problem:

1) $MDF(\tau): \min\Sigma_{(u, v)}\in E\, d(u, v) f(u, v)-(\tau+1)\phi$

s.t.

2) $\Sigma_{(s, v)}\in E\, f(s, v)-\phi = 0$

3) $\Sigma(v, t)\in E\, f(v, t)-\phi = 0$

4) $\Sigma_{(u, v)}\in E\, f(u, v)-\Sigma_{(v, u)}\in E\, f(v, u) = 0, u\neq s, t$

5) $0\le f(u, v)\le b(u, v), (u, v)\in E$

Let (φ, f) be an optimal solution to the above LP. Then, the flow f can be decomposed into a set of s-t arc-chain flows and the maximum amount of flow from s to t in σ time units is:

$$\chi(\tau) = (\tau+1)\phi-\sum_{(u, v)\in E} d(u, v) f(u, v) \tag{7}$$

The minimum cost flow problem can be solved in polynomial time (Ford Jr. and Fulkerson, 1958a, b;). Let $\chi(\tau)$ be the maximum amount of flow from s to t in τ time units (obtained by solving the maximal dynamic flow problem). It follows from Theorem 1 that the answer to the multichannel routing decision problem is YES if $\chi(\tau)\ge\sigma$ and NO otherwise.

Figure 2 shows the kind of paths which are considered in this study. As an aid to understand concepts of transmission and delay, we consider a sample network shown in Fig. 2a. There are different ways to transmit 9 units of data (σ = 9), through single path p = <s, x, y, t_1> from s to t_1 illustrated in Fig. 2a. One of them is the quickest way which is as follows. Let us assume that each node has a buffer space large enough to store excess data. We assume that data transmission starts from node s at time 0. Considering edge (x, y), the maximum available bandwidth along path P is 5. At time unit 2, 5 units of data arrives at node x, leaving 4 units of data at the node s. Since, there is a queuing delay of 3 at node x, no data can go out of node x until time unit 5. At time unit 5, 5 unit of data leaves node x along edge (x, y).

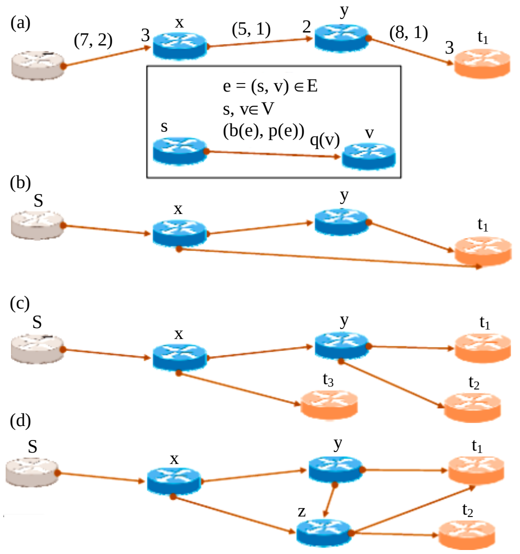

Fig. 2: Some sample networks with a source node s and destination nodes t_1, t_2 and t_3; a single or unicast path <s, x, y, t_1>; b) a unicast multichannel path including two single paths <s, x, y, t_1> and <s, x, t_1>; c) a multicast tree including three single paths <s, x, y, t_1>, <s, x, y, t_2> and <s, x, t_3> and d) a multicast multichannel path including six single paths s-t_1 and s-t_2

Note that at time unit 1, the other 4 units of data can go out of node s and follow 5 unites of data node-by-node. At time unit 6, 5 unit of data arrives at node y and at time unit 8 leaves node y. Since, there is a transmission delay of 1 at edge (y, t_1) and there is a queuing delay of 2 at node t_1, the 5 units of data are finally received by destination node t_1 at time unit 11.

The other 4 units of data are received by node t_1 at time unit 12 and transmission will be completed in 12 time units. As mentioned for a single path, the transmission of a message can be done for a tree such as Fig. 2c. Note that in a tree, single paths may diverge at a node and data must be duplicated. The duplication may produce delay and this delay must be computed. Duplication capacity and duplication delay will be discussed in the next Sections. Now, we need to recall some notations which have been presented before (Isazadeh and Heydarian, 2008):

- Unicasting node: this is an intermediate node that must receive packets and only forward them to the next neighbor nodes. In other words, it dose not duplicate any arrival packets and dose not use any duplication capacities

- Multicasting node: this is an intermediate node that receives arrival packets and duplicates some of them and sends duplicated packets to next neighbor nodes. Note that each duplicated packet belongs to a destination node and must be forwarded to that node. The set of the multicasting nodes in a network is shown by "Multicast"
- Duplication: each packet that is dispatched by a source node must be multiplied by multicasting nodes in accordance with the number of destination nodes. The maximum capacity of duplication in a multicasting node $v \in V$ is shown by the "Capacity (v)". Also, dup (v) shows the amount of data duplication in multicasting node v which must be done by v until the required packets for the destination nodes are produced. Each node v is labelled by dup (v [Capacity (v), c (v)])
- Duplication delay: this is the time units required for duplicating arrival packets in a multicasting node $v \in V$. It is shown by $c(v) \geq 0$. If $v \in V$ be a unicasting node or dup (v) = 0 then c (v) = 0
- Multicast path delay: for each path $\pi = \langle v_1, ..., v_k \rangle$ the path delay is:

$$D(\pi) = \Sigma_{1<j\leq k}(p(v_{j-1}, v_j) + q(v_j)) + \Sigma_{v_j \in \text{Muticast}} c(v_j)$$

To facilitate the description of dynamic concepts and presentation of the dynamic routing problem, we need to define the following notations:

- Unicast Single-Channel Path (USCP): as mentioned in Definition 1 it is a single channel path $v_1\text{-}v_k = \langle v_1, v_2, ..., v_k \rangle$. Figure 1a shows an USCP
- Unicast Multi-Channel Path (UMCP): it is a group of USCPs (more than one USCP) which is rooted in a source node s and have the same destination node. These USCPs may have some shared links or nodes. Note that an UMCP includes at least one loop. Figure 1b shows an UMCP
- Tree: it is a graph (or group of USCPs) rooted in a source node s and ended to destination nodes $t_1, t_2, ..., t_n$ which dose not include any loops. Note that each USCP used by tree can has some shared links or nodes with other USCPs but can not form any loop in the tree. Figure 1c shows a tree
- Multicast Multi-Channel Path (MMCP): because there are n destination nodes $t_1, t_2, ..., t_n$ in a multicast session therefore corresponding to each t_i we have an UMCP. Thus, we have n UMCPs which is called an MMCP. In fact, an MMCP is a group of UMCPs (more than one UMCP) which is rooted in the source node s and each UMCP will be ended to one different t_i. Figure 1c shows a MMCP. We can transform a tree to an MMCP by adding one or more than one loops to it: in fact an MMCP is a tree including some loops but cannot be exactly equal to a tree. An MMCP has an important property: if one unite of data be sent out from s, each destination node t_i must receive just one copy of it.

Traffic engineering based routing (modelling and constructing paths): A traffic engineering routing algorithm is based on the mathematical concepts such as linear programming, graph theory, fuzzy logic, statistical modeling and etc. We know that OMMR is based on the graph theory and LPF.

OMMR (Isazadeh and Heydarian, 2008) gives a solution for the following problem: let $\sigma > 0$ be the size of the mes-sage to be transmitted from source node s to destination nodes $t_1, t_2, ..., t_n$ whereas each $s\text{-}t_i$ path i = 1, 2, ..., n is a multichannel path, then determines minimum number of the time units in this transmission. OMMR solves a sequence of Multicast Dynamic Flow problems (M-MDF(τ)) to find the smallest integer τ which guarantees YES answer to the multichannel routing decision problem. MDF (τ) transmits data from a source node to one destination node but M-MDF(τ) transmits data from a source node to more than one destination nodes. OMMR supports QoS by decreasing end to end delay and employs multichannel paths by using M-MDF(τ) formulation but dose not guarantee traffic distribution optimally and dynamically. M-MDF(τ) is as following:

1) $\text{M-MDF}(\tau)\text{: } \min \Sigma_{(u, v) \in E}\, d(u, v)\, f(u, v) +$
$\Sigma_{v \in V}\, c(v)\text{Dup}(v) - (\tau + 1)n\phi$
s.t.
2) $\Sigma_{(s, v) \in E}\, f(s, v) - \phi = 0$
3) $\Sigma_{v \in E}\, f(v, t_i) - \phi = 0 \;\; (i = 1, 2, ..., n)$
4) $\Sigma_{(u, v) \in E}\, f(u, v) + \text{Dup}(v) - \Sigma_{(v, u) \in E}\, f(v, u) = 0,$
$(u \neq s, t)$
5) $\Sigma f(s, v) = \Sigma f(u, t_i), v \in V \{(s, v),$
$(u, t_i)\} \in \pi_{ij}, j \in \{1, 2, ..., k_i\}$
6) $(m-1)\, \Sigma f(u, v) \geq \text{Dup}(v), v \in \text{Multicast},$
m is the number of output links of node v
7) $\Sigma_{(u, v) \in E}\, f(u, v) \geq f(v, u), v \in V$
8) $0 \leq f(u, v) \leq b(u, v), (u, v) \in E$
9) $0 \leq \text{Dup}(v) \leq \text{capacity}(v), (v) \in V$

Let (φ, f, Dup) be an optimal solution to the above LP problem. Then the flow f can be decomposed into a set of $s\text{-}t_i$ arc-chain flows i = 1, 2, ..., n; for each malticasting node $v \in V$, Dup (v) can be distributed along $v\text{-}t_i \in \pi_{ij}$ paths and the maximum amount of data from s to all of the destination nodes t_i in τ time units is:

$$X(\tau) = (\tau+1)n\phi - \Sigma_{(u,v)\in E}\, d(u,v)\, f(u,v) - \Sigma_{v\in V}\, c(v)Dup(v)$$

OUR NEW DYNAMIC APPROACH

Removing weaknesses of OMMR can produce a new more Capable Routing algorithm. OMMR transmits data units from a source node to a group of destination nodes. OMMR cannot change the number of destination nodes continuously and dynamically. In fact OMMR cannot add a new destination node to the group of current destination nodes and also cannot remove any node of current destination nodes. To solve this problem we will present Optimal Dynamic Multicast Multichannel Routing (ODMMR) algorithm. Against OMMR, ODMMR by using and changing M-MDF(τ) can enforce two behaviors adding new destination node and removing a current destination node.

Formal definition of the problem: Definition 1 let n be number of destination nodes t_i, i = 1, 2, ..., n. Suppose that from the source node s to each destination node t_i there are k_i USCPs as π_{ij}; j = 1, 2, ..., k_i. Furthermore, $\sigma>0$ be the size of the message to be transmitted from s to each destination node t_i and positive integer τ be the number of consumed time units in this transmission. The ODMMR problem asks the existence of a decomposition $\sigma = \Sigma_{1\le i\le n,\ 1\le j\le ki}\sigma_{ij}$, $\sigma_{ij}\ge 0$ that part σ_{ij} must be transmitted along path π_{ij} from s to t_i. Also bandwidth of edge $(u, v)\in\pi_{ij}$ must be decomposed as:

$$b(u,v) = \sum_{1\le i\le n,\ 1\le j\le k_i} b_{ij}(u,v),\ (b_{ij}(u,v)\ge 0) \qquad (8)$$

Furthermore, for each multicasting node $v\in\pi_{ij}$, Dup_{ij} (v) is computed until the following result is obtained:

$$\mathrm{Max}_{1\le i\le n,\ 1\le j\le k_i}\, T(\pi_{ij}, B_{ij}(\pi_{ij}), \sigma_{ij}) \le \tau$$

Finally, when some current destination nodes are removed or some new destination nodes are added to current destination nodes, ODMMR must re-compute new decompositions of σ, b (u, v) and Dup_{ij} (v) by using the former (previous) decompositions.

Increasing in number of destinations (adding destination nodes): ODMMR at first constructs M-MDF (τ) and next adds some variables and constraints to it for joining new destination nodes to current multicast session. ODMMR uses the following steps to adding new node dynamically:

- Determine the new node which must be joint to current multicast session
- Create new variables and constraints and add them to M-MDF(τ) (constructing new M-MDF(τ))
- Solve new M-MDF(τ) using post-optimality computations for achieving new dynamic paths
- Implement new dynamic paths using label switching mechanism for transmitting multi-cast packets from source node to all destination nodes (previously and following nodes)

Post-optimality computations reduce computations in ODMMR as compared to OMMR. OMMR is based on the IP forwarding but ODMMR is based on the label switching forwarding and it is an advantage for ODMMR. Label switching removes weaknesses of IP forwarding.

Decreasing number of destinations (removing destination nodes): Many applications in communication networks need to decrease the number of destination nodes in a multicast session. ODMMR can remove some destination nodes in the current multicast session which has been established with OMMR. ODMMR performs this using the following steps:

- Determine a destination node such as node A which must be removed from the current multicast session
- Vanish variables f_i of those links in M-MDF(τ) which have been connected to the node A (constructing a new M-MDF(τ)). Those flows which transmit packets to node A must be vanished and some new flows must be computed and assigned
- Solve new M-MDF(τ) using post-optimality computations for achieving new dynamic paths
- Implement new dynamic paths using label switching mechanism

Implementing odmmr using label switching: In this study as an important advantage we will show that ODMMR can be implemented with label switching because label switching is widely used technology in new communication technologies.

We use the label switching mechanism to implement ODMMR. Label switching is a solution to remove weaknesses of the IP forwarding. Label Switching (LS) has emerged as an important new technology for the internet which represents the convergence of two fundamentally differ-ent approaches in data networking: datagram (Pranggono and Elmirghani, 2011; Rangan, 1993) and virtual circuit (Black, 2002). Tradi-tionally IP forwarding in the internet such as OSPF, Border Gateway Protocol (BGP) (Cheng *et al*., 2011; Li *et al*., 2011), Enhanced Interior Gateway Routing Protocol (EIGRP)

(Riesco and Verdejo, 2009) and RIP is based on the data-gram model: routing protocols precalculate the paths to all destination networks by exchanging routing information and each packet is forwarded independently based on destination address. Asynchronous Transfer Mode (ATM), Frame Relay (FR) and Multiprotocl Label Switching (MPLS) which are based on the LS on the other hand are connection oriented a virtual circuit must be set up explicitly by a signaling protocol before packets can be transmitted into the network (Lai and Chang, 1999; Baroncelli *et al*., 2011; Kocak *et al*., 2009).

A Virtual Channel Connection (VCC) is setup between two end nodes through the network and a variable-rate, full-duplex flow of fixed-size cells is exchanged over the connection (Stallings, 1999; Baroncelli *et al*., 2011). A Virtual Path Connection (VPC) or a virtual circuit is a bundle of VCCs which transmits same packets from a node to another node together and successively. In this study, our new framework can consider and compute VCCs and VPCs as USCPs.

As compared to traditional IP forwarding, LS increases network efficiency and removes many switching and routing problems. In this study, our new dynamic routing framework uses LS and achieves a new powerful switching-routing method to transmit packets trough the modern digital networks.

Some basic concepts and architecture of label switching which are necessary in this study are achieved by Wang, Black, Aslam and Aziz:

- Label: a short, fixed-length, locally significant identifier that is used for LS and is inserted in the packet header to forward packets
- LSR and LSP: a Label Switch Router (LSR) uses the label in the packet header as an index to find the next hop and the corresponding new table. The packet is sent to its next hop after the existing label is swapped with the new one assigned for the next hop. The path that the packet traverses it through a network, Label Switch Path (LSP) is defined by the transition in label values. An LSP is determined by the initial label value at the first LSR of the LSP
- Hierarchical label stack: LS allows more than one label to be encoded in a packet, referred to as a label stack since the labels are organized as a last-in first-out stack. A label stack is used to support nested tunnels
- Label-switching table: maintains the mapping between an incoming label to the outgoing interface and the outgoing label. A row of the table includes four data entries: incoming label, outgoing label, next-hop address, pre-label state
- Label Distribution Protocol (LDP): set ups the state for LSPs in the network and is a set of procedures by which two LSRs learn each other's LS capabilities and exchange label-mapping information. For explicitly routed, LSPs or LSP that require QoS guarantees, CR-LDP and RSVP-TE can be used
- Label assignment and distribution: the decision to bind a particular Forwarding Equivalency Class (FEC) is always made by the downstream LSR with respect to the flow of the packets. An FEC can be expressed as a set of classification rules that determine if a packet belongs to the FEC
- Label merging: two or more LSPs may be merged into one. It may substantially reduce the requirement on label space
- Route selection and explicit routing: during the label distribution process an LSR needs to determine which is the next hop for the LSP that is tries to establish. There are two basic approaches to determine this: hop-by-hop routing that relies IP information to set up LSPs and explicit routing that is often referred to as constraint-based routing

SIMULATIONS AND NUMERICAL RESULT (COMPUTATIONS AND COMPARISONS)

In this study, we will consider some network samples and apply three algorithms OMMR, MOSPF and ODMMR to these samples. Then we compare the obtained values of metrics of these samples to achieve this fact that our new algorithm, ODMMR is more efficient than the other algorithms.

Metrics: Before presenting network samples and numerical results, we need to present the following terminologies:

- σ: it is the size of the message to be transmitted with a multicast session
- Consumed Bandwidth (CB): it is required free bandwidth which must be consumed until message σ is transmitted from source node S to destination nodes in a multicast session
- Wasted Bandwidth (WB): when a Routing algorithm performs a multicast session it can not consume all available bandwidth optimally and efficiently. Therefore, some available bandwidth is wasted. Note that we can have: WB = (total available bandwidth)-CB. A Routing algorithm is more efficient than other routing algorithms if it reduces WB and increases CB
- φ: it is the input flow which is loaded with the source node into the network

- τ: it is required time units for transmitting message σ from source node S to destination nodes during a multicast session
- Time computation of algorithm or CPU Time (CPUT): all computations will be done by a PC with following system information: Pentium III, CPU 1000 MHz, Ram 256 MB, Windows XP. In some algorithms such as OMMR and OMDMR a Linear Programming Formulation problem (LPFp) must be solved by QSB tool and MATLAB Softwares so that an optimal solution be obtained. In each algorithm, CPUT is time required to solve the LPFp by PC
- Iteration: for solving a linear programming formulation we use Simplex Method which is an iterative method. “Iteration” item is the number of execution of simplex tableau which is repeated until optimal solution is computed
- Data Rate (DR): for each multicast session which is performed with a Routing algorithm, DR is equal to σ

Static data transmission: In this study, we consider sample network shown in Fig. 3. Figure 3 consists of one MMCP which starts from S and terminates to two destination nodes T_1 and T_2 Suppose that the size of message to be transmitted from S to two destination nodes T_1 and T_2 is equal to $\sigma = 60$. In this sample this MMCP includes three UMCP as the following:

- The first UMCP: starts from S and terminates to T_1 and includes two USCPs: P_1 = <S, A, B, T_1> and P_2 = <S, A, D, B, T_1>
- The second UMCP: starts from S and terminates to T_2 and includes an USCP: P_3 = <S, A, C, T_2>
- The third UMCP: starts from S and terminates to T_1 and includes an USCP: P_4 = <S, A, C, T_1>

Performance of OMMR algorithm: In Fig. 3 we see that node D can not affect the traffic flows of three above UMCPs because the traffic does not pass this node. Therefore we do not consider two flows f_2 and f_3. By applying M-MDF (τ) to Fig. 3 we obtain the following linear problem formulation:

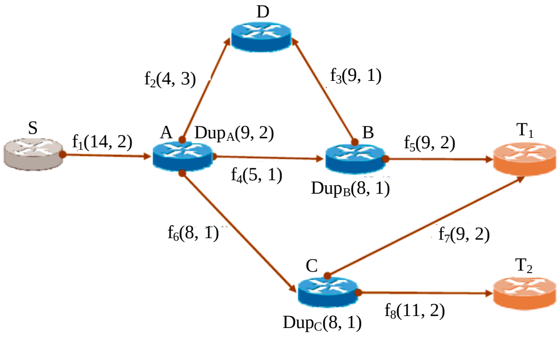

Fig. 3: A sample network consisting of two destination nodes T_1 and T_2 and 4 intermediate nodes A, B, C and D

$$\min\ (2f_1+f_4+2f_5+f_6+2f_7+2f_8+2Dup_A+2Dup_B+Dup_C-2(\tau+1)\phi)$$

$$\begin{array}{ll}
1)\ f_1-\phi = 0 & 2)\ f_6+f_7-\phi = 0 \\
3)\ f_8-\phi = 0 & 4)\ f_6-f_8 \geq 0 \\
5)\ f_1+Dup_A-f_4-f_6 = 0 & 6)\ f_4+Dup_B-f_5 = 0 \\
7)\ f_6+Dup_C-f_7-f_8 = 0 & 8)\ 2f_1-Dup_A \geq 0 \\
9)\ f_4-Dup_B \geq 0 & 10)\ f_6-Dup_C \geq 0 \\
11)\ f_4-f_5 \geq 0 & 12)\ f_1-f_4 \geq 0 \\
13)\ f_1-f_6 \geq 0 & 14)\ f_6-f_7 \geq 0
\end{array}$$

By solving above linear programming problem we will obtain the following optimal solution: $f_1 = f_6 = f_7 = f_8 = Dup_C = \varphi = 8$, $f_2 = f_3 = f_4 = f_5 = 0$ and $\tau = 10.5$. The flows and their values of this optimal solution and remainder capacities have been presented in Fig. 4. Figure 4 shows that the optimal solution is an MMCP which is similar to a tree. The result of OMMR has been shown in Table 1.

Performance of ODMMR: In this case ODMMR produces result which is similar to OMMR because their M-MDF(τ) are similar. The similar results of these algorithms have been shown in Table 1.

Performance of MOSPF: After applying MOSPF to Fig. 3 this algorithm uses the tree which has been shown in Fig. 5. This tree is not optimal and we see that maximum

Table 1: Obtained results and values of metrics of applying OMMR, ODMMR and MOSPF to Fig. 3

Sessions	σ	CB	WB	φ	τ	Iteration	CPUT	DR
OMMR	2×60	32	47	8	10.5	11	0.015	11.43
ODMMR	2×60	32	47	8	10.5	11	0.015	11.43
MOSPF	2×60	25	54	5	18.0	-	0.015	6.70

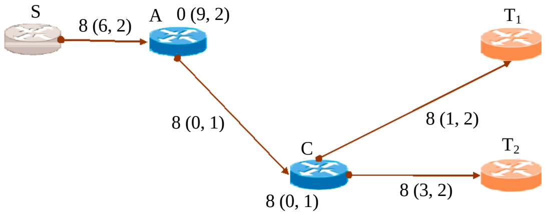

Fig. 4: Showing the remainder or unused flows (black numbers) and the optimal solution (red numbers) obtained from applying OMMR algorithm to Fig. 3. Path P_2 = <S, A, D, B, T_1> has been not shown

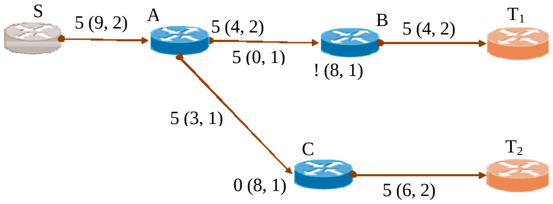

Fig. 5: The remainder flows and the values of optimal solution obtained from applying MOSPF algorithm to Fig. 3

flow in this tree is 5. The values of the metrics of applying MOSPF to Fig. 3 has been shown in Table 1. This Table shows that OMMR and ODMMR as compared to MOSPF reduce WB and increase DR and this means that OMMR and ODMMR are more efficient that MOSPF.

Dynamic data transmission (joining a new destination node to a current multicast session): Now we suppose that at time unit 8 node D is became changed to destination node T_3 and joins the multicast session dynamically which transmits data units from S to two destination nodes T_1 and T_2. In other words, we will have a multicast session which transmits data units from S to three destination nodes T_1, T_2 and T_3. Figure 6 shows the new sample which consists of three destination nodes T_1, T_2 and T_3 and 3 intermediate nodes A, B and C.

Performance of OMMR: At first there is a multicast session consisting of two destination nodes T_1 and T_2. At time unit 8 node D is changed to destination node T_3. In this case OMMR can not add node T_3 to current multicast session dynamically and at first OMMR disconnects current session at time unit 8 and then re-computes another optimal solution which supports 3 destination nodes. For achieving this, OMMR constructs the following linear programming formulation using M-MDF(τ):

$$\min(2f_1+3f_2+f_3+f_4+2f_5+f_6+2f_7+2f_8$$
$$+2Dup_A+2Dup_B+Dup_C-2(\tau+1)\phi)$$

1) $f_1-\phi=0$ 2) $f_6+f_7-\phi=0$

3) $f_8-\phi=0$ 4) $f_2+f_3-\phi=0$

5) $f_1+Dup_A-f_2-f_4-f_6=0$ 6) $f_4+Dup_B-f_3-f_5=0$

7) $f_6+Dup_C-f_7-f_8=0$ 8) $2f_1-Dup_A\geq 0$

9) $f_4-Dup_B\geq 0$ 10) $f_6-Dup_C\geq 0$

11) $f_1-f_2\geq 0$ 12) $f_1-f_4\geq 0$

13) $f_1-f_6\geq 0$ 14) $f_4-f_3\geq=0$

15) $f_4-f_5\geq 0$ 16) $f_6-f_7\geq 0$

17) $f_6-f_8\geq 0$

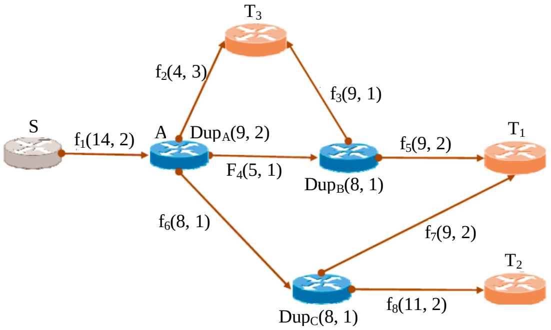

Fig. 6: Transforming node D to destination node T3 in Fig. 3 and establishing a multicast session including three destination nodes

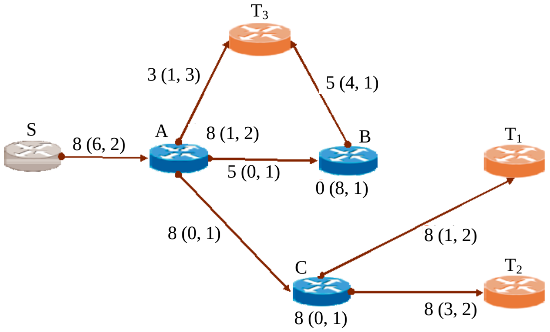

Fig. 7: Transforming node D to destination node T3 in Fig. 6 and establishing a muylti-cast session including three destination nodes and applying OMMR to this multicast session

Table 2: Obtained dynamic results and values of metrics of applying OMMR, ODMMR and MOSPF to Fig. 6

Sessions	σ	CB	WB	φ	τ	Iteration	CPUT	DR
OMMR	3×60	40	32+39	8	13+8	16	0.017	8.57
ODMMR	3×60	40	39	8	13+6	4	0.005	9.47
MOSPF	3×60	30	49	5	18+10	-	0.016	6.43

OMMR by solving this linear problem produces the following optimal solution: $f_1 = 8$, $f_2 = 3$, $f_3 = 5$, $f_4 = 5$, $f_5 = 0$, $f_6 = 8$, $f_7 = 8$, $Dup_A = 8$, $Dup_B = 0$, $Dup_C = 8$, $\varphi = 8$, $\tau = 13$. This optimal solution has been illustrated in Fig. 7. This optimal solution shows that OMMR needs 8+13 = 21 time units to transmit 3H60 data units from S to 3 destination nodes. The values of metrics of applying OMMR to Fig. 6 have been shown in Table 2.

Performance of ODMMR: In this case after applying ODMMR to Fig. 6, ODMMR similar to OMMR establishes the MMCP which has been presented in Fig. 7. But ODMMR does not disconnect current multicast session and uses post-optimality computations. The post-optimality computation transforms current session to new session and adds destination node T_3. As compared to OMMR, ODMMR using post-optimality

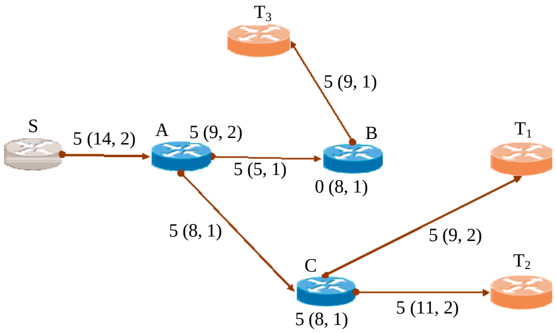

Fig. 8: Transforming node D to destination node T_3 in Fig. 6 and establishing a muylti-cast session including three destination nodes and applying MOSPF to this multicast session

reduces computations and number of Iterations. Against OMMR, ODMMR transmits 3×60 = 180 data units from S to three destination nodes T_1, T_2 and T_3 within 13+6 = 19 time units. The values of metrics of applying ODMMR to Fig. 6 have been shown in Table 2. This table shows that ODMMR as compared to OMMR and MOSPF increases data rate, consumed bandwidth and decreases wasted bandwidth, number of iteration and CPUT.

Performance of MOSPF: By applying MOSPF to Fig. 6 the tree which has been shown in Fig. 8 is obtained. The values of metrics of applying MOSPF to Fig. 6 have been shown in Table 2. This table shows that ODMMR as compared to OMMR and MOSPF reduces WB and increases DR and this means that ODMMR is more efficient that OMMR and MOSPF.

Dynamic data transmission: removing a current destination node from a current multicast session: In Fig. 6 a multicast session consisting of three destination nodes T_1, T_2 and T_3 receive data units from source node S. Now we suppose that destination node T_2 at time unit 5 will be removed from the multicast session. In this case two algorithms ODMMR and MOSPF remove node T_2 dynamically and OMMR at first disconnect data transmission and then re-computes paths and restarts data transmission to two destination nodes T_1, T_3. For removing node T_2 in Fig. 6, we must vanish flow f_8. Therefore, we must set $f_8 = 0$. This shows that ODMMR does not need to re-compute new optimal solution and ODMMR using post-optimality can compute new optimal solution using current optimal solution. The current optimal solution includes three destination nodes T_1, T_2 and T_3 whereas new optimal solution includes two destination nodes T_1 and T_3. Table 3 shows the results of applying OMMR, ODMMR and MOSPF to Fig. 6 briefly for removing destination node T_2. Solutions are as the following:

- Solution of OMMR: $f_1 = 9$, $f_2 = 4$, $f_3 = 5$, $f_4 = 5$, $f_5 = 5$, $f_6 = 4$, $f_7 = 4$, $Dup_A = 4$, $Dup_B = 5$
- Solution of ODMMR: Is similar to OMMR
- Solution of MOSPF: $f_1 = 5$, $f_3 = 5$, $f_4 = 5$, $f_5 = 5$, $Dup_B = 5$

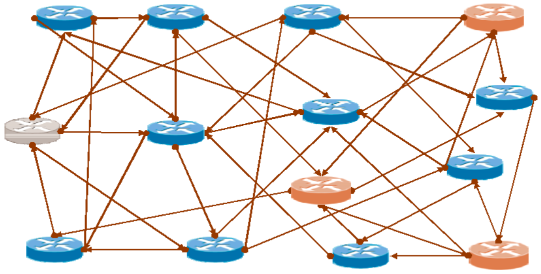

Fig. 9: A sample network consisting of 14 nodes and 34 links. Each multicast session includes one source node and three destinations nodes which will be randomly selected

Table 3: Obtained dynamic results from removing destination node T_3 at time unit 5 in Fig. 6 and values of metrics of applying OMMR, ODMMR and MOSPF to this figure

Sessions	σ	CB	WB	φ	τ	Iteration	CPUT	DRs
OMMR	2×60	36	40+43	9	5+10.25	16+15	0.032	7.9
ODMMR	2×60	36	36	9	12.00	5+15	0.020	10.0
MOSPF	2×60	20	59	5	5+12.00	-	0.018	7.0

Table 3 shows that ODMMR as compared to OMMR and MOSPF increases data rate, consumed bandwidth and decreases wasted bandwidth, number of iteration and CPUT.

Large sample networks: At first we consider the sample network Fig. 9 consisting of 14 nodes and 34 links. All links in this figure have been randomly produced. The amount of propagation delay of each link is randomly selected from values 1, 2 and 3 and also the amount of bandwidth belongs to numbers {8, ..., 15}.

Duplication delay and duplication capacity are randomly selected from sets of numbers {1, 2, 3} and {8, ..., 15}, respectively. After that we will select a source node (gray node) and some destination nodes (red nodes) randomly. By applying MOSPF, OMMR and ODMMR algorithms to the sample network, we will obtain optimal trees and MMCPs for transmitting packets from source node to destination nodes. During data transmission, the number of destination nodes can increase or decrease and we will compute metrics for comparing these algorithms. In our simulation in each time unit, more than one session can be established if there is enough available bandwidth.

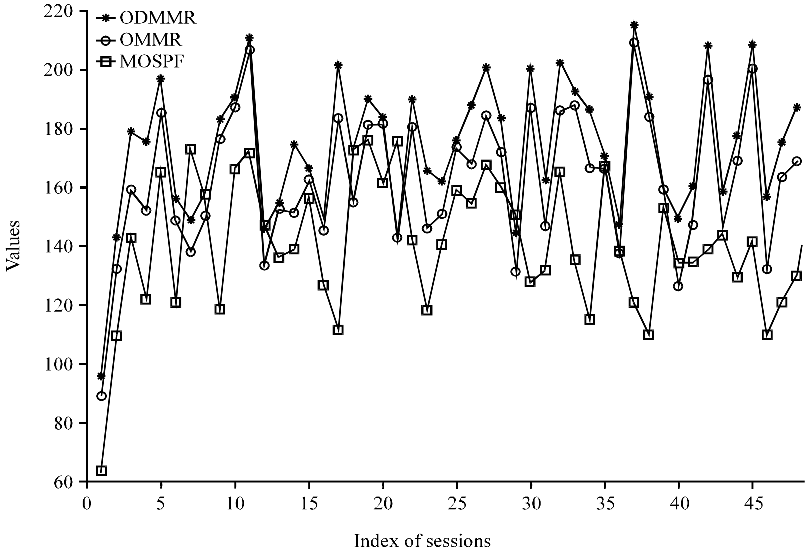

Fig. 10: Total bandwidth consumption of the current sessions

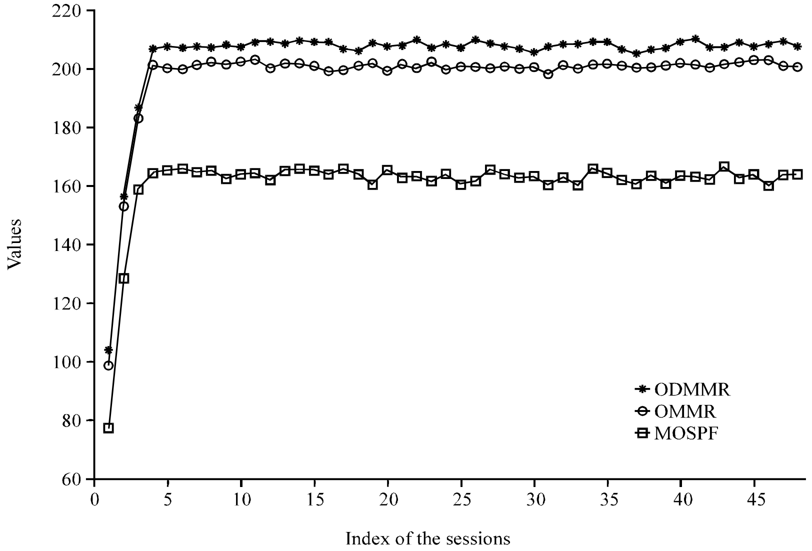

Fig. 11: Average of total bandwidth consumption of the current sessions for 100 iterations

Minimum and maximum time of data transmission for each multicast session is 16 and 25 time units and σ will show the number of data units which is transmitted through the session.

For each algorithm, we run 50 multicast sessions and we will compute two metrics Data Rate (DR) and Consumed Bandwidth (CB).

We suppose that an established multicast session consists of three destination nodes that one of them can be randomly disconnected or one new node can be randomly joined to them at time unit 10. In each case, we will compute metrics for each algorithm and based on these metrics values, we will compare the efficiency of the algorithms.

At first we must form the Linear Programming Formulation (LPF) of ODMMR for topology of the network. This LPF consists of all links and nodes and variables of bandwidth and traffic. When a node is added to the group of destination nodes, some variables must be greater than zero and when a node is removed, its variable will be vanished. Figure 10 and 11 show the results of applying three algorithms ODMMR, OMMR and MOSPF to sample network shown in Fig. 9. In Fig. 11 each algorithm is applied to Fig. 9 and average value of bandwidth consumption is computed. These figures show that ODMMR as compared to OMMR and MOSPF uses more bandwidth and this means that ODMMR uses bandwidth efficiently. Figure 12 shows that average data rate of DOMMR is more than data rate of OMMR and MOSPF. These results show that ODMMR as compared to OMMR and MOSPF increases data rate and decreases wasted bandwidth.

CONCLUSION

In this study, we presented a new dynamic Routing algorithm which supports optimal multicast multichannel routing method and also can guarantee QoS. The new algorithm can remove or can add dynamically some new destination nodes from/to a current multicast session. The new algorithm is an Optimal Routing algorithm and transmits maximum number of data units from a source node to a group of destination nodes in the minimum tim units.

Obtained numerical results show that our new Routing algorithm is more efficient than other available algorithms such as MOSPF and OMMR. New algorithm is based on the Simplex Method and post-optimality computation. ODMMR as compared to OMMR and MOSPF increases data rate and decreases computations and wasted bandwidth.

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