A Novel Network Traffic Management Scheme through Optimization of Logarithm Barrier based Multipath Protocol

S.Thirunavukkarasu  
Dr.K.P.Kaliyamurthie

1Research Scholar, Department of CSE, Bharath University, Email: ststarasu@gmail.com  
2Professor & Dean, Department of CSE, Bharath University, Email: kpkaliyamurthie@gmail.com

Abstract

Traffic management is an essential component for Internet. It will adjust the source rates and routing to efficiently handle the network resources. In today’s internet is mainly based on network resource management and Traffic Engineering. Traffic management point out the controlling how much traffic moves over each path in a network. In this paper we extend one additional parameter to primal and dual decomposition problem. It helps us to improve the performance of network utility maximization over the source rates and also balance the effective feedback capacity and actual link capacities.

Keywords: Network utility maximization, multipath routing, Traffic management, network resource management, LBMP

I Introduction

The Internet has developed into very large and various composite systems interconnecting with different end-hosts and Communication links, with number of applications running over it. Traffic management doesn’t provide to the strong operation of the Internet. To solve this type of problem, various traffic management tools have been developed, including TCP congestion control at end-hosts, traffic engineering by network operators, and routing protocols performed by set of routers, as shown in Fig1. In today’s Internet, congestion control run by users of the source system to accommodate their sending rates at the edge of the network. Routers run shortest path routing based on link weights. To minimize a cost function, operators tune link weights. These tools are mainly based on the optimization decomposition and distributed algorithms such as TRUMP [Traffic Management using Multipath Protocol] and LBMP [Logarithmic Barrier Based Multipath Protocol] [6]. A distributed algorithm is mainly used to they adjust the sending rates based on the round-trip-time (RTT) and can reply quickly to traffic changes [17].
In a Multipath routing, there are many routers and links between the source and the destination [22]. Some of the packets may take long time to reach the destination. So, they need more bandwidth than other paths. Which types of problems are easily solved over TRUM algorithm [8][9][10]. For a single path routing with given routes, where all the traffic goes on one path. It does not make the convex and thus it is a difficult optimization problem. Suppose if we allow multi paths and flexible splitting between them, then the optimization problem is convex.

II Background and Related Works

A Network Model

Consider a network consisting of set of links, \( l \in L \) and source destination pair represents a source of traffic in the network. Associated with a source is a set of routes, and each being a set of links. The routing matrix can be represented by \( R_{ls} \) that captures the set of sources \( S \) traversing over the links and link of capacity \( C_l \). As shown in [9][10], the network utility maximization problem can be written as

\[
\begin{align*}
\text{maximize} & \quad U_i(x_i) \\
\text{Subject to} & \quad Rx \leq c, R, x \geq 0 
\end{align*}
\]

(1)

Here \( R \) and \( x \) are variables. We assume that the utility function \( U_i \) is increasing, strictly concave, and twice continuously differentiable. A single path matrix in \( R_{ls} \) is an 0-1 matrix.

\[
R_{ls} = \begin{cases} 
1, & \text{if link } l \text{ is in a path of source } s \\
0, & \text{otherwise}
\end{cases}
\]
B Utility Maximization for Multipath

Utility maximization for multipath occurs in lot of resource allocation problem in communication networks. For example, multipath flow control [1], the optimal quality of service (QoS) routing [5][6] and the optimal network pricing [4]. To get multipath routing, we initiate $Z_j^s$ to represent the sending rate of source S on its jth path. We also represent available path by a matrix $H$ where

$$H_{lj}^s = \begin{cases} 1, & \text{if path j of source s uses link l} \\ 0, & \text{otherwise.} \end{cases}$$

$H$ does not necessarily present all possible paths in the physical topology, but a subset of paths chosen by network operators or the routing protocol. Then the problem (1) can be rewrite as

$$\begin{align*}
\text{maximize} & \quad \sum_s U_s (\sum_j Z_j^s) \\
\text{subject to} & \quad \sum_s \sum_j H_{lj}^s Z_j^s \leq c_l, \forall l
\end{align*}$$

In this form of problem (2) is a convex optimization problem. It has no duality gap.

C Dual based Utility Maximization Protocol (DUMP)

A Dual-based Maximization protocol (DUMP) is constructed by distributed solution problem of (2) using decomposition method, which one is similar to TCP dual algorithm in [9]. Sometimes DUMP gives the poor convergence, because the sources can only reduce their sending rate whenever packet losses. Where a dual variable is introduced to relax the capacity constraint. To solve the poor convergence properties of DUMP, we introduce for an alternative minimize objective function given below.

$$\text{minimize} \quad \sum_l f\left( \sum_s R_{lj} x_s / c_l \right)$$

where $f$ is a convex, non-decreasing, and twice-differentiable function that gives increasingly heavier penalty as link load increases, e.g.

$$\sum_e R_{lj} x_e / c_l$$
To construct a better traffic management objective, we should combine with users objective and operators objective through joint optimization over (X, R):

\[
\text{maximize } \sum_s U_s(x_s) - w \sum_i f \left( \sum_s R_{i,s} x_s / c_i \right)
\]

subject to \( R_x \leq c, x \geq 0 \) \hspace{1cm} (4)

Here \( w \) is a parameter which adjusts the balance between the utility function and the cost function. When \( w \) is small, the algorithm is very near to DUMP, when \( w \) is large, the solution is more conservative and reduce the high link utilization. The above problem (4) can also be written as a convex optimization problem:

\[
\text{maximize } \sum_s U_s \left( \sum_j \mu_j x_{j,s} \right) - w \sum_j f \left( y_j / c_j \right)
\]

subject to \( y \leq c \) \hspace{1cm} (5)

\[ y_j = \sum_l H_{lj} x_{j,l}^*, \forall l \]

### III LBMP Problem Based on Multipath Utility Maximization

It is a Barrier function technique \cite{9}, a barrier function is a continuous function whose value on a point increases to infinity as the point approaches the boundary of the feasible region of an optimization problem, which translates a constrained optimization problem into sequence of simpler unconstrained optimization problems. The barrier function method in the multipath traffic management will provide the three main benefits. First, choosing cost function is simple. Second, logarithm barrier function gives the accurate solution to the multipath utility maximization. and finally, every link to be used with different control parameters.

### A Primal Decomposition Problem

The primal decomposition problem doesn’t use the price per unit at link 1. It allows to direct resource allocation problem for communication networks.

\[
\text{maximize } \sum_s U_s \left( \sum_j \mu_j x_{j,s} \right) + \mu \sum_s \sum_j h_n z_{j,s} + \left( 1 - \mu \right) \sum_j m_j h(c_j - y_j)
\]

subject to \( y \geq 0 \) \hspace{1cm} (6)

subject to \( y \geq H_z \) \hspace{1cm} (6)
Here, \( m_l \) represents the barrier parameter associated with \( y_i \leq c_i \), and the control parameter can be viewed through the link operator \( l \).

**B Dual Decomposition Problem**

\[
L(z, y; \mu, p) = \sum_s U_s (\sum_j z^*_j) + \mu \sum_s \sum_j \ln z^*_j + (1 - \mu) \sum_s m_s \ln (c_i - y_i) + \sum_l p_l (y_l - \sum_j z^*_j)
\]

\[
= \sum_s U_s (\sum_j z^*_j) + \mu \sum_s \sum_j \ln z^*_j + \sum_s m_s \ln (c_i - y_i) + \sum_l p_l (y_l - \sum_j z^*_j)
\]

\[
= \sum_s (U_s (\sum_j z^*_j) + \mu \sum_j \ln z^*_j - \sum_j z^*_j \sum_{i \in s} p_l) + \sum_s m_s \ln (c_i - y_i)
\]

\[
= -\mu \sum_l m_l \ln (c_l - y_l) + \sum_l p_l y_l
\]

\[
= \sum_s (m_s \ln (c_i - y_i) - \mu m_l \ln (c_l - y_l) + p_l y_l)
\]

(7)

The dual objective function can be written as \( D(p) = \max_{z, y \geq 0} L(z, y; p) \)

The dual problem (7) to be separable in two terms. Notice that the first term is separable in \( z^* \), and the second is separable in \( y_i \). Hence, we can written as \( D(p) = \sum_s B_s (p^*) + \sum_l B_l (p_l) \)

Where

\[
B_s (p^*) = \max_{x \geq 0} U_s (\sum_j z^*_j) + \mu \sum_j \ln z^*_j - \sum_{j \in s} z^*_j p^*_j
\]

(8)

\[
B_l (p_l) = \max_{y_l \geq 0} (m_l \ln (c_l - y_l) - \mu m_l \ln (c_l - y_l) + p_l y_l)
\]

(9)

Here, \( p^* = p^*_j, p^*_j = \sum_{j \in s(i, j)} p_l \). The dual problem of (6) then becomes the selection of the dual vector \( p = (p_l, l \in L) \), so as to

\[
p = (p_l, l \in L)
\]
\[
\min_{p \geq 0} \sum_l B_l(p^*) + \sum_l B_l(p_l)
\]  
(10)

Here \( p_l \) as the price per unit bandwidth at link \( l \). Then \( p^*_l \) is the total price per unit bandwidth for all links in the path \( j \) of source \( s \). Therefore, \( B_l(p^*) \) can gives the maximum benefit of the source \( s \) can accomplish at the given vector price \( p^* \). For a fixed link load \( y_i \), always lesser than the link capacity \( c_i \),

Here \( y_i p_l \) is an income of the network operator from link \( l \) and \( ln(c_i - y_i) \) is the cost. The network operator apply the tradeoff parameter \( m_l \). It can be set to zero or a small positive value for a non-critical and non-bottleneck link. For a bottleneck link, \( m_l \) should be set to a large positive value. The flow of data is controlled according to the bandwidth of various system resources. It carries \((1 - \mu)m_l ln(c_i - y_i) + p_l y_i \) provides the net benefit of transmitting at traffic \( y_i \), and \( B_l(p_l) \) provides the maximum benefits \( l \) can accomplish at the given price \( p_l \).

**Lemma 1:** The dual objective function \( D(p) \) is convex and continuously differentiable with \( p \geq 0 \). The \( lth \) component of first derivatives \( \nabla D(p) \) is given by

\[
\frac{\partial D}{\partial p_l}(p) = y_j(p) - x'(p)
\]  
(11)

Where \( y_j(p) = \begin{cases} \mu m_l \frac{m_l}{p_l}, & \text{if } p_l \geq \frac{m_l}{c_i} \\ 0, & \text{otherwise} \end{cases} \)  
(12)

and for all source \( s \) and path \( j \) can be written as

\[
U_j = \sum_i z^*_i(p) + \frac{\mu}{z^*_j(p)} - p^*_j = 0
\]  
(13)

and \( x'(p) = \sum_{s,j \in (s,j)} z_j(p), p^*_j = \sum_{l \in (s,j)} p_l \)
Proof:

The objective function of (6) is strictly concave; hence, the dual objective function D(p) is convex and the first derivative $\nabla D(p)$ already exists and $\nabla D(p) = y(p) - H \ast z(p)$, where $y_i(p)$ is the solution to problem (8) and $z^\ast(p)$ is the solution to problem (7).

Let $f(y_i) := (1 - \mu)m_i h(c_i - y_i) + p_i y_i$. We need to find the maximize of $f(y_i)$ in the interval $[0, c_i]$. If $p_i = 0$, it is clearly that $y_i(p)$ also zero for $(1 - \mu)m_i h(c_i - y_i)$ decreasing with $y_i$. If $p_i > 0$, note that $f(y_i)$ is strictly concave, so we have to find the stationary point of $f(y_i)$, i.e.,

$$(1 - \mu)(c_i - \frac{m_i}{p_i}).$$

Suppose if $(1 - \mu)(c_i - \frac{m_i}{p_i}) < 0$, we have $y_i(p) = 0$ for $f(y_i)$ decreasing with $y_i$ in the interval $[0, c_i]$; otherwise, we have $y_i(p) = (1 - \mu)(c_i - \frac{m_i}{p_i})$. $z^\ast(p)$ is a solution to (8) if and only if $z^\ast(p)$ is the stationary point of the objective function of problem (7), i.e. the Eq.(13) holds for all $j$.

It is clearly know that the dual problem is a convex. Lemma 1 shows that the problem is differentiable. Here after we can apply a gradient projection method.

C. Control Parameters versus congestion Measures:

We derived one theorem for control parameters and the link congestion measure based on our barrier-based approach.

**Theorem 2:**

Given $m$ with $m_i > 0$ for all link $l \in L$. Let $y_i$ be a solution to problem (10), and $z_i$ and $y_i$ be solution to problems (8) and (9) with $p = p^\ast$ respectively, we have.

i) $(z_i, y_i)$ is a solution to (6) with

$$y_i = \sum_{s, j \in s(x, j)} z_i^s.$$  Moreover,

We have $p_i = \frac{m_i}{c_i - y_i}$ if $y_i > 0$;
ii) Let \((z_*, p_*)\) be a limit point of \((z_m, p_m)\) as \(m\) converges to zero, then \(z_*\) is a solution to problem

\[
\text{maximize } \sum_s U_s \left( \sum_j z^s_j \right) + \mu \sum_j \sum_i \ln z^s_j \\
\text{subject to } Hz \leq c
\]  

(14)

Here \(p_*\) is the corresponding Lagrange multiplier.

Proof:

i) Through the optimality of \(p_*\), we have \(\frac{\partial D}{\partial p_*} = 0\) if \(p_* > 0\) and \(\frac{\partial D}{\partial p_*} \geq 0\) if \(p_* = 0\) with Eq.(10), we have \(y_{l*} \geq 0\) \(\sum z^s_{ij} \) holds for all link \(\forall l\). It can be seen that \((z_*, y_*)\) is feasible problem (6) and

\[
\sum_s \left( u_s \left( \sum_j z^s_j \right) + \mu \sum_j \ln z^s_j \right) + (1-\mu) \sum_l m_l \ln(c_l - y_{l*}) = L(z_*, y_*; p_*) = D(p_*)
\]

By the weak duality, \((z_*, y_*)\) is a solution to problem (6). Since \(\ln(c_l - y_{l*})\) strictly decreases with \(y_{l*}\), we have \(y_{l*} = \sum z^s_{ij}\) by the optimality of \(y_*\). By Lemma we get

\[
y_{l*} = (1-\mu)(c_l - \frac{m_l}{p_{l*}})
\]

\[
\frac{y_{l*}}{1-\mu} = c_l - \frac{m_l}{p_{l*}}
\]

\[
\frac{m_l}{p_{l*}} = c_l - \frac{y_{l*}}{1-\mu}
\]

\[
p_{l*} = \frac{m_l}{c_l - \left( \frac{y_{l*}}{1-\mu} \right)}
\]
Suppose if \( \mu = 0 \).

\[
p_r = \frac{m_i}{c_i - y_{ri}} \quad \text{If } y_{ri} > 0.
\]

(ii) Given the optimality (12) of \( z_{ri} \), we have

\[
u_i \left( \sum_j z'_{ij} \right) - p'_{rj} + \frac{\mu}{z'_{rj}} = 0 \quad (15)
\]

for all source \( s \) and path \( j \), where \( p'_{rj} = \sum_{j \in (s,j)} p_{rj} \). Given the optimality condition (12) of \( y_{ri} \), we have

\[
p_r (c_i - \frac{y_{ri}}{1 - \mu}) \leq m_i \quad (16)
\]

Let \( m \to 0 \), by the continuity of \( u'_i \), the Eq. (15) becomes

\[
u_i \left( \sum_j z'_{ij} \right) - p'_{rj} + \frac{\mu}{z'_{rj}} = 0, \text{ for all sources } s \text{ and path } j.
\]

Let \( m \to 0 \) and \( \mu \to 0 \), we have

\[
p_r (c_i - y_{ri}) = 0 \text{ from the Eq. (16)}
\]

Where \( y_{ri} = \sum_{(s,j) \in (s,i)} z'_{ij} \). Hence, \( y_{ri} = c_i \) where \( p_r > 0 \), and \( p_r = 0 \)

Where \( y_{ri} < c_i \). Therefore, \( z \) satisfy a KKT (Karush-Kuhn-Tucker) point of (14), and \( p_r \) is the corresponding Lagrangian multiplier, since (14) is a convex programming problem with a unique solution to (14), and \( p_r \) is a solution to dual of (14).

Theorem 2 communicate the relationship between the solution of (6) and (10), suppose, if we solve the dual problem (10), we can also obtain the solution of (6), and such relationship as \( p_r = \frac{m_j}{c_i - y_{ri}} \) exists between them. \( \frac{m_j}{c_i - y_{ri}} \) can be considered as the approximation for the network congestion measure, or
\( m_j \approx p_j(c_l - y_l) \). Hence, \( c_l - y_l \) increases with the increasing of \( m_j \), improving the ability of link \( l \) in referring with the network traffic bursts.

IV. LBMP PERFORMANCE: NUMERICAL INVESTICATION

(a) Ring Type Topology

(b) Star Type Topology

Fig 2: Two realistic network topologies.

One common objective function for the traffic management system is to maximize aggregate user utility, where utility \( U_i(x_i) \) is a measure of “satisfaction” of user \( i \) as a function of the total transmission rate \( x_i \). \( U \) is concave, non-negative, increasing and twice-differentiable function. e.g. \( \log(x_i) \), it can also represent the elasticity of the traffic or resolve fairness of resource allocation.
In the above diagram (a) and (b) we choose six source-destination pairs (1-4, 1-5, 2-5, 2-6, 3-5, 4-6) for Ring-type and seven source-destination pairs (1-5, 1-6, 2-7, 2-8, 3-4, 3-6, 4-9) for each of which we choose three minimum-hop paths as possible paths. We set the link capacity $c_l = 100$ Mbps.

(a) Ring Type Topology Graph

(b) Star Type Topology Graph

A. Link Utilization and Aggregate Throughput
We first solve (2) by using function ‘fmincon’ in MATLAB. It calculates the link utilization and aggregate throughput for the optimal rates allocation. The results are shown in Table 1.

Table 1. The optimal link utilization and aggregate throughput

<table>
<thead>
<tr>
<th>Topology</th>
<th>NT(Mbps)</th>
<th>NU(%)</th>
<th>NF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ring Type</td>
<td>330</td>
<td>100</td>
<td>4</td>
</tr>
<tr>
<td>Star Type</td>
<td>275</td>
<td>100</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 2. MATLAB-based Results for TRUMP and LBMP

<table>
<thead>
<tr>
<th>Topology</th>
<th>TRUMP</th>
<th>LBMP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>m NT(Mbps) NU(%) NF</td>
<td>m NT(Mbps) NU(%) NF</td>
</tr>
<tr>
<td>Ring Type</td>
<td>0.25</td>
<td>308.6</td>
</tr>
<tr>
<td>Star Type</td>
<td>0.15</td>
<td>280.4</td>
</tr>
</tbody>
</table>

The results in Table 2 indicate both TRUMP and LBMP. The TRUMP reaches full link utilization before finishing the optimal throughput, which is not attractive because it will make the delay. When we go for LBMP, still maintains reasonable link utilization when finishing the optimal throughput.

In the table the LBMP uses the parameter value and different network topologies. In Theorem 2, a relation between the control parameters and congestion measures based on our barrier-based approach.

V CONCLUSION AND FUTURE WORK

This paper determined a decomposition problem using LBMP protocol for Internet traffic management. It converts the multipath utility maximization problem into a sequence of unconstrained optimization problem, with infinite logarithm barrier being deployed at the constraint bounds. In this paper, we applied an additional parameter to improve the performance of utility optimization. It has proved best result of numerical level simulation and packet level simulation from the previous work. We see several possible extensions of this work by using different Non-Linear programming Problem based on different Algorithm to improve the quality of maximum utility optimization.

REFERENCES:


