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Review of traffic control algorithms in computer networks

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Abstract. This paper presents comparison of popular traffic control algorithms in computer networks. It also contains descriptions of functioning of these algorithms. The first part of this paper contains description of evaluation criteria of traffic control algorithms (from system and user viewpoint). The second part of article contains description of new algorithms, which are theoretically improved or brand new, just introduced for practical use. These algorithms are developmental and eliminate disadvantages of already existing algorithms. The third part of this paper contains description of classical algorithms, which are well known, described and researched. It contains also propositions of modifications of classical linear programming algorithms. These modifications are for adjusting these algorithms to described problem.

Keywords. Traffic control algorithms, computer networks, traffic control in computer networks.

1 Characteristic of evaluation criteria

First of all we have to describe concept of traffic control. Traffic control is a process which is up to division existing network traffic in given infrastructure. It has to be done for optimization of given evaluation function.

Evaluation criteria are measure which can describe quality, reliability or efficiency of network in given conditions. The basic division of criteria can be viewpoint. Viewpoint describes the point of view and priorities of particular person or entity. Well known are two viewpoints – system and user.

1.1 System viewpoint criteria

System viewpoint criteria are as follows: global performance of network, loss ratio, allowed ratio, link utilization, throughput, queue length, robustness.

Global performance of network is a criterion that contains parameters of utilization of network resources, throughput of network, qualification whether the load of network is balanced or not, qualification whether it is possible to avoid network overload or not. This criterion is crucial from system viewpoint, because it affects maintenance costs of working network.

Loss ratio is also system viewpoint criterion. It says which part of transfer is lost. This criterion describes the percentage of data that are lost in proportion of whole transmission. It can be used as well for whole network as for particular nodes.

Another criterion – allowed ratio, describes what portion of data reaches its destination in single time unit. Allowed ratio is expressed in megabits per second. This representation allows to compare amount of data that reaches destination with maximal capacity of link.

Link utilization ratio is a criterion that describes which part of link is used (in percent). It is obvious that aim is to maximize this criterion, because every unused link we have to maintain generates costs.

Throughput of network is a criterion which says what portion of data reached its destination in single time unit. It is measured in packets.

Queue length criterion is measure that describes occupancy of queue in particular switch. This measure considers time. The longer queue in switch, the larger delay in packet sending and more packets are lost (in case of buffer overload).

1.2 User viewpoint criteria

User viewpoint criteria are as fallows: quality of service criterion, fairness among users.

When we are looking at functioning network from user point of view we can say that using network satisfies users when they are able to use various network services (i.e. applications). These services usually have different requirements for bandwidth, delays or loss ratios. All of those criterion decide that quality of service is good or not from particular user point of view. Well constructed traffic control algorithm should satisfy various users (using various network applications) demands.

Another user viewpoint evaluation criterion is fairness. Network resources are finite good, thus when sum of users network resources demands is less than network capabilities network traffic can be effectively controlled. However when demands are greater than capabilities, some of users have to stay unsatisfied. Traffic control algorithm has to isolate some users (or data streams) in order to thread all users fair. In this meaning fairness is situation when there are no such users that get more resources than others nor those who are completely isolated from resources.

Sometimes criteria from those two classes described above are contrary to each other, thus crucial issue is selection of criteria that help evaluate traffic control algorithm.

2 Algorithms characteristics

This chapter contains description of selected traffic control algorithms in computer networks. It discusses advantages, disadvantages and working mechanisms of those algorithms.

2.1 ERICA (Explicit Rate Indication for Congestion Avoidance)

First of described algorithms was presented by R. Jain, S. Kalyanaraman, R. Goyal, S. Fahmy, oraz R. Viswanathan in 1997 in [1, 2]. It is an ABR (Available Bit Rate) traffic control algorithm for ATM networks.

The main concept of algorithm is monitoring (in every network switch) number of incoming packets from every traffic source. Next used traffic is compared with target desired network utilization (usually about 90-95%). If traffic is less than target, adequate ratios send to traffic sources are increased, otherwise ratios are decreased.

ABR is loss-sensitive more than delay-sensitive (like video or audio streaming). Network traffic sources dynamically establish amounts of transmission intensity in range between MCR (Minimum Cell Rate) and PCR (Peak Cell Rate). Those rates are calculated on base of unused network throughput value. Rates establishing takes place in closed loop with feedback – network switches send (base on data collected from network) proposed rates values to traffic sources. Traffic sources respond by changing the traffic, which is noticed by switches and so on.

ERICA algorithm is described by four parameters. These parameters are as follows: target utilization (U), δ, t and *count*. δ parameter is used for defining the cause of total number of requests being close to target load. t parameter is a amount of time (in seconds) of averaged interval. *Count* parameter describes number of cells that have to income in order to calculate length of averaged interval (before t time passes).

Main advantage of ERICA algorithm is fulfillment of fairness criterion. This criterion is important form user point of view. The target of ERICA algorithm is fair assignment of available network throughput in aspect of requested demands. ERICA algorithm fulfills also link utilization criterion, which is system viewpoint criterion. Algorithm provides link utilization of 90 – 95 percent.

Algorithm is not used in delay-sensitive networks, so delay limit criterion is not its priority and is not fulfilled.

2.2 ERICA+

ERICA+ algorithm is used in the same type of networks as ERICA algorithm.

ERICA+ was proposed in work [1,2]. It is an improved ERICA algorithm. One of the modification of ERICA algorithm is that authors removed target utilization parameter and replaced it by target queuing delay parameter. Another modification is redefinition of parameters used for setting adaptation amount. New parameters are based on steady-state convergence and thus faster than old ones.

ERICA+ mechanism is based on calculating (in every network switch) number of incoming packets from given traffic source and then exchanging steering rates in switch – source loop.

ERICA+ algorithm has seven parameters: three of them are from ERICA algorithm (δ, t and *count*) and four new (D, a, b and *QDLF*).

The D parameter is target queuing delay parameter. The a and b parameters describes two hyperbolic functions for achieve smoother rate adjustments around the desired equilibrium point. Usually values of these parameters are as follows: a = 1.15, b = 1.05. The *QDLF* parameter is queue drain limit factor, it bounds the rate adjustment function.

Replacing U parameter with the new target queuing delay parameter (D) caused better than for ERICA fulfillment of link utilization criterion (100%) but also caused slightly bigger delays.

2.3 DEBRA (Dynamic Explicit Bid Rate Algorithm)

DEBRA algorithm was proposed by R. Gurski and C. Williamson in 1996 in work [3]. This algorithm is based on rate-based congestion control strategy also called loss-load curves.

The basic mechanism of algorithm is that network switches calculate aggregate demand (of traffic) basing on incoming data. Switches are able to broadcast value of allocation function to the traffic sources. Sources use those data for optimization of its demands value. If demands are less than or comparable with available capacity then allocation is given to demanding source, otherwise partial allocation takes place for every source (using allocation ratio – calculated using formula 2.1)

$$\tau = r \cdot (1 - p) \qquad (2.1)$$

where:

τ – allocated bandwidth,
r – demanded bandwidth,
p – loss probability.

DEBRA algorithm is described by three parameters: K, C and V. The C parameter controls target utilization ratio. The V parameter describes what fraction of bandwidth is broadcasted to the sources. The K parameter controls reactivity, aggressiveness and convergence time of algorithm. The bigger value of K parameter, the less aggressive algorithm, less reactive and smaller convergence of algorithm.

The algorithm favours traffic sources with smaller demand ratios, another words greedy sources can get small allocation or even do not get allocation at all. This characteristic of the algorithm causes fulfillment of fairness criterion. Also DEBRA guarantees 100% link utilization.

2.4 MGCRA (Modified Generic Cell Rate Algorithm)

MGCRA algorithm is used in networks which provide video-on-demand service. The algorithm was proposed by Ren-Hung Hwang and Min-Xiou Chen in 1999 in work [4].

MGCRA algorithm was developed from GCRA algorithm (created in 1996 by the ATM Forum) and jitter-EDF algorithm (jitter-Earliest Deadline First). The simple schema of MGCRA algorithm is shown on Picture 2.1.

$ExA^k_i \leftarrow ExA^k_{i-1} + X$
$Ahead \leftarrow \max(ExA^k_i - AT^k_i, 0)$
Keep packet for *Ahead* time
$Deadline \leftarrow ExA^k_i + d^k_i$
Mark packet with deadline time
Schedule packet according to deadline value

Picture 2.1. MGCRA algorithm schema

Value of $ExA^k{}_i$ is a expected arrival time of *i*th packet from *k*th session. Expected arrival time is increased by value of *X* which is reciprocal of PCRTT ratio (Piecewise Constant Rate Transmission and Transport). The AT^k_i value is calculated in every network switch. It is the real time of *i*th packet arrival from *k*th session. If packet arrives before it is expected arrival time it is kept for *Ahead* time. The deadline of packet is always defined as sum of expected arrival time value and guaranteed delay in nodes. This formula does not change whether packet arrived before its expected arrival time or not.

Deadline in meaning described above allows to control packet total delay criterion. MGCRA algorithm is able to fulfill throughput criterion, because the algorithm guarantees throughput for every transmission.

2.5 Dahlin algorithm

Dahlin algorithm is one of the simplest and wider used dead time compensation algorithms. The algorithm is useful when time limit is larger than the dominant process time constant. This method demands reliable approximation of process time limit.

Propositions of use Dahlin algorithm combined with artificial intelligence methods (i.e. neural networks) are also present in literature. This approach is used by Shen Wei, Feng Rui, Shao Huihe in their work [5].

The main concept of algorithm is that every network switch has traffic controller assigned to every VC (Virtual circuit – route between source and destination that were set before). Source parameters for given VC are controlled (depending on actual queue buffer filling) in purpose of maintaining queue filling level in desired bounds. Feedback information is send by RM packets (resource management). RM packets are send after certain number of data packets or after amount of time. This transmission uses the same link as data. Every node on VC route sets its RM in time periods given by traffic controller. RM after achieving the destination returns to source using the same VC route. It does so for giving source feedback information about connection. However feedback connection has broadcast delay, which has negative influence on described traffic control algorithm.

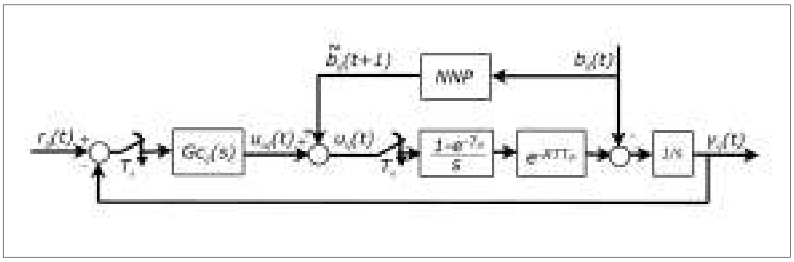
In order to eliminate delay of feedback connection, Dahlin algorithm is used. The algorithm is used to project feedback controller. Moreover the algorithm has small complexity and thus fulfills requirement of traffic control software simplicity.

In order to predict bandwidth required for connection (in ABR approach) model based on traffic statistics has to be created. If created model will be too simple it cannot describe enough actual network state. On the other hand if created model will be too complicated, computational complexity makes difficult real-time traffic control.

Authors [5] proposed use of neural network in order to build model. Neural networks are adaptive and fast, because of their learning ability and ability to concurrent computations. This features makes neural network appropriate for solving traffic control problem. In the described algorithm the recursive Ellman neural network is used. This network is used for approximation of complicated, non-linear relations between ABR bandwidth in past, present and future. Inputs of neural network are ABR bandwidths from past. Output of this network is predicted bandwidth in next point of time in future. For training neural network uses the square root of error value between predicted value and real one.

In every network switch, traffic controller collects data about buffer queue fillment level. The trafic controller is steering the traffic using this data .

Authors [5] uses Laplace transform and Z-transform as mathematical instrument for analysis and projecting traffic control system. Picture 2.2 presents block scheme of traffic control system.



Picture 2.2. Scheme of traffic control system

The variables used in Picture 2.2 are as follows:

- *u(t)* – source rate – control variable,
- *y(t)* – buffer queue level – control variable,
- *b(t)* – ABR bandwidth – tread as disturbance,
- *r(t)* – begin value of buffer queue level,
- $G_c(s)$ – transfer function of feedback controller,,
- *1/s* – transfer function of integrator,
- e^{-RTTs} – transfer function of delay (RTT – Round Trip Time from source to destination),
- *Ts* – sample time,
- *i* – ith VC,
- *j* – jth switch,
- *NNP* – Neural Network Predictor.

In this algorithm use of Dahlin algorithm in creating feedback controller caused increase of speed and stability of control and also eliminated delay impact on this two characteristics. Use of Ellman neural network caused reduction of noise and provided efficient usage of bandwidth.

Link utilization criterion is fulfilled in 98-100 percent by this algorithm. Packets loss criterion (normalized and given in percent) is about 0–1,5%. These parameters combined with fair operating speed cause that the algorithm is useful.

2.6 Virtual Clock

In modern high-speed networks which supports variate applications which has different requirements, crucial issue is network overload control.

One of the approach to solve overload control problem is Virtual Clock algorithm. It is a packet scheduling algorithm used in IP routers.

The basic concept of the algorithm evolved from TDM (Time Division Multiplexing) systems. Those systems eliminates interference between users by assigning time slots to them. In those time slots users can occupy transmission medium and send data. However TDM systems have main disadvantage – users are limited to fixed stream of transmitted data and channel capacity is wasted every time when time slot is assigned to stream which has nothing to send.

The feature that differs Virtual Clock from TDM system is that networks controlled by Virtual Clock provides throughput rate for every data stream. Reservation protocol defines the size of bandwidth that is needed by every stream. After that Virtual Clock (base on reserved transmission rates) defines which packet should be forwarded next (if there is more than one packet waiting in queue).

Every network switch examines parameters which are used for traffic control. Those parameters for *i*th stream entering network switch are as follows:

- AR_i – average transmission rate (packets per second),
- IR_i – packet arrival time (seconds),
- AI_i – average observation interval (seconds), it is quotient of total amount of sent data and AR parameter (values are in range 1/AR<=AI<=data flow time).

Virtual Clock algorithm assigns two values for every stream: VC (virtual clock) and auxVC (auxiliary virtual clock). Picture 2.3 presents scheme of data forwarding process in Virtual Clock algorithm.

When first packet from *i*th stream arrives
    VC_i and $auxVC_i \leftarrow present\ time$
During recieving packets from ith stream
    $Vtick_i \leftarrow 1/AR_i$
    $auxVC_i \leftarrow \max(\text{real time}, auxVC_i)$
    $auxVC_i \leftarrow auxVC_i + Vtick_i$
    $VC_i \leftarrow VC_i + Vtick_i$
Mark packet with $auxVC_i$ value
Insert packet into outgoing queue
Serve packet in ascending order of mark value

Picture 2.3. Data forwarding scheme in Virtual Clock

Picture 2.4 contains simple scheme of data flow monitoring process in Virtual Clock algorithm.

For every *i*th stream algorithm calculates control value according to formula: $AIR_i = AR_i \times AI_i$

After receiving number of packets equal AIR_i, the following conditions are checked:

If (VC_i – real time) < T (control threshold), then source of *i*th stream is warned

If (VC_i < real time), then $VC_i \leftarrow$ real time

Picture 2.4. Data flow monitoring scheme in Virtual Clock

In context of scheme on Picture 2.4, value of VC is kind of flow meter and it is increased for every stream according to established packet incoming rate. Value of auxiliary VC avoids collecting bandwidth by the streams.

Virtual Clock algorithm fulfills guaranteed throughput criterion from TDM systems and at the same time provides statistical multiplexing which is characteristic for packet-switching networks.

2.7 Linear programming algorithms

Linear programming algorithms are widely used in various aspects of life (i.e. Business, military). These algorithms are able to solve many different problems (as well good formalized problems as problems without mathematical model). Also network traffic control problem can be solved with use of methods and techniques of linear programming.

2.7.1 Simplex Method

One of the best known and the longest used linear programming algorithm is simplex method.

The method starts with first, permissible solution and improves it in iterative process. Process ends when optimal solution is found. The geometrical figure is also called simplex. This figure is triangle generalized into more dimensions.

Every linear programming problem can be solved when we assume that values of variables are placed on polyhedron's edges. In this case we have to calculate value of evaluation function on the vertices of the polyhedron. If number of vertices is very large it becomes difficult to find optimal vertex that fulfills limitation conditions of the problem.

The simplex method in next iterations walks through edge connecting selected vertex and another one at the end of this edge. The next vertex is selected when it has better value of target function. The method stops when selected vertex has the best value of target function.

Wann-Ming Wey and Jayakrishnan, R. in their work [6] created complete formalism of network traffic control scheme. In the model authors thread traffic streams as flows represented by the graph edges. With those formalisms authors reduced problem to the integer linear programming problem. The model does not consider constant cycle lengths, but considers full information about external inputs, it can be used in sensor-based environment and feedback control framework. This problem can be solved with use of modified simplex method.

As the classic simplex method can be not efficient enough for described above problem, authors proposed their modification of the method. They also describes comparative researches with other traffic control algorithms and classic simplex method.

2.7.2 Transportation problem

Transportation problem is a linear programming method that can solve many practical problems.

Transportation problem is one of the general linear programming problems. This problem was first mentioned in 1941 by F.L. Hitchcock. He assumed that there is number of suppliers of some goods (each of them wants to sell a certain amount of goods) and number of consumers (each of them needs a certain amount of goods). Author assumed also that sum of demands equals sum of supplies. Any pair supplier – consumer is described by numeric value (i.e. Cost of transportation, time, distance). Solution of this problem is set of numbers (amounts of goods transported from each supplier to each consumer). Solution should minimize (sometimes maximize) target function.

Problem described above is called classic transportation problem. This method allows to solve problems that are subset of problems solvable by simplex method. However transportation problem methods thanks to more precise model are much faster than simplex method.

Traffic control in computer network problem can be reduced to linear programming problem (precisely to transportation problem). Network traffic sources can be threaded as suppliers of goods and destination nodes – as consumers of goods. One of the transportation problem variants considers intermediate nodes (as magazines) – in traffic control problem these can be switches or nodes on route. Target function in this problem can be one of the evaluation criteria and connections between nodes in network should be described by value depending on what criterion will be chosen.

The described problem can be solved with one of well known, classic transportation problem solution methods. However for large, mass problems with many evaluation criteria, classic methods are not efficient enough. As answer to this disadvantage it is reasonable to use artificial intelligence methods. For large searching space those techniques have the advantage over classic methods because they find good enough (but not optimal) solution in satisfying time.

2.8 Concurrent algorithms

Concurrent algorithms are ideal for decentralized traffic control in computer network. Those algorithms are able to divide computation load between small agents.

Other advantage of concurrent computation is reliability – when one of agents would not complete its job other agents will be load with portion of dead agent computation and whole process will succeed. This behaviour is impossible for centralized control algorithms.

As it was mentioned in chapter 2.7. traffic control problem can be reduced to linear programming problem. This kind of problems have well known solution methods. However in concurrent approach concurrent methods of artificial intelligence should be used. One of those methods are ant algorithms.

Ant algorithms are based on behaviour of insects living in colonies. The main aim of those insects is to keep whole colony alive (sometimes with cost of particular entity's life). In aspect of solving numeric problems it is interesting how ants are searching the shortest route to the food source.

Every ant is able to find food source. While insect is moving it marks ground with odorous substance – pheromone. Ants are able to smell pheromones and are created to follow the route of the strongest smell of it.

If on route between anthill and food appears obstacle, the first ants will try to go around it using two ways with equal probability. But those ants which chosen shorter way around will be back in anthill faster and will leave more pheromone on this route. The stronger smell will attract more ants and then after while ants will be using the shortest possible path again.

Example above shows interesting feature of social insects – the highly structuralized colony build with simple individual entities. Thanks to that the whole colony (not single insect) is able to adapt to changing environment.

The model of living ant colony was adapted to optimization system for solving combinatoric problems.

It is possible to adapt ant colony algorithm for solving traffic control problem. In this approach ants will be simple small agents that would simulate the traffic. Each of them will be able to find route from source to destination but only whole colony would be able to optimize target function. Target function and connections between nodes should depend on chosen evaluation criteria as it was mentioned in chapter 2.7.2.

3 Summary

Algorithms described in chapters 2.1 – 2.6 are decentralized, deterministic algorithms which evolved from classic traffic control algorithms. First five of them is dedicated to ATM networks and in this type of networks they are used. This algorithms are developing and improving their predecessors.

The ERICA algorithm provides fair bandwidth allocation among the users and also 90-95 percent network utilization. The improved ERICA algorithm (called ERICA+) increased network utilization to 100% and also fulfills fairness criterion.

The DEBRA algorithm (as ERICA+) provides 100% utilization of network. But it defines fairness in different way – the algorithm favors less demanding traffic sources and eliminates greedy ones. The MGCRA algorithm provides control over total packet delay. This is a feature that former algorithms do not have. Moreover it was immolate to fulfill other criteria. The MGCRA algorithm guarantees bandwidth for every transmission. The Dahlin algorithm with neural networks has different criterion priorities. It provides network utilization on level of about 100% and negligible packet loss rate (up to 1.5%). The algorithm does not try to fulfill fairness criterion (as DEBRA and ERICAs) and also does not guarantee bandwidth (as MGCRA). It controls packets delays, to be more precise – it eliminates impact of those delays on traffic control. Due to this features the algorithm is not created to use in networks where crucial task is bandwidth guarantee. Described algorithm works fine in networks which demand link utilization and small loss ratio.

The Virtual Clock algorithm is decentralized, universal algorithm. It can be applied to various types of networks. It was created to use in packet-switching networks. The algorithm is not based on mathematical theory, authors do not create model of functioning of it. Virtual Clock (like MGCRA) fulfills guaranteed bandwidth criterion. It also avoids cumulating bandwidth by single transmission – provides fairness (like ERICA and DEBRA).

Linear programming algorithms have the best developed theory. Through the years of using them for solving various types of problems mathematical models based on linear programming theory was created. This is main advantage of this class of algorithms. The main disadvantages are: centralized computation and small accommodation to dynamic environment changes.

In aspect of dynamic of network we have to mention artificial intelligence algorithms adapted to solving problems in dynamically changing environment. It is still young science discipline and thus not well formalized but it gives hopeful results wherever it is used.

In summary the chose of traffic control algorithm should depend on type of network in which traffic will be controlled. Creating hybrid algorithms that combine advantages of couple well known algorithm is one of the directions in future of traffic control.

Authors of this paper are going to create computer network simulator which will provide researching over different types of traffic control algorithms and evaluation of these algorithms with chosen evaluation criteria. The detailed analysis of algorithms in aspect of described criteria will be made in second part of this paper.

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