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(editors)

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OPTIMIZING ROUTING PROCESS WITH A KINETIC METHOD

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***Abstract**: The article describes a "native" algorithm for getting packet forwarding decision, based on considering a network to be an ionic gas. Therefore necessity for the information becomes a field intensity, with distribution function gradient showing the best forwarding way to bring the system to a minimal energy state and all the nodes having an equal information set. The proposed algorithm can be optimized on any of function parameters versus metrics only in classic routing algorithm.*

***Keywords**: Packet forwarding, Boltzmann equation, Vlasov equation, Thermal grid, Kinetic algorithm*

***ACM Classification Keywords**: C.2.2 Network Protocols - Routing protocols*

Introduction

The aim of the proposed research is consideration and optimization of packet forwarding direction decision making as one aspect of a "quality of service" problem in point-to-point networks. A task to increase a "quality of service" level while decreasing transit nodes load does appear in modern networks because of frequent reaching top load level (even causing packet loss) in some network parts with non-equivalent network load distribution in other parts. It is clear that for the task mentioned above we need to build some algorithm, which allows optimizing node interaction, taking into consideration different requirements caused by many kinds of information, e.g. we must optimize routing (packet forwarding) algorithm. It is clear that the algorithm we are looking for may fit the following requirements:

- an RSVP-method should not be used;

- flooding network traffic should not be generated or the traffic should be minimal, if it is not possible to do without it;

- the algorithm should be fast enough to find a solution to forward the next packet while the current packet is being transmitted; in doing so it is desirable to reach the solution with a low CPU utilization;

At present, a Bellman-Ford routing algorithm is a mainly used one, for example, in a 'routed' daemon. This algorithm is rather simple and fast, but its realization needs sending up routing tables across the network (thus flooding it with a service-special traffic) every 30 seconds. Moreover, this method has no capabilities of adjusting itself for optimizing data transfer process for some special conditions of networking tasks and different parameters of network parts, because one and the only parameter it uses is a "metric", which can be referred to as a statistical value, implicitly depending on a number of network characteristics; the function used to describe this dependency being very complicated. Adjusting capabilities of packet routing algorithm make up a base for "quality of service" question when adopting a network for the type of information being transferred by it, because this will allow taking into account this information type and its requirements at the very moment of taking a decision regarding packet forwarding. Recently some research attempts have been made with the aim of finding a routing algorithm with a capability to optimize packet forwarding direction decision making with dependence on the information type and network characteristics. Among such algorithms one can find the "Thermal grid" algorithm (provided by H. Unger, [Unger, 2009]), the "Ant pheromone" algorithm (given in particular in [Singh, 2010]). Note the idea of describing a networking process through classical physics analogies. The idea itself is not new. An example of an earlier work using a "temperature state of a system" appears in [Yong Cui, 2003].

Techniques of research

A proposed "Kinetics" algorithm is based on "Thermal grid" algorithm and is aimed at increasing its efficiency, because the latter can give improvement in delivery time only when it is used in about 50% of decision making [Unger, 2009]. In their later works the authors of a "Thermal grid" algorithm added two parameters [Lertsuwanakul, 2009], having influence on each method "weight" in a decision making (considering not only "temperature", i.e. load of a buffer, but also transmitting time), taking a partial step backward towards classical routing methods based on metrics.

As the "Thermal algorithm" is based on associating a buffer load of a node with a temperature, the "Kinetics algorithm" basis is associating networking characteristics (e.g. connection speed, buffer size, switching time etc.) with the identical physical quantity (mass, temperature, electric charge or so). In such a conception, every node in a network (or grid) can be described by

a) in case of a network

a system of nodes:

- each node has some information and demands some information;
- each node has some direct connections;
- each node has a limited channel width and each node has a limited cache;
- each node has a stability rate;

b) in a case of electromagnetic field:

a system of cells with particles on it, mainly one particle per cell;

- any particle (ion) has its electric charge;
- each particle can interact with any number of particles only around it;
- each particle has some limited velocity (or temperature. Here a meaning of a “temperature” acquires a new meaning and describes not only a cache size, but a connection speed too);
- each particle has a mass-property.

It is clear that these parameters can be associated with each other. Thinking in such a way, we can associate networking nodes with particles and describe our system (remembering it is a P2P-network really) with Boltzmann kinetic equation:

$$\frac{\partial f}{\partial t} + \frac{\partial f}{\partial x} \cdot \frac{p}{m} + \frac{\partial f}{\partial p} \cdot F = \left.\frac{\partial f}{\partial t}\right|_{st}, \qquad (1)$$

Here f is a particle distribution function;

t is time;

x is a coordinate;

p is a particle impulse;

m is a particle mass;

F is a field of external(*) forces wherein a particle exists;

$\left.\frac{\partial f}{\partial t}\right|_{st}$ is a so called "collision integral" showing an impact interaction of particles in classical mechanics.

For vacuum or collisionless plasma this integral is considered to be a zero. In our case it would be non-zero only when we want to take overload of some network parts and impossibility for transferring data through that path into

account. This equation contains a particle distribution function – unsteady in time parameter, describing a probability density distribution of containing a particle in a infinitely-small volume dV. Solving this equation to find this function is rather a hard task in general [Vlasov, 1938], though this task is well solvable by iteration schemes in many cases and even analytically for some particular cases. The task was solved, for example, for plasma (by A. A. Vlasov himself). It is known that it was solved for colloids in a two-dimensional approach etc. While one should take a look at the mentioned equation, one may note, that if we associate, say, a necessity for information with an electric charge, a field F (mind an asterisk near it) would be a self-consistent one. This field can be easily found particularly with a "clouds-in-cell" method. So, we can model our system by describing it with Vlasov-Maxwells equation system [Vlasov, 1938] and solving it numerically.

$$\frac{\partial f_i}{\partial t} + div_r v f_i + \frac{q_i}{m_i}\left(E + \frac{1}{c}[v,B]\right) grad_v f = \sum_j \left(\left.\frac{\partial f}{\partial t}\right|_{st}^{i,j}\right),$$

$$divE = 4\pi\rho, \quad rotE = -\frac{1}{c}\frac{\partial B}{\partial t}, \tag{2}$$

$$divB = 0, \quad rotB = \frac{1}{c}\frac{\partial E}{\partial t} + \frac{4\pi}{c} j,$$

Here we came across with parameter qi - a charge of particles of i type. Remembering that the data transferred by the network can be of many types, each of those types gives us a new type of particles (i), but to avoid an interaction of different information types, we should mark the nodes (particles) not only with a charge but with a color.

The second interesting parameter in this equation is j - a "current density". This parameter indicates a channel load (but not a buffer load!). A field tension is defined in the same way as defined in a classical physics. A total number of variable type parameters in the equation amounts to twelve, so the algorithm can be easily adapted to many various requirements of numerous data types even without using any other forwarding decision making algorithms.

The above mentioned system (2), [Vlasov, 1938], allows finding a distribution function state in any time moment if its state is known at the starting (zero) time. Our aim consists in not just solving the system in terms of finding a distribution function, but finding its changes in small time moments. Thus the information about preferred forwarding way should be found in the spatial gradient of derivate of the distribution function with respect to time. After network points are positioned in the cells of some grid and known system characteristics, associated with physical quantities in a mentioned way, are substituted into the system (2), we can start iterations, which will give us some shift of the distribution function's extreme points. This shift will give us the preferred way of packet forwarding. The difference between a network node and a real particle is that the latter one has many degrees of freedom, in opposite to the network node, which can forward a single packet only one way at any moment (indeed, we do not take a parallel data transfer and duplexes into account here, because these parameters are certain to occur in a modeled system, but we must exclude a broadcasting as mentioned in the task before). So, we have to choose one and the only way for packet forwarding each time, and we will assume it to be a direction of maximum extreme point shift. It is clear, we have to correct our model after the forwarding has been done before the next iteration takes place, because the model assumes a distribution function and a space to be continuous, while the forwarding is made in a discrete space of network nodes. Thus the model needs correction after each iteration takes place. But while correcting a model we can quickly adjust it to the changes in a network topology (e.g. some new points can appear in a net, while some links go down etc.) so the subsequent iteration will use up-to-date data both about the structure and state of the network.

For the equation system (2) we must build a finite-difference scheme to start iterations on. After all we have said above, we can just use a simple scheme of a first order regardless of its instability, because of data correction after each iteration. Moreover, we consider all the variables to be normalized. A consequence of actions for each iteration looks like:

1) gather the data about the current network state;

2) dispose the nodes over the cells;

3) calculate a field E (after calculating charge and current densities);

4) calculate a field B (no networking equivalent this time);

5) calculate a distribution function f;

6) find a $\frac{\partial f}{\partial t}$ – derivate of the distribution function with respect to time and its spatial gradient;

7) perform the forwarding and correct a model etc.

The scheme can be found to look like

$$\frac{f - f_{-1}}{t - t_{-1}} + v \cdot div_r f + \frac{q}{m}\left(E + \frac{1}{c}[v,B]\right) grad_v f = \left.\frac{\partial f}{\partial t}\right|_{st}, \tag{3}$$

Now we can see the external field component is not present, but there can be a charge source in the net (i.e. a system is not a complete and closed-up in a general occasion). Today we discard this fact, because one can easily notice that this will not have a significant affect on a result. The equation (3) transfers into a working formula for iterations:

$$\begin{aligned} &w = grad_r \frac{\partial f}{\partial t}, \\ &where \frac{\partial f}{\partial t} = f - f_{-1} = + \left.\frac{\partial f}{\partial t}\right|_{st} - v \cdot div_r f - \frac{q}{m}\left(E + \frac{1}{c}[v,B]\right) grad_v f. \end{aligned} \tag{4}$$

In the system (4) the variable we are looking for is the projection of the vector W on our coordinate grid, where the node (point) is positioned on and described by, and (again) we choose a direction where this projection is maximal as a primary forwarding one. Note the time is excluded in the last equation. It is implicitly present as we are working with the system within one technically infinitely small time period.

A modeling itself runs a rather simple algorithm (though now it has many limitations). The algorithm below can be described by these five steps:

1) get a matrix of connectedness;

2) mark the nodes having some information;

3) mark the nodes needed the information (targets);

4) start iterations:

   a) find routes ;

   b) look if the forwarding target node is already busy on this step;

   c) if this node is busy, skip one iteration, otherwise perform data transfer;

   d) correct the model according to the transfers which have just taken place;

5) if the information is delivered to the targets, the job is done; otherwise continue from the step 4-a.

The step 4-a includes making a decision on a packet forwarding route. The model is to run two times: first the routing will be done with a classical algorithm (excluding a step 4-d), then with an alternative algorithm.

The open question is currently a transit node transfer. We have mentioned above that all the points will be marked with a color (but, in opposite to quarks our particles-nodes can carry many colors at the same time). This is figured out by a necessity for simultaneous transferring many different types of data, while not mixing these data. In a field of each color a node may be charged positively (it has certain information), negatively (it does need that information), or neutral. The problem is that in many cases the dominant part of transit nodes will be neutral in one particular color, but at the same time it can carry a heavy charge of other color. This might be interpreted as the node does not need and is not loaded with the information of current type, but is heavily loaded with an active transfer of other information. This is partially described by the node temperature, but for more accurate modeling this fact needs taking a right part of a Boltzmann equation, i.e. “collision integral” into consideration, which rises a complexity of a model together with making the solving of equation more difficult at every step, slightly decreasing an efficiency.

Experiment and results

For the experiment a simulating program was written using GNU Octave. No more special simulation software was used. The simulating program consists of 3 big modules. The main one is used for simulating a network itself, and the other two are simulating routing algorithms. Within the main module the information about connections (in a matrix form, N×N nodes, where N is the number of points in the network, now 256) and about data presence is stored. A network topology is available on a fig. 1.

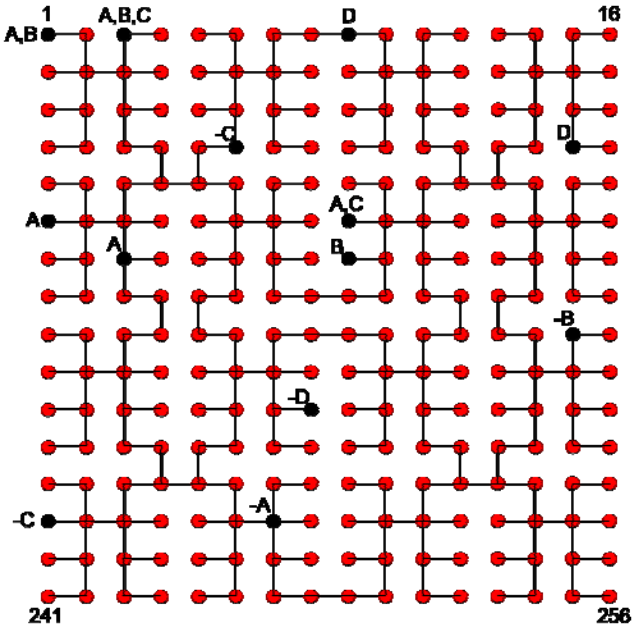
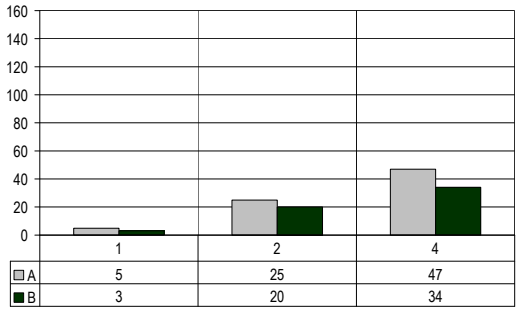


Fig. 1 – a simulated network topology with the color marks

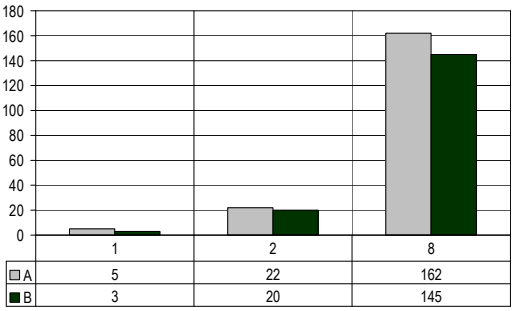
The only characteristic of the connection was “metric” and no node parameters were used except for data presence. The buffers of nodes were considered to be infinite and the nodes stored a copy of all the packets for infinite time.

Each information type was marked with a color by a letter (A to L), and the letter “N” found on a node represents that the node is empty. The nodes were queried in a cycle, and when the node is queried, it looks up if it has the data of each color and, if so, forwards these data to one neighboring node. A destination node was chosen by a classical Dijkstra algorithm (program module 2) on the first run and with a "kinetic" algorithm (program module 3),

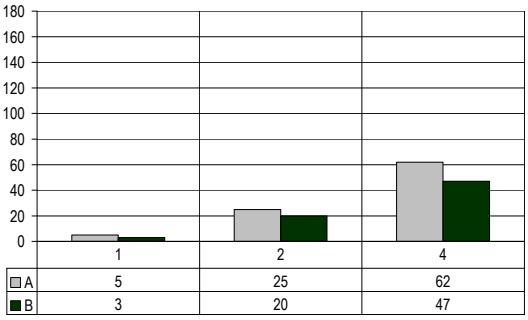
we switched to on the second model run. A node that gets a forwarded packet becomes marked with a packet color, and then the next node is queried. After the last one node is queried, a model looks up if all the nodes which needed the information have received it, and if they have not, the nodes are queried for transferring the information packets once more. The map of nodes marked by color is printed after each modeling cycle. The number of nodes marked colors A and B is shown with the diagram on a fig.2., on first, second and last steps.



a)



b)



c)

Fig. 2 – nodes of the colors A and B on first, second and last steps of modeling.
a) the classic algorithm used, b) the “kinetic” algorithm with two (no electric field) and
c) the “kinetic” algorithm with three parameters were used

An experiment was provided twice with the kinetic forwarding: the first time only the information presence on nearest nodes and the speed of connections were taken into consideration. The result was that the information was spread equally over the network (see fig.2), regardless of the fact whether it was needed by the node or not. This looks like particles of paint that are spread equally over the volume when the paint is dropped into a glass of water. The network seams to be flooded with the packets. On the second run the field was calculated and taken into consideration. The nodes having information were marked positive, the nodes needed that information were marked negative, and the electric field was found as it is defined from the nodes potentials (by Kirchhoff's circuit laws).

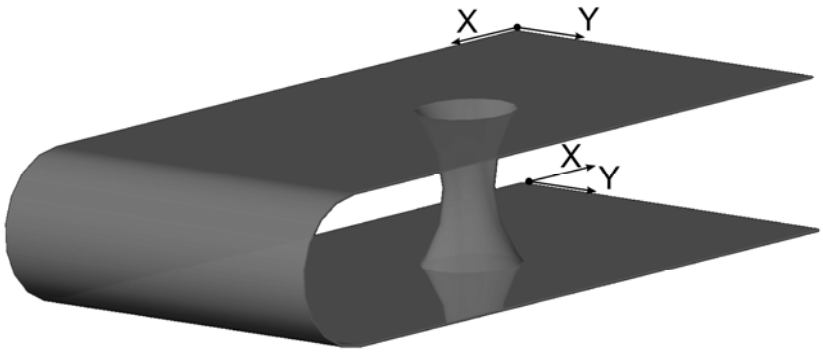


Fig. 3 – The “wormhole” - a ground of using multidimensional system when different parts of the network are connected directly. The hole is in Z-coordinate, X and Y are shown on a bent surface.

While programming, it was chosen finally to use multidimensional system. The connections then were separated over the dimensions so that the node could have only one connection in each dimension. An explanation for associating the connections with the multidimensional structure can be seen on a fig. 3: each direct connection jumps over the layer of a subnet and can shortly connect nodes like a direct wormhole. The longitude part of Vlasov equation (5) (see [Vlasov, 1938] for explanations) was solved then on a multi-dimensional field:

$$\frac{\partial f}{\partial t} + div_r vf + \frac{q}{m} E \cdot grad_v f = 0. \qquad (5)$$

The result was that the performance of forwarding process had been dramatically improved: the information was forwarded almost the same way it was forwarded by a classical algorithm, so the kinetic method proved to be rather effective even on the system, which was initially built to model transfers by Dijkstra algorithm. A table showing the number of forwards by each color with classic algorithm, the “kinetic” algorithm without field and the “kinetic” algorithm including field is shown below (Table 1). The Dijkstra algorithm was in ideal conditions for its performance, while the conditions for the “kinetic” algorithm were very poor: only few of possible optimization parameters could be taken into account. There were no overloaded nodes; the connections were infinitely stable and so on. The “kinetic” algorithm proved to be flexible enough to be optimized on each network parameter (since the performance of the algorithm had been dramatically improved after taking the “electric” field into account).

Table 1. An average number of forwards for 4 colors with a classic and “kinetic” algorithm.

Color	Classic algorithm	“Kinetic” algorithm	
		without field component	including field component
A	46	161	61
B	33	144	46
C	92	255	121
D	26	115	37

Conclusion and future work.

The described method looks rather complex and easily optimizable. At the current step of modeling we achieved efficiency over 70% of the speed of Dijkstra algorithm (efficiency is measured as time elapsed on transmission itself, not including time elapsed on taking forwarding decision). Any way we should consider an algorithm to be

quite good if it gives efficiency slightly less versus classical algorithms when dealing with a system within the same parameter set. This can be understood easily if we turn to the fact that any iteration algorithm gives less accurate result within a longer period of time versus analytical solutions. But we must remember that in some cases analytical solution does not exist or can hardly be found, thus on occasion when we need taking not only metrics and even more than metrics and buffer, alternative algorithms would show greater performance. Within our experiment we have put Dijkstra's algorithm into ideal conditions for its performance while our "kinetic" algorithm was used with only small parts of its parameters. Even in such a poor occasion for its performance the algorithm proved to be a) rather effective versus classic algorithm and b) this algorithm gives good adjustment possibilities, as we can see by adding just one parameter to the equation. In the future it is desired to build a more complex model with 64K nodes, including unstable nodes, small-buffered nodes and overloaded nodes. In such a model it is expected to find performance of this algorithm much more perfect than classic algorithm, and to avoid packet losing on overloaded networks (this cannot be done by a classical algorithm). In order to achieve maximum efficiency ([Unger, 2009] and [Lertsuwanakul, 2009]) it is still recommended to apply many algorithms with different "weights" to decision making. In the nearest future, the model will be optimized for running on non-linear grids and more accurate physical analogy will be found for networking.

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