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Modeling of UDP Hole Punching in P2P Network Using Petri Net

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Abstract. NAT(Network Address Translation) effectively eases the problem of IP address exhaustion, but it also brings some difficulties to Peer-to-Peer communication,so NAT traversal has become a problem to be solved by P2P application.Petri net is widely used in the simulation and analysis of discrete event system because of the features such as simplicity,direct viewing and strong potential sumulation capability. Firstly,this paper simply analyzed the necessity of UDP hole punching technique in P2P network and the advantages of Petri net modeling,then the UDP hole punching process was detailedly described and the Petri net related definitions were given, finally,the UDP hole punching was modeled using Petri net and this paper further maked the reachability analysis.In this way,this paper showed the UDP hole punching process in a more intuitive way.

Keywords: P2P network;UDP hole punching;modeling using Petri net

1. Introduction

NAT doesn't require each host on the network has a registered public IP address.Host in a LAN converts the private IP address to a public address of the Internet,enabling the address multiplexing.Hosts after different NATs can not recognize each other and thus can not directly exchange information,while P2P network is peer to peer communication and requires each host can directly exchange information with others,therefore the application of P2P network must solve the NAT traversal problem to realize the bidirectional direct communication.At present the methods of NAT traversal based on UDP protocol are relatively mature and UDP hole punching is used the most widely.UDP hole punching can effectively maintain the transparency of the NAT environment.It does not need to understand the network topology information and it does not need the support of other special software environment.It can be implemented by the common applications[1].

Given the formal description,having relevant operational model and the suitability for automatic analysis[2],Petri net is widely used in the network protocol.This paper uses Petri net to model UDP hole punching,showing the UDP traversal process in a more intuitive way.

2. UDP hole punching

2.1. The main idea of hole punching

We first introduce two common terms:

Public endpoint address:can communicate directly on the Internet ,the only [IP address,port] pair.

Private endpoint address:only can communicate on the private network,not the only [IP address,port] pair.

The main idea of UDP hole punching:Make use of a server with a public endpoint address which any client can reach.Store and maintain in advance the clients' public endpoint addresses which have been obtained from the registered messages.When one side needs to communicate with the other side,they obtain the opposite side's public endpoint address by the sever's "introdction"[1],and send the connection request to each other's public endpoint address to open a "hole" to opposite side on respective NAT.

2.2. Punching process

We will take the most common situation that both communicating parties are after NATs as an example to show the process of UDP hole punching and ignore the packet loss because of network congestion.Suppose both of host A and B have established connections with the sever,and now host A wants to communicate with B.The specific process is as follows.

1)Host A sends a request message to the server,hoping to establish a connection with host B.

2) Server sends host B's public endpoint address to host A,and sends host A's public endpoint address to host B,telling host B that host A hopes to establish a connection with it.

3)Host A sends a hole punching message to Host B's public endpoint address,that is to open a hole in the direction of host B's public endpoint address on NAT A.At the same time host B also sends a hole punching message to host A's public endpoint addrss,that is to open a hole in the direction of host A's public endpoint address on NAT B.

4)The hole punching message that host A sends to host B reaches NAT B.If the hole punching message that host B sends to host A has passed NAT B,that is the hole in the direction of host A's public endpoint address on NAT B has been opened,the hole punching message that host A sends to host B can pass NAT B to reach host B,otherwise it will be discarded.Process the hole punching message that host B sends to host A in the same way.

5)The hole punching message that host A sends to host B reaches host B and the hole punching message that host B sends to host A reaches host A.From now on host A and host B after different NATs can directly communicate with each other without the help of the server.

2.3. UDP idle timeout

UDP is a connectionless protocol.The NAT mapping for UDP transmission is dynamic.If there is no data to pass for a period of time,the mapping will be automatically discharged[3],that is the hole used to implement the UDP connection will be closed.If we want to maintain a free UDP connection after establishing a hole punching connection,we can set a timer.The timer periodically sends a packet to stay connected in order to make sure the hole punching connection on the NAT won't be closed due to expiration[3].

3. Petri net related definitions[4]

Petri net can not only describe the structure of the system, but also simulate the operation of the system.

Definition 3.1 The triple N = (S,T; F) which satisfies the following conditions is called a net:

1) $S\cup T\neq\Phi$

2) $S\cap T=\Phi$

3) $F\subseteq(S\times T)\cup(T\times S)$

4) $dom(F)\cup cod(F)=S\cup T$

of which

$dom(F)=\{x\in S\cup T|\exists y\in S\cup T:(x,y)\in F\}$

$cod(F)=\{x\in S\cup T|\exists y\in S\cup T:(y,x)\in F\}$

S and T are two disjoint sets (Generally we can assume they are finite sets),and they are the basic elements of net N.An element of set S is called S-element or place.An element of set T is called T-element or transition.F is the flow relation of net N.In the graphical representation of the net,S-element is represented by a small circle and T-element is represented by a small rectangle.For $x,y\in S\cup T$,if $(x,y)\in F$,we draw a directed edge from x to y.Directed edge only exists between a small circle and a small rectangle.There is no directed edge between any two small circles or two small rectangles.

Definition3.2 Let N=(S,T;F) be a net.For $x\in S\cup T$,denote

${}^{\bullet}x=\{y|y\in S\cup T\wedge(y,x)\in F\}$

$x^{\bullet}=\{y|y\in S\cup T\wedge(x,y)\in F\}$

${}^{\bullet}x$ is called preset or input set of x.$x^{\bullet}$ is called postset or output set of x.

Definition3.3 Let N=(S,T;F) be a net,and the mapping M:S->{0,1,2,...} is called a marking of net N.Tuple <N,M>(namely the quadruple<S,T;F,M>) is called a marked net.

In the graphical representation of the marked net,for $s\in S$,if M(s)=k,put k small black spots in the small circle which represents the place s(When k is large ,write the number k directly.).We can say that there are k tokens or markings in the place s.

Definition3.4 A net system is a marked net Σ=(S,T;F,M) and it has the following transition firing rules:

1)For the transition $t\in T$,if $\forall s\in S$:$s\in {}^{\bullet}t$->$M(s)\geq 1$,we can say the transition t is enabled at the marking M,and denote M[t>.

2)if M[t>,the transition t can fire at the marking M.A new marking M′ can be obtained from the transition t at the marking M(denot M[t> M′).For $\forall s\in S$, $M'(s)=\begin{cases} M(s)-1, s\in {}^{\bullet}t-t^{\bullet} \\ M(s)+1, s\in t^{\bullet}-{}^{\bullet}t \\ M(s), otherwise \end{cases}$

There is an initial marking M_0 in the net system.It describes the initial state of the simulated system.At the initial marking M_0, Maybe several transitions are enabled.One of them(optionally) fires,then a new marking M_1 is obtained.(If different transitions fire,generally the markings obtained are different.)

Reachability is the most basic dynamic property of Petri net.We give the definition of reachability as follows.

Definition3.5 Let Σ=(S,T;F,M) be a Petri net.If there exists $t\in T$ such that M[t>M′,we can say M′ is directly reachable from M.If there exist transition sequence $t_1,t_2,...,t_k$ and marking sequence $M_1,M_2,...,M_k$ such that $M[t_1>M_1[t_2>M_2\ldots M_{k-1}[t_k>M_k$,we can say M_k is reachable from M.The set of markings which are reachable from M is denoted R(M).

4. Modeling and analysis of UDP hole punching using Petri net

4.1. The common idea of Petri net modeling

Petri net is successful because of their essential strengths in accurately describing a system's static structure and its dynamics,the availability of mathematical analysis methods and their graphical nature. As a graphical tool, in addition to visual description of similar to the flow chart and network diagram, Petri net can simulate the behavior of dynamic activities by the flow of token, so it is also called a dynamic graphic tool. As a mathematical tool, Petri net can describe the behavior of the system by setting up state equations, algebraic equations and other mathematical models[5].

In the system modeling using Petri net, the place usually represents state or condition,and the transition represents event.We usually adopt the transition-oriented modeling method and mainly consider the combination of events.State or condition can be obtained from the partial order relation between events. As the Petri net object is a closed set of place and transition, it has contacted with other objects through the port, such a Petri net object is a "black box", but the boundaries of a Petri net object have no effect on implementation of Petri net model[5].Therefore when modeling ,we can construct each communication entity into a Petri net object.

To use Petri net modeling a real system, it is necessary to not only understand the basics of Petri nets, but also have the professional knowledge of the real system. Only really understanding the relationship between the various components of the real system and knowing how to use Petri net to describe the relationship can building a appropriate Petri net model for the real system.For the real system modeling, we can take a hierarchical and stepwise refinement modeling approach. The first step is only to build the outline model of the system. In the outline model,a subsystem was represented by one basic element(place or transition). To further show the details of the system, then use Petri net to model the subsystems ,which uses a subnet to replace the basic element of the outline model. For the complex real system, hierarchical modeling approach can be used repeatedly.This approach needs to well deal with the connection relationship between the subsystem models and th outline model.

4.2. The Petri net modeling of UDP hole punching

The host A and B after different NATs open the holes on respective NAT with the assistance of the server,and then they can communicate directly.In order to maintain an idle UDP connection in the the communication,the timer needs to be turned on to send the UDP packets regularly.The Petri net modeling of this process is showed as Fig.1(a).

Places and descriptions are showed as Table 1. Transitions and descriptions are showed as Table 2.

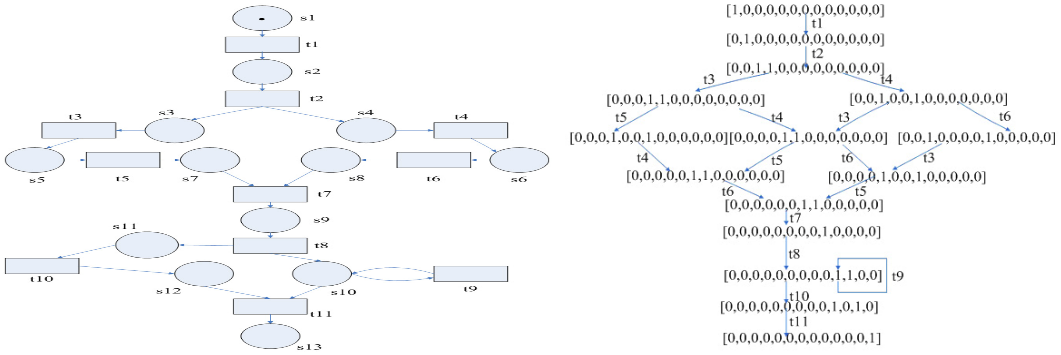

Fig.1. (a) The Petri net model of UDP hole punching; (b) The reachable marking graph of Petri net model about UDP hole punching

Table 1. Places and descriptions

place	description
s1	Host A is ready to communicate with host B.
s2	The sever receives the request message of host A,and it is ready to send messages to host A ,B.
s3	Host A obtains host B's public endpoint address,and is ready to send the hole punching message.
s4	Host B obtains host A's public endpoint address,and is ready to send the hole punching message.
s5	The hole punching message that host A sends arrives at NAT A.
s6	The hole punching message that host B sends arrives at NAT B.
s7	The hole punching message that host A sends completes the hole punching of NAT A.
s8	The hole punching message that host B sends completes the hole punching of NAT B.
s9	The hole punching message that host A sends reaches host B,and the hole punching message that host B sends reaches host A.
s10	The timer starts timing.
s11	The communication starts.
s12	The communication finishes.
s13	Termination.

Table 2. Transitions and descriptions

transition	description
t1	Host A sends a request message to the server and hopes to establish a connection with host B.
t2	The server sends host B's public endpoint address to host A,and sends host A's public endpoint address to host B.
t3	Host A sends the hole punching message to host B.
t4	Host B sends the hole punching message to host A.
t5	The hole punching message that host A sends passes NAT A.
t6	The hole punching message that host B sends passes NAT B.
t7	The hole punching message that host A sends passes NAT B and The hole punching message that host B sends passes NAT A.
t8	Host A starts to communicate with host B,and opens the timer.
t9	Send UDP packets regularly.
t10	Communicate.
t11	Stop the communication and close the timer.

4.3. Model analysis

The Petri net of Fig.1(a) is built on the foundation that host A,B have established connections with the server and we ignore the packet loss because of the network congestion.In Fig.1(a),circle represents place and rectangle represents transition.The initial state is that place s1 has one token and other places are empty.The whole process includes two parts:the hole punching procss that the two communicating parties carry out for communicating and the communicating process after the hole punching process.In the hole punching process host A and B perform similar operations so it is symmetric in the Petri net.In the communicating process in order to ensure the hole won't be closed because of the too long packet interval,we must set a timer.Every time after a certain time T,the transition t9 is triggered and sends UDP packets to maintain the connection.Then the timer becomes zero and starts timing again until the communicaion is complete and the timer is closed.

Reachability analysis technology is to generate all the reachable states in order to check that they meet the states which the protocol requests to occur and the desired behavior characteristic or not.The desired behavior characteristic usually includes deadlock ,unexpected accepting/sending,transition activity and boundness of the place marking.Reachability analysis starts form the initial global marking,generates the branch nodes according to every fired transition or concurrent transition set(the set of transitions that meet the fired requirements) and forms the reachable marking graph as a whole[6].The reachable marking graph of Petri net model about UDP hole punching is showed as Fig.1(b).

5. Conclusion

The hole punching tecnology can simply and effectively achieve the goal that two hosts on different private networks establish direct P2P communication without being blocked by the NAT on the network[7].It is an excellent NAT traversal solving plan.Petri net is intuitive,easy to understand and easy to use,taking both of the strict semantic and graphic language into account[8].This paper combines them to clealy show the hole punching process in P2P network which has certain significance to the research on NAT traversal.

6. References

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