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New Multi-path Routing Protocol in Ad Hoc Network

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Abstract: This paper aims at the topological structure of traditional Ad Hoc network model, proposes an original multi-path network model which based on graph theory analysis. On this foundation, linear program theory is used to optimize this model, take analysis and solution. Then, the resulting conclusion is used to select the multi-path routing of practical Ad Hoc Networks, this paper takes the each link's average packet delay of and node's bandwidth as the optimization objective, to design and analyse the routing protocol. On this basis, this paper proposes a multi-path routing algorithm which suit for general Ad Hoc or wireless sensor network, and we establish an integrity source-destination multi-path routing protocol. Simulation results show that this method has 30% performance gain compare with traditional single-path routing, and has good adaptability and network performance.

Keywords: Ad hoc network, graph theory, multipath routing, linear program, optimization.

1 Introduction

Routing protocols are key technologies for mobile ad hoc networks. At present, there are a variety routing protocols which based on network topology information used in Ad Hoc network, such as DSDV, DSR, AODV [1,2]. But these are all single path routing protocols, the wireless channel bandwidth is limited, it is easily to cause network congestion, increase time-delay, especially undesirability in transfer some video multimedia service.

In some video multimedia service applications, the nodes of Ad Hoc network need to play video uninterrupted, smooth, which require a high demand with the network quality of service (Quality of Service, QoS), but in Ad Hoc networks, due to the inherent characteristics of wireless links, the bandwidth is smaller than wired link. Meanwhile there is no central node in Ad Hoc network, the nodes mobility may cause network circuit frequently, which is unacceptable for some real-time video services [3,4,5].

Aim at these problems, there are a lot of research proposing multi-path algorithms, and they had done a lot of QoS guarantee about the bandwidth and time-delay. References [6,7,8] proposed a multi-path scheme, the main idea is via once probe, it can find a number of disjoint paths to improve the traditional single path's shortage. However, the above algorithms do not consider the specific control of data grouping transmission time-delay and packets sequence problem, the receiver must have a large buffer to wait for all data arrived, then it can transmit data to the next node. References [9,10,11] proposed a heuristic multipath routing protocol, this algorithm searched for the maximum flow paths collection in the network, and then found the shortest path in this collection, it solved the problem of bandwidth allocation, but did not consider the time-delay problem. References [12,13,14] focused on the ”cross-layer optimization” strategies with the OSI level, for example, we can accord the video transmission characteristics, use video decoding, error control, routing protocol design and other methods to optimize the system from application layer to physical layer.

Multi-path transmission has better flexibility than single path transmission, it can avoid congestion, increase the utilization of network [15]. Some research suggest that multi-path transmission obviously improve the video quality. [16] aimed at multi-path video transmission in Ad Hoc wireless network, simply used the multiple paths from the perspective of video coding, but it did not research about packets scheduling on multiple path, lead the receiver packets reordering, time-delay was long, the buffer required larger and some such issues [17].

To sum up the past Ad Hoc network multi-path routing algorithms, it is generally existed the following

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two questions: First, parallel transmitting data generates the disorder packets; Second, it is difficult to deploy the network. For the disorder packets problem, [18] used the TCP retransmission and recovery mechanisms to take some improvement, and it should establish a pre-estimation model for the three ACK repeats response packets. [19] used a single link list to present the disorder which the multi-path generated, and it also improved the TCP protocol that the handshake can support the multiple path negotiation. [20] modified the TCP's Reno congestion control algorithm, it used a central controller to schedule all parallel multi-path parameters, transmitted packets from a total queue to the available paths, while each available path need to build a virtual retransmission queue, and the receiver's response data must follow the same path to feedback. References [21,22,23] designed a hybrid retransmission strategy, which distinguished the fast retransmission and time-out retransmission, it sent the fast retransmission packets along the original path, and sent the time-out retransmission packets to the alternate route.

Before this paper's research, we do some premises work, such as following: Let's suppose that each node working in half duplex mode, the channel is time slot allocated. The transmission time slot is organized by frame, each frame contains a fixed time slots number, and the entire network is synchronous, each frame is divided into two phases: control phase and data phase. The time slot in control phase is much smaller than the data phase. Control phase is used to realize all control functions, e.g. handshake protocol, routing selective and so on. The time slot in data phase is allocated according to the bandwidth requirement. The control phase uses a common frequency f_0 , each nodes take turns to broadcast their information to the neighbour in the pre-defined time slot, so the network control function is distributed. At the same time, for the disorder problem, we use the source node scheduling scheme, which control all the parallel multipath parameters. We use the source node which like a "total queue" send packets to the available path, this method can ensure that the destination node can assemble the grouping data into an original packet correctly.

2 System Model

Let's abstract the network model to be a graph, the system model is shown in Fig.1. In Ad Hoc network, we assume that there has I senders transmitting data to Jreceivers in the node's one hop range, moreover $i \in I$, $j \in J$, the target is choosing multi-path routes which could transmit the data packets as grouping multi-path manner to the receivers j, order the total sending flow is S_i, the total receivers receiving flow is C_j; set the link time-delay (from $i$to j) is d_{ij}, the bandwidth is r_{ij}. System model functions are as follow:

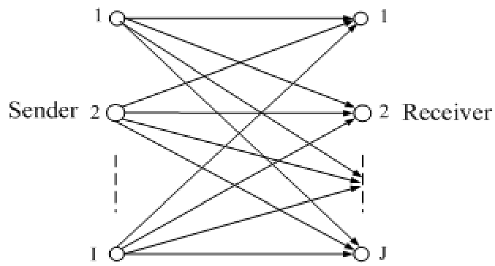

Fig. 1: graph theory model

$$\min F(x) = \sum_{i=1}^{I}\sum_{j=1}^{J} d_{ij} r_{ij} \tag{1}$$

$$s.t. \sum_{j} r_{ij} = S_i \quad \forall i = 1,2,...,I \tag{2}$$

$$\sum_{i} r_{ij} = C_j \quad \forall j = 1,2,...,J \tag{3}$$

$$x_{ij} \geq 0 \quad \forall i,j \tag{4}$$

In addition, we assume that the sending flow and receiving flow are equal, that is non-error transmission. It is content the following constraints:

$$\sum_{i} S_i = \sum_{j} \mathrm{R}_j \tag{5}$$

Eq. (1) is the path chosen criterion. From the graph theory, Eqs. (2) and (3) have $I \times J$variables of r_{ij}, have $(I+J-1)$ constraint equations, in their coefficient matrix, the number $i$and $i+j$of coefficient r_{ij}'s column vector P_{ij} is 1, and the rest is 0, that is:

$$P_{ij} = (0\cdots 1\cdots 1\cdots 0)^T = e_i + e_{i+j} \tag{6}$$

Where, $e_i = (0,0\cdots 1,0\cdots 0)^T$1 is on the position i. From the directed graph's coefficient matrix, we can know that there only $I+J-1$variables has non-zero value on the optimal solution, the other variables are zero. In other words, in this graph, only $I+J-1$arcs have flow, that is the ultimate optimal solution obtained multiple path collection. (specific process is in section 3). From the above analysis, the problem is transformed into this: when nodes I transmit data to nodes J, we should design $I+J-1$paths as the multi-path routing, the grouping data packets can transmit data according with this multiple routes, so it can optimize the network performance, save the energy consumption and other purposes. Before the specific calculation procedure, each node exchanges information through the MAC protocol (RTS\CTS\DATA\ACK), and get the average time-delay d_{ij} of each link and the node's bandwidth resource information r_{ij}, so they can serve as the Eq (1)'s parameters, simultaneous those equations, use the linear programming theory to calculate the minimum value of objective function $minF(x)$.

3 Algorithm Description

3.1 Searching multi-path

For the above system model, we consider it from the view point of linear programming, Eq.(1) has only $I+J-1$ solutions in the optimal solution. Intuitively, in the final multi-path routing, only $I+J-1$arcs has data flow. This characteristic is the foundation of these research problems, now we give the algorithm steps:

Step one: Initialize the only $I+J-1$ arcs has data flow as an initial feasible solution.

Step two: Check whether it can improve the solution by increasing a certain empty arc. If not, stop the operation, else, continue.

Step three: On the condition of constraint equations, decide how much flow can be arranged to the empty arc.

Step four: Adjust the other arcs' flow, update the network and go to the step two.

In the above algorithm implementing process, it always keeps $I+J-1$ arcs have data flow, these arcs are "foundation arcs" which corresponding to the linear programming (Lp)'s "foundation variables". When the second step determines to increase one empty arc, the fourth step must remove one original foundation arc, that is—one arc enters, one arc leaves.

The first step. The process of checking network arc's flow. The inspection process of arc (i,j) is:

(1) if $S_i < C_j$, this means the total sending flow is less than the receiving, then S_i will be arranged into arc (i,j), remove node i and the arcs which lead from node i, and update $C_j = C_j - S_i$.

(2) if $S_i > C_j$, then C_j will be arranged into arc (i,j), remove node j and the arcs which point to node j, and update $S_i = S_i - C_j$.

(3) if $S_i = C_j$, then S_i will be arranged into arc (i,j), remove node i and the arcs which lead from node i, and remove node j and the arcs which point to node j.

In the process of above inspection, who is first checked is very important, it determines the initial feasible solution is good or bad, when the algorithm executes only one sender and one receiver, it can be stopped. At this moment, if the network lefts only one sender, we arrange its all data flow on the corresponding arcs according to the receivers required flow, if the network lefts only one receiver, we assign all the senders surplus flow to it.

An effective checking arc's sequence is called " penalty" method. This method assigns each node a penalty value first, then the maximum nodes' penalty is selected. If the node is a sender, e.g. node i, let $\min_j\{d_{ij}\} = d_{is}$'s arc (i,s) first be checked; If the node is a receiver, e.g. node j, let $\min_j\{d_{ij}\} = d_{rj}$'s arc (r,j) first be checked. One arc is checked over, we update the network, and then recalculate the nodes' penalty value, till left only one sender or receiver.

Node's penalty value calculation:

For the sender node, the node i's penalty value $p_i = |d_{is} - d_{is'}|$, where $d_{is} = \min_j\{d_{ij}\}$,$d_{is'} = \min_{j\neq s}\{d_{ij}\}$;

For the receiver node, the node j's penalty value $p_j = |d_{rj} - d_{r'j}|$, where $d_{rj} = \min_i\{d_{ij}\}$, $d_{r'j} = \min_{i\neq r}\{d_{ij}\}$.

The following example illustrates this solving process.

Fig.2 contains four senders and three receivers, each node's flow r_{ij} is shown in the figure, the arc is marked the weight d_{ij}. The target is determining a set of multi-path routing to make the network consumption minimum.

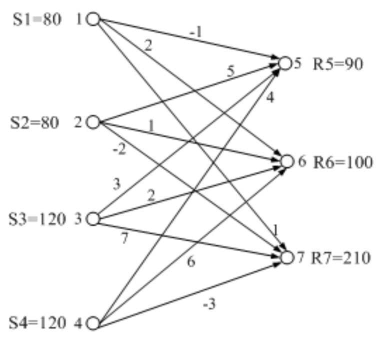

Fig. 2: The network topology structure

Table 1 shows the node's "penalty value". As can be seen from the table, node 4 has the highest penalty, and there has three arcs send out from node 4, (4,7) is the minimum cost, so the arc (4,7) is first checked. The continuous node's calculating and arcs checked are similar with the node 4.

Table 1: node's "penalty value"

sender	1	2	3	4
penalty value	2	3	1	7
receiver	5	6	7	
penalty value	4	1	1	

Fig.3 shows the solution process.

The initial feasible solution is summarized in Fig.4, the arcs that does not draw are empty arc.

The second step. The arc which enter the "foundation arcs" should make the objective function value improved. An effective way of determining what kind arc can enter the "foundation arcs" is to investigate the constraint Eqs. (2) $\sim$ (3)'s dual variables. Let's assume the Eqs. (2) $\sim$ (3)'s dual variables are $\{u_i\}$ and $\{\lambda_i\}$. Then the objective

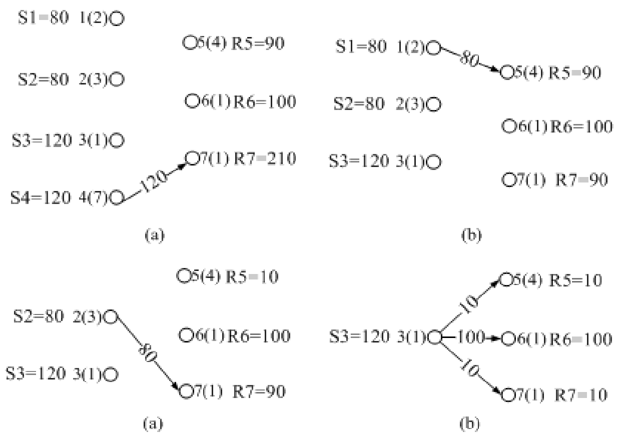

Fig. 3: The process of solving the initial feasible solution

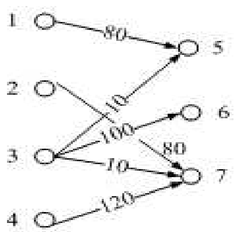

Fig. 4: The initial feasible solution (foundation arcs)

function $F(x)$'s minimum conditions are:

$$(d_{ij} - u_i - \lambda_i)x_{ij} = 0 \quad (7)$$

$$d_{ij} - u_i - \lambda_i \geq 0 \quad (8)$$

In fact, the algorithm's target is to find a solution $\{x\}$ that can satisfy the Eqs. (7) $\sim$ (8), make the $(I+J-1)$ arcs have flow, and they are foundation arcs, while the left $(IJ - I - J + 1)$ arcs are empty. Obviously for the foundation arcs, Eqs. (7) $\sim$ (8) should satisfy: $x_{ij} \geq 0$, then $d_{ij} - u_i - \lambda_i = 0$; for the non-foundation arcs, due to the iteration has not reached the optimum, Eqs. (7) $\sim$ (8) are remain not satisfied, then,

$$e_{kl} = d_{kl} - u_k - \lambda_l < 0 \quad (9)$$

Where e_{kl} is the "residual cost", if part of the foundation arcs transfer into the arc (k,l), order $r_{kl} > 0$, then $e_{kl} < 0$, and this is not violated Eqs. (7) $\sim$ (8) conditions, then the iteration stride forward the optimal solution. If the "residual cost" has more than one arc, it could random choose one arc into the foundation arcs. If the arc which content Eq.(9) does not exist, the iteration can be stopped, it means we have already found the optimal solution.

In order to calculate the "residual costs", we must know all dual variables $\{u_i\}$ and $\{\lambda_i\}$. For the foundation arcs, $r_{ij} \geq 0$, then $d_{ij} = u_i + \lambda_i$, like this equations have number of $(I+J-1)$, while the unknown variables $\{u_i\}$ and $\{\lambda_i\}$ have number of $(I+J)$, so it must set an arbitrary value (such as set u_1=0) to the one of the unknown variables, the other unknown variables will be determined as independent, the value of dual variables are confirmed as follows:

$$[u_1 = 0] \rightarrow [\lambda_5 = -1] \rightarrow \begin{bmatrix} \lambda_6 = -2 \\ \lambda_7 = 3 \end{bmatrix} \rightarrow \begin{bmatrix} u_2 = -5 \\ u_3 = 4 \\ u_4 = 6 \end{bmatrix}$$

Then we can calculate the "residual costs" of all non-foundation arcs, as shown in Table 2, the "residual costs" of arc (1,7) is negative, so it can enter the foundation arcs, till to now, the algorithm's second step is completed.

Table 2: "residual costs" of all non-foundation arcs

to / from	5	6	7
1		4	-2
2	11	8	
3			
4	11	14	

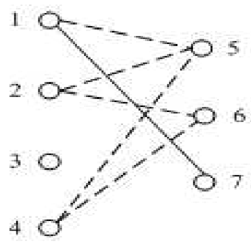

Fig. 5: Non-foundation arc enter into the foundation*[1]

The third step. This step is to determine how much flow should be arranged into the entered foundation arcs, and which arc should be get away from the foundation arcs (the flow turn into zero). It can search a "closed chain" which contains the entered foundation arcs to achieve this target. In the undirected graph which consists with foundation arcs and prepares to enter the foundation arcs, the "closed chain" is the closed arcs sequence which consisted with this undirected graph's edge.

As shown in Fig.6, the "closed chain" which contains arc (1,7) is indicated by the solid line, they contain the nodes 1,5,3,7.

When the "closed chain" is found, if the arc (1,7) increases the flow, then its adjacent arcs flow have to

[1] Note: The solid line means get into the foundation arcs

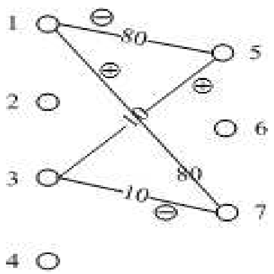

Fig. 6. "closed chain" schematic diagram

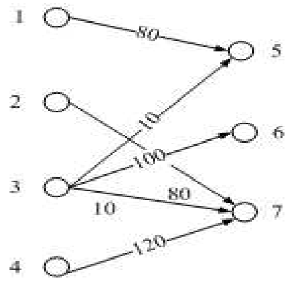

Fig. 8. The result of linear programming algorithm

reduce, this relationship always set up in the adjacent arc. According to this principle, we mark all "closed chain" arcs with signs, $\oplus$ means the arc should increase flow, Θ means the arc should reduce flow.

Now we arrange the flow that entered the foundation arc (2, 4), it should be the minimum value which marked with Θ arcs in the existing flow, in Fig.6, this value is $\min\{10,80\} = 10$. So the flow of arc (1,7) flow will increase from 0 to 10, the flow of arc (1,5) will reduce from 80 to 70, the flow of arc (3,5) will increase from 10 to 20, while the flow of arc (3 , 7) will reduce from 10 to 0, and it is arranged out of the foundation arcs.

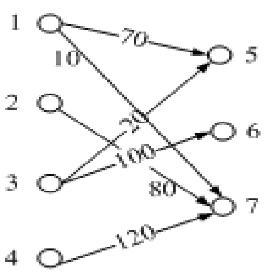

Fig. 7. optimal solution (multi-path routing result)

Fig.7 shows the result after the changes, this is the fourth step of this algorithm. In this step, only one arc enter into the foundation arcs, one arc exit out the foundation arcs, this can ensure the foundation arcs number always has $(I+J-1)$ in the iteration process. Go to the step two, the calculated dual variables and "residual cost" are shown in Fig.7, because all of the "residual cost" are positive value at this moment, so the algorithm can be stopped, and Fig.7 is the optimal solution. The corresponding objective function value is $\min F(x) = -320$.

The same topological structure, [9] which used the linear programming algorithm get the foundation arcs is shown in Fig.8, the corresponding objective function value is $\min F(x) = -310$. Thus it can be seen that this paper's algorithm has some improvement in network time-delay and bandwidth consumption.

3.2 Dynamic parameters

Based on the above algorithm, now we use it into the multi-hop network, the aim is to find $(I+J-1)$paths in $I+J$nodes, and choose one route which make the objective function $F(x)$'s value smallest. From $\min F(x) = \sum_{i=1}^{I}\sum_{j=1}^{J} d_{ij}r_{ij}$, if we get the average link time-delay and each node's bandwidth, take them as the parameters of Eq.(1), then we can find the optimal route.

Parameter one: time-delay. For a single node in the Ad hoc network, time-delay is from the data stream's queuing delay, processing delay, transmission delay and so on. For a single packet, queuing delay is influenced by the network congestion, while the processing delay and transmission delay are more fixed. From the queuing theory, we know that nodes receiving and sending data could use Markov $M/M/1$ service model to analyse. According to Little formula, the average time-delay of data packets is given as follow:

$$D = \frac{\lambda}{\mu(\mu-\lambda)} \tag{10}$$

Where, λ is the packet arrival rate, μ is the packet transmission rate, and $\mu > \lambda$. Eq.(10) is generally used in wired network, because the nodes in wired network are not affected with each other, but in Ad hoc network, each node uses the same wireless channel, they will be interference with each other, here we need to introduce a variable B which represents the node's service rate, and it will replace the Eq.(10)'s μ.

Definition 1:

$$\mu = B - \lambda \tag{11}$$

Then the average time-delay of the packet is:

$$D = \frac{\lambda}{(B-\lambda)(B-2\lambda)} \quad \lambda < \frac{B}{2} \tag{12}$$

Parameter two: bandwidth. In the process of Ad Hoc Network's video service transmission, to guarantee QoS requirements, the most important thing is how to calculate and set aside the available bandwidth. In order to calculate the bandwidth restrict route, it is not only to know each link's available bandwidth, but also to know how to schedule these bandwidth. Resource scheduling is described in the multi-path routing design section, here we use the leisure time-slots to measure each link's available bandwidth. Before introducing the bandwidth, let's do the definition of following variables:

Definition 2: the hidden terminal and exposed terminal bring about the packets collision problem can be shown as the conflict graph, we import the conflict limited function $conflict(i,j,t)$, 1 means the link i and j have conflicted at time-slot t, otherwise it equals 0.

$$conflict(i,j,t) = \begin{cases} 1 & if \quad clash \\ 0 & else \end{cases} \tag{13}$$

We colour the time axis to indicate conflict and non-conflict time slots, which constitute a packets collision collection. In this collection, packets are not conflicted, and they can be transmitted; for the conflict packets, here we use traditional binary backoff algorithm to retransmit the packets. For this reason, we set $L(t)$ is the time t's $conflict(i,j,t)$ collection before the definition 3, it presents the packets collision collection of certain moment on the time axis.

Definition 3:

$$I_x = \begin{cases} 1 & if \quad true \\ 0 & else \end{cases} \tag{14}$$

Where, symbolic function I_x is imported, 1 means the constraint condition is true, otherwise it equals 0. The constraint condition refers to the time slot which $conflict(i,j,t) = 0$ in the link collection $L(t)$ at the moment t, they are also the packets non-conflicted time slots.

Definition 4: $R_{it}(t)$ is the average bandwidth of link i at the moment t.

$$R_i(t+1) = \frac{t_c - 1}{t_c} R_i(t) + \frac{1}{t_c} r_i(t) I_{i \in L(t)} \tag{15}$$

Where, t_c means the average size of the statistic time window. $r_i(t) I_x L(t)$ are already defined.

To sum up, let's take Eqs. (12) and (15) into (1), that is:

$$\min F(x) = \sum_{i=1}^{I} \sum_{j=1}^{J} D_{ij} R_i(t+1)_{ij}$$

$$= \sum_{i=1}^{I} \sum_{j=1}^{J} \frac{\lambda_{ij}}{(B_{ij}-\lambda_{ij})(B_{ij}-2\lambda_{ij})} \times (\frac{t_c-1}{t_c} R_{ij}(t) + \frac{1}{t_c} r_{ij}(t) I_{ij \in L(t)})$$

$$= \sum_{i=1}^{I} \frac{\lambda_i}{(B_i - \lambda_i)(B_i - 2\lambda_i)} \sum_{j=1}^{J} (\frac{t_c - 1}{t_c} R_j(t) + \frac{1}{t_c} r_j(t) I_{j \in L(t)}) \tag{16}$$

So the multi-path we selected is to make the Eq.(16) minimum. The grouping multi-paths are:

$$R = \{R_i | F_i = \min F_j, j \in (1,2,\cdots I+J-1)\} \tag{17}$$

4 Source-destination route establishment

Eq.(17) is generally used for theoretical analysis, it provides the basis of choosing routes. Actually, the average time-delay of Ad Hoc network has some deviation with Eq.(17). According to Eq.(17), it is imprecise to distribute the dynamic flow. so we present an adaptive flow distribution algorithm which suit for the practical network, then take resource consumption as the direct target. Because the path time-delay and bandwidth resources can be measured through the Internet Control Message Protocol (ICMP)'s Packet Internet Grope (PING) function, so we multiply these two parameters as the flow distribution criterion, achieve the total flow's dynamic allocation in the multi-path. We according to the above multi-path algorithm and the actual characteristics of mobile multi-hop network, present the following source-destination route establishment process:

Step 1, start the initial state, as shown in Fig.9, the source node S broadcasts the grouping data packets, transmit them to the I nodes within one hop range, set the allocation factor $a_{k,0} = L/I$, I is the path number, L is the total flow of source.

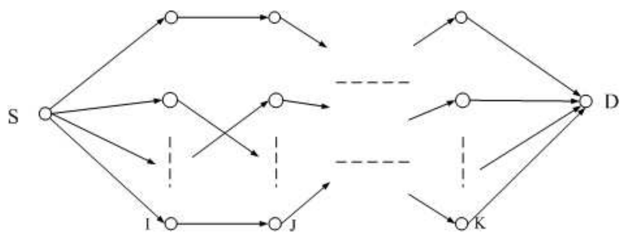

Fig. 9. Ad Hoc multi-path flow distribution model

Step 2, the I nodes receive the grouping data packets, according to the multi-path algorithm in section 3.1, in one hop range, the nodes send these multi-streaming data packets to next hop J nodes (find $I+J-1$ paths in $I+J$ nodes).

Step 3, we stat the detection process of grouping data time-delay and the node's surplus bandwidth resources. Time-delay detection is similar with IGMP's PING function, the source node sends test packets along with each path, and marks with time stamps T_i on them, when the test packets arrive the destination node D, mark with time stamps T_j again, and return these packets on the original path, so the average time-delay is $E(T_j - T_i)$. Node's bandwidth resource is calculated through each node needs to maintain a bandwidth field, the specific calculation process is shown in Fig.10, where each node respectively calculates their bandwidth through *DATA* and *CTS* frames according to Eq.(15), at the same time all test packets load their bandwidth information and return on the original path. When the test packets return to the source node, it will calculate the multiply of each link's average time-delay and bandwidth according to the test packets information. The multi-path has been allocated, then each path's data flow is redistributed according to the returned test packets, so that it can generate the dynamically adaptive routing.

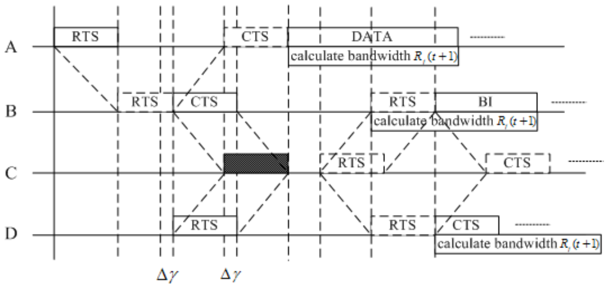

Fig. 10. time sequence diagram of calculating bandwidth

Step 4, delay after a measurement interval, repeat steps 2-3.

Based on the above analysis, the route takes the time-delay and bandwidth as the measurement criterion. For the changes of network inherent and pre-distribution flow, the algorithm could adaptively adjust, so the routing protocol can also dynamically adjust, then the network will achieve the purposes of load balancing. This way can make network resources consumption minimum, always make the self-organizing network working in the optimal state.

5 Simulation Results

In order to validate this paper's algorithm MNMRP (Maximum Network Multi-Path Routing Protocol) effectiveness, we build up the simulation experiments to verify the analysis. We use NS-2 and the CMU (Carnegie Mellon University) which providing the wireless expansion modules to simulate. Simulation uses NS-2 modules to generate the node, the mobile nodes are average distributed in 2000m $\times$ 2000m area. We set the link available bandwidth average distributed from 110*Mbps*. In order to facilitate the experiment, the source node is set at (0m, 1000m), and the destination node is set at (2000m, 1000m), and the bandwidth requirement of source node is set 5*Mbps*. The nodes number are 10, 20, 30, 40, 50, then we respectively simulate the selectivity shortest path algorithm (choosing the shortest path which satisfy the bandwidth requirement), heuristic multi-path routing (searching for the network maximum flow) [7] and this paper's algorithm (MNMRP).

The simulation emulates the success rate of searching path first. It can be seen from Fig.11, the selectivity shortest path algorithm has low success rate, and with the nodes density increase, the success rate of their searching path has little changed, and it will gradually decrease. The other two algorithms consider the bandwidth's optimal problem, their searching path have higher success. But with the network nodes density increasing, the network consumption will be gradually increased. When it reaches the maximum loading, these three algorithms will greatly reduce the success rate of searching path, and the link interrupt will increase, this is also the multi-path routing's bottleneck, the general multi-path routing suit for the scene with little nodes number. the selectivity shortest path algorithm also consider the bandwidth requirement, but it only chooses one path, so its performance is still lower than the multi-path routing, especially under the high bandwidth requirement.

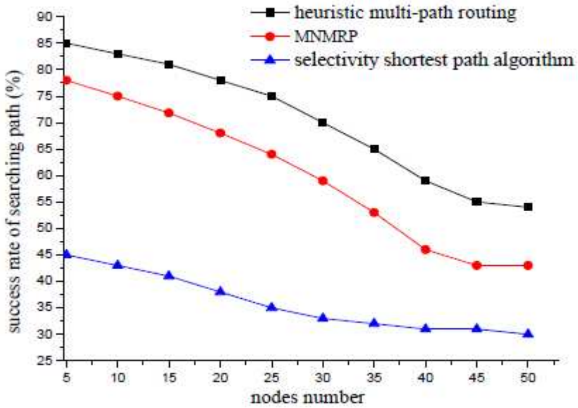

Fig. 11. the success rate of algorithms search path

In the case of little nodes number, MNMRP's success rate of searching path is little difference with the optimal heuristic algorithm, this is because the heuristic algorithm have priority considered the high bandwidth links, it is easily satisfied the bandwidth requirement, while the advantage of MNMRP fully considers the time-delay and bandwidth factors which make the best of network resources, it has the practical operation. With the nodes density increasing, the system needs the time-delay requirement more and more accurate, then the advantage of MNMRP is obviously advanced, and these two curves tend towards accordance finally.

Let's re-use the above environment, compare with the time-delay of every routing algorithms, as shown in Fig.12. We select the longest path time-delay as the multipath time-delay. This is because the multi-path transmission data generally transmit on each path as grouping data packets, these packets reach the receiver usually disorder, it needs to set up a buffer to cache these packets at the receiver, we can assemble all packets sequence after the longest path packets arrive.

In the Fig.12, because the selectivity shortest path algorithm only considers the bandwidth requirement, it will remove the link which dissatisfy the bandwidth condition, thus it increases the number of hops, causes the nodes which on the route path have large number, and too long time-delay. The heuristic multi-path routing algorithm has the similar reasons, the multi-path routing reduces the number of routing hops, but it sacrifices the link's time-delay to exchange for the bandwidth utilization. MNMRP takes into account the time-delay and bandwidth factors, its time-delay performance is most close with the selectivity shortest path algorithm. With the nodes number increasing, the bandwidth utilization increases, and the link time-delay gradually reduces, finally the curves tend towards stable.

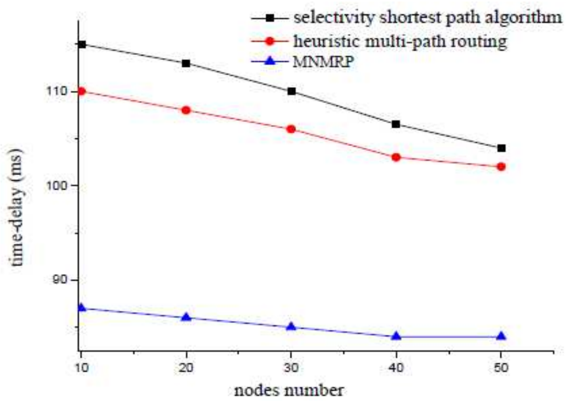

Fig. 12. time-delay comparison

6 Conclusion

This paper presents a classic model of multi-path graph theory, uses the linear programming theory to optimize and analyse this model, then uses the final conclusion into the practical application of Ad Hoc Network multi-path routing. We take each link's average time-delay and node's bandwidth as the optimal target, then design the Ad Hoc Network multi-path routing. On this basis, according to the actual network conditions, this paper presents a multi-path routing algorithm which suits for general Ad Hoc or wireless sensor network, and builds an integrated source-destination route algorithm, this algorithm has great advantage on the grouping data time-delay and network bandwidth consumption. Simulation results show that without considering the network's interrupt, the comprehensive terms of network bandwidth utilization and average packet time-delay performance have improved about 30% more than traditional single-path route. The future research will focus on the routing reliable, and reduce the probability of interrupt route.

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