Interfering-aware QoS Multipath Routing for Ad Hoc Wireless Network

Ying-Hong Wang
Department of CSIE, Tamkang University
inhon@mail.tku.edu.tw

Hung-Zu Lin
Department of CSIE, Tamkang University
g7190063@tkgis.tku.edu.tw

Shu-Min Chang
Department of CSIE, Tamkang University
691190317@s91.tku.edu.tw

Abstract

Mobile nodes are interconnected by multihop routing paths consist of unstable radio links in ad hoc wireless network. It is complex and difficult to provide QoS routing in such network because of imprecise network information, insufficient bandwidth and dynamic topology. For improving network stability and throughput, multipath routing protocols are proposed. A sender node will discover multiple disjoined routing paths and spread traffic into multiple streams according to their delay or bandwidth. For real-time streaming, unstable throughput or insufficient bandwidth will invite unexpected delay or jitter if it is a multimedia streaming. Some multipath routing protocols pre-evaluate available bandwidth of paths and select enough total bandwidth from them if real-time applications demand for QoS constraint. For minimizing the cost of these paths, a path with smaller hopcounts will be prior selected. These disjoined paths are general too closed with each other and the total throughput cannot just be sum up because of "paths interfering". Discovering and selecting multiple high-interfering paths is ineffectual and the total available bandwidth is not precise. In this paper, we proposed an interfering-aware QoS multipath routing protocol for QoS-constraint multimedia and real-time applications in ad hoc wireless network. We apply a scheme to evaluate available bandwidth according to the network capacities with different Media Access Control (MAC) protocols. A concept of "Interfering ratio" of multipath will be discussed and we evaluate the stability and throughput improvement by simulations.

1. Introduction

In ad hoc wireless network, mobile nodes communicate to another without any fixed and preset infrastructure. Mobile nodes may roam to any place at any time arbitrarily. In order to communicate to another node beyond the sender's radio range, one of multihop routing protocols is used for discovering a routing path and the intermediate nodes belong to this path forward the packet voluntarily. The wireless radio link may be interrupted because one of the mobile nodes moves out from the original radio radius, run out of its battery or just be turn off by user. The routing path between sender and the receiver is also be fractured. Many well-studied ad hoc wireless routing protocols, like Dynamic Source Routing (DSR) or Ad hoc On-Demand Distance Vector Routing (AODV), will rebroadcast the "*Path Discovery Messages*" and try to search another routing path. A new discovered path may become impossible instantly even before starting to route if the changes in network topology occur too frequently. The network topology may change again before the last topology updates are propagated to all intermediate nodes.

In a multimedia application, it would lead to delay and multimedia objects unsynchronized while constructing a new routing path. If there are too many high-mobility nodes in this network, the characteristic of this unstable topology will bring path discovery messages flooding into the whole network. Furthermore, the new routing path may not have enough available bandwidth to serve the original quality-of-service (QoS). To alleviate this problem, many new protocols were proposed by extending "backup nodes" or "backup paths" scheme to DSR or AODV for forwarding packets temporarily until a new routing path discovered. Backup Routing in Ad hoc Networks (AODV-BR), proposed by Lee and Gerla in [1], was for alleviating packets delay problem while rediscovering a new routing path by intermediate backup nodes. Those backup nodes are arranged when route discovery phase and would forward packets automatically if they detect the original radio link is failure.

Real-time or multimedia applications in ad hoc wireless network are restricted by the unreliable radio link and insufficient bandwidth. Backup nodes or backup paths protocols can forward packet temporarily but cannot increase the total throughput if the original routing path have no sufficient bandwidth. Thus, a backup routing path can be used to increase the total throughput by sender dispatch traffic into those disjoined backup paths. This notion of multiple routing paths protocol not only increases network throughputs but also advances the stability in the ad hoc wireless network. Tsirigos and Haas proposed a scheme in [2] for fragmenting packet into small block and distributed those block into available multiple paths. It will add some overhead to each packet, but it is also with a lower failure probability. Network

Proceedings of the 18th International Conference on Advanced Information Networking and Application (AINA'04)
0-7695-2051-0/04 $ 20.00 © 2004 IEEE

traffic is dispatched over multiple disjoined paths to minimize the packet drop ratio and improve the end-to-end delay. In addition to, there are numbers challenges must be overcome to construct and maintain multiple loop-free routing paths dynamically. Multipath Source Routing (MSR) [3] proposes a multiple paths routing protocol extended from DSR. The route discovery phase in DSR will return multiple disjoined paths intrinsically. MSR chooses a round-robin load distribution "*Weight*" according to a heuristic equation. Multipath Source Routing protocol (MP-DSR) proposed by Leung in [4], focuses on "end-to-end reliability". A selection algorithm is used for selecting multiple "low-fail-probability" paths and those low-fail-probability paths are associated by stable radio links. Marina and Das proposed an Ad-hoc On-demand Multipath Distance Vector routing protocol (AMODV) in [5] based on the concept of link reversal extending from AODV. Different with constructing disjoined paths in other DSR-based routing protocols, AMODV discovery multiple disjoined "links" for traffic distribution. Thus, the paths connected with those links in AMODV may have one or more common nodes and may lead to paths looping. To avoid this, AMODV introduce the "advertised hopcount" and "route list" into routing table entries.

For real-time applications, how to maintain a stable and sufficient bandwidth are key issues. Unstable network traffic will lead to multimedia presentation delay or jitter; insufficient bandwidth will interrupt presentation and wait for multimedia objects transmission. Allocating a great buffer may mitigate this problem, but it will increase the buffer prefetching time and consume the network resources in wireless multimedia system. A proper solution is QoS-constraint routing protocol. But many proposed protocols only support best-effort service, it transport packets to their intended destination without any guarantee. Chakrabarti present some basic concepts and discussion about QoS issues in ad hoc wireless network in [6]. Many challenges and solutions about path repairing, alternative routing and redundant multipath routing are also been discussed. Hwang and Varshney proposed a QoS constraint multiple paths on-demand routing protocol (ADQR) in [7]. ADQR is an ADOV-based protocol; the sender will broadcast Route_Request packet with QoS metrics, link classes and the other information if it has no route to receiver. In order to provide end-to-end QoS, ADQR assumes each node can evaluate the link bandwidth. Multiple disjoined paths with evaluated bandwidth will be discovered.

To minimize routing costs, the second disjoined and the other paths are generally beside the first one because the hopcounts of the first path is minimized. But, if the two disjoined paths or links are too close, the nodes belong to those paths will interfere with each other while transmitting. The total throughput of two high-interfering paths will not achieve to their pre-evaluated bandwidth.

2. Media Access Control Protocols

For ad hoc wireless network, sharing channel and contention-based random access protocols are proposed without central arbitration. The network performance or capacity is based on MAC protocol in use. For example, a pure ALOHA protocol, the maximum capacity is 0.184 and the maximum capacity of slotted-ALOHA is 0.368 shown in [10]. The channel utilization will decrease if more traffic load arrives. A MAC protocol must be designed carefully for frame collision and offer more efficient frame transmission. In order to increase the throughput, Carrier Sensing Multiple Access (CSMA) and CSMA with Collision Avoidance (CSMA/CA) are proposed for lower frame collision probability. For example, IEEE 802.11 Distributed Coordination Function (DCF) can be involved for avoiding the frame collisions. However, collisions are still possible if more then one frames come to a node at the same time. "Hidden terminal" and "exposed terminal" problems still impact on capacity of ad hoc network. Many researches try to solve these problems by RTS/CTS dialogue. But, RTS/CTS type MAC protocols solve neither the hidden- nor the exposed-terminal problems. Haas and Deng illustrated these problems in [9] and proposed a Dual Busy Tone Multiple Access (DBTMA) scheme to solve these problems by a separated busy tone channel.

3. Interference and bandwidth evaluation

In common channel ad hoc wireless network, packet transmission might be not successful because of collision. The transmitting frame will be harmed if other mobile node, within the interfering range of receiver, transmits another frame simultaneously. Fig. 1 shows a mobile node j will receive a frame from node i successfully if $| j - i |$ (the distance between j and i) $< \boldsymbol{R}$ (the communication radius) and another other node k does not send another frame using the same channel within the interfering radius $\boldsymbol{R}_{\mathrm{I}}$.

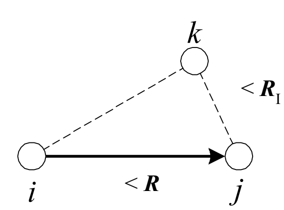

Figure 1. Node *k* will restrict its transmission if node *j* is receiving frame from node *i* using the same channel

0-7695-2051-0/04 $ 20.00 © 2004 IEEE

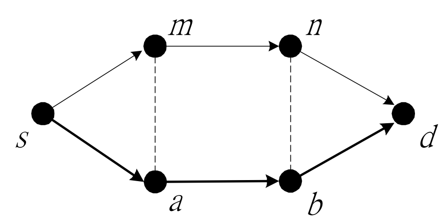

Figure 2. A simple multipath interfering scene

The transmission power of sender needs to be regulated. The transmission power is bounded to high enough to reach the intended receiver with a minimal transmission power. The higher transmission power led to longer radius to interfere other neighbor nodes. This will impair the capacity of wireless network and diminish the battery life of mobile devices. But, lower transmission power with a short communication radius would cause the routing hops increment and transmission delay extension

The heavy network load would decrease the network utilization because frames collision, deferred access and random back-off contention windows. For example, consider the scene shown in Fig.2 using a pure ALOHA scheme, we assume that node M pre-evaluates its available bandwidth to N is δ bits/sec. If A tries to send γ Kbit/sec to B, it will generate $\hat{\gamma}$ frames because of frames collision probability with the other network traffic arriving according to Poisson distribution.

$$\hat{\gamma} = \gamma \cdot e^{2\lambda t} + \Delta$$

If node A sends $\hat{\gamma}$ Kbit/sec frames to B, the other nodes, which are receiving frames within radius of A, will also increase their frame collision probability. Their senders will try to retransmit more frames if they want to maintain their QoS persistently. We assume extra Δ frames will be sent into the region by node A. Furthermore, node M will re-evaluate its available bandwidth $\hat{\delta}$ by:

$$\hat{\delta} = \delta \cdot e^{-2\lambda t} \cdot e^{-\hat{\gamma}}$$

If more and more frames are sent into the region, the pure-ALOHA will attain its maximum effective channel utilization ratio to 0.184 and the slot-ALOHA will attain to 0.368, analyzed in [10]. A high performance MAC will increase total channel throughput in ad hoc networks. The effective channel utilization is generally given by

$$S = \frac{\overline{U}}{\overline{B} + \overline{I}}$$

where $\overline{U}$ is the average utilization period, $\overline{B}$ is the expected duration of a busy period and $\overline{I}$ is the expected time of the idle period. Let P_s is the probability of success of transmitting a packet, T_s is the successful transmission period, T_f is the average failed busy period and the packet transmission time is δ. The average utilization period is given by

$$\overline{U} = P_s \delta$$

and the expected duration of a busy period is given by

$$\overline{B} = P_s T_s + (1 - P_s) T_f$$

An idle period is the time between two consecutive busy periods. We assume the packets arriving rate is λ and we have

$$\overline{I} = \frac{1}{\lambda}$$

Finally, we obtain the channel throughput

$$S = \frac{P_s \delta}{P_s T_s + (1 - P_s) T_f + 1/\lambda}$$

The available bandwidth can be mathematically evaluated by calculating how many packets are transmitting into the network and the probability of success transmitting P_s. But, in ad hoc wireless network, available bandwidth is complicated to be pre-evaluated according to complicated landform and varied topology.

4. System Model

A network ***G*** is modeled as a graph ***G*** = (***V***, ***E***) as a finite set ***V*** of the mobile nodes. Each mobile node has a unique ***ID*** and can migrate arbitrarily. ***E*** is a set of bi-direction, wireless radio links between the mobile nodes. A one-hop communication radius of node i is defined as ***R***(i). The one-hop communication link is defined as ***L***(i, j) $\in E$ if a mobile node i , $j \in$ ***V*** is within the one-hop communication radius ***R***(i). The communication link ***L*** may disappear because of the node mobility or just the mobile device be power off. The neighbors of node i are defined as ***N***(i) which is a set of mobile nodes within the one-hop communication radius ***R***(i). A path from source node s to destination node is defined as ***P***(s, d) = {s…d}, which is as a sequence of intermediate nodes between node s and node d without loops. ***MP***(s, d) is defined as the set of all possible disjoint paths from s to d, such that

$$MP(s, d) = \{ P_1(s, d), P_2(s, d), \ldots , P_n(s, d)\}.$$

4.1 QoS Metrics

The evaluated available bandwidth ***B*** between adjacent nodes i and j is represented by ***B***(***L***(i, j)). In this paper, we assume any mobile device in ad hoc network can measure the available bandwidth. The available bandwidth between i and j is evaluated not only by the packets flow through the radio link ***L***(i, j) but also the other background packet flow through ***N***(i) because of

Proceedings of the 18th International Conference on Advanced Information Networking and Application (AINA'04)
0-7695-2051-0/04 $ 20.00 © 2004 IEEE

interference. We assume available bandwidth of all links from a sender node is all the same $\boldsymbol{B}(i) = \boldsymbol{B}(\boldsymbol{L}(i, \boldsymbol{N}(i)))$. The bandwidth $\boldsymbol{B}(\boldsymbol{L}(i, j))$ and $\boldsymbol{B}(\boldsymbol{L}(j, i))$ might not be equal because their capacity region is not the same. $\boldsymbol{B}(\boldsymbol{P}(s, d))$ is defined as the available bandwidth of the routing path from source node s to destination node d and

$$\boldsymbol{B}(\boldsymbol{P}(s, d)) = \text{minimum}\{\boldsymbol{B}(\boldsymbol{L}(s, i)), \boldsymbol{B}(\boldsymbol{L}(i, j)), \ldots, \boldsymbol{B}(\boldsymbol{L}(k, d))\}.$$

The total available bandwidth with multiple path routing is defined as

$$\boldsymbol{B}(\boldsymbol{MP}(s, d)) = \sum \boldsymbol{B}(\boldsymbol{P}_i(s, d)), \text{ where } \forall\, \boldsymbol{P}_i \in \boldsymbol{MP}(s, d),\ 1 \le i \le n.$$

In this paper, we define the operator " || " to represent two or more links (or paths) transmitting data simultaneously at a short "time period". The bandwidth cannot represent the actually network throughput, we represent the actually radio link throughput by $\boldsymbol{T}(\boldsymbol{L}(i, j))$ and a path throughput by $\boldsymbol{T}(\boldsymbol{P}(s, d))$. As the bandwidth, if two or more paths transmission data simultaneously, the total actual throughput is represented as $\boldsymbol{T}(\boldsymbol{P}_1 \parallel \boldsymbol{P}_2 \ldots \parallel \boldsymbol{P}_n)$ and the actual total throughput by transmitting through multiple paths is represented as

$$\boldsymbol{T}(\boldsymbol{MP}(s, d)) = \sum \boldsymbol{T}(\boldsymbol{P}_i(s, d)), \text{ where } \forall\, \boldsymbol{P}_i \in \boldsymbol{MP}(s, d),\ 1 \le i \le n.$$

4.2 Interfering Ratio

Interfering ratio, in this paper, is not the precise electromagnetic theory. We do not focus on the electromagnetism meticulously or the special wireless communication hardware, like antenna, output power, or the other electromagnetic properties. We assume the interfering ratio can be measure by the wireless device or be preset by the engineer based on the multiple access methods. The path interfering ratio is evaluated and represented by

$$I(P(s_1, d_1), P(s_2, d_2)) = \frac{T(P(s_1, d_1) \parallel P(s_2, d_2))}{B(P(s_1, d_1)) + B(P(s_2, d_2))}$$

where $\boldsymbol{B}(\boldsymbol{P}(s_1, d_1), \boldsymbol{P}(s_2, d_2)) \neq 0$, and $\boldsymbol{T}(\boldsymbol{P}(s_1, d_1) \parallel \boldsymbol{P}(s_2, d_2)) \le (\boldsymbol{B}(\boldsymbol{P}(s_1, d_1)) + \boldsymbol{B}(\boldsymbol{P}(s_2, d_2)))$.

4.3 Path-Stable-Time

The Link-Stable-Time is assigned the time value of pre-evaluated link stability according to the relative moving speed, distance and the strength of signal. With the variation of signal strength, we can appraise A wireless link with a short stable time under a threshold would not participate in routing paths. The Link-Stable-Time is represented by $\boldsymbol{S}(\boldsymbol{L}(i, j))$ and the Path-Stable-Time is represented by

$$\boldsymbol{S}(\boldsymbol{P}(s, d)) = \text{minimum}\{\boldsymbol{S}(\boldsymbol{L}(s, i)), \boldsymbol{S}(\boldsymbol{L}(i, j)), \ldots, \boldsymbol{S}(\boldsymbol{L}(k, d))\}.$$

The path-stable-time is used in route maintenance. If the stable time of a path is going to be expired, the source node will discover a new path with available bandwidth that is equal or larger then the original one.

4.4 Problem statement

A source mobile node $\boldsymbol{S}$ tries to communicate to its destination mobile node $\boldsymbol{D}$ with a bandwidth constrained δ. Many multiple disjointed routing paths from $\boldsymbol{S}$ to $\boldsymbol{D}$ will be discovered and source node will try to select multiple paths $\boldsymbol{MP}'(\boldsymbol{S}, \boldsymbol{D})$ with authentic total bandwidth $\boldsymbol{T}(\boldsymbol{MP}'(\boldsymbol{S}, \boldsymbol{D})) \ge \delta$, where $\boldsymbol{MP}'(\boldsymbol{S}, \boldsymbol{D}) \subseteq \boldsymbol{MP}(\boldsymbol{S}, \boldsymbol{D})$.

5. Interfering-aware Multipath Routing Protocol

In this paper, we propose an Interfering-aware Multipath Routing Protocol (IMRP) with QoS constraint for real-time or multimedia applications. IMRP is a source initialized, on-demand, and multiple paths routing protocol. With available bandwidth pre-evaluation and Interfering susceptibility, IMRP will reduce the call dropping rate and improve the QoS stability. A well-designed multipath routing protocol will make $\boldsymbol{I}(\boldsymbol{MP}')$ approximate to 1 (the evaluated bandwidth is approximate to real throughput).

5.1 Route Discovery Phase

If a mobile node tries to transmit data to its designated destination but does not have any routing information in its routing table, or those paths have insufficient bandwidth to this destination, it pre-reserves the bandwidth and broadcasts a "Route Discovery Packet" (RDP) packet into the network. This packet carries <request ID, source ID, destination ID, intermediate nodes, QoS metric, QoS constraint, Time-To-Live (TTL) and Path-Stable-Time> routing information. Another node, which receives this packet, will broadcast this packet again. If it has no available bandwidth, discard it. If a source node does not need to specify QoS constraint, it set <QoS constraint> to zero. The following procedure shows a DSR-based route discovery process with QoS constraint.

```
/*When a node (with a unique identification = <this ID>)
  receives a route discovery packet*/
IF this RDP has been received or S(L(<preceding ID>,<this
  ID>)) is smaller then threshold
    Discard this packet
END IF
IF <destination ID> is not this node
    IF no more available bandwidth or <TTL> is zero
        Discard this packet
```


Proceedings of the 18th International Conference on Advanced Information Networking and Application (AINA'04)
0-7695-2051-0/04 $ 20.00 © 2004 IEEE

```
    ELSE
        Append <this ID> to <intermediate nodes>.
       <QoS metric>=minimum{<QoS metric>,B(L(<preceding
           ID>,<this ID>))}.
        "Pre-Reserved bandwidth" = <QoS metric> with a "Pre-
        Reservation Timeout" record, and informs neighbor
        nodes.
       <Path-Stable-Time> = minimum{<Path-Stable-Time>,
       S(L(<preceding ID>,<this ID>))
        Modify <TTL>
        Broadcast to neighbor nodes.
    END IF
ELSE /*this node is the destination <destination ID>=<this
      ID>*/
  IF <intermediate nodes> is not disjoint from the other paths
     Discard this packet
  ELSE /*found a valid path*/
     Append <this ID> to <intermediate nodes>
    <QoS metric>=minimum{<QoS metric>,B(L(<preceding
        ID>,<this ID>))}
       <Path-Stable-Time> = minimum{<Path-Stable-Time>,
       S(L(<preceding ID>,<this ID>))
       Send back "Route Reply Packet" to source node
  END IF
END IF
```

A path with more hop-counts or smaller bandwidth will increase its transmission delay. If a route path with smaller transmission delay, the RDP along this path will get to destination in advance. This path is generally with minimum hop-counts or maximum available bandwidth. The "Pre-reservation Timeout" could be set to the double TTL time of route discovery. If "Pre-reservation Timeout" time record has expired, the pre-reserved bandwidth would be freed by mobile node. If this node receives "Route-Reply-Packet" before timeout, the available bandwidth of this node will be reserved actually until "Path-Stable-Time". The "Path-Stable-Time" is used for selecting a stable path and pre-discovering another new routing paths if the original one is about to be expired.

5.2 Route Reply Phase

If the destination node receives a RDP, it will reverse the <intermediate nodes> record and send back a "Route Reply Packet" (RRP) to the source along the original routing path discovered by RDP. The destination node will also reserve the available bandwidth recorded in <QoS metric> of RDP. The RRP packet carries <request ID, source ID, destination ID, intermediate nodes (reserved from RDP), QoS metric, QoS constraint, Time-To-Live (TTL) and Path-Stable-Time> information. If an intermediate node receives a RRP, it will clear the "Pre-Reservation Timeout" record, reserve the bandwidth and forward to "previous" node. The following procedure algorithm shows the procedure.

```
/*When a intermediate node received RRP */
Reset "Pre-Reservation Timeout"
IF <QoS constraint> is not set to zero
   Reserves bandwidth recorded in <QoS Metric> for L(<this
     ID>, <preceding ID>)
END IF
Insert (<source ID> <destination ID>) into its routing table
Update bandwidth information
Insert (<destination ID> <source ID>) into its routing table
  with bandwidth information (Without bandwidth reservation)
Forward the RRP along <intermediate nodes> of the Route
  Reply packet.
```

If the source node receives a RRP, it will select this path and insert the routing information into its routing table and reverse the bandwidth recorded in <QoS metric>. If total bandwidth of multiple paths is not sufficient, it must adapt its QoS requirement.

```
/*When the source node receives RRP*/
Clear "Pre-Reservation Timeout"
IF <QoS constraint> is not set to zero
   IF T(MP') < δ
        Reserves bandwidth recorded in <QoS Metric> for
        L(<this ID>, <preceding ID>)
   END IF
END IF
Insert (<source ID> <destination ID>) into its routing table
Update bandwidth information
```

6. Simulations

A simple simulation about interference between two routing paths is shown in Fig. 3. We setup a simple scenario with 12 nodes in ns-2 [8]. This simulation use IEEE 802.11 MAC and the normal bit-rate is 2Mbits simulated from a commercial shared-media radio interface card with frequency 914MHz. The communication radius is 250 meters and a FTP-flow (with TCP windows size 50 and packet size 512) from the same source node to destination is monitored. As this simulation shown in Fig. 3, average throughput of single routing path is 81 Kbits/sec. The average total throughput of two high-interfering paths is 91Kbits/sec. The two high-interfering routing paths increase about 12% through. The two low-interfering paths increase the average total throughput to 134 Kbits/sec and improve 65% then a single routing path.

As shown in Fig.3, multiple low-interfering paths can increase the total throughput but cannot maintain the stability without bandwidth reservation. In Fig.4, we show a simulation by our own C program. It simulates the extension of bandwidth pre-evaluation and reservation for QoS constraint applications. The QoS constraint is set to 100 Kbits/sec and we reserve extra 20 Kits/sec for

0-7695-2051-0/04 $ 20.00 © 2004 IEEE

covering one link failure or unexpected bandwidth variation. We did not focus on specific MAC scheme or routing protocol nowadays. It simulates the property of the improved scheme. The throughput is more stable if we reserve the bandwidth and the average throughput is 122 Kbit/sec.

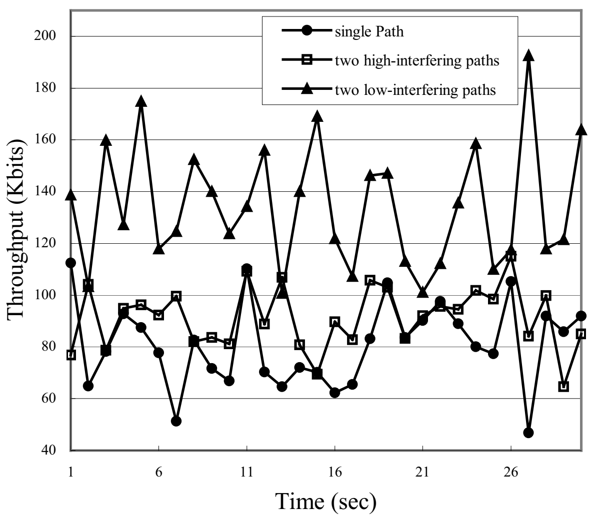

Figure 3. Throughput about single, two high-interfering and two-low interfering routing paths

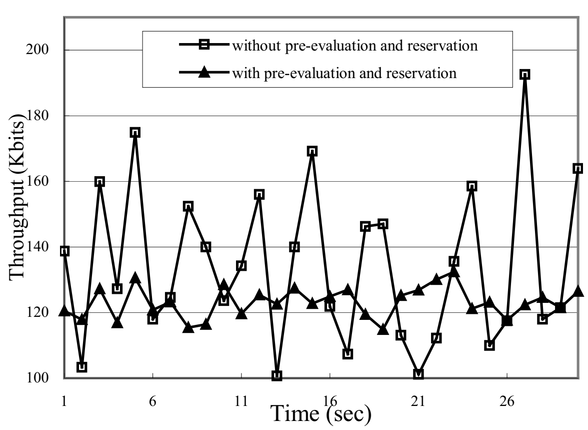

Figure 4. Throughput about extension of pre-evaluation and reservation

7. Conclusion

It is resource consuming to maintain multiple routing paths with stable bandwidth in ad hoc wireless network. The improvement of bandwidth is sometimes impractical through the excessive overhead of a routing protocol. More precise available bandwidth evaluation will decrease the probability of QoS inconsistence. A MAC protocol must offer the abilities of bandwidth pre-evaluation and reservation. The routing protocol will avoid routing packets into a region with its maximum network capacity. A MAC protocol with power control scheme will decrease the interfering ratio between routing paths. But, the bandwidth evaluation will be more difficult due to the dynamic transmitting power. The MAC with power control scheme must evaluate its available bandwidth according to its maximum transmitting power. The extra bandwidth if it transmits with a small power will be released for other applications.

References

[1] Sung-Ju Lee and Mario Gerla, "AODV-BR: Backup Routing in Ad hoc Networks", Wireless Communications and Networking Conference 2000, IEEE, Sep. 2000, Volume: 3, pp. 1311 -1316

[2] Aristotelis Tsirigos and Zygmunt J. Haas, "Multipath Routing in the Presence of Frequent Topological Changes", IEEE Communications Magazine, Nov. 2001, pp. 132-138.

[3] Lei Wang, Lianfang Zhang, Yantai Shu, Miao Dong, "Multipath source routing in wireless ad hoc networks", Canadian Conference on Electrical and Computer Engineering, 2000, Vol.1, pp479-483

[4] Leung, R., Jilei Liu, Poon, E., Chan, A.-L.C. and Baochun Li, "MP-DSR: a QoS-aware multi-path dynamic source routing protocol for wireless ad-hoc networks", 26th Annual IEEE Conference on Local Computer Networks (LCN), Nov. 2001, pp. 132 –141.

[5] Mahesh K. Marina and Samir R. Das, "On-demand Multipath Distance Vector Routing in Ad Hoc Networks", Network Protocols Ninth International Conference on ICNP 2001, Nov. 2001, pp14 –23

[6] Satyabrata Chakrabarti and Amitabh Mishra, "QoS issues in ad hoc wireless networks", IEEE Communications Magazine, Vol. 39 Issue: 2, Feb. 2001, pp. 142 –148.

[7] Youngki Hwang and Pramod Varshney, "An Adaptive QoS Routing Protocol with Dispersity for Ad-hoc Networks", Proceedings of the 36th Hawaii International Conference on System Sciences (HICSS'03), Jan. 2003, pp302 –311

[8] The editors of NS-2, "The Network Simulator - ns-2", http://www.isi.edu/nsnam/ns/

[9] Zygmunt J. Haas and Jing Deng, "Dual busy tone multiple access (DBTMA)-a multiple access control scheme for ad hoc networks", IEEE Transactions on Communication, vol. 50, no. 6, Jun. 2002, pp. 975-985

[10] Leonard Kleinrock and Fouad A. Tobagi, "Packet Switching in Radio Channels: Part I - Carrier Sense Multiple-Access Modes and Their Throughput-Delay Characteristics", IEEE Transaction on Communications, vol. 23, no. 12, Dec. 1975, pp1400-1416

Proceedings of the 18th International Conference on Advanced Information Networking and Application (AINA'04)