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Multipath QoS Routing with Interference Provision in Ad Hoc Wireless Network

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Mobile nodes are interconnected via multihop routing paths that consist of unstable radio links in ad hoc wireless network. Providing QoS routing for such networks is complex owing to imprecise network information, insufficient bandwidth and dynamic topology. Many multipath routing protocols have been proposed to improve network stability and throughput. The sender node discovers multiple disjoined routing paths and spreads traffic among them according to their delay or available bandwidth. For real-time multimedia application, insufficient bandwidth or unstable throughput invite unexpected delays or jitters. Some multipath routing protocols pre-evaluate available path bandwidth and select sufficient bandwidth from them. To minimize the path cost, paths with smaller hopcounts are selected in advance. These selected paths are generally too closed and the total network throughput cannot simple be summed due to "path interference". Discovering and selecting multiple high-interference paths is ineffectual and the total available bandwidth is not precise. In this paper, we proposed an interference-aware QoS multipath routing protocol for QoS-constraint multimedia or real-time applications in ad hoc wireless network. Specifically, this paper applied a scheme for evaluating available bandwidth according to the network capacities with different Media Access Control (MAC) protocols. In this paper, we show the "Interference ratio" of multipath and we also evaluate the stability and throughput improvement is assessed through simulations.

Keywords: ad hoc networks, multipath routing, interference, QoS, multimedia

1. INTRODUCTION

In ad hoc wireless networks, mobile nodes communicate without any fixed and pre-set infrastructure. Mobile nodes can roam arbitrarily without spatial or temporal constraints. To communicate with another node beyond the radio radius of sender, one of the multihop routing protocols is used to discover a new routing path, and the intermediate nodes belonging to this path forward packets voluntarily. The wireless radio link may be interrupted owning to one of the mobile nodes moving out from the original radio radius, running out of battery or being turn off by the user. The routing path between sender and the receiver can also be fractured. Numerous well-studied ad hoc wireless routing protocols, such as Dynamic Source Routing (DSR) or Ad hoc On-Demand Distance Vector Routing (AODV), rebroadcast the "*Path Discovery Messages*" and seek another routing

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path. Newly discovered paths may become unuseful even before the start of routing if network topology changes too frequently. Moreover, the network topology may change again before the last topology updates are propagated to all intermediate nodes.

In multimedia applications, delays and unsynchrony of multimedia objects may occur during new routing path construction. If the network contains too numerous high-mobility nodes, the characteristic of this unstable topology will cause path discovery messages to flood the whole network. Furthermore, the new routing path may not have sufficient available bandwidth to serve the original Quality-of-Service (QoS) of multimedia application. To alleviate this problem, many new protocols were proposed by extending the "backup node" or "backup path" scheme to DSR or AODV, and forwarding packets temporarily until a new routing path was discovered. Backup Routing in Ad hoc Networks (AODV-BR), proposed by Lee and Gerla in [1], alleviated the packet delay problem while rediscovering a new routing path using intermediate backup nodes. These backup nodes were arranged during the route discovery phase, and forwarded packets automatically if they detected failure of the original radio link.

Real-time streaming or multimedia application in ad hoc wireless networks is restricted by the unreliable radio link and insufficient bandwidth. Backup nodes or backup paths protocols may forward packets temporarily, but cannot increase the total throughput if the original routing path has insufficient bandwidth. Notion of multiple routing paths protocols increases not only throughput but also stability of the ad hoc wireless network. Tsirigos and Haas proposed a scheme in [2] for fragmenting packet into small blocks and distributing these blocks among multiple available paths. This scheme increases the overheads for each packet, but also reduces the failure probability. Network traffic is spread into multiple streams and dispatched over multiple disjoined paths. The proposed scheme reduces the packet drop ratio and the end-to-end delay. Additionally, numerous challenges must be overcome to construct and maintain multiple loop-free routing paths. Multipath Source Routing (MSR) [3] proposes a multiple paths routing protocol based on DSR. The route discovery phase in DSR returns multiple disjoined paths. MSR selects a round-robin load distribution "*Weight*" according to a heuristic equation. The Multipath Source Routing protocol (MP-DSR) proposed by Leung in [4], focuses on end-to-end reliability. A selection algorithm is used to select multiple "low-fail-probability" paths. Marina and Das proposed an Ad-hoc On-demand Multipath Distance Vector routing protocol (AMODV) in [5] based on the concept of link reversal from AODV. Unlike the construction of disjoined paths in other DSR-based multipath routing protocols, the AMODV discovered multiple disjoined "links" for traffic distribution.

Maintaining stable and sufficient bandwidth is a key issue for real-time streaming. Unstable network traffic causes multimedia presentation delay or jitter, and insufficient bandwidth interrupts the multimedia presentation and wait for multimedia objects transmission. Allocating a large buffer may reduce this problem, but also increases the buffer prefetching time and wastes the host resources. The other solutions are QoS-constraint routing protocols. Chakrabarti presented some basic concepts about QoS issues in ad hoc wireless networks in [6]. Many challenges and solutions related to path repairing, alternative routing and redundant multipath routing are also discussed in [6, 7].

To minimize routing costs, the other disjoined paths are generally placed beside the first one because the hopcounts of the first path are minimized. However, if the two disjoined paths or links are too close, the nodes belonging to those paths will interfere with one another during path transmission. The total throughput of two high-interference paths is less than their pre-evaluated bandwidth. Fig. 1 shows a simple simulation regarding path interference. This study establishes a simple scenario with 12 “static” nodes using a manual setup in ns-2 [8]. The MAC protocol of this simulation is based on IEEE 802.11 and the normal bit-rate is 2Mbits simulated via a commercial shared-media radio interface card. A FTP-flow from the same source to the destination is monitored. The average throughput of single routing path is 81 Kbits/sec. Moreover, the average throughput of the two high-interference paths is 91 Kbits/sec. The throughput of two high-interference routing paths increases 12% throughput to single path routing. The two low-interference paths increase the average throughput to 134 Kbits/sec and achieve a 65% improvement compared to a single path routing.

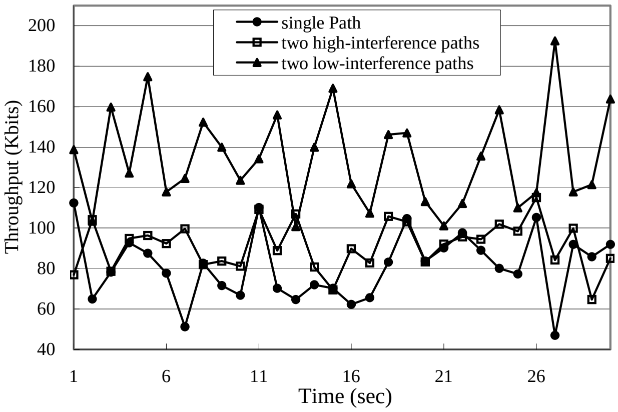


Fig. 1. Throughput about single, two high-interference and two-low interference routing paths.

This paper is organized as follows. Section 2 explains some technicalities relating to the multiple access protocols and discusses about interference ratio. Section 3 then defines a network model and some expressions for the proposed protocol. Next, section 4 proposes an interference-aware QoS routing protocol for ad hoc wireless network. Subsequently, section 5 presents the simulation results, and illustrates the performance and protocol overhead. Finally, section 6 gives the conclusions.

2. INTERFERENCE AND BANDWIDTH EVALUTION

In an 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 the MAC protocol being used. The channel utilization decreases as more traffic arrives. A MAC protocol must be designed carefully for frame collision, and must offer more efficient frame transmission. To increase the throughput, Carrier Sensing Multiple Access (CSMA) and CSMA with Collision Avoidance (CSMA/CA) are proposed to reduce the frame collision probability. For example, IEEE 802.11 Distributed

Coordination Function (DCF) can be used to avoid the frame collisions. However, collisions may still occur if multiple frames arrive at a node simultaneously. "Hidden terminal" and "exposed terminal" problems still impact ad hoc network capacity. Many studies solve this problem via RTS/CTS dialogue. But, RTS/CTS-based MAC protocols were found that they solve neither the hidden- nor the exposed-terminal problems. Haas and Deng illustrated both groups of problems in [10], and proposed a Dual Busy Tone Multiple Access (DBTMA) scheme via a separated busy tone channel. More studies recently have examined ad hoc wireless network capacity and the MAC performance protocol in [9-11].

In common channel ad hoc wireless networks, collision may cause packet transmission failure. The transmission frame is damaged if another mobile node (within the interference range of the receiver) transmits another frame simultaneously. Fig. 2 shows that a mobile node j successfully receives a frame from node i if $|j - i|$ (the distance between j and i) $< R$ (the communication radius), and another other node k does not send another frame using the same channel within the interference radius R_I.

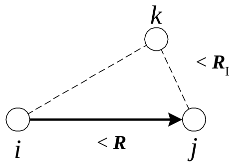


Fig. 2. Node k will restrict transmission if node j is receiving frame from node i using the same channel.

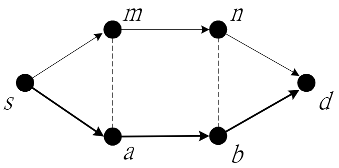


Fig. 3. A simple multipath interference scene.

The transmission power of the sender needs to be regulated, and is bounded sufficiently high to reach the intended receiver with minimal transmission power. The higher transmission power thus interferes with more neighbor nodes. The interference impairs the wireless network capacity and diminishes the battery life of mobile devices. However, lower transmission power increases routing hop number and transmission delay. Routing extra packets into a network already at maximum capacity decreases the network utilization because of frames collision, deferred access and random back-off contention windows.

For example, we assume the scenario shown in Fig. 3 is based on the pure-ALOHA scheme and the pre-evaluated available bandwidth of node m to n is δ bits/sec. If A tries to send γ Kbit/sec to B, it will generate $\hat{\gamma}$ frames because of the probability of frames collision with the other network traffic arriving according to the Poisson distribution.

$$\hat{\gamma} = \gamma \cdot e^{2\lambda t} + \Delta \tag{1}$$

If node A sends $\hat{\gamma}$ Kbit/sec frames to B, the other nodes receiving frames within the interference radius of A, will also increase their frame collision probability. The senders of these nodes will try to retransmit more frames if they want to consistently maintain their throughput. We assume that an additional Δ frames are sent to the region by node A. Furthermore, node M re-evaluates its available bandwidth $\hat{\hat{\delta}}$ by:

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

If an increasing number of frames are sent into the region, the pure-ALOHA will reach its maximum channel utilization ratio (the pure-ALOHA is 0.184 and the slot-ALOHA is 0.368, analyzed in [9]). A high performance MAC will increase total channel throughput in ad hoc networks.

The channel throughput, as discussed by Kleinrock and Tobagi in [9], can be expressed as

$$S = \frac{\bar{U}}{\bar{B} + \bar{I}} \tag{3}$$

where $\bar{U}$ denotes the average utilization period, $\bar{B}$ represents the expected duration of a busy period and $\bar{I}$ is the expected time of the idle period. Moreover, let P_s denote the probability of success of transmitting a packet, and T_s represent the successful transmission period, and T_f be the average failed busy period, while the packet transmission time is δ. The average utilization period is then given by

$$\bar{U} = P_s\delta \tag{4}$$

and the expected duration of a busy period is given by

$$\bar{B} = P_s T_s + (1 - P_s)T_f. \tag{5}$$

An idle period is the time between two consecutive busy periods. The packets arrival rate is assumed to be λ, in which case:

$$\bar{I} = \frac{1}{\lambda}. \tag{6}$$

Finally, the channel throughput is obtained:

$$S = \frac{P_s\delta}{P_s T_s + (1 - P_s)T_f + 1/\lambda}. \tag{7}$$

The maximum channel throughput can be mathematically evaluated by calculating the number of packets that are transmitted into the network, and the probability of successfully transmitting P_s.

3. SYSTEM MODEL AND DEFINITIONS

A network G is modeled as a graph $G = (V, E)$, and a finite set V is the mobile nodes. Each mobile node has a unique *ID* and can migrate arbitrarily. Meanwhile, E denotes a set of bi-directional wireless radio links between the mobile nodes. One-hop communication radius of node i is defined as $R(i)$. Moreover, the one-hop communication link is defined as $L(i, j) \in E$ if a mobile node $j \in V$ is within the one-hop communication radius

$R(i)$. The communication link L may disappear because of the node mobility or the user switching the 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 the source node s to the destination node is defined as $P(s, d) = \{s \dots d\}$, which is a sequence of intermediate nodes between node s and node d without loops. Finally, $MP(s, d)$ is defined as the set of all possible disjoint paths from s to d, such that

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

3.1 QoS Metrics

The available bandwidth B between adjacent nodes i and j is represented by $B(L(i, j))$. This paper assumes that any mobile device in the ad hoc network can evaluate its available bandwidth. The deliberation of available bandwidth between i and j is not only by the packets through the radio link $L(i, j)$ but also on the other packets through $N(i)$ because of interference. Bandwidth $B(L(i, j))$ and $B(L(j, i))$ may not be equal owing to having different interference regions. $B(P(s, d))$ is defined as the available bandwidth of the routing path from source node s to destination node d and

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

The total available bandwidth with multiple path routing is defined as

$$B(MP(s, d)) = \sum B(P_i(s, d)), \text{ where } \forall P_i \in MP(s, d), 1 \leq i \leq n.$$

This paper defines the operator " || " to represent two or more links (or paths) transmitting data simultaneously. The bandwidth cannot represent the real network throughput, and the real throughput of radio link is represented here by $T(L(i, j))$, while the throughput of a path is represented by $T(P(s, d))$. Regarding the bandwidth, if two or more paths transmit data simultaneously, the total throughput is represented as $T(P_1 \| P_2 \dots \| P_n)$, and the real total throughput of multipath is represented as

$$T(MP(s, d)) = \sum T(P_i(s, d)), \text{ where } \forall P_i \in MP(s, d), 1 \leq i \leq n.$$

3.2 Interference Ratio

In this paper, interference ratio is not defined according to electromagnetic theory. This paper does not focus meticulous on the electromagnetism meticulously or special wireless communication hardware. This study assumes that the interference ratio can be measured by the wireless device, or can be preset by the engineers based on the multiple access protocols. The paths interference ratio is evaluated and represented by

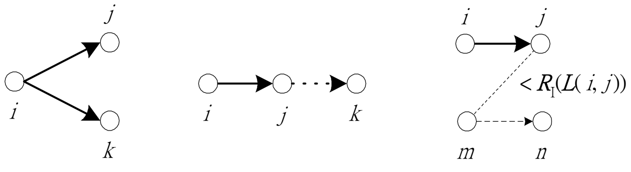
$$I(P(s_1, d_1), P(s_2, d_2)) = \frac{T(P(s_1, d_1) \| P(s_2, d_2))}{B(P(s_1, d_1)) + B(P(s_2, d_2))}$$

where $B(P(s_1, d_1), P(s_2, d_2)) \neq 0$, and $T(P(s_1, d_1) \| P(s_2, d_2)) \leq (B(P(s_1, d_1)) + B(P(s_2, d_2)))$.

Regarding the definition, the interference ratio of multiple paths from the same source and destination is represented by

$$I(MP(s, d)) = \frac{T(MP(s, d))}{B(MP(s, d))}.$$

In Fig. 4 (a), the available bandwidth from node *i* to node *j* is reduced by packet flow from node *i* to node *k*. This paper assumes that these available bandwidths are evaluated independently. In the scenario in Fig. 4 (b), the available bandwidth from node *i* to node *j* or node *j* to node *k* is also evaluated independently. In Fig. 4 (c), if $|m - j| < R_I(L(i, j))$, node *m* must defer its transmission to node *n* to prevent collision. Furthermore, $T(P(i, j)) \neq B(P(i, j))$ and $T(P(m, n)) \neq B(P(m, n))$ if $P(i, j) \parallel P(m, n)$.



(a) (b) (c)

Fig. 4. Transmission interference.

3.3 Link-Stable-Time and Path-Stable-Time

The Link-Stable-Time is assigned the time value of evaluated link stability according to their relative moving speed and distance as well as the signal strength. The variation of signal strength then can be used to appraise the wireless link stability. Links with a stable time under a threshold are not be selected for inclusion in routing paths. The Link-Stable-Time is represented by $S(L(i, j))$ and the Path-Stable-Time is represented by

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

If the stable time of a routing path is going to be expired, the source node will discover another new path with available bandwidth equal to or exceeding the original one.

4. INTERFERENCE-AWARE MULTIPATH ROUTING PROTOCOL

A source mobile node *S* tries to communicate with its destination mobile node *D* with a bandwidth constrained δ. Many disjointed routing paths from *S* to *D* are discovered and source node tries to select multiple paths $MP'(S, D)$ with total bandwidth $B(MP'(S, D))$ exceeding δ, where $MP'(S, D) \subseteq MP(S, D)$ and $B(MP'(S, D)) \geq \delta + \Delta$. The additional bandwidth Δ is additional reserved for bring more network traffic stability.

In this paper, we propose an Interference-aware Multipath Routing Protocol (IMRP) for real-time or multimedia applications in ad hoc wireless networks. IMRP is a source-initialized, on-demand, and multipath routing protocol. With available bandwidth pre-evaluation and Interference susceptibility, IMRP reduces the call dropping rate and improves the QoS stability. A well-designed multipath routing protocol must make $I(MP(s, d))$ approximately equal 1 (evaluated bandwidth approximates the real network throughput).

4.1 Route Discovery Phase

If a mobile node attempts to transmit data to its designated destination but does not have any routing information in its routing table, the source node pre-reserves the bandwidth specified by multimedia application and broadcasts a “Route Discovery Packet” (RDP) packet over 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, broadcasts this packet again. If this node has no available bandwidth, it discards this packet. 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 than 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
    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 Time-out” 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
```

Paths with higher hopcounts or smaller bandwidth have increased transmission delay. Thus, the RDP will get to destination in advance if the path has a smaller number of hopcounts. This path generally has higher available bandwidth. The “Pre-reservation Timeout” can be set to the double the TTL time of route discovery. If the “Pre-reservation Timeout” time record has expired, the pre-reserved bandwidth can be freed by the mobile node. If this node receives the “Route-Reply-Packet” before timeout, the available bandwidth of this node is reserved until “Path-Stable-Time”. The “Path-Stable-Time” is used to select a stable path and pre-discover another routing paths if the original path is going to expire.

4.2 Route Reply Phase

If the destination node receives a RDP, it reverses the <intermediate nodes> record and returns a “Route Reply Packet” (RRP) to the source along the original routing path. The destination node also reserves the available bandwidth recorded in the <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 clears the “Pre-Reservation Timeout” record, reserves the bandwidth and forwards this packet to the next node. This algorithm is shown in the following procedure.

If the source node receives a RRP, it selects this path, inserts the routing information into its routing cache and reserves the bandwidth recorded in <QoS metric>. If the total bandwidth of multiple paths is insufficient, a bandwidth insufficiency is reports to the upper layer.

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

4.3 Route Maintenance Phase

Maintaining multiple paths in an ad hoc wireless network consumes considerable resources. Moreover, migration of the mobile nodes frequently invalidates radio links. Maintaining stable network throughput for real-time streams is important. But, route path throughput can not be maintained if one of the intermediate nodes enters a region with insufficient bandwidth (shown in Fig. 5). Some studies have proposed solving this problem by modifying the MAC protocol. Proposed solutions involve reserving available bandwidth in all two-hop-away neighbor nodes [12, 13] via multi-phase negotiation.

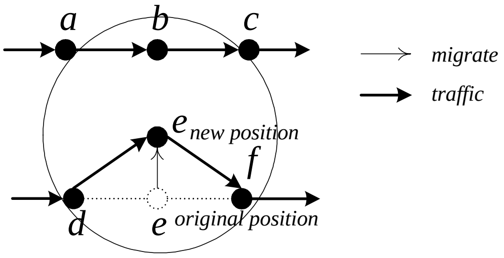


Fig. 5. If mobile node *e* migrate to its new position, it will defer forwarding even radio link is still connected.

However, those schemes decrease bandwidth utilization, and can have difficulty in evaluating and reserving bandwidth precisely. Thus, many proposed MAC protocols based on two-hop reservation scheme are proposed for Time Division Multiple Access (TDMA) protocol. TDMA is easier to calculate free time slots and to optimize bandwidth utilization than CSMA. Without being bound on particular MAC protocol, we assume a MAC protocol with capacity of bandwidth prediction and reservation capacity, and simulate this protocol in section 5.

Multipath routing alleviates the path-loss by distributing traffic into multiple streams and transmitting these streams simultaneously. With bandwidth prediction and "extra" bandwidth reservation, "unexpected" path loss is solved by temporarily forwarding via other routing paths, and a new Route Discovery will be triggered. Similarly, the route discovery is also triggered before the predicted path stable time. A "Route Failure Packet" (RFP) is sent back to the source node if a node finds that its next-hop node is not forwarding packets correctly. When the source node receives RFP from a path *p*, or when the stable time of a path *p* is about to expire, the source node riggers Discovery Phase, and sets <QoS constraint> to *B*(*p*).

```
/* When the source node receives RFP */
01 Clear Routing Cache Information about this path
02 Set <QoS constraint > of RDP to $B(p)$ recorded in RFP
03 Re-allocate Packets Distribution
04 Trigger Route Discovery Phase
```

The other intermediated nodes free the reserved bandwidth for path *p* when the stable-time expired, and update their routing cache about path *P*.

5. SIMULATION RESULTS

This section presents the simulation developed here. A generalized DSR-based multipath routing protocol is simulated and compared with the proposed IMRP. This simulation does not focus on Physical or MAC performance. An IEEE 802.11-like MAC was simulated as a foundation, and the bandwidth evolution was assumed to be accurate.

Table 1. Regulative parameters of simulation.

Parameters	Values
DSSS PHY/MAC	
Bit rate	2 Mbits
Slot time	20 us
SIFS	10 us
CWmin	31
CWmin	255
PLCP preamble	144 bits (1 Mbits)
PLCP header	48 bits (1 Mbits)
FragmentationThreshold	2346 Bytes
Routing Protocol (IMRP)	
RDP size	128 Bytes
RRP size	128 Bytes
RFP size	32 Bytes

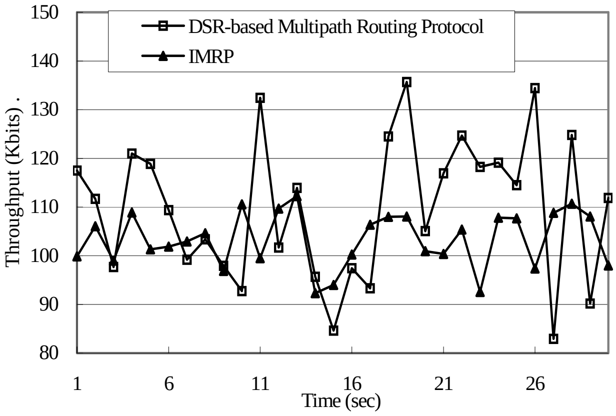


Fig. 6. Stability of network throughput.

FTP (by TCP) and UDP packets are sent for simulating multimedia streaming. Table 1 lists the regulative parameters of the simulation, and assumes that the interference radius equals the communication radius.

Fig. 6 shows the simulation results on throughput stability via simulated FTP application. The bandwidth constraint is set to 100 Kbits/sec, and an additional 20 Kits/sec is reserved for covering protocol overheads, link failure, or unexpected bandwidth variation. The throughput is more stable if more additional bandwidth is reserved, but the bandwidth utilization is also decreasing. We use a simple queue to shape traffic for simulating bounded bandwidth in IMRP. The average throughput of the DSR-based Routing protocol is around 110 Kbit/sec. The average throughput of IMRP is 103 Kbits/sec, but IMRP is more stable and less lavish than simulated simple DSR-based multipath Routing Protocol. More stable data streams bring fewer jitters.

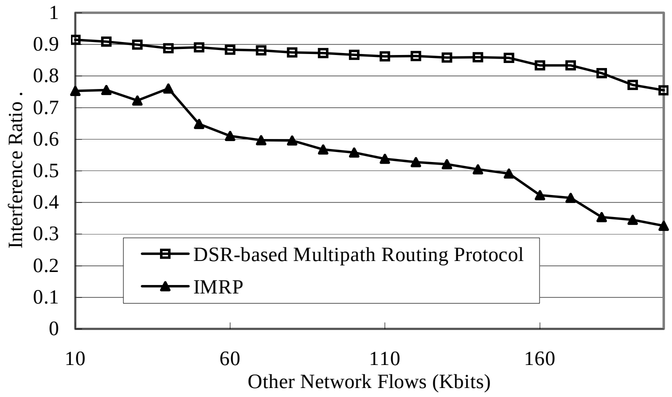


Fig. 7. Simulation result of interference ratio.

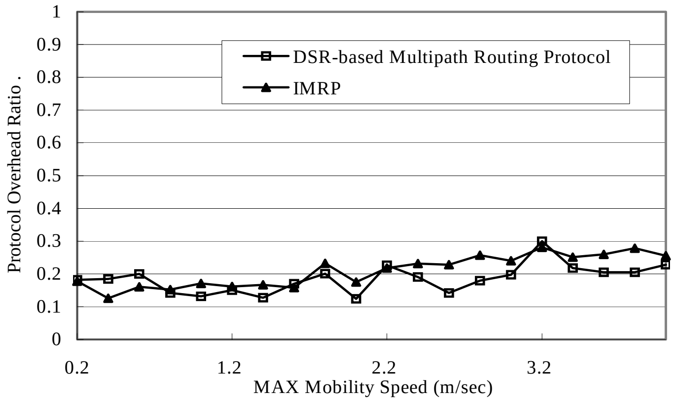


Fig. 8. Simulation result of protocol overhead ratio with max mobility speed.

Fig. 7 shows the simulation of Interference Ratio (*I*(*MP*)) . The available bandwidth (*B*(*MP*)) of multipath discovered by Routing Discovery Phase is monitored and compared with the real incoming packets (*T*(*MP*)) received by the destination node. A Constant Bit Rate (CBR) flow is deployed for data transmission and transmitted with the other random generated flows simultaneously. The interference ratio of IMRP is more stability than the simulated DSR-based multipath routing. Moreover, the DSR-based multipath routing decreases with other increasing flows because lacks of interference control and bandwidth reservation.

The protocol overhead ratio shows performance of IMRP. Since IMRP is also based on DSR, the routing overhead is smaller than for AODV-based multipath routing protocols. Fig. 8 shows the simulation results for the IMRP overhead. The average protocol overhead of IMRP is 12% higher than that using the simulated DSR-based multipath routing protocol developed here. This higher routing overhead results from the need to maintain stable throughput in IMRP. IMRP triggers another route discovery phase even if the radio link is still functional. Beside, IMRP employs a pre-rerouting mechanism via predicted path-stable-time. The pre-rerouting mechanism also increases the protocol routing overheads. The routing overhead is greater in IMRP if the max speed is increasing.

6. CONCLUSION

This paper shows the multipath routing problems of real-time streaming in ad hoc wireless networks. Any further multipath protocol can be improved by extended interference provision. This paper also shows multipath routing protocol without interference provision will not fit the throughput of real-time streaming. IMRP will pre-evaluate the interference of routing path and prevents the routing of extra packets into an area operating at maximum network capacity. Moreover, IMRP provides more stable throughput and more reliable end-to-end transmission for multimedia streaming in ad hoc wireless networks. Maintaining multiple routing paths and real-time streams in an ad hoc wireless network consumes considerable resources. The improvement of other multipath routing protocol is sometimes impractical because of the excessive routing overheads. The additional routing overheads of IMRP become tolerable with its improvement of stability and throughput. Precise bandwidth evaluation removes the need to spend additional network resources to discover another new path. MAC protocol with the ability to accurately evaluate available bandwidth accurately is more adequate for IMRP. A MAC protocol with a power control scheme decreases the interference ratio between routing paths. However, bandwidth evaluation becomes more difficult due to the dynamic transmitting power. IMRP can not prevent sudden interference and nodes failure, reserving extra bandwidth is resource consuming. Similarly, network throughput is decreasing rapidly with increasing routing hops.

REFERENCES

1. S. J. Lee and M. Gerla, “AODV-BR: backup routing in ad hoc networks,” in *Proceedings of the IEEE Wireless Communications and Networking Conference*, Vol. 3, 2000, pp. 1311-1316.
2. A. Tsirigos and Z. J. Haas, “Multipath routing in the presence of frequent topological changes,” *IEEE Communications Magazine*, Vol. 39, 2001, pp. 132-138.
3. L. Wang, L. Zhang, Y. Shu, and M. Dong, “Multipath source routing in wireless ad hoc networks,” in *Proceedings of the IEEE Canadian Conference on Electrical and Computer Engineering*, Vol. 1, 2000, pp. 479-483.
4. R. Leung, J. Liu, E. Poon, A. C. Chan, and B. Li, “MP-DSR: a QoS-aware multi-path dynamic source routing protocol for wireless ad-hoc networks,” in *Proceedings of the 26th Annual IEEE Conference on Local Computer Networks*, 2001, pp. 132-141.
5. M. K. Marina and S. R. Das, “On-demand multipath distance vector routing in ad hoc networks,” in *Proceedings of the 9th International Conference on Network Protocols*, 2001, pp. 14-23.
6. S. Chakrabarti and A. Mishra, “QoS issues in ad hoc wireless networks,” *IEEE Communications Magazine*, Vol. 39, 2001, pp. 142-148.

7. Y. Hwang and P. Varshney, "An adaptive QoS routing protocol with dispersity for ad-hoc networks," in *Proceedings of the 36th Hawaii International Conference on System Sciences*, 2003, pp. 302-311.
8. The Network Simulator-ns-2, http://www.isi.edu/nsnam/ns/.
9. L. Kleinrock and F. A. Tobagi, "Packet switching in radio channels: Part I – carrier sense multiple-access modes and their throughput-delay characteristics," *IEEE Transactions on Communications*, Vol. 23, 1975, pp. 1400-1416.
10. Z. J. Haas and J. Deng, "Dual busy tone multiple access (DBTMA): a multiple access control scheme for ad hoc networks," *IEEE Transactions on Communications*, Vol. 50, 2002, pp. 975-985.
11. P. Gupta and P. R. Kumar, "The capacity of wireless networks," *IEEE Transaction on Information Theory*, Vol. 46, 2002, pp. 388-404.
12. C. Zhu and M. S. Corson, "A five-phase reservation protocol (FPRP) for mobile ad hoc networks," in *Proceedings of the IEEE INFOCOM, 17th Annual Joint Conference of the IEEE Computer and Communications Societies*, Vol. 1, 1998, pp. 322-331.
13. S. Jiang, J. Rao, D. He, X. Ling, and C. C. Ko, "A simple distributed PRMA for MANETs," *IEEE Transactions on Vehicular Technology*, Vol. 51, 2002, pp. 293-305.

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