Multipath Doppler Routing with QoS Support in Pseudo-linear Highly Mobile Ad Hoc Networks

Ehssan Sakhaee[†], Abbas Jamalipour[†], and Nei Kato[‡]

[†]School of Electrical & Information Engineering, University of Sydney, Australia

[‡]Graduate School of Information Sciences, Tohoku University, Japan

***Abstract*—Sustaining long link durations in highly mobile ad hoc networks presents a great challenge, mostly untreated in recent literature. In this paper we introduce a new routing algorithm based on the relative velocity of mobile nodes, which also incorporates Quality of Service (QoS), termed QoS Multipath Doppler Routing (QoS-MUDOR). The primary aim of QoS-MUDOR is to maintain long link durations, whilst meeting QoS constraints. The routing protocol proposed is based on data retrieval from nodes, where nodes act as content providers. This simulates scenarios such as downloading a file, a web page, or any form of data from other nodes which can provide it. We will show how utilizing the relative velocity of nodes using the Doppler shift subjected to packets assists in selecting stable paths, whilst maintaining the QoS requirements in highly mobile pseudo-linear systems such as an aeronautical ad hoc network.**

I. INTRODUCTION

Mobile Ad hoc NETworks (MANETs) present an infrastructure-less means of communication among mobile entities. The effective implementation of a MANET must consider specific applications and how they can be best utilized by taking into account the various characteristics of the system such as mobility and Quality of Service (QoS) issues. In this paper we will present several schemes that can be used for sharing of data in a large network, where we have chosen a commercial aeronautical ad hoc network as the medium for implementing the proposed routing protocol and algorithm. The application of data sharing using ad hoc networking is the primary aim of the network, where nodes act as data or content providers. Unlike most routing algorithms where there is a defined source and destination node, in the proposed routing model there is a defined source and an undefined destination node. The destination address field for the proposed scheme is replaced by a unique *Hashed Data Identifier* (HDI) that identifies the requested data, and hence any node which can provide the data is considered a candidate as a destination node. What determines a suitable destination node and a suitable path depends on several factors such as QoS requirements and the *stability* of the path. Here, path stability refers to a path which has a long duration before it expires. I.e. the nodes on such a path move in such a way that they will remain within each other's communication range for an acceptable period of time. Thus, the longer the path duration, the more stable the path. The main difference between a traditional network and the considered network in which the proposed routing schemes are implemented is that every node acts as a provider of data, from which other nodes may wish to obtain these data. The fundamental notion of caching data and sharing among other nodes, and nodes being content providers has been proposed in [1] [2] where nodes retrieve data via ad hoc networking. We will extend this idea and integrate several novel approaches into it in order to make it sufficient and efficient in a pseudo-linear highly mobile ad hoc network. Schemes introduced will increase path duration, minimize flooding and incorporate QoS into the proposed routing protocol.

Data sharing works on the basis of one node obtaining the data, caching, and then sharing the data among many other nodes. The main motivation behind sharing of data via ad hoc networking in commercial aircraft is due to the continual increase in future in-flight Internet services [3] [4] which could eventually exhaust satellite resources. Another reason is that passengers would normally be accessing similar data, such as travel and destination information, accommodations and the like [5]. The sharing of data between planes may thus be the most effective solution for utilizing resources effectively and efficiently, where satellites would only be used to update and retrieve data that are not already available in the Aeronautical Ad Hoc Network in the sky, proposed in [6], which works on the basis of ad hoc networks. Fig. 1 illustrates the general approach to this concept. Further advantage is given to delay-sensitive Internet applications which will benefit from bypassing the long propagation delay of the satellite link and take advantage of the shorter links provided by the ad hoc network.

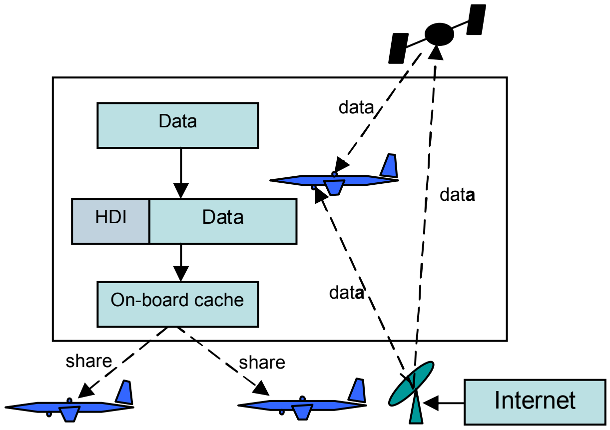

Fig. 1. Sharing of data among planes.

1-4244-0355-3/06/$20.00 (c) 2006 IEEE

The proposed on-demand routing algorithm termed Quality of Service Multipath Doppler Routing or QoS-MUDOR designed for the mentioned system is similar to the Dynamic Source Routing (DSR) protocol [7] as it uses full route caches, and the Associativity Based Routing (ABR) [8] as its primary concern is lifetime of routes. There are also several schemes derived from such algorithms which also take into account QoS, such as QoS-ASR [9]. However the fundamental difference between QoS-MUDOR and other previous algorithms is that it uses relative velocity of nodes in addition to QoS in order to discover best paths. It does this by taking into account the Doppler shift of reply packets, and uses this information to determine the stability of discovered paths. It is assumed that nodes are pseudo-linear in nature and have high speeds to the extent that Doppler shift of radio communication between nodes becomes relatively apparent and measurable. This is the case in aeronautical systems [10]. The other distinction is that it incorporates a unique scheme called the *FOrward Best REQuest* (FOBREQ), where only "best" packets are forwarded and the rest discarded, and consequently this prevents excessive request flooding. Furthermore, unlike previous reactive protocols and their multipath derivatives [11] [12], QoS-MUDOR considers *non-disjoint* paths. The reason for this is that by considering certain combination of nodes on these paths, more stable paths could be achieved as described in [6]. The second mechanism that prevents mass flooding is the traditional QoS checking of packets at node, also proposed in [9].

The remainder of the paper is organized as follows. Section II will briefly present related work, section III will introduce the proposed routing algorithm and protocols and section IV will simulate the proposed algorithm and show its effectiveness against traditional algorithms in relation to path stability. Finally we conclude the paper with discussions, conclusions and future work in section V and VI.

II. RELATED WORK

There are various routing algorithms for MANETs, ranging from on-demand (reactive) [8] [11]-[15] to proactive [16]-[19], and hybrid approaches [20] [21]. Some of these protocols have been extended to support QoS by eliminating routes that do not meet the QoS requirements. Particularly QoS-ASR [9] incorporates both application specific QoS (bandwidth, delay) as well as ad hoc specific QoS (power, congestion and stability of routes) in its algorithm. However with regard to the path's lifetime which reflects path stability, the batteries lifetime is taken into account. This may be a very limiting factor for nodes which do not have this resource limitation, such as the aeronautical system. In fact path stability in a MANET is more to do with the mobility of nodes rather than anything else [22] [23]. In [8] node mobility is taken into account to estimate link stability, however this protocol may not be suitable for continuously moving pseudo-linear mobile systems [6]. Furthermore there are extensions of previous protocols to support multipath routes [11] [12]. These extensions ensure that there are *alternative* paths, in case the primary path fails. However, these approaches focus on finding disjoint paths. In a way although this may be advantageous in preventing reply floods, it does not ensure optimal stability of paths. It is certainly possible to mitigate reply floods and at the same time consider non-disjoint paths to find more stable paths as described in the next section.

The caching and sharing of data in an ad hoc scenario is not entirely new. In [2] the notion of caching data and sharing it with other nodes is presented. Instead of each node directly fetching data from data centers, they download them from other nearby nodes, up to a few hops away, and hence avoid overloading the actual data centers. The data are either cached locally or the path which leads to such data is stored, by which a node has knowledge of where to obtain the data, and hence if another node sends a request for the data, it can respond efficiently saving time and bandwidth. In relation to nodes acting as content providers, [1] provides an interesting partial downloading mechanism for sharing of data among vehicular networks using a swarming protocol.

III. QOS-MUDOR ROUTING PROTOCOL

The routing scheme proposed is particularly useful for large scale systems with no power limitations, and high mobility such as the aeronautical ad hoc network and other similar mobile networks whose mobility is linear or pseudo-linear and continuous (with no pause times). We have introduced several concepts to enhance the proposed routing scheme, which will be described in this section.

A. Hashed Data Identifier

The *Hashed Data Identifier* (HDI) is a unique identifier for every unique block of recognizable data. The data could be a webpage or a file, or anything which represents a coherent piece of information. Each block of such data that a node (aircraft) possesses is tagged with its corresponding HDI and stored on an on-board cache. On the user side, the user input which can be the website address, or the name of a song is subjected to a hash function and the HDI is outputted. First this HDI is checked against the on-board cache to see whether the current node already has the required data in its on-board cache. If it doesn't, the outputted HDI is added to a request packet header and broadcasted. Nodes which can provide the data can produce a reply. Detailed description of these mechanisms will be given throughout this paper.

B. Estimating Link Duration using Doppler Shift of Packets

In [6] the Doppler shift of control packets were used to estimate the link stability of paths. For a detailed derivation of the Doppler Value and its relation to link duration and stability, please refer to [6]. The Doppler Value is calculated using the Doppler shift of a packet received from a node and reflects the stability of the link to that node. It is given by

$$\begin{aligned} \textit{Doppler Value} &= -v \text{ (if } v \text{ is negative. i.e. approaching)} \\ &= +2v \text{ (if } v \text{ is positive. i.e. receding)} \\ &= -c\,(f\,/\,f_0 - 1)\ \ldots\ (\text{if } f\,/\,f_0 < 1) \quad \text{... approaching} \\ &= +2c\,(f\,/\,f_0 - 1)\ \ldots\ (\text{if } f\,/\,f_0 < 1)\ \text{... receding} \end{aligned}$$

where v is the relative velocity of respective nodes, c is the speed of light, f is the expected frequency of the received packet and f_0 is the observed frequency of the received packet. The Doppler Value represents the cost used to estimate the link stability on multihop paths as shown in the proposed algorithm in part G of this section.

C. QoS Support and Effective Cost

The term QoS is a broad term. It may be classified into two main QoS derivatives: node QoS (e.g. queue delay, bandwidth) and link QoS (e.g. attenuation, propagation delay). Furthermore, QoS can be categorized into additive, multiplicative or concave metrics [24]. The single mixed metric *QoS Cost* is defined as

$$Cost(QoS) = \sum_{i=1}^{n} k_i \cdot \cos t(p_i) \tag{1}$$

where k_i is the weight for the cost of parameter p_i and n is the total number of parameters each representing a QoS metric.

The *Effective Cost* when node stability also becomes a factor in our routing is given by

$$Effective\ Cost = w_1 Cost(QoS) + w_2 DopplerVal_N \tag{2}$$

where w_1 and w_2 are the weights corresponding to the significance of QoS and path stability respectively in the cost metric. The $DopplerVal_N$ corresponds to the effective Doppler Value as described in part B. The least cost path is always taken as the primary (best) path for routing. If an application has strict QoS constraints and path duration is not important, w_1 can be set to 1 and w_2 to zero, and as path duration becomes a concern, w_2 can be increased with respect to w_1. It is important to note here that (2) is only evaluated at the source node, where all replied paths have already met the QoS constraints. Hence the effect of w_1 and w_2 will only allow selecting more stable paths among paths that already meet QoS requirements. Setting w_1 to zero and w_2 to 1 chooses the most stable path that also meets the QoS constraints.

D. Dynamically Trimmed Routing Table

The Dynamically Trimmed Routing Table (DTRT) are an effective approach to maintaining cached routes and purging (trimming) them and updating them with new routes upon new route discovery processes. Routes are stored in this table at the source node as the reply packets are received and are stored in ascending cost as given by the local source node's weights for Doppler Value and QoS, and cost is calculated according to (2). When the primary path fails, the second path from the table is chosen. The DTRT can store several alternative paths, hence the multipath nature of QoS-MUDOR.

E. FOBREQ Broadcast Optimization Scheme

There is the traditional mechanism which checks a request packet and if the cost is not met, it will drop the packet, and hence limit broadcasting. In addition to this, we propose a second mechanism called the *FOrward Best REQuest* (FOBREQ). The FOBREQ scheme forwards only Route Request (RREQ) packets that have *cost values* smaller than the previous RREQ packet. For example if a node had previously received an identical RREQ from node *A* that had a *better* cost value than the currently received RREQ from node *B*, it will drop node *B*'s RREQ and will not rebroadcast it. However if it receives the same request with a better cost value, it will first replace the old entry at node with the new (lower) cost and then rebroadcasts it. Fig. 2 illustrates the FOBREQ scheme. In the initial model the cost value used by FOBREQ is only based on QoS cost, in order to ensure QoS constraints are met.

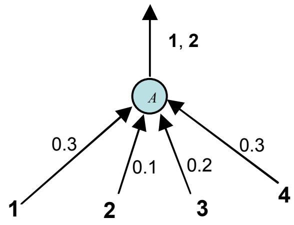

Fig. 2. FOBREQ scheme in action.

In Fig. 2 assume that there are several identical RREQ packets which reach node *A* via different paths (from the same source). The first RREQ has a cost value of 0.3, the second, third and fourth requests have cost values of 0.1, 0.2 and 0.3 respectively, and arrive at node *A* consecutively. When node *A* receives the first RREQ, it stores the cost value recorded in the request packet (0.3) into the *minCostValueSoFar* (for the same identical RREQ packet) variable at the node. When the next identical RREQ arrives, its cost function is compared to the stored value and since the newly arrived RREQ has a cost value smaller to that of the stored value (0.1 < 0.3), its cost value replaces the old *minCostValueSoFar* and this RREQ packet is also rebroadcasted. When the third consecutive RREQ arrives, again its cost value is compared to that of the *minCostValueSoFar*, and since this time the cost value of this newly arrived RREQ is greater than the *minCostValueSoFar*, it is dropped and hence not rebroadcasted. The same happens with the fourth RREQ. In this way, the broadcasting of identical RREQ packets is minimized, and as a result less traffic is generated.

F. Packet Format for QoS-MUDOR

The RREQ packet used in QoS-MUDOR incorporates several fields to ensure that QoS requirements are effectively met during the path discovery phase. A QoS-MUDOR RREQ packet format is

<CNA><HDI><QoSC><QoSW><QoSOF> <hopcount>

CNA is the Cached Node Addresses, containing the address of all nodes so far on the current path. HDI field contains the unique data Identifier used to check for the existence of the requested data. The QoS Constraint (QoSC) field contains each of the QoS requirements: minimum bandwidth, maximum delay, and an optional sub-field used for a multiplicative metric QoS. The QoS Weights (QoSW) field contains the respective QoS weights corresponding to the relative significance of each QoS parameter to the overall (single mixed) cost metric in (1). The QoS So Far (QoSOF) field is updated at each node with the respective operations for each of the QoS sub-fields. i.e. if it is bandwidth, the bottleneck will be taken (concave operation), if it is delay an additive operation, and for the third field a multiplicative operation. The QoSOF is updated on the forward path to be used by the FOBREQ process. Each RREQ packet also has a *hopcount* field similar to [25], which is initially set to the maximum hopcount and is decremented at each node as the packet is rebroadcasted. When this value reaches zero, the packet is discarded and not rebroadcasted. This prevents mass-broadcast floods throughout the entire network. The Route Reply (RREP) packet format is

<CNA><HDI><QoSOF><Doppler Value>

The CNA is copied from the RREQ packet into the RREP packet. The actual QoSOF field in the RREP packet is updated as the packet traverses back to the source node. This is so that the most updated QoS parameters reach the requesting node. The previously analogous QoSOF field in the RREP packet was used only to assist the FOBREQ process. The Doppler Value field is updated at each node on the upstream (reply) path. When the Doppler (shift) Value subjected to the RREP packet is greater than that of the one in the packet's header, the packet's header is updated with this new Doppler Value (concave metric).

G. *QoS-MUDOR Routing Algorithm*

QoS-MUDOR is a reactive (on-demand) algorithm. The fundamental characteristics of QoS-MUDOR are its non-disjoint path discovery, its combinational use of Doppler shift of packets (relative velocity of nodes) and QoS in selecting best paths, reflected as the integration of path stability and QoS into the algorithm. Additionally QoS-MUDOR incorporates FOBREQ (part E) in order to minimize broadcast overhead. The basic algorithm for QoS-MUDOR is as follows.

REQUEST PROCEDURE

1) Source Node:

```
User Input -> Hash Function -> HDI
    If HDI exists in DataCache or in DTRT
        Supply/obtain data
    Else
        Broadcast RREQ to all nodes within communication range
```

2) Receiving Node:

```
If Request is in FOBREQ table
    If QoSOF value < FOBREQ value
        If HDI exists in DataCache or in DTRT
            Produce RREP
            Store in FOBREQ table
        Else if hopcount > 0
            Update QoSOF in RREQ packet
            Store in FOBREQ table
            hopcount = hopcount – 1
            Rebroadcast RREQ
        Else drop packet
        End if
    Else drop packet
    End if
Else
    If QoSC is met
        If HDI exists in DataCache or DTRT
            Produce Reply
            Store in FOBREQ table
        Else if hopcount > 0
            Update QoSOF in RREQ packet
            Store in FOBREQ table
            hopcount = hopcount – 1
            Rebroadcast RREQ
        Else drop packet
        End if
    Else drop packet
    End if
End if
```

REPLY PROCEDURE

1) *Destination Node:*

```
Produce RREP packet
Forward RREP to the previous node on path (towards source)
```

2) Receiving Node (intermediate node i.e. not source):

```
Update QoSOF of RREP packet
If current Doppler Value > RREP header Doppler Value
    Update RREP header Doppler Value
    Forward RREP to previous node
Else forward RREP to previous node
End if
Cache data path (CNA) along with corresponding HDI in DTRT
```

3) Source Node:

1. Obtain RREP.
2. Calculate the QoS cost using (1) from the RREP using the QoSOF and preset individual QoS Weights.
3. Calculate the Effective Cost (2) for the path using the QoS Cost, Doppler Value (from RREP) and the preset weights for QoS and Doppler Value.
4. Store data path in DTRT.
5. Repeat steps 1 to 4 for all RREP packets received.
6. At time *t* sort paths in the DTRT according to Effective Cost (smallest to highest cost).
7. Select first entry path in DTRT as the *primary path* for obtaining data.

Note that process 6 onwards must initiate at a predefined time *t* by which at least *one* entry must exist in the DTRT at the source node. When a node unexpectedly fails or moves out of range, it sends a Route Error (RERR) message back to the source, in which case a new route from the DTRT (usually the first alternative path i.e. second path in DTRT) is selected. The FOBREQ table contains the RREQ packet's source address, HDI and its corresponding cost value used as a discriminator by the FOBREQ process. When a new identical RREQ arrives with a better *cost* value, it replaces the previous entry for the identical RREQ in the FOBREQ table. Additionally, the DTRT at each intermediate node stores the path information leading to the HDI. This is a passive process as a node simply obtains this information directly from the RREP packet before it forwards it on towards the source. Hence it is not only the source node which learns a path to such data but also all the intermediate nodes on the path. There is a separate *DataCache* where the actual data are stored on-board at the providing (destination) node and eventually at the requesting (source) node. Note how the procedure first checks the FOBREQ table, instead of the QoSC field. The logic is that if the current packet's cost value is less than the one in the FOBREQ table of the identical request, then it must also meet the QoS constraints.

IV. SIMULATION OF PROPOSED SCHEME

We have developed a simulation package in Java entitled the AeroManet™, which can simulate the proposed scheme by changing different parameter values such as node density, communication range, percentage of nodes having the requested data, and different QoS parameters (additive, multiplicative and concave). An actual real-world scenario is simulated, with average number of planes from [26] over a large continent such as North America, actual plane speeds, and average intra-continental flight durations. The communication range chosen is less than the estimated physical maximum range of 670km between airplanes at altitude of

10km [6], to minimize the possible effect of signal attenuation caused by atmospheric conditions [10].

The simulation parameters consist of 5000 nodes spread over an area of 9 million km^2, where each node has a constant speed of 840km/h and travels linearly and with no pause time for 3.8 hours for the duration of the simulation. A maximum communication range of 300km is considered between nodes. Node positions and directions are randomly generated for each simulation case. The variable parameters are maximum hops, percentage of nodes having the required data, the individual QoS constraints, and the respective weights of the QoS and Doppler Values in (2). The number of handoffs is noted at the end of the simulation for each of the scenarios, which corresponds to the average path duration for each case. Hence if there are fewer handoffs, the average path durations would be longer (i.e. inversely proportional). It is also important to note that this paper focuses on simulations relating to path stability, and not traffic, which will be dealt with in future simulations.

For the first set of simulations the propagation delay and attenuation due to path loss are chosen as the QoS measure, and therefore the metric used here is the distance, which is an additive metric. In the first simulation we have variable weights, given as the Doppler Value Weight (DVW) to QoS Weight (QoSW) ratio. The QoS cost constraint, defined as the *threshold,* is set to 300km. Percentage of nodes possessing requested data is set to 10%. Fig. 3 illustrates the simulation result. The average hop count for this scenario is 2. The QoS cost slightly increases as the Doppler Value Weight to QoS Weight ratio increases. Note that the QoS cost is of 1:50 factor in graph. Table I shows the simulation results. Incrementally the relative value of the Doppler Value Weight is increased descending down the table. In this simulation the number of handoffs decreases, whilst the average path distance increases. Table II and Table III show simulation results where 5% and 1% of nodes have the required data with QoS constraints of 300km and 600km respectively. It is important to note that in Table II the average path distance is more irregular with increasing Doppler Value Weight. This phenomenon is explained in the next section. The shaded region entry in the table (zero Doppler Value Weight) corresponds to traditional reactive protocols such as QoS-ASR, AODV, DSR, and shortest path algorithms with distance being the metric for shortest path and QoS. The non-zero Doppler Value weights following it correspond to the effect of QoS-MUDOR that chooses the paths which both meet QoS constraints and consider path stability. Fig. 4 shows the bandwidth simulation. Here the QoS cost increases regardless of node motion as the Doppler Value Weight to QoS Weight ratio increases. The bandwidth constraint is however met.

Table I. Simulation results (10% nodes have data – threshold 300)

Doppler Value Weight	QoS Weight	No. Handoffs	Ave. No. of Hops	Ave. Path Distance (km) (QoS)
0	1	9	2	157.6145
0.5	1	7	2	158.5106
1	1	5	2	177.7437
1	0.5	3	2	204.9964
1	0	3	2	205.7744

Table II. Simulation results (5% of nodes have data – threshold 300)

Doppler Value Weight	QoS Weight	Ave. No. Handoffs	Ave. No. of Hops	Ave. Path Distance (km) (QoS)
0	1	10	2	180.8767
0.5	1	6	2	250.4471
1	1	6	2	249.0621
1	0.5	2	2	232.8859
1	0	1	2	239.0049

Table III. Simulation results (1% of nodes have data – threshold 600)

Doppler Value Weight	QoS Weight	Ave. No. Handoffs	Ave. No. of Hops	Ave. Path Distance (km) (QoS)
0	1	13	2	246.7923
0.5	1	8	2	278.063
1	1	7	2	315.3804
1	0.5	3	2	574.6311
1	0	3	3	582.5297

Table IV. Simulation results (10% nodes have data – threshold 300)

DVW:QoSW	Ave. No. Handoffs	Ave. No. of Hops	Ave. Path Distance (km) (QoS)
0	13	2	133.8183
0.4	8	2	95.4792
0.8	7	2	93.39689
1.2	7	2	93.39689

Table V. Simulation results (3% nodes have data – threshold 300)

DVW:QoSW	Ave. No. Handoffs	Ave. No. of Hops	Ave. Path Distance (km) (QoS)
0	9	2	163.3819
0.4	8	2	164.0601
0.8	8	2	164.0601
1.2	7	2	171.3759

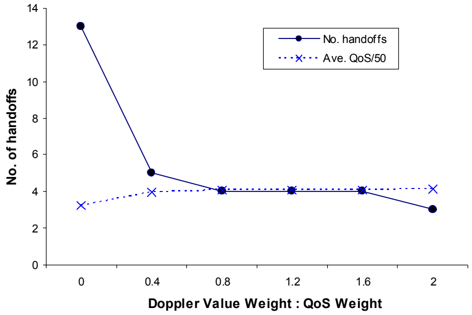

Fig. 3. Distance simulation.

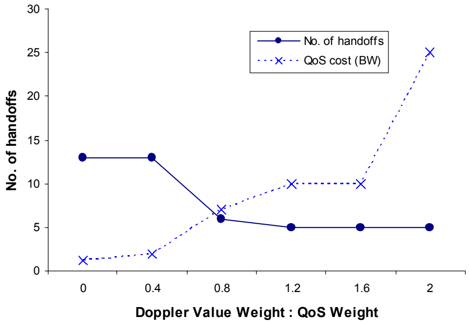

Fig. 4. Bandwidth simulation.

V. RESULTS AND DISCUSSION

From Table I, II and III we can see that as we increase the Doppler Value Weight relative to the QoS Weight, the number of handoffs decrease. Particularly, note the special case of Table IV and to a lesser extend Table II. In these two simulations the average QoS cost actually decreases when the DVW to QoSW ratio increases. This may be explained as in this scenario the paths selected have nodes which may reach their maximum communication range less frequently than the shortest path algorithm which consequently causes nodes to reach their maximum range more frequently (as it does not take into account relative velocity of nodes) and hence the average path distance is greater than that of the former. Table II also implies this idea in a more irregular manner. Thus in general we may not always compromise distance related QoS when we choose stable paths, and in fact we may get shorter average path lengths as a result of choosing more stable paths. It is also important to note that actual weights do not correspond to actual number of handoffs and can only act as a general rule. Actual number of handoffs and QoS/handoff tradeoffs vary from scenario to scenario. With regard to setting QoS constraints, they should ideally be loose enough to ensure that at least one path can be found at all times.

VI. CONCLUSIONS AND FUTURE WORKS

In this paper we introduced several schemes for ad hoc routing aimed at highly mobile pseudo-linear mobile ad hoc networks such as an aeronautical ad hoc network. Proposed schemes are aimed at the application of data sharing, and focus on integrating QoS and relative velocity of nodes in selecting stable paths that also meet QoS. This is done by observing the Doppler shift of reply packets in addition to checking QoS constraints at each node during route discovery. Other schemes integrated into the routing model look at minimizing flooding by only rebroadcasting "best" packets. Results show that the proposed algorithm termed QoS-MUDOR is effective in finding stable paths which have significantly higher duration whilst also meeting QoS constraints. Future work should focus on comparison studies of traffic and throughput of QoS-MUDOR relative to other reactive routing protocols. The optimization of the relative weights of QoS and Doppler Values should also be the subject of future research. Additionally further simulations involving multiple metrics should be performed and analyzed against other algorithms to verify the proposed schemes in diverse applications and scenarios.

Acknowledgement: This work is partly supported by the Australian Research Council under a Discovery Project grant.

REFERENCES

[1] A. Nandan, S. Das, G. Pau, M. Gerla, and M. Y. Sanadidi, "Co-operative downloading in vehicular ad-hoc wireless networks," in *Proc. WONS'05*, pp. 32-41, Jan. 2005.

[2] L. Yin and G. Cao, "Supporting Co-operative Caching in Ad Hoc Networks," in *Proc. IEEE INFOCOM*, 2004.

[3] Connexion by Boeing http://www.connexionbyboeing.com.

[4] M. Holzbock, et al., "Evolution of aeronautical communications for personal and multimedia services," *IEEE Commun. Magn.*, vol. 41, no. 7, pp. 36-43, Jul. 2003.

[5] A. Rogoyski, O. Franzrahe, S. Tudge and M. De Sanctis, "The market for wireless in-cabin aeronautical communications," in *Proc. 12th IST summit on Mobile and Wireless Communications*, pp. 623-627. Aveiro, Portugal. Jun. 2003.

[6] E. Sakhaee and A. Jamalipour, "Aeronautical Ad Hoc Networks," in *Proc. IEEE WCNC'06*, Las Vegas, NV, USA, April 2006.

[7] D. Johnson and D. Maltz, "Dynamic source routing in ad hoc wireless networks," in *T. Imielinski and H Korth, editors, Mobile Computing*, Chapter 5, pp. 153–181, Kluwer Academic, 1996.

[8] C-K. Toh, "Associativity-Based Routing For Ad-Hoc Mobile Networks," in *J. on Wireless Personal Commun.*, vol. 4, no. 2, 1997, pp. 1-36.

[9] H. Labiod and A. Quidelleur, "QoS-ASR: an adaptive source routing protocol with QoS support in multihop mobile wireless networks," in *Proc. IEEE VTC*'02. vol.4, pp. 1978 – 1982, Sept. 2002.

[10] M. Holzbock, M. Werner, A. Jahn, and E. Lutz, "Future broadband communications for airliners," in *Proc. EMPS'00*, pp. 221-226, London, UK, Sep. 2000.

[11] A. Nasipuri and S. R. Das, "On-Demand Multipath Routing for Mobile Ad Hoc Networks," in *Proc. ICCCN*, 1999.

[12] M. K. Marina and S. R. Das, "On-demand multipath distance vector routing in ad hoc networks," in *Proc. ICNP'01*, 2001, California, USA.

[13] C. E. Perkins and E. M. Royer, "Ad hoc on-demand distance vecor routing," in *Proc. IEEE WMCSA*, pp. 90-100, New Orleans, LA, USA. Feb. 1999.

[14] R.V. Boppana and S. P. Konduru, "An Adaptive Distance Vector Routing Algorithm for Mobile Ad Hoc Networks," in *Proc. IEEE INFOCOM'01*, vol. 3, pp. 1753–1762, Anchorage, 2001.

[15] V. D. Park and M. S. Corson, "A highly adaptive distributed routing algorithm for mobile wireless networks," in *Proc. IEEE INFOCOM'97*, pp. 1405-1413, Kobe, Japan, Apr. 1997.

[16] C. E. Perkins and P. Bhagwat, "Highly dynamic destination-sequenced distance-vector routing (DSDV) for mobile computers," in *Proc. ACM SIGCOMM*, pp. 234-244, London, UK, Sep. 1994.

[17] S. Murthy and J. J. Garcia-Luna-Aceves, "An efficient routing protocol for wireless networks," *ACM/Baltzer Mobile Networks and Applications*, pp. 183-197, 1996.

[18] T. Clausen et al., "Optimized link state routing protocol," http://hipercom.inria.fr/olsr/rfc3626.txt , October 2003, RFC 3626.

[19] R. Ogier, M. Lewis, and F. Templin, "Topology dissemination based on reverse-path forwarding (TBRPF)," http://rfc3684.x42.com , RFC 3684, Feb. 2004.

[20] Z. Haas and M. Pearlman, "The performance of query control schemes for the zone routing protocol," *IEEE/ACM Trans. on Networking*, vol. 9, no. 4, pp. 427-38, 2001.

[21] C. Santivanez, R. Ramanathan, and I. Stavrakakis, "Making link-state routing scale for ad hoc networks," in *Proc. ACM MobiHoc*, pp. 22-32, Long Beach, California, USA, Oct. 2001.

[22] F. Bai, N. Sadagapan, B. Krishnamachari, and A. Helmy, "Modeling Path Duration Distributions in MANETs and Their Impact on Reactive Routing Protocols," *IEEE JSAC*, vol. 22, no. 7, Sep. 2004.

[23] S. Cho and J. P. Hayes "Impact of Mobility on Connection Stability in Ad Hoc Networks," in *Proc. WCNC*, New Orleans, LA, USA, Mar. 2005.

[24] Z. Wang and J. Crowcroft, "Quality-of-service routing for supporting multimedia applications," *IEEE JSAC*, vol. 14, pp. 1228-1234, 1996.

[25] Z. J. Haas, "A new routing protocol for the reconfigurable wireless networks," in *Proc. IEEE ICUPC'97*, vol. 2, pp. 562-566, 1997.

[26] National Air Traffic Controllers Association (NATCA) http://www.natca.org/mediacenter/bythenumbers.msp.