Maximally Node Disjoint Congestion Aware Multipath Routing in Wireless Networks for Delay Minimization

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ABSTRACT

Many multipath routing schemes have recently been proposed to improve the performance of wireless networks. Multipath routing is helpful for reducing end-to-end delay, for distributing the load among paths and also for increasing the throughput. However, multipath routing is not always efficient in terms of delay as, mutual interference between multiple paths may degrade the performance of routing scheme. Therefore, selection of proper paths eventually determines the performance of multipath routing. If the different paths under concern are mutually interference free as well as load balanced, then, multipath routing can lead to better performance. It is shown through simulation that multipath routing with less coupling and congestion improves the efficiency of system in terms of end-to-end delay and load balancing than single path routing. In this paper, we have proposed interference and also congestion aware routing paths selection algorithm for parallel distribution of data packets in wireless networks. Simulation results show that congestion and interference aware multipath routing improves the network quality of services (QoS).

General Terms

Connectivity graph, Algorithm, Dijkstra Shortest Path Algorithm.

Keywords

Link Interference, link traffic load, routing, node-disjoint paths, wireless networks.

1. INTRODUCTION

A wireless network is a self-organizing and dynamically reconfigurable network with no fixed infrastructure. Two nodes in a wireless network can converse with each other if they are within the communication range of both. Due to the limited radio propagation range of wireless devices, the routes are often 'multi-hopped'. Finding paths (or routing) is a challenging issue to support multi-hopped transmission. Single path routing protocols such as DSR [9] do not always ensure vital characteristics like high throughput, shorter delay, and low overhead and also effective utilization of bandwidth. To improve the performance of wireless networks in terms of shorter end-to-end delay and high throughput, multipath routing schemes are considered as one of the potential solutions. When packets are simultaneously transferred over several paths between source-destination pair, the throughput and end-to-end delay are improved. Unlike the single path routing, multipath routing enhances both bandwidth utilization and throughput; it also minimizes end-to-end delay, overhead and congestion.

Although multipath routing algorithms are often used for distributing the packets/ traffic over several paths, to improve the reliability of data delivery it is obligatory to use node-disjoint multi paths to ensure path reliability. However, paths having no common nodes or links may still interfere with each other primarily due to the broadcasting nature of communication. Multiple flows traversing through a common area could contend for the resources/channel, resulting in degradation of performance. Hence, physically separated routing paths could be used to improve the performance [6]. In [7], a performance study of node-disjoint multipath routing in VANET has been presented. They choose two node-disjoint paths in such a way that the inter-path interference between the paths are minimized. Another work on sensor networks [8] determines triple node disjoin path set < primary path, secondary path, back up path > for multipath routing based on the inter-path interference of nodes that interfere beyond transmission range. They propose a congestion control mechanism that adjusts the data rate dynamically in each path so that active paths are loaded at the potential rate.

Many works such as [1][2][3] discover multiple link or node-disjoint paths but use only the best path for data transmission-the alternative path is used if the primary path fails; this is sufficient to improve the reliability and overhead. However, these works do not consider the effects of interference like low throughput and delay among the nodes for path selection. Some works [4][5] modify the DSR protocol for multipath load balancing and use multiple disjoint paths simultaneously for data routing without taking into account any type of interference. Wu and Harms [6] define correlation factor of two node-disjoint paths as the number of links connecting the two paths and, use it as the path selection metric to select a pair of least interference paths for simultaneous transmission, assuming that there is no interference beyond transmission range. In [12], authors showed that how to set up multiple best paths which are node disjoint.

In this paper, we propose a least congested and interference minimizing multipath routing for simultaneous transmission in wireless networks. The proposed algorithm is used to evaluate the quality of a path set for multipath load balancing. First, we need to find a set of least congested node-disjoint paths between source and destination pairs to show the interference between them. A least congested node-disjoint path set can be found using Dijkstra's shortest path algorithm [11] where each edge weight is set to the quantity of packets flowing between two nodes together with the number of packets buffered at head node. To get the effect of both wireless interference as well as interference due to the nodes beyond the transmission ranges, we use the conflict graph [10] to model the first one, i.e., wireless interference. If two links are mutually conflicting then these two links cannot be active simultaneously. Link interference for each node-disjoint path can be derived from a conflict graph. Using both link interference degree and link congestion status, total interference for the path set is determined. This total interference describes whether paths are having fewer coupling or high coupling (considering inter and intra path interference and congestion level).

The rest of the paper is organized as follows. Section 2 presents the underlying model and related parameters. Section 3 describes the proposed path set evaluation technique for multipath load balancing. Section 4 describes the experiments for validation and evaluation followed by results and discussion. Section 5 concludes the paper.

2. THE PROPOSED PATH PAIR SELECTION TECHNIQUE

Before we describe the proposed path pair selection technique for multipath routing, we first introduce the network model, load congestion metric and link interference and path interference parameters used for path-pair determination.

2.1 Network Model

Consider a network G modeled as a connectivity graph G (V, L) where V is set of mobile nodes and L is set of bi-directional links. Each node has unique id and transmission radius R_i . The distance between two nodes i and j is written as d_{ij}. The link from node i to j (i, j ∈ V) is defined as $l_{ij} \in L$ if node i and j are within the transmission range of each other. The neighbors of node i is defined as $N^1(i)$ - it is the set of nodes within the transmission range R_i. For simplicity we assume that all the nodes in the network have uniform transmission range R and interference range I where usually $R \leq I \leq 2R$. However without loss of generality it is assumed that I=R.

2.2. Definitions

In this section, we provide some necessary definitions used in the subsequent sections of the paper.

Definition 1 (Loop free path):

If s is the single source and d is the single destination then the loop free path from s to d is defined as P(s, d)={s,….,d} which is a sequence consisting of the source node, intermediate nodes and the destination node.
If MP_D(s, d) is the set of all possible disjoint paths from s to d , it can be expressed as

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

The two paths P_i and P_j where P_i, $P_j \in$ MP_D are two disjoint paths if $(P_i) \cap V(P_j)=\{s,d\} \land V(P_i) \subset V \land V(P_j) \subset V$, where $V(P_i)$ is the set of nodes in path P_i and $V(P_j)$ is set of nodes in path P_j.

Definition 2 (Interference free path):

If $d_{ij} > I$ for $\forall i \in V(P_i)-\{s, d\}$ and $\forall j \in V(P_j)-\{s, d\}$, then two paths are said to be interference free.

Definition 3 (Path Congestion Metric):

Routing protocols that do not consider load status of a route could result in serious congestion problems causing performance degradation. Therefore load status plays an important role on route selection criteria. The weight of each link l_{ij} from i to j in G is half of the sum of the number of packets buffered at each head node j and number of data packets passing through the link l_{ij}. This link weight is used to determine node-disjoint least congested routing path set P_N from any source to destination

$$l_{ij} =(Queue\_length(j)+f_{ij})/ 2, \forall l_{ij} \in L \text{ and } j \in V$$

where, Queue_ length (j) is number of packets buffered at head node j and f_{ij} is total flow over the link l_{ij}. Since path load metric is the sum of the link load metrics of all the links in the path, the path congestion metric of the ith path, denoted as L_{Pi}, where $P_i \in$ MP_D is defined as

$$L_{pi} =l_{si}+ \ldots +l_{ij}..+l_{jd} \text{ where each link belongs to path } P_i$$

Definition 4 (Connectivity graph for multi path set):

For any s-d pair, we formulate connectivity graph $G_1(V_1,L_1)$ for a multipath set where V_1 is set of nodes of node- disjoint least congested path set and L_1 is the set of unidirectional links. For any two nodes i and j ($i,j \in V_1$) there is a link between i and j if either (1) i and j are within the transmission range of each other or (2) i and j are within the interference range of each other.

Definition 5 (Conflict graph for multipath set):

For a single application flow from s to d, we derive the conflict graph H (E, C) for a multipath set. The vertex set C (of H) are the links of node-disjoint least congested path set and two vertices C1, C2 ∈ C has a link if they are mutually conflicting. This conflict graph is used to evaluate the link interference degree of two node-disjoint least congested paths. The two links C1 and C2 where $C1=l_{ij}$,$C2= l_{kl}$ ($l_{ij} \in P_i$, $l_{kl} \in P_k$ and $P_i, P_k \in P_N$) are mutually conflicting with each other when node k is within the interference range of node j or node l is within the interference range of node i. Again, l_{ij} and l_{kl} are also conflicting if they have the common node (i=k or i=l or j=k or j=l). Based on the conflict graph H, we formulate the following definitions.

Definition 6 (Link Interference):

Link interference η_{ij} of link $l_{ij} \in H$ is defined as the number of edges incident on it. Based on the amount of link interferences of each path we can determine path interference degree.

Definition 7 (Path Interference):

Path interference η_{P_i} is defined as the sum of link interference degree of all the links that belong to path P_i. So for selection of paths, we consider both the link level congestion and link level interference on each path. This is evident as high traffic load as well as high interference could increase end-to-end delay and also reduce the packet delivery ratio.

Definition 8 (Total Interference):

For any node-disjoint path pair, total interference η combines individual link weights that account for both link interference and link load level of each path as follows.

$$\eta = \frac{\sum_{(i,j) \in P_i} \eta_{ij} + \sum_{(k,l) \in P_k} \eta_{kl}}{2}$$

where, $P_i , P_k \in P_N$

Example: Using the following example we can illustrate the link interference degree and total interference degree between node-disjoint path pair. Let a network consists of one source, one destination and four intermediate nodes. The two node-disjoint path pair in shown in figure 1 and the corresponding conflict graph H is shown in figure 2. From the figure 1. we can compute one hop interfering nodes of node S,A,B,D,E,F etc. Dash lines represent interfering edges .One hop interfering node set of node A, B, E, F, S, D is given by A={S, B, E} , B={A, E, D} ,E={S, F, A, B} F={E, D} ,S={A, E} ,D={B, F} respectively. Two node disjoint paths from S to D are {S A B D} and {S E F D}.

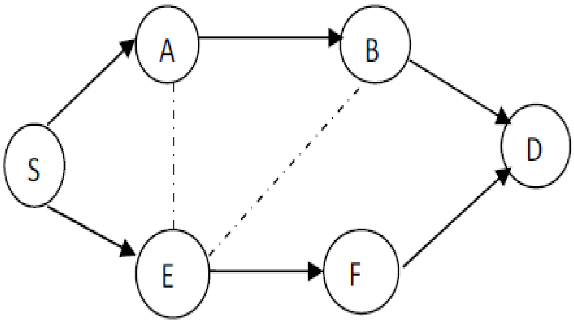

Fig 1: Connectivity Graph between two node-disjoint paths

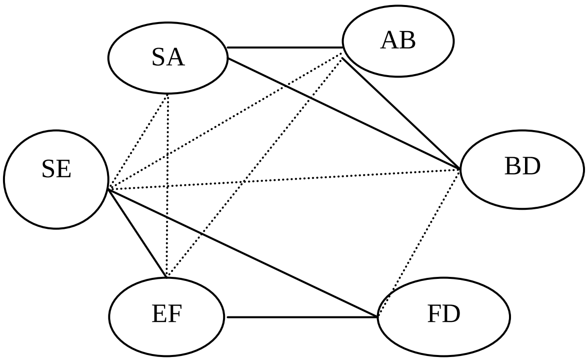

Fig 2: Conflict Graph H for two node-disjoint paths

We can formulate an Edge –Interference Matrix (EIM) of each node-disjoint path pair in following way:

$$EIM(i,j)=\begin{cases}1, & \text{i and j incident in conflict graph H of } G_1\\ 0, & \text{Other wise}\end{cases}$$

Table 1. Edge-Interference Matrix

Edges	**SA**	**AB**	**BD**	**SE**	**EF**	**FD**
SA	0	1	1	1	1	0
AB	1	0	1	1	1	0
BD	1	1	0	1	0	1
SE	1	1	1	0	1	1
EF	1	1	0	1	0	1
FD	0	0	1	1	1	0
∑	4	4	4	5	4	3

Table 2. Timing Diagram Table

Slots	**Path 1 { S A B D}**	**Path2 {S E F D}**
1	S—A	
2	A—B	
3		S—E
4	B—D	E—F
5		F—D

Table 3. Interference Calculation Table

Edges	**Load level of edges**	**Link interference value from EIM**	**Amount of interference produced by each edge**
SA	0.7922	4	3.1688
AB	0.9595	4	3.8380
BD	0.6557	4	2.6228
SE	0.0357	5	0.1785
EF	0.8491	4	3.3964
FD	0.9340	3	2.8020
η			8.00325

3. THE PROPOSED INTERFERENCE AND CONGESTION AWARE MULTIPATH ROUTING ALGORITHM

Here, we focus on the interference and congestion aware multipath routing for data transmission from source to destination in wireless networks. The proposed algorithm consists of four phases: (i) Least congested node-disjoint path set determination; (ii) Interference minimized primary and secondary path pair determination, (iii) Data transmission and finally (iv) Path maintenance. The source uses primary and secondary paths concurrently for load balancing and invoke the path maintenance procedure if any of the path fails, thus minimizing the route discovery overheads. First we discuss a lemma to be used in the scheme being proposed.

Lemma 1: For any given source node s with $N^1(s)$ number of 1-hop neighbors within its transmission range, the maximum possible number of node-disjoint multipath it can have is $N^1(s)$.

Proof: Menger's theorem [13] in graph theory says that number of node disjoint paths from a node is always bounded by the degree of the node. Let $N^1(s)$ be the degree of the source node s .Therefore the node s has $N^1(s)$ number of node-disjoint paths by Menger's theorem. All the 1-hop neighbors of s are used to set up node disjoint paths. Now assume that s is going to compute an extra path between itself and intended destination. In this case s will find that it has no unexplored 1-hop neighbors to construct the path, otherwise the neighbor will be counted twice. Again this is the violation of the definition of disjoint routing path .Therefore; the extra path is no longer possible for s. So, maximum number of node-disjoint routing path of any node is restricted to the number of its 1-hop neighbors $N^1(s)$.

Algorithm1: Finding a set of least congested node-disjoint paths P_N

```
Input: Graph $G (V, L)$, source $s$ and destination $d$.
Output: A set of least congested node –disjoint path set $P_N$
Initialization: $P_N = \emptyset$, $N^1(s)$ = number of 1-hop neighbors of s
for i =1: $N^1(s)$
$P_i \leftarrow$ least congested path from $s$ to $d$ in $G$
if $P_i$ = nil
    terminate the algorithm
else
    $P_N \leftarrow P_N \cup \{ P_i \}$
for each $j \neq s$ and $j \neq d$ on $P_i$
for each $k \in N^1(j)$
    $L \leftarrow L-\{(j,k)\}$
    $V \leftarrow V-\{j\}$
end if
end for
end if
end for
return $P_N$
```

Algorithm 1 finds the least congested path from source to destination from the original graph G (V, L) where link cost is set to sum of packet occupancy in buffer at head node and the number of packet passing through the link for s-d transmission. We use the Dijkastra's O (V^2) algorithm to determine least congested path on G. If there is only one path the algorithm terminates. To obtain more disjoint paths, we delete all the nodes and also links incident on those nodes on the path obtained from previous iteration and get modified graph $G^/(V^/, L^/)$. We rerun the algorithm again until no more paths are available. The complexity of the algorithm is O (V^3).

Algorithm 2: Finding interference minimized least congested path pair for data transmission

/* $P_N (s, d)$: Node-disjoint least congested path set from s to d e.g. $P_N = \{P_1, P_2, ..., P_n\}$*/

/* *all pair* (P_N): all possible combination of two elements that is path pair chosen from P_N, e.g. $\{(P_1, P_2), (P_2, P_3), (P_1, P_3)\}$*/

```
Input: Least congested node-disjoint path set PN, Edge-Interference Matrix (EIM)
Output: Interference minimized least congested path pair
minimum_correlation←∞, path_pair={}
if $P_N = \emptyset$
    terminate the algorithm
    exit
else
for ant two path $P_i, P_k \in$ all pair($P_N(s,d)$)
    compute the link interference degree of each link belongs to $P_i$
    compute the link interference degree of each link belongs to $P_k$
    $\eta = \frac{\sum_{(i,j)\in P_i} \eta_{ij} + \sum_{(k,l)\in P_k} \eta_{kl}}{2}$
 if $\eta$ < minimum_correlation
    path_pair←$\{P_i\} \cup \{P_k\}$
    minimum_correlation← $\eta$
end if
end for
end if
```

Algorithm 2 finds the most suitable disjoint path with lower interference and lesser congestion. If there exists V number of disjoint paths for a s-d pair, then the complexity to select two paths from V paths is O (V^2) .The time complexity of finding a path pair having least path interference is O(V^2). Therefore the overall complexity of algorithm is O (V^2).

3.1 Data Transmission

After successful path discovery, source loads its data packets into primary-secondary path pair based on the congestion level of each path. Let, the selected primary-secondary path pair for data transmission from source to destination be $\{P_1, P_3\}$ and congestion levels of P_1 and P_3 are L_{P1}, L_{P3} respectively. Then source transmits (L_{P1}/(L_{P1}+ L_{P3}))*100 percent of data over path P_1 and (L_{P3}/(L_{P1}+ L_{P3}))*100 percent of data over P_3 repetitively until either P_1 or P_3 fails.

3.2 Route Maintenance

A source node periodically sends probes to destination node over each primary-secondary path pair to check whether the paths are valid or not. If the source node does not receive any reply from destination it assumes that the corresponding path has failed and it is thus deleted from the routing table. When a path failure occurs the source sends the packets through another valid path. Route discovery is instantiated again when both primary-secondary path pair is failed.

4. SIMULATION EXPERIMENT

Simulations were conducted covering an area of 100m×100m, where some nodes were distributed randomly. Transmission range is 250 m, which is same as the interference range. Nodes are static in nature and spread over the whole region; source and destination nodes are selected randomly Each simulation lasted 30sec.We evaluate the performance of the proposed method via C++ simulator and compare the result with node disjoint multi paths with lowest delay is set up between source and destination. The node disjoint paths are used to minimize end to end delay but there is no such mechanism was used to avoid both inter path and intra path interference completely.

4.1 Impact of packet generation rate on delay

In this experiment, the packet generation rate of source node was varied from 4 to 18 in order to evaluate the protocol with increasing network traffic load. The delay is directly proportional to traffic load. Figure 3 shows the variation of delay is shown by using both node disjoint high interfering paths and interference aware multipath (using two paths) transmissions for sending packets from source to destination. With increase in packet generation rate the delay of interfering paths increases rapidly whereas delay in proposed scheme increases slowly. This is because paths established by proposed method has much low inter path and intra path interference while does not consider in lowest delay node disjoint multi paths.

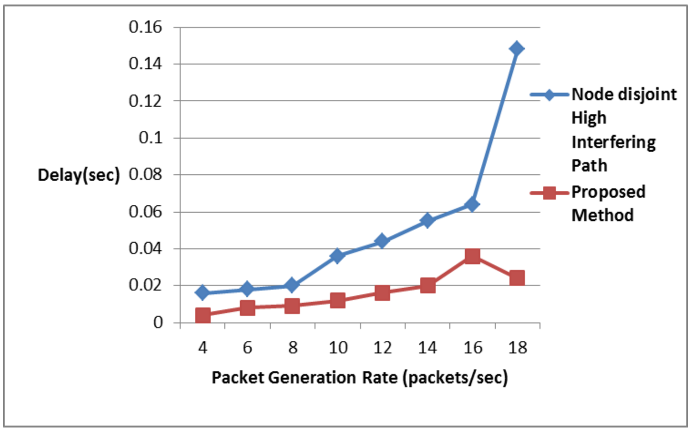

Fig 3: Packet generation rate vs. Delay

4.2 Impact of number of packets on energy consumption

In figure 4, we also consider both single path and multipath techniques for sending packets to destination. The number of source generation packets was varied from 10 to 50. The energy required for sending one packet using the least congested path is 0.4 unit and that using other alternate path is 0.6 unit. Here, load balancing has been considered. The number of packets going through both will be in the ratio 6:4 when we use both the paths i.e. 6 packets will go through the least congested path and 4 by alternate path considering a group of 10 packets. Here we see that the energy consumption with multipath transmission is higher as the packets are being sent through two disjoint paths.

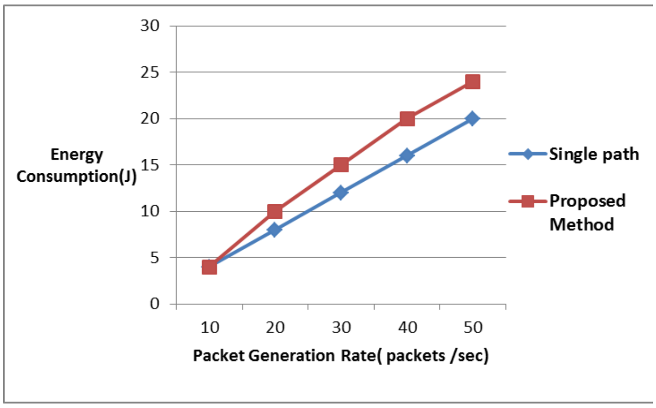

Fig 4: Number of packets vs. Energy consumption

4.3 Throughput Analysis

From the simulation shown in figure 5, average throughput of single path routing is around 80 Kbits/ sec whereas the average throughput of two high interfering paths is 91Kbits /sec. Thus, average improvement of throughput in this case is 14%. On the other hand, two non-interfering paths increase the average throughput to 134 Kbits/sec and improvement is 67% than the single path routing and 47% than two high interfering paths.

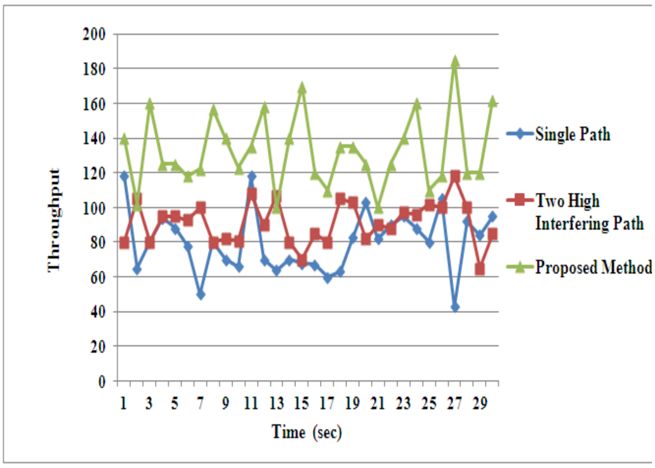

Fig 5:Time vs. Throughput

4.4 Impact of Balance Load Distribution

Figure 6 shows that the impact of packet load distribution over two non-interfering paths. It is clear from the figure that delay decreases if packets are distributed over the multi path based on current network condition. Instead of equal distribution of the packets over the path , it is always beneficial to distribute the packets based on the paths current laod value.

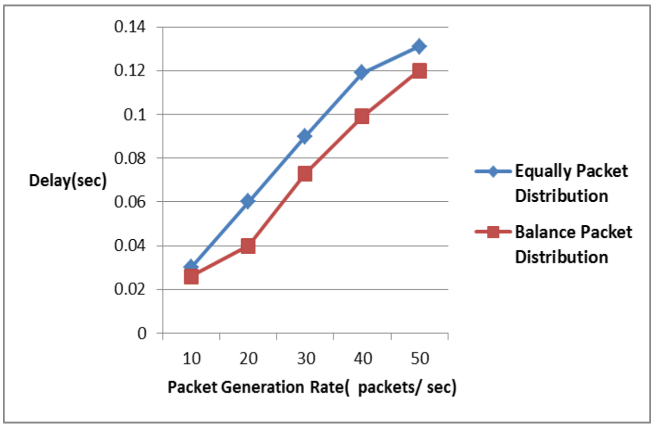

Fig 6: Number of packets vs. Delay

5. CONCLUSIONS

In this work, we have proposed a method to find the node-disjoint path pair with less coupling and congestion level for multipath load balancing scheme. In the path set selection procedure, we consider both the inter path interference and interference of nodes beyond the transmission range. Based on the congestion level on each path, traffic is distributed accordingly on each path pair. The simulations results show that the method proposed here improve the performance of wireless network in terms of delay and energy consumption. The work is being extended to consider the problem of multiple path interference coexisting for different source destination pairs - a reasonable situation in the current state of affairs.

6. ACKNOWLEDGMENT

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