Simple Routing Algorithm for Multi-hop Wireless Network

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ABSTRACT

Routing of data packets through wireless multi-hop networks is challenging, particularly when there are large number of nodes and objective is to optimize end to end throughput or delay. Simple route construction algorithm becomes attractive as it requires fewer computations and various routes are compared with less expenditure of computational energy. In this paper, a simple routing and scheduling algorithm is proposed, which can be implemented in centralized or distributed way. In this algorithm when the user node (U) tries to reach the base station (BS) through intermediate nodes (IMs), it draws a reference line to the BS, chooses the intermediate node at minimum angle with the reference line, from its neighboring nodes within one transmission range. The other links of the route to the BS through the IMs are also found in the same way. We call it minimum angle (MA) routing and distributed scheduling (DS), MA-DS. The minimum angle (MA) routing and centralized scheduling (CS) is initiated by the BS using the same principle to reach the user node (U), we call it MA-CS. Any node can find the next node on the route towards a destination and hence the algorithm can be used to pre-compute the whole route independent of the user. The algorithm requires only the position (x-y co-ordinate) information and the burst profile of the nodes.

Keywords: *Wireless mesh network, Routing, Scheduling, Interference, Throughput, Capacity*

1. INTRODUCTION

Wireless multi-hop networks are becoming more and more advanced in its technology for both acting as access networks or carrying high data rate communications. It is very important to have competitive broadband access technology to connect to wired Internet for global communication. The demand for media data transmission with ever increasing user numbers requires the capacity of the wireless links to be enhanced with sophisticated signal processing and receiver design. The signal design to cope with the fading characteristics of the wireless channel is particularly significant development. When a wireless network consists of a large number of nodes spread over a geographical area, it becomes more important to design routing and scheduling algorithms that is simple and requires fewer computations than to have it satisfying parameters like providing a best route for throughput or delay.

The wireless mesh network (WMN) is a new proposition [1] which is being used to interconnect to wired network localities or wired internet and is found to provide a number of benefits. Also the problems to develop WMN as the most viable broadband access technology are many. In WMNs, user nodes act as both a host as well as router to forward others' packets. The WMN is connected to the wired Internet through a base station (BS) or a gateway, all traffic between users and wired part of the communication network goes via BS.

A recently developed WMN that provide high capacity broadband connectivity is IEEE WiMax/8021.6 standard. The nodes in IEEE 802.16 are fixed and a user which may be mobile or fixed may connect to any of such nodes to upload or download its data to a distant server. When the user nodes or the network nodes may also be mobile, the stability of such network is a concern [2] as it may affect adversely on the throughput behavior of the network. As an alternative to wired backbone network in the metropolitan areas which is many a times difficult in its deployment, TDMA based wireless backhaul networks (WBNS) are being considered. Since the wireless channel is very error prone and suffers from fading attenuation, providing quality of service is a big issue. In [3], the problem of quality of service (QoS) guarantees in such networks is discussed and an integrated joint routing and scheduling scheme proposed.

The problem of interference becomes a bottleneck in the design of large wireless networks. Avoidance of interference totally while deciding a route obviously limits total network throughput. Optimal capacity allocation and the problems of interference in wireless mesh networks are addressed in [4]. Route construction algorithms in WMNs are attractive research [5] that decides the traffic of packets between users and BS. The scheduling of packets on the routes is designed for optimal achievement of throughput and delay. Also a fair allocation of capacity to all users is a natural requirement independent of their distances from the BS or the Gateway. The problem of fair allocation of throughput to all user nodes at different distances from the BS of the WiMax network is addressed in [6]. In [7], [8] the authors discuss joint centralized scheduling and channel assignment to improve the performance of WiMax 802.16 networks eliminating interference problem with multichannel transmission.

It is always possible that some links pertaining to the same route or different routes in a WMN may be activated simultaneously provided any link operation is not interfering with any other link operations. Concurrent transmission [10], spatial reuse [11], and formation of transmission groups [12], on different links of different routes of WMNs, are important consideration for minimizing frame scheduling length [9] and higher throughput between users and BS. For mitigating the problem of multiple access interference in multi-hop WMNs,

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the authors in [13] proposes a cross-layer design of interference aware routing and scheduling scheme to achieve high spectral efficiency. A comprehensive work on the different routing functions for wireless multi-hop networks, with their unifying and distinguishing features is seen in [14].

Our work here considers multi-hop wireless networks consisting of one or more intermediate fixed nodes (IMs) that receive and forward packets through wireless links for communication between two end nodes, the user U and the BS. The user node may be mobile while the IMs and the BS are fixed providing connectivity to the wired part of the network.

A simple routing and scheduling algorithm is proposed in this report. In this algorithm when the user U trying to reach the BS through IMs draws a reference line to the BS, chooses the IM at minimum angle with the reference line, from its neighboring nodes within one transmission range. The other links of the route to the BS through the IMs are also found in the same way. We call it minimum angle routing MA. This is particularly useful for delay sensitive applications. In [15] we reported MA-DS based routing and scheduling results for two example networks.

Some characteristics of the routes constructed by this algorithm are as follows. The route constructed is fixed between a particular user and the BS. To have different route to the BS, the user is required to change its location. The route part from any IM to the BS or the user is also fixed and it can be pre-computed before any user node's route requirement. The two routes between a user and BS, obtained by starting from the user to BS and from BS to user may be completely disjoint or some links may be common. Thus between a user and BS two routes are possible which may have different end to end throughput and the best may be chosen. The user or the BS as the starting point is not required to compute the full route. In the event of any IM node failure, the next minimum angle node or the node at minimum distance in the neighbor node set may be selected. The link between two nodes have data rate depending on its length and the burst profile of the nodes. Assuming that the locations (x-y coordinates) of all the nodes including the BS and user are known, it is easy to compute the throughput of a route or part of a route. The user may change its positions in the network to try for better throughput. The only information needed as input to the algorithm is the node's positions and burst profile.

While performing routing and scheduling, the criteria for primary and secondary interference are considered, as discussed in [4]. Link activation of a route depends on the user activity in the network. When simultaneously more users are active or the BS needs to send data to more users at the same time, transmission groups of links may be formed for concurrent transmission which results in higher spectrum spatial reuse and as a result higher system throughput [12].

2. METHODOLGY

In this section we discuss our proposed routing and scheduling technique for route construction for a given network nodes set.

A. Routing

In a multi-hop network, it is the responsibility of the routing protocol to find a path between two nodes through intermediate nodes (IMs), IMs acting as relays or forwarders. The data traffic then proceeds through the IMs from the source to the destination.

In our proposed routing algorithm to perform routing on a set of nodes, every user U (or BS) tries to maintain a path which doesn't deviate much from the BS (or the user U) in case of DS (CS). This is particularly useful when a large sensor network is deployed with large number of nodes and a route is to be constructed between a sender and a destination. We explain the minimum angle based routing with distributed scheduling (MA-DS) with the help of Fig. 1(a).

Here the user node U1 constructs a route to the BS by first drawing a reference line to the destination node. It then chooses the IM in its neighborhood of one transmission range that makes minimum angle with the reference line. Following the same procedure and by transferring the role of the starting node to the chosen IM node, the BS is finally reached. In each step, the reference line is drawn connecting the sending node, which may be the user node at the beginning and IM nodes while the route construction continues, and the BS. Thus a wireless node is selected, based on minimum angle, from the neighbor nodes of the user or the IM in the respective step to relay data packets. As is shown in Fig. 1(a), the packets from user U1 reaches the BS through the route U1 - node 4 - node 7 - BS.

For MA-CS, as shown in Fig. 1(b), the route construction is initiated by the BS. The BS draws a reference line to U1, chooses the node from its one transmission range neighbor nodes that makes the minimum angle with the reference line. And then continuing the process through the IMs, finally reaches the destination U1. The IMs of the route are chosen based on the same minimum angle criteria with the respective reference line to the user U1 as explained above.

It is clear from the Figs. 1 (a) and 1(b), that the packets reaches the destination from the sender through minimum number of hops and hence the least delay, provided the links have the best rates possible.

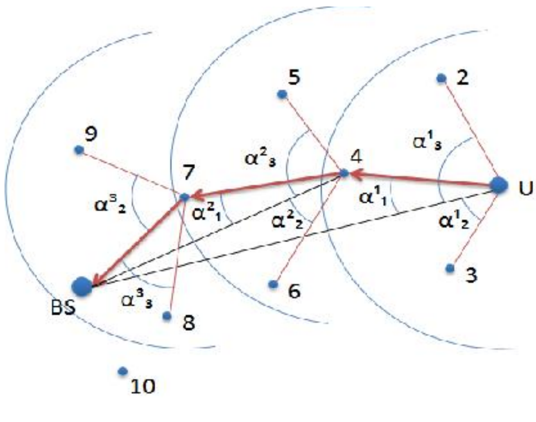

Fig. 1 (a) Routing based on Minimum Angle - DS

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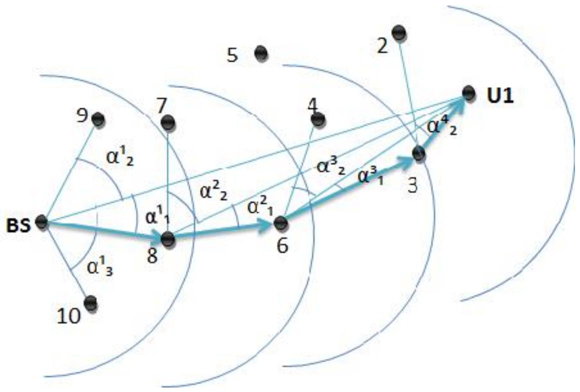

Fig.1 (b) Routing based on Minimum Angle - CS

It may be noted that for the same pair of end nodes, as explained above, the MA-DS and MA-CS may provide two different routes. The two routes may not also have the same end-to-end throughput performance. This is a distinguishing feature of our proposed routing algorithm. This may provide added advantage for uploading and downloading of packets through different routes.

B. Scheduling

The radio communication channel of WMNs is broadcasting. Thus, the problem that is experienced by WMNs is the reduction of the total capacity due to interference caused by simultaneous transmissions of nodes. The most popular technique to achieve robust and collision free communication is the link scheduling. Here different links are activated at different slot times and the slot duration as well as its activation time may be fixed or variable. For spatial reuse and higher spectral efficiency, transmission groups may be formed for simultaneous transmissions over the links of the group.

In this paper, we assume that one user node (or the BS) has data to send to the BS (or one user) at a given time, thus activating only the links on the route from the user (BS) to the BS (user), the route computed either by using MA-DS or MA-CS algorithm. In case at any given time more users have data ready to send to the BS, or the BS needs to send data to more users, the users or the BS take turns to send data to the destination(s). All users are at multiple hop distances from the BS. For each case, we compute the end-to-end throughput for comparison of the MA-DS and MA-CS algorithms for a given pair of source-destination.

3. PERFORMANCE EVALUATION

C. Route Construction and Scheduling

For performance evaluation of our algorithm, we consider four network scenarios of medium size, and find the routes for various users to the BS, using MA-DS and MA-CS algorithms. It is assumed that the users have position (x-y co-ordinate) information of all nodes, including the BS. Table 1 shows particulars of the four network scenerios.

TABLE 2

Network Scenerio	No of Users	No of IMs	No of BS	Range (Km.)	Area of Network (appx.) (Km^2)
1	6	31	1	4/4.4	24x24
2	7	13	1	4	20x20
3	7	35	1	4	24x24
4	6	28	1	5	25x25

We also assume that the nodes have burst profiles with modulation and code rates to obtain different data rates over various transmission distances (link lengths), as shown in Table 2.

TABLE 2 BIT RATES AND TRANSMISSION RANGES

Modulation	Coding Rate	Transmission Range (Km)	Bit Rate (Mbps)
QPSK	1/2	5	2
16-QAM	1/2	3.5	5.5
64-QAM	3/4	2	11

The use of the Table 2 is as follows. The nodes burst profile describes different modulations with code rates such that over the link distances as indicated in the table, different bit rates can be achieved when data is transmitted over the wireless medium. This provides the nodes with better data rates over smaller distances, and as a result higher end to end throughput achieved. It is assumed here that the nodes can operate with different modulations and code rates as needed. We calculate the time slot T_i (second) over i^{th} link with bit rate ***BR*** (Mbps) required to transmit a given file of size ***F*** (Mb), applying a code rate ***r*** by the following equation $T_i = (F/r)/BR$. The end to end throughput ***ETH*** over a route is obtained as $ETH = sum(T_i)/F$, where $sum(T_i)$ is total time required through all the links to reach the destination. We only consider the transmission times and ignore propagation times, processing times for coding, decoding, modulation and demodulation of data signals.

In the first network topology, shown in Fig. 2(a) the nodes are placed around the BS, x-y co-ordinates of all nodes are as shown in the figure. There are 38 nodes including a BS in the center and six users which are denoted as U1, U2, U3, U4, U5 and U6, respectively. All nodes have same 4 km transmission range. The routes for the users are also shown in the Fig. 2(a), constructed by using MA-DS algorithm. Hence the routes are formed from the users to the BS. For the same network, Fig. 2(b) show the routes between the users and BS using MA-CS algorithm, routes computed from the BS to users with 4.4 Km. range. It is seen that for the same pair of user-BS, two routes as obtained from MA-DS and MA-CS are different.

Fig. 3(a) and Fig. 3(b) show the routes computed in the second network scenario using MA-DS and MA-CS, respectively. Similarly, for the third and fourth network scenarios Fig. 4(a), Fig. 4(b), and Fig. 5(a), Fig. 5(b) shows the routes computed using MA-DS and MA-CS algorithms. Various network parameters are as noted in Table 1.

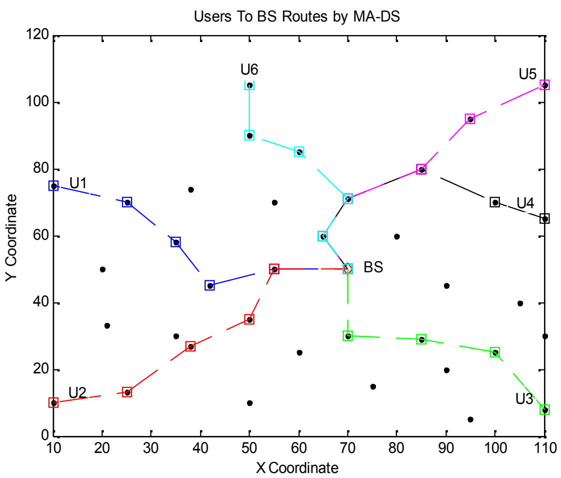

Fig. 2(a) Range of nodes=4 km, Total nodes=38

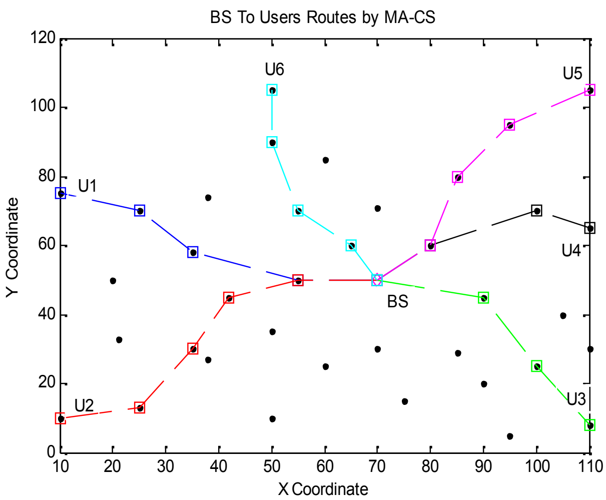

Fig. 2(b) Range of nodes=4.4 km, Total nodes=38

TABLE 3 End to End Throughputs for First Network

User No.	End To End Throughput (MBPS)	
	MA-DS Algorithm	MA-CS Algorithm
1	0.55	0.4783
2	0.4074	0.4074
3	0.3667	0.333
4	0.4074	0.5789
5	0.3235	0.2973
6	0.55	0.4783

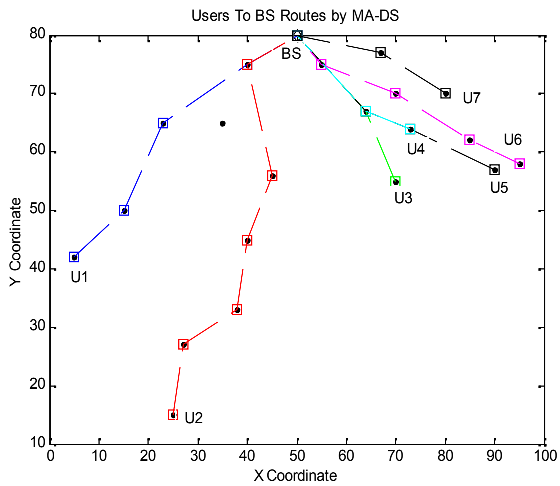

Fig. 3(a) Range of nodes=4 km, Total nodes=21

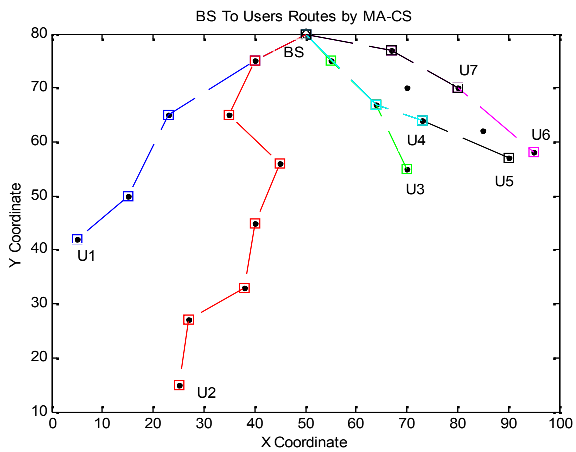

Fig. 3(b) Range of nodes=4 km, Total nodes=21

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TABLE 4 End to End Throughputs for Second Network

User No.	End To End Throughput (MBPS)	
	MA-DS Algorithm	MA-CS Algorithm
1	0.4783	0.4783
2	0.3548	0.3929
3	0.7333	1.1786
4	0.4714	0.4714
5	0.8250	0.5789
6	0.8919	0.8919
7	1.3750	1.3750

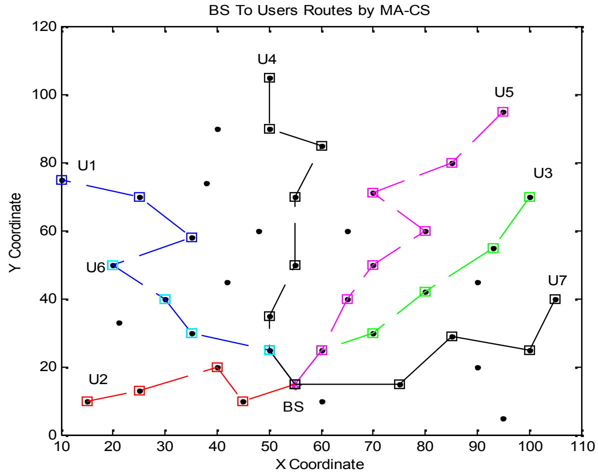

Fig. 4(b) Range of nodes=4 km, Total nodes=43

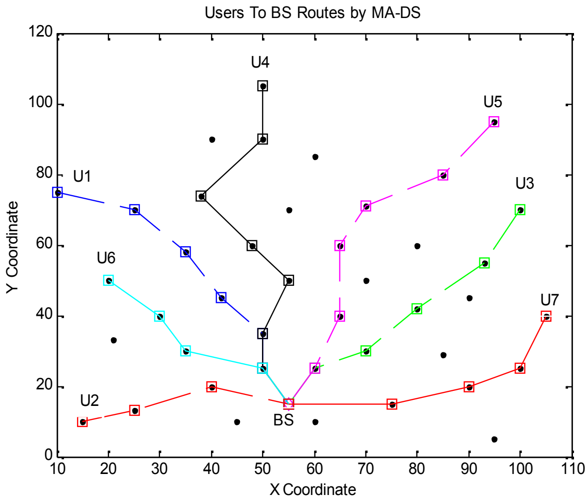

Fig. 4(a) Range of nodes=4 km, Total nodes=43

TABLE 5 End to End Throughputs for Third Network

User No.	End To End Throughput (MBPS)	
	MA-DS Algorithm	MA-CS Algorithm
1	0.5156	0.3929
2	0.9167	0.6875
3	0.4074	0.4074
4	0.3402	0.3402
5	0.2895	0.3143
6	0.6875	0.6875
7	0.4783	0.4783

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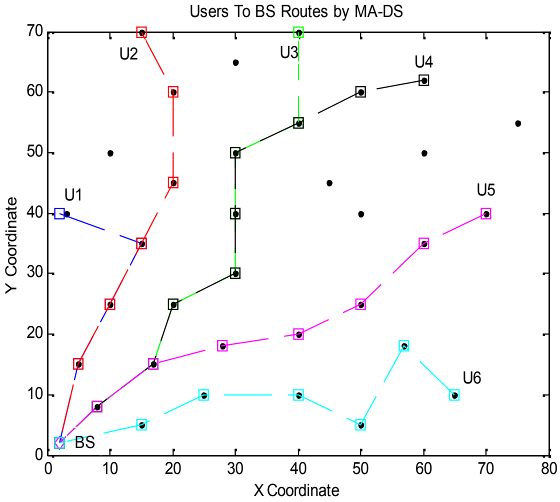

Fig. 5(a) Range of nodes=5 km, Total nodes=35

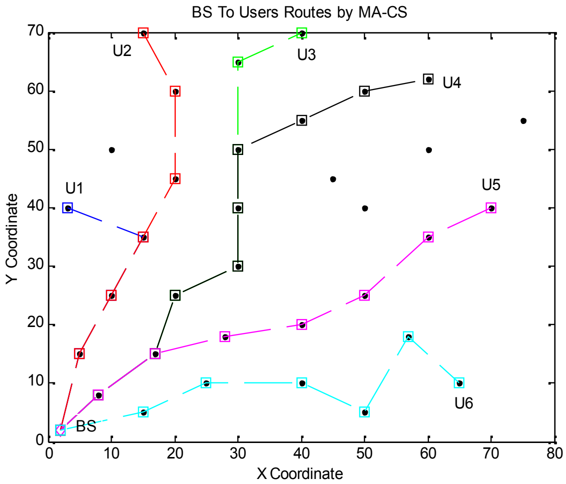

Fig. 5(b) Range of nodes=5 km, Total nodes=35

TABLE 6 End to End Throughputs for Fourth Network

User No.	End To End Throughput (MBPS)	
	MA-DS Algorithm	MA-CS Algorithm
1	0.25	0.25
2	0.1667	0.1667
3	0.1833	0.1833
4	0.1719	0.1719
5	0.1571	0.1571
6	0.1667	0.1667

The actual x-y coordinates of nodes, in network 1, 2, and 3 are to be obtained by dividing the shown x-y coordinates by 5, and for network 4 by dividing by 3.

D. *Throughput Performance: Results and Discussion*

For performance evaluation of minimum angle based routing and scheduling, following cases are possible:

- When only one user node (or the BS) is ready with data for sending to BS (or a user), it first finds the corresponding route and activates the links sequentially.
- When more than one user (or the BS) is ready with data to send to the BS (or to more than one users), corresponding routes are constructed, and links of each route is activated sequentially, the senders taking turns to transmit.
- When more than one user (or the BS) is ready with data to send to the BS (or to more than one users), corresponding routes are constructed, transmission groups are formed for concurrent transmissions. The time slot allocated to a group corresponds to the longest link length in that group.

We assume that every user has an 11Mb file to transfer, and the base station BS has aggregate rate of 11 Mbps. The time duration for which the links are activated, or the transmissions groups are activated, is based on the burst profiles of the nodes shown in Table.2.

We consider only the first and second cases for computing the end to end throughput for four different networks, parameters of which are noted in Table 1, using MA-DS and MA-CS algorithms. Some of our results for two networks considering all three cases above are reported in [15] for the uncoded case with full bit rates.

In this report we show our results for the first case in tables from Table 3 to Table 6. For the second case results are shown Table 7. For the first network we see from Table 3 that MA-DS and MA-CS provide similar end to end throughput for each pair of user-BS route, except for U4-BS pair where MA-CS performs better. Also the routes constructed using MA-DS and MA-CS differs as is seen from Fig. 2(a) and Fig. 2(b). Table 4 shows that in the second network, for the U3-BS pair MA-CS provides better results, whereas for U5-BS pair MA-DS result is higher. For other user-BS pairs, both algorithm computes same or similar end to end throughput.

For the third network scenario, Table 5 shows that MA-DS provides better end to end throughput for U1-BS and U2-BS pairs. For U2-BS pair obtains more throughput from MA-CS. For the fourth network, we see from Table 6 that both the algorithms provide same results for all the user-BS pairs.

When all the users belonging to a network have data to transmit at the same time, they form a scheduling frame of time length equal to sum of all times for all routes for all user (BS)-BS (user) pairs, and every pair take turns to transmit and receive once every scheduling frame length. Here although throughput obtained by each pair is less, all pairs get fair treatment by the network. Table 7 shows the results in different networks for MA-DS and MA-CS algorithms.

TABLE 7. Frame Schedule Length & Throughputs

Routing Algorithm	Network	Frame Schedule Length (seconds)	Throughput (Kbps)
MA-DS	1	158	69.62
	2	126	87.3
	3	169.7	64.82
	4	370	29.73
MA-CS	1	162	67.9
	2	123	89.43
	3	177.33	62.03
	4	370	29.73

We observe from Table 7 that, both the algorithms perform well in all the networks. In first and second network scenarios MA-DS perform better whereas in third network MA-CS provides more throughputs.

4.CONCLUSION

In this paper a simple routing algorithm is proposed for improving the performance of a multi-hop mesh network. The advantages and disadvantages of the proposed algorithm are also discussed. The performances of the proposed routing algorithm, with different cases of scheduling, on the throughput of four network topologies are also shown by simulations. We consider both distributed and centralized computations of minimum angle based route construction. The links of the routes are activated sequentially when only one user node has data to transmit, or the user nodes takes turns to transmit when a number of user nodes have data to transmit at the same time, without forming transmission groups. Route construction algorithm is simple and requires only position (x-y co-ordinate) information and the burst profiles of the nodes. The distributed or centralized route computations refer to taking the starting node as the BS or the user node, respectively. Assuming that the locations (x-y coordinates) of all the nodes including the BS and users are known, it is easy to compute the throughput of a route or part of a route. The user may change its positions in the network to try for better throughput. The only information needed as input to the algorithm is the node's positions and burst profile.

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