THROUGHPUT ENHANCEMENTS FOR IEEE802.16J NETWORKS USING QUEUE AWARE SCHEDULING WITH DIRECTIONAL ANTENNAS

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ABSTRACT

WiMAX Cellular Networks with Multi-hop Relays(MR), standardized as IEEE 802.16j networks, have been proposed for the improvement of overall throughput by providing last mile high speed broadband service to the users. The scheduling algorithm at Base Station(BS) plays a vital role in optimal resource allocation. In Queue aware scheduling, Concurrent Transmission Scenarios(CTS) are identified based on high back pressure links, which are used as input for linear programming model that determines the transmission schedules to maximize the overall throughput with simultaneous transmissions over Independent Links(IL). As shown in the results of Queue aware scheduling algorithm, the increase in the number of Concurrent Transmission Scenarios, improves the throughput and reaches a steady state after a level because of the limited number of independent links. In this paper, the installation of Directional Antennas at Base Station(BS), Relay Stations(RS) is proposed and studied the impact of increase in independent links, so as the concurrent scenarios with Directional Antennas, and observed some improvement in throughput. Simulation results showed that the proposed Queue aware scheduling with Directional Antennas outperforms even when the Mobile Stations(MSs) are at the edge of the cell coverage.

KEYWORDS

IEEE 802.16j,Throughput, Base Station, Relay Stations, Mobile Stations, Spatial Reuse, Directional Antennas, Concurrent Transmissions, Independent Links, Queues.

1. INTRODUCTION

IEEE 802.16j[3] was proposed as an amendment to IEEE 802.16e[4] standard to provide high speed wireless broad band service even to the last mile user by introducing the concept of Multi-hop Relay Stations. The advantages of 802.16j networks are its low cost, high range, improved throughput, high speed and scalability. Different Scheduling algorithms were proposed in the literature for Down Link(DL) and/or Up Link(UL) [6][7][8][9] because the scheduling of MAC Protocol Data Units(MPDUs) was not specifically mentioned in the standard and left open for research. None of these algorithms addressed the concept of Queues at Relay Stations. The Queue aware scheduling [1] is a dynamic algorithm focused on the current Queue sizes of Base Station (BS) and Relay Stations (RSs) as well. This algorithm achieved high throughput with reasonable fairness in Mobile Multi-hop Relay (MMR) wireless cellular networks by considering the concurrent transmission technique. Here, the BS and RS maintain one Queue for each Mobile Station connected to it directly or indirectly. Queue aware scheduling algorithm, identifies the Concurrent Transmission Scenarios (CTS) based on independent links by using a Greedy Algorithm. The total number of concurrent transmission scenarios, K, has profound influence on

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throughput as shown in the simulation results of [1]. With the increase of K, network throughput also increases because larger K enable linear programming model to yield result more close to the optimum solution. When K reaches to a certain value, the improvement in throughput is marginal. This is because of the relation between independent links and concurrent transmission scenarios. A CTS is nothing but a set of Independent Links (IL), whose transmitting and receiving nodes are different and can do simultaneous transmissions. Hence if Independent Links are increased in some way, K also can be increased, so the throughput. The ILs can be increased by introducing more RSs, but that also increases the delay and reduces the throughput. The other way to increase the ILs is the installation of Directional/Smart Antennas both at BS and RSs. Typically the BS and RSs employ Omni-directional antennas to serve users and to communicate with each other. In this scenario, to eliminate inter channel interference, the minimum value of the frequency reuse factor should be 2 and that obviously decreases the capacity of the network. In [2], the authors proposed a system with directional antennas equipped at both the base station and relay stations with the frequency reuse factor 1 and the system throughput dramatically increased as compared to the system with Omni-directional antennas. Hence, to increase the ILs, the installation, of minimum 4 Directional Antennas at Base Station and minimum one Relay Station per Antenna, is suggested. In this paper, the impact of increase in independent links, concurrent scenarios with Directional Antennas [2] is studied, and observed some improvement in throughput. Simulation results showed that the proposed Queue aware scheduling with Directional Antennas with increase in K, performs well even when the Mobile Stations (MSs) are at the edge of the cell and unevenly distributed. So, it is observed that the target of enhancing the throughput in an economical way is fulfilled. The rest of paper is organized as follows. Section II discusses the Related Work. Section III describes the proposed system setup with different configurations and scheduling methods. Section IV depicts the results comparison. Section V concludes the paper and suggests future work.

2. RELATED WORK

In this section some resource scheduling schemes related to Mobile Multi-hop Relay WiMAX cellular networks are presented. The IEEE 802.16j standard proposed OFDMA (Orthogonal Frequency Division Multiple Access), to access the channel, which succeeds in reducing the intracell interference. But intercell interference problem is still there in these Relay based cellular systems. By using some frequency reuse schemes and subchannel allocation methods, the effect of intercell interference can be reduced in the WiMAX systems. Some strategies are proposed in the standard [12], and some others in the existing literature on multi-hop communications. But, the specified strategies limited to some fixed reuse patterns or routine assignment of subchannels in similar static network environments. As an example, let us consider the systems in [11][12], the authors in [11] analyzed non hexagonal cellular structures by applying fixed frequency reuse patterns. The authors in [12] discussed the effects of interference in Relay environment, where the positions of RSs are fixed. Here the subchannel assignments are static but different. Similarly [13], [14] only consider a traditional hexagonal infrastructure. These strategies did not focus on the traffic changes over time, where some Base Stations need more bandwidth in peak hours than the neighboring Base Stations. Thus, for multi-hop scenarios, where the load balancing and capacity enhancements in variable conditions are required, these fixed strategies are not relevant. In [10] a multi-hop wireless network is considered. The Relay Stations receive traffic from Base Station or other Relay Stations for its connected Mobile Stations. To maximize the throughput, a linear programming model is used to calculate the minimum time to send a fixed number of data packets from Base Station to every Relay Station. But, they neither consider the queue size at RS, nor consider the frame-based feature of WiMAX networks. In [1], the authors focused on the Queue size at each RS and consider the frame-based feature of WiMAX networks, also the authors specified that throughput can be increased with increased number of Concurrent Transmission Scenarios (CTS), *K*. Hence, in this paper it is focused on the ways to increase the

Independent Links (IL) and CTSs in an economical way. In [5] the authors studied the effect Omni Directional antennas, i.e., with no spatial reuse, on throughput and specified that, within a mobile multi-hop relay network environment where the users are distributed uniformly in the cell, the enhancement of throughput is around 5% only. In [2] a resource scheduling scheme was proposed for 802.16j, where directional antennas are used to exploit the spatial reuse in an urban area with highly dense constructions. The authors specified that throughput can be enhanced to a maximum of 6 times more when compared with omni directional antenna structure. In order to find a method to increase the ILs, *K* for Queue aware scheduling, scenarios with 4 Directional Antennas, 6 Directional Antennas at Base Station and minimum one Relay Station per Antenna, are studied.

3. THROUGHPUT ANALYSIS

Relay network architectures can provide significant benefits over classical cellular architectures in terms of throughput, coverage and network capacity. In the early stages of network deployments, when the subscriber base is very less, the operators look forward for economical infrastructure facilities. They never mind to invest at a later stage in case of increase in customer base. In such situations the low priced Relay based infrastructures motivate them than the high priced Base Station only solution. Apart from this, there are other scenarios where Relays only can provide economically viable alternative. Thus the Relays can be used to compensate coverage holes or shadows of buildings, to increase the network capacity within the range of a cell and also to increase the coverage area of a cell. Resource scheduling is an important factor in improving the overall throughput and is discussed in the following sections.

3.1 Queue aware Scheduling Advantages

Table 1 specifies the advantages of Queue aware scheduling algorithm over Non Queue aware scheduling algorithms.

Table 1. Queue aware Vs Non Queue aware

Queue aware	**Non Queue aware**
Resource Allocation is Dynamic	Resource Allocation is Static
Efficient use of Resources	Wastage of Resources with Static allocation
Varying Queue sizes at Relay Stations are considered in scheduling	Queue sizes at Relay Stations are not considered at all
High throughput with spatial reuse	Average throughput without spatial reuse
Spatial Reuse and Concurrent Transmissions	No Concurrent Transmissions and Spatial Reuse

In an architecture of simple Relay Based Network of IEEE 802.16j [3] with frame-based transmissions of Q aware scheduling, the BS connects to RS and/or MS, and each RS can connect further to other RS and/or MS. Base Station and Relay Stations maintain one Queue per Mobile Station connected to it directly or indirectly. In Queue aware scheduling, Base Station collects the current queue sizes of all the connected Relay Stations to it directly or indirectly using uplink bandwidth. For this, the uplink bandwidth consumption is very less and negligible. Once the information is received, Base Station executes the scheduling algorithm to get the downlink scheduling results and then they are passed to the connected RSs and MSs using broadcast messages. Because of the simultaneous transmissions the throughput is increased in Queue aware scheduling and is based on the number of CTSs, *K*. To increase throughput further, more Independent Links and CTSs are needed. For this Directional Antennas can be used. Table 2 differentiates the properties of Omni-Directional and Directional Antennas in brief.

Table 2. Omni Directional Vs Directional Antennas

Omni Directional Antennas	Directional Antennas
Easy to install	LOS adjustment is needed
Frequency Reuse Factor is minimum 2	Frequency Reuse Factor can be 1
No Spatial Reuse	High Spatial Reuse
Network Capacity is Low	Network Capacity is High
Less number of Concurrent Transmission Links	More number of Concurrent Transmission Links
Has a wider 360^0 angle to cover all the directions	Has strong but narrow beam

3.2 Scheduling with Omni-directional Antennas

Scheduling with Omni-directional antennas is discussed in this section. Here the BS and RSs use the Omni-directional antennas and it requires six transmission phases to transfer the packets between the BS and MSs, as shown in Fig. 1. Every phase contains both downlink and uplink transmissions. Here it is assumed that all the phases are completed in a frame. In the first 4 phases, the BS takes turns to serve RSs and MSs in its LOS area. By taking the advantage of distance and direction of the antennas, RS1 and RS3 transmit data packets to their MSs simultaneously in Phase 5, and RS2 and RS4 transmit their data packets in Phase 6. As specified in [2], in case of multi cell environment with all omni directional antennas, the minimum frequency reuse factor would be 2, which would reduce the overall system capacity.

3.3 Scheduling with Smart/Directional Antennas

The system performance can be improved using Smart/Directional Antennas. In [2] the authors specified the design of scheduling methods using smart antennas to increase the system capacity. To exploit the advantage of shadowing, narrow beam focus of the smart antenna and distance between the Relay Stations, the installation of Smart Antennas is proposed. The Base Station is equipped with 4 Smart Antennas pointed to different directions so as to focus an angle of width 90^o each and thus by covering the whole 360^o area as shown in Fig.2. The radio resources can be reused completely in the opposite direction of antennas, as there will be no interference, due to their mutually exclusive angle of focus. Thus the Relay Stations can be grouped based on their level of interference in such a way that all the Relay Stations in a group can simultaneously communicate with Base Station or the Mobile Stations connected. This is very much similar to Concurrent Transmission Scenarios in Queue aware scheduling. As shown in Fig. 2, there are two Relay groups A and B. In Group A there are two Relay Stations, RS1 and RS3. Group B contains the other two Relay Stations RS2 and RS4. To complete the two-hop transmissions, it requires the phases equal to the number of Groups with Independent Relay Stations in the system. Here, two phases are required to complete the two-hop transmissions. Also each phase completes both uplink and downlink transmissions. When the BS serves the RSs in Group A and MSs in its Line-Of-Site (LOS), the RSs in Group B serve their MSs, which is possible because of the distance between the Relays. Service areas are indicated in blue. Alternatively, in Phase 2, as illustrated in Fig. 2, the BS serves the RSs in Group-B and MSs in its LOS areas, while the Group-A RSs serve MSs in their service areas. As specified in [2], the frequency reuse factor can be 1, i.e., universal frequency reuse, even in multi-cell setup with synchronization of neighboring cell Base Stations.

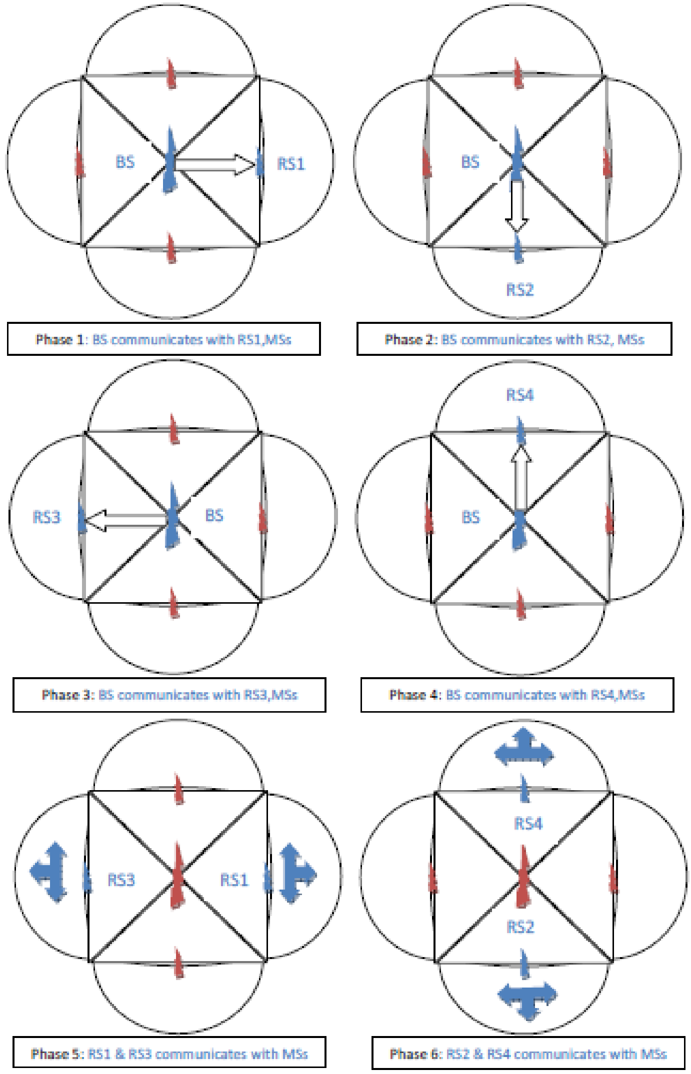
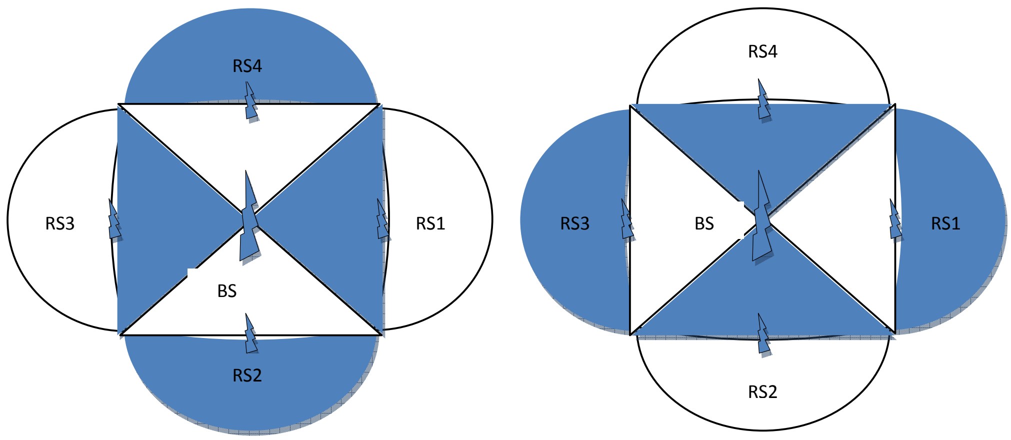


Fig. 1: Resource scheduling with Omni-directional antennas

Hence, increase in throughput in multi cell infrastructure can be achieved up to 6 times when compared with Omni directional scenario. As seen in Fig. 3, with 6 RSs and 6 Directional Antennas at BS, it is possible to achieve better throughput.

3.3.1 Proposed System Setup with Q-aware Scheduling

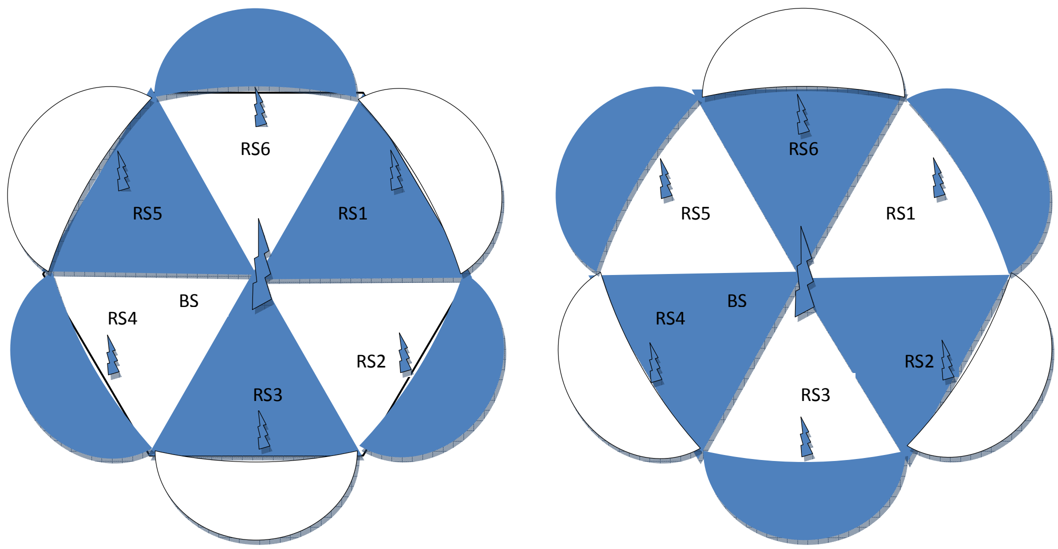
Let us examine power of Queue aware scheduling with increased number of Independent Links, CTSs with Directional Antennas at BS and RSs. Consider a simple network of one BS and four RSs with in a cell. As shown in Fig. 2, the BS is located at the centre of the cell with the four RSs deployed at equal distances from BS with an angle of 90 degrees from each other. The Relay Stations are installed at a distance of 600meters from the Base Station and the total cell coverage area radius is 1 Km from the Base Station. As specified in the standards of IEEE 802.16j, direct backhaul network connection to the Relay Station is not required and the Base Station, Relay Stations should use the same spectrum. To increase the number of Independent Links and number of CTSs, *K*, the BS and RSs are equipped with smart antennas to communicate with MSs and/or with each other. The service area of each station is also shown in Fig. 2 in blue, where the BS serves the nodes (RSs and MSs) in its line-of-sight (LOS) area with single-hop connections, while RSs serve MSs in the BS's non line-of-sight (NLOS) area and line-of-site(LOS) area of its own through two-hop connections. As specified in [1], the increase in *K* value, of Q aware scheduling algorithm, also increases the overall system throughput with the above specified setup of Directional Antennas. The proposed Q-aware Scheduling Algorithm with Directional Antennas in 802.16j Networks improved the overall throughput both in 4 and 6 Directional Antenna Scenarios when compared with Omni-directional antenna case.



Phase 1: BS communicates with RS1,RS3 and MSs and RS2, RS4 communicates with MSs

Phase 2: BS communicates with RS2,RS4 and MSs and RS1, RS3 communicates with MSs

Fig. 2: Two Phase transmission with 4 Directional antennas at BS and 4 RSs



Phase 1: BS communicates with RS1,3,5 and MSs and RS2, RS4, RS6 communicates with MSs

Phase 2: BS communicates with RS2,4,6 and MSs and RS1, RS3 communicates with MSs

Fig. 3: Two Phase transmission with 6 Directional antennas at BS and 6 RSs

3.3.2 Comparison of 'K' values with Simple Examples

Case 1- With Omni Directional Antennas

Consider an example network with 1 BS, 4 RSs and 4 MSs with Omni Directional Antennas installed at BS and RSs. There are 8 Links among the nodes in the network. The Links between the nodes are:

L1:BS<->RS1, L2:BS<->RS2, L3:BS<->RS3, L4:BS<->RS4,
L5:RS1<->MS1, L6:RS2<->MS2, L7:RS3<->MS3, L8:RS4<->MS4

To calculate the total number of concurrent scenarios, K, first consider the Super Sets of Independent Links.

{L1,L6,L7,L8}, {L2,L5,L7,L8}, {L3,L5,L6,L8}, {L4,L5,L6,L7}

Now consider the Sub Sets of the above Four Super Sets, and find out the complete set of concurrent scenarios.

Sub Sets of First Super Set *{L1,L6,L7,L8}* are as follows:

{L1,L6,L7},{L1,L6,L8},{L1,L7,L8},{L6,L7,L8},
{L1,L6},{L1,L7},{L1,L8},{L6,L7},{L6,L8},{L7,L8}

Similarly, 4+6 Sub Sets for each Super Set with a minimum of two links can be found.

The total number of concurrent scenarios $K = 4*(1+4+6) = 44$

In general, to find the total number of concurrent scenarios with minimum two links the below formula is proposed in this paper.

$$\boldsymbol{K = N * [\,{}^{S}C_{S} + {}^{S}C_{S-1} + \ldots\ldots\ldots + {}^{S}C_{2}\,]}$$

where '*N*' is the number of Super Sets and '*S*' is the size of the Super Set.

Here K = **44**

3.3.3 Case 2- With Directional/Smart Antennas

Consider the same example network as in case 1 with 1 BS, 4 RSs and 4 MSs, but with Directional Antennas installed at BS and RSs. There are 8 Links among the nodes in the network. Because of the spatial reuse, angular beaming nature of Directional Antennas, the links *L1* and *L3*, *L2* and *L4* became independent and can transmit at the same time without any interference. Hence, all the sets of Independent Links, with minimum size 2, are to be found. The total number of concurrent scenarios, *K,* is drawn as follows.

First consider the Super Sets of Independent Links.

Along with the super sets of Omni Directional case, i.e.,

{L1,L6,L7,L8}, {L2,L5,L7,L8}, {L3,L5,L6,L8}, {L4,L5,L6,L7}

There are some more super sets with Directional Antennas, They are

{L1,L3,L6,L8}, {L2,L4,L5,L7}

There are total 6 super sets in this case.

So $K = 6*(1+4+6) =$ **66**

If compare case 1 is compared with case 2, the *K* value is **44** and **66** respectively, which shows the advantage of Smart Antennas.

3.3.4 Case 3: 1BS, 4 RSs and 8 MSs

Consider the case with 1 BS, 4 RS and 8 MSs, where 2 MSs are connected to a RS.
With Omni Directional Antennas,
Number of Super Sets N=32,
Size of a Super Set S=4,

Then $K= 32*(1+4+6) = 352$

With Directional Antennas,
Number of Super Sets N=32+8 =40,
Size of a Super Set S=4,

Then $K= 40*(1+4+6) = 440$

So, with Omni Directional Antennas ***K*=352** and with Directional Antennas ***K*=440**
Thus, with Directional Antennas an increase of the Independent Links can be observed, so as the number of Concurrent Scenarios, *K*.

4. RESULTS COMPARISON

To compare the performance of the proposed Q-aware Scheduling algorithm, using Directional/Smart Antennas installed at BS and RSs, with other scheduling algorithms in terms of Throughput, the Simulations have been carried out using OPNET 14.5 simulator [15] . The results show that Q aware scheduling with Directional Antennas performed well when compared with Q aware with Omni-directional antennas, Non Q-aware and Direct transmission scheduling algorithms.

The basic network setup consists of 1 Base Station, 4 Relay Stations, and up to 50 Mobile Stations. The MS are deployed randomly at different locations in a cell with a radius of 1km, and random way point model is chosen for MS's mobility with the speed of MS is chosen at random between 0 and 5m/s. The 4 RS are placed in fixed positions, with distance from BS to each RS set to 600m, and the angle between two neighboring RS set to 90^o. The BS and RSs are equipped with smart antennas pointed to different directions respectively, as shown in Fig. 2. The radio resource can be completely reused in different antenna directions. The TDD frame for DL channel is assumed and frame bandwidth is 100Kbps, frame duration is 20ms. Traffic is generated in BS with various traffic rates and the packet arrival is described by Batch Markovian Arrival Process (BMAP).

4.1 Throughput Comparison

The throughput of Queue aware scheduling with Directional Antennas is compared with Queue aware scheduling with Omni Directional Antennas, Non Queue aware scheduling and Direct Transmission also known as 802.16e networks. The throughput averaged is studied over all MS and over 90000 frames, and the result is shown in Fig. 4. It is observed that the downlink traffic request for each MS is below 0.4Mbps, all four scheduling algorithms can perform equally well. When each MS's request increases from 0.4Mbps to 1.4Mbps, the queue-aware scheduling algorithms, both Directional and Omni Directional can satisfy the request. Above 1.6Mbps only queue-aware scheduling with Directional/Smart Antennas satisfied the request. This shows that relay links help in improving network throughput compared to direct links, also proves the benefit of spatial reuse with Directional Antennas.

4.2 Impact of Number of Scenarios

The impact of K, the total number of concurrent transmission scenarios, on network throughput for the proposed queue-aware scheduling algorithms with Directional Antennas and with Omni Directional Antennas, is shown in Fig. 5. With the increase of K, network throughput increases, and intuitively this is reasonable since larger K enable linear programming model to yield result more close to the optimum solution. When K reaches a certain threshold value, the improvement in throughput is nominal. For example, for $K = 50$ and $K = 60$ there is no significant increase in throughput in Q aware scheduling with Omni directional antennas, as shown in Fig. 5. This is due to the fact that when K reaches to certain threshold value due to the limited number of Independent Links and CTSs in Omni-Directional Antenna networks. Thus adding more concurrent scenarios will not increase the network throughput, however an increase is observed in throughput for $K = 40$, $K = 50$ and $K = 60$ in Q aware scheduling with Directional Antennas. This is due to the availability of more number of Independent Links as explained in section 3.3, so as the increase in CTSs resulting from the spatial reuse and frequency reuse factor 1 of Q aware scheduling with Directional Antennas. In practice, a reasonably large value to K is applied to achieve near optimal result. Hence by increasing the number of Independent Links and CTSs, the throughput can also be increased in Q aware scheduling algorithm.

4.3 Impact of Distance

The impact of distance between BS and RS and the distance between BS and MS, on network throughput is studied in this section. The SNR of each data link in the network is related not only to link distance, but also to the interference caused by other concurrent transmissions. As shown in Fig. 6, with the reduction of distance of MS from BS, all scheduling algorithms increase their throughput performance, and the differences between queue-aware approach and the other approaches also decrease gradually. One reason is that when MS is close enough to BS, direct transmission already has high throughput, thus limited room is left for relay link to improve the throughput. The other reason is that when nodes are close to each other, concurrent links may interfere with each other and have negative effects on network throughput. But the performance of Q aware with Directional Antennas has shown a difference because of less interference due to the angular beam focus of Directional Antennas.

4.4 Impact of Number of Mobile Stations

The impact of increase in Mobile Stations on network throughput with respect to the four scheduling algorithms is shown in Fig. 7. The throughput increases when the number of MS increases, and this is because more MS brings more concurrent transmissions with more spatial reuse possibilities. The Queue aware scheduling algorithm with Directional Antennas has higher throughput than the other scheduling algorithms. The Direct Transmission i.e., 802.16e, has the least performance compared to Non Queue aware scheduling of 802.16j. The Queue aware scheduling with Omni Directional Antennas performance is in between Queue aware with Directional Antennas and Non Queue aware scheduling. Thus, in Fig. 7, it can observed that the performance of Queue aware scheduling with Directional Antennas at BS and RSs performs well with the increase in number of Mobile Stations even if they are distributed unevenly.

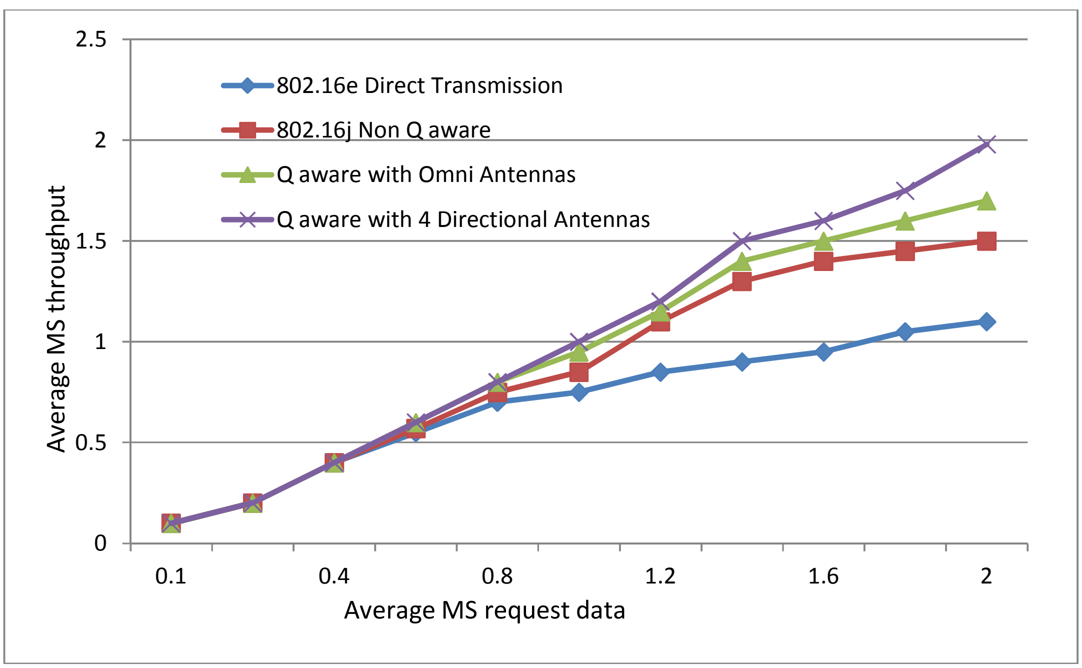


Fig 4: Throughput Comparison

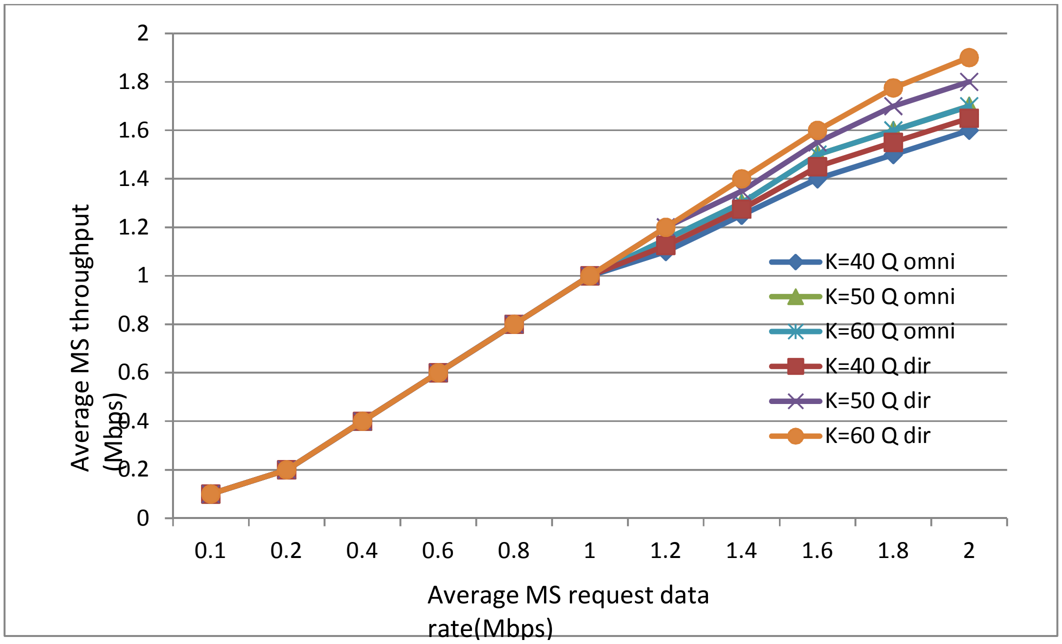


Fig 5: Impact of Number of Scenarios(K)

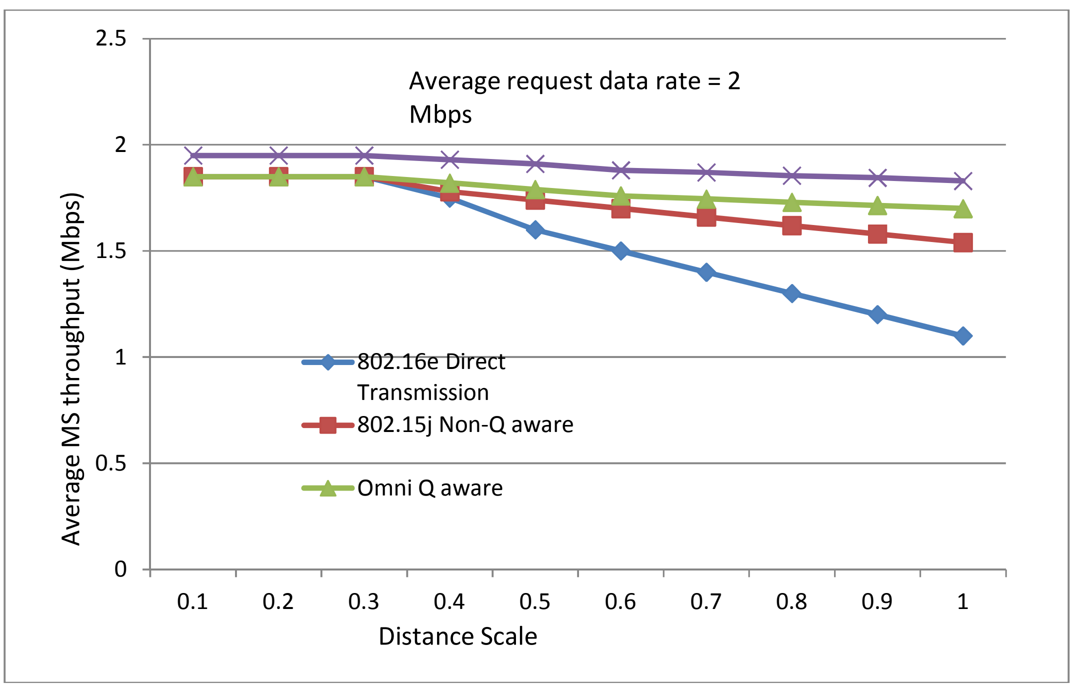


Fig 6: Impact of Distance

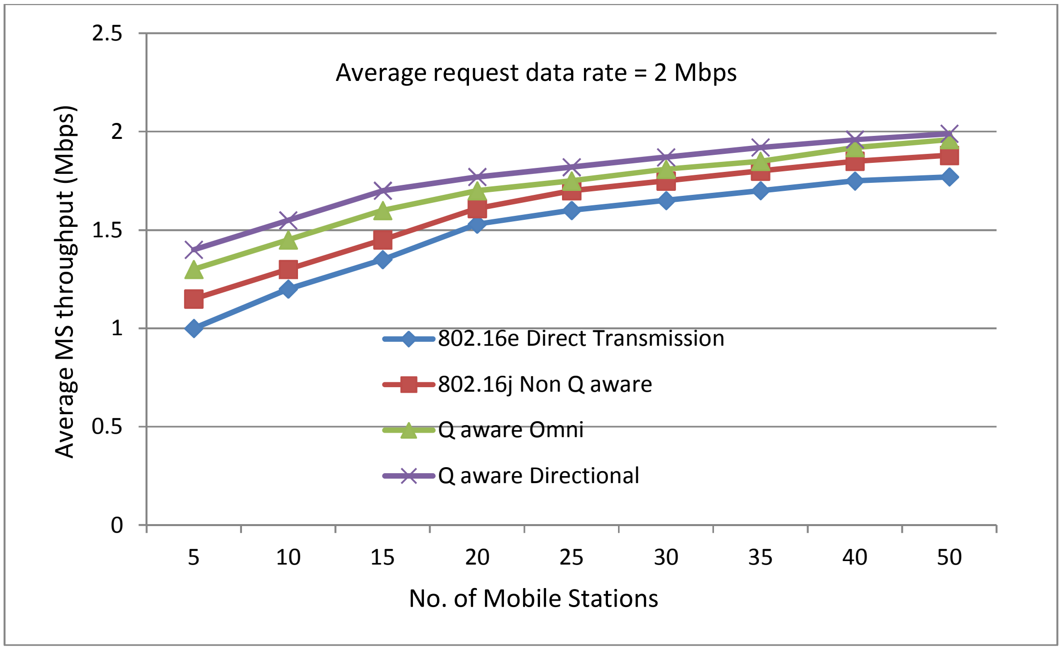


Fig 7: Impact of Number of Mobile Stations

5. CONCLUSION & FUTURE WORK

In this paper, the installation of Directional Antennas at BS and RSs is proposed and studied the impact of increase in the number of Concurrent Transmission Scenarios, *K*, on the network throughput of Q aware scheduling algorithm in 802.16j wireless cellular networks. It is observed from the results that the throughput is increased to a next level because of the spatial reuse and increase in the number of concurrent transmission scenarios [1]. The available bandwidth also increases up to 6 times with Directional Antennas [2] and the available Independent Links are increased a lot. Hence, the Queue aware scheduling which depends upon concurrent transmissions performs well even in uneven distribution of Mobile Stations in the cell. This work can be extended further to study the impact of MIMO antennas at BS, RS and MSs.

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