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A Scheduling Policy with Low Complexity That Can Perform Optimally in Terms of Delay and Can Achieve Optimal Throughput in 4G Wireless Networks

Arun. C.M[1] N. Rajesh[2]
[1]P.G Student [2]Assistant Professor
[1,2]Department of Information Science and Engineering
[1,2]NIE, Mysore, India

Abstract— In this paper, our goal is to develop a scheduling policy for downlink of a multichannel wireless networks (e.g. OFDM based networks). We focus on single-cell with the aim developing a scheduling policy that can perform optimally in terms of delay and throughput with low complexity. Before designing our scheduling policy we make some assumptions on arrival process and develop some sufficient conditions for delay optimal and throughput optimality. Our sufficient conditions allow us to prove that Oldest Packet First (OPF) policies are delay optimal and Maximum Weight in Fluid Limit (MWF) policies are throughput optimal. By carefully combining the policies from the class of oldest packet first and maximum weight in fluid limit policies and by exploring special features of our sufficient conditions, we develop a new hybrid policy which can achieve optimal throughput and optimally perform in terms of delay with low complexity of *O (n¼ log n)* where 'n' is number of users or channels in the system.

Key words: OPF, MWF, OFDM

I. INTRODUCTION

In a wireless network like 4G designing a high performance scheduling algorithms has been considered as a challenge. In this kind of wireless networks a large bandwidth will be divided into n-orthogonal subbands, which has to schedule among large number of users. Among many dimensions of network performance metrics, the most difficult ones are delay, throughput and complexity. Now the problem is: How we a scheduling policy that can lower the delay with high throughput and also with low complexity.

We consider a multichannel multiuser system with 'n' channels and 'n' users whose connectivity is time varying due to channel fading. Our focus is on single hop multichannel multiuser system. We assume that base station maintains separate first-in first-out queue that buffers the packet destined for each user. Our setting can be referred to as multichannel multiuser system with asymptotic regime. The delay metric we focus on this paper is asymptotic decay-rate of probability that largest packet waiting time will exceed certain threshold if both the number of users and channels go to infinity. Next we can overview some key related works which will be helpful for our design. In [1], the authors considered a single-queue model with time-varying channels and showed that the longest-connected-queue (LCQ) algorithm minimizes the average delay for the special case of symmetric (i.i.d. Bernoulli) arrival and channel. Later, the results were generalized for a multiqueue model in [2]. The authors of [3] further generalized the multiqueue model by considering more general permutation-invariant arrivals (that are not restricted to Bernoulli only) and multirate channel model. Hence, the problem of minimizing a cost function of queue lengths (includes minimizing the expected delay) studied in [3] becomes harder. There, for special cases of ON–OFF channel model with many users or allowing for fractional server allocation, an optimal scheduling algorithm was derived. Note that in contrast to this paper, the above studies help in minimizing queue lengths and delay which is a difficult problem in general.

As we go along with this paper another body of related works [4]-[7] focuses on multi-user multi-channel system with asymptotic regime which is similar to our work. From the above study we can observe that author has developed queue-length based scheduling policies that perform optimally in terms of delay i.e, in a queue-length based scheduling when' n' goes to infinity the probability that largest queue-length in the system will exceeds a fixed threshold will be small. These queue-length based schedulers which can perform optimally in terms of delay and throughput has a complexity of O (n^3) which is higher. But the key limitation of this scheduler is that it can perform optimally only under some situations like, when arrival process are i.i.d across users and also across time. Another scheduling policy which was recently developed called Delay Weighted Matching can perform optimally in terms of delay, in which idea is to schedule the nth oldest packet in the system. But its drawback is its complexity O (n^3) and it has unclear delay in general conditions. Hence it is necessary to design to scheduling policy that can perform optimally in terms of delay and can achieve throughput optimally with low complexity. First we develop some sufficient conditions which will be helpful in designing our scheduling policy. Secondly we develop delay weighted matching (DWM-n) policy which 'n' number of oldest packets in the system which has complexity O(n¼ logn) and is delay optimal but not throughput optimal and can perform very poorly when n is less. Thirdly by exploiting some special features of our carefully chosen sufficient conditions and intelligently combining policies from the class of oldest packet first and maximum weight in fluid limit we develop a scheduling policy with low complexity of O (n¼ logn) which can achieve high throughput and lower the delay.

II. System Design

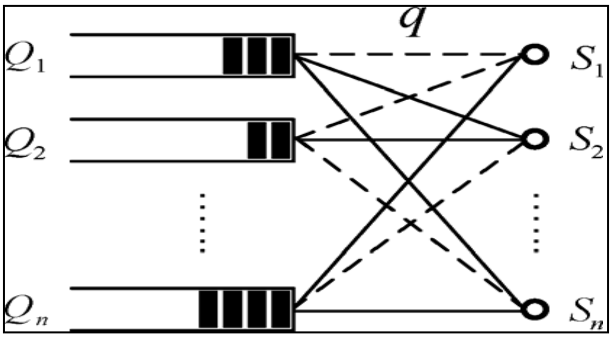

Fig. 1: System Model. The Connectivity between Each Pair Of Queue 'Qi' And Server 'Si' Is ON With Probability Q And Will Be OFF Otherwise

We consider a multi-channel multi-user system with 'n' orthogonal channels and users that can be modeled as multi-queue multi-server system with time varying connectivity as shown in Fig. 1. Let us assume that number channels will be equal to number of users for ease of presentation. Throughout we interchangeably use "queue" for users and "servers" for "channels". We also assume that time is slotted and at each time a channel can be allocated one user but a user can get service from many channels. The connectivity between user and the channel will be time varying i.e, ON-OFF with probability 'q' and 'q-1'.Let us assume that base station maintains separate FIFO queue for each users and buffers the packet destined for each receivers.

The notations used in this paper are: let 'Q_a' be the FIFO queue at base station assigned for a-th user and let 'S_o' be o-th server in the system. Let 'A_a (t)' is the number of packets arrival at queue 'Q_a' at the beginning of the time slot't'. We assume that packet arrival occurs at the beginning of each time slot and packet departures at the end of each time slot. Head-of-line delay of the packet will be incremented by one when it is not served in the previous time slot. Delay is calculated as the difference between packet arrival time and the packet departure time.

We now state some of the assumptions on the arrival process for throughput optimality and delay optimality.

1) Assumption-1: For each user 'a' ∈ {1,2,….,n} the arrival process 'A_a(t)' is an irreducible markov chain with countable state space and should satisfy the strong law of large numbers.
2) Assumption-2: Bounded arrivals.
3) Assumption-3: The arrival process is i.i.d across users.
4) Assumption-4: channel will be ON with probability 'q' and will be OFF with probability 'q-1' where q ∈ (0, 1).

III. Characterization

Some of the authors developed a scheduling policy which is delay optimal in work [8], [9] known as DWM policy which incurs complexity of O (n^5) and also can be throughput optimal when 'n' is smaller. Idea is simple, among 'n' FIFO queue select a queue which has highest HOL delay among 'n' queues and transmit a packet from that queue. A class of Oldest Packet First is DWM (Delay Weighted Matching) policy can be pictorially represented as:

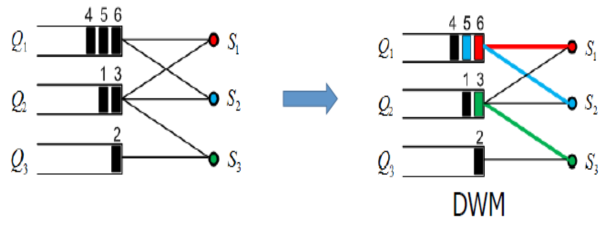

Fig. 2: DWM Policy when n=3.

Let us consider 3 users and channels as shown in the above figure for the purpose of understanding DWM concept. At beginning of each round scheduling policy looks up for largest HOL(Head Of Line) delay among 3 queues, here queue 'Q_1' has largest HOL delay which is '6' hence one packet from queue-1 will be transmitted. Update HOL delay table before proceeding to next round. At second round policy selects queue-1 because now largest HOL delay will be '5', so a packet from that will be transmitted from that queue, once again update HOL delay table. Same procedure will be repeated until all packets from all queues got service, at this stage queue-2 will be selected because of lack of channels assigned for first queue. A packet from second queue gets served. Author proves that DWM policy is delay optimal but has high complexity of O (n^5). We need a scheduling policy that can be both delay and throughput optimal with low complexity. We can prove that, under assumption 2 and 3 a scheduling policy 'S' which can serve 'p' oldest packets in each time slot can be delay optimal for largest value of 'p'. Due to space constraint we have provided only idea for more details see work done in [8], [9].

Next we proceed to list some of special conditions for throughput optimality. In work [10], [11], [12] we can see that author has designed a beautiful scheduling policy which is throughput optimal with complexity of O (n^2) but not delay optimal, this policy will have poor performance in terms of delay. This policy can be referred as 'D-MWS' (Delay based Maximum Weighted Scheduling) which is a class of maximum weight in fluid limit. Idea of this policy which is somewhat similar to DWM policy. At each round it selects a queue with largest HOL delay and transmits 'n' packets if 'n' channels are allocated to that queue. Concept of D-MWS policy can be analyzed from below examples:

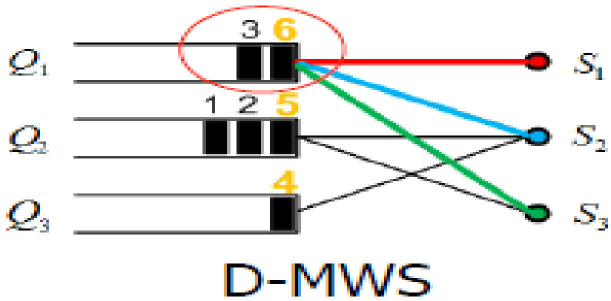

Fig. 3: D-MWS policy when n=3

Let us consider a wireless system with three users and channels, now apply D-MWS policy for that system. In the above example scheduling policy first selects queue with largest HOL delay here first queue will be selected because of largest delay of '6' and 'n' packets will be transmitted from that queue i.e, 3 and 6 packet will be transmitted which can throughput optimal. Demerit of this scheduling policy is that it can be throughput optimal for largest value of 'n'. Let us consider a system which has packets less than 'n' in this condition bandwidth will be wasted badly. From this work we can analyze that a scheduling policy which can serve 'n' packets at each time slot can be throughput optimal. D-MWS policy is only throughput optimal but has poor delay performance and also has complexity of O (n^2). We need to design a scheduling policy which can be throughput and delay optimal with low complexity. For proof of D-MWS policy see work done in [11], [12]. In next section we come across our new scheduling policy which can perform optimally in terms of delay and throughput with low complexity. At this stage of work we have gone through some of scheduling policies for analysis of achieving optimal delay and throughput by minimizing complexity which can be optimal scheduling policy in terms of delay and throughput.

IV. OPTIMAL SCHEDULING POLICY

In this section we come across our new scheduling policy which is both delay and throughput optimal which incurs low complexity of O ($n^{2.5}$ log n). We design our new scheduling policy by intelligently combining policies from class of Oldest Packet First (OPF) and class of Maximum Weight in Fluid Limits (MWF). Our policy operates in two stages i.e, at each time 'n' packets will be transmitted in two stages. Consider a multichannel multiuser wireless system with equal number of users and channels which is 'n'. Let us consider 'n=3' at the beginning of each time slot update HOL delay table from all 'n' queues. Now in first stage select queue with the largest HOL delay and transmit that packet, remove the selected HOL delay from table and once again update HOL delay table. At second stage select queue with largest HOL delay and transmit 'n-1' packets from that queue. Hence at each time slot our scheduling policy serves largest HOL delay packet and also serves 'n' packets in each time slot which will be delay and throughput optimal with less complexity. For the analysis purpose let us consider an example by which we can clearly understand our concept. Let us consider a system with three users and three channels with three FIFO queues at base station maintained for each transmitter which can be pictorially represented as follow:

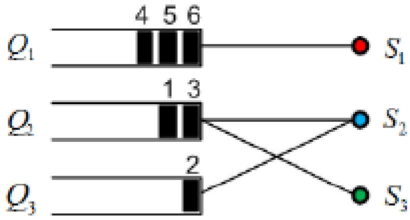

Fig. 4: Arrival of packets at the beginning of time slot 't_1'

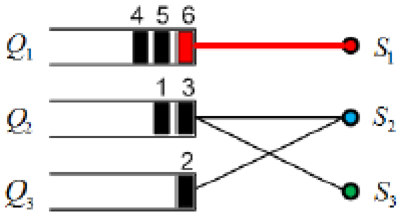

Fig. 5: First Stage of Our Scheduling Policy. First Queue Has Largest HOL Delay Of '6' So That Packet Will Be Transmitted From Channel-1 As Shown In The Figure.

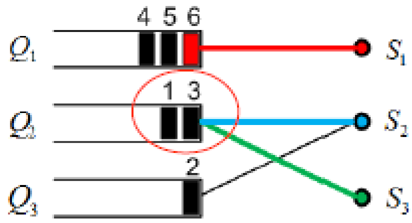

Fig. 6: Second Stage of Our Scheduling Policy. Second Queue Will Be Select and Packets With HOL Delay 3 And 1 Will Get Service.

As shown in the above figures we can analyze our scheduling policy. In figure-4 we first show packets arrival at the beginning of time slot 't_1', after arrival of packets now list HOL delay into from each queue into a table. At first stage select the packet with the largest HOL delay from table in this case HOL delay=6 will be selected and transmitted. Now remove the selected packet HOL delay from table and update the HOL delay table. At second stage select the queue that has a packet with largest HOL delay now second queue will be selected instead of first queue because only one channel has been allocated to first queue in which packet with HOL delay=6 will be transmitted hence second queue will be selected instead of first queue. Packets 3 and 1 will be transmitted. At time slot 't_1' packets with HOL delay 6, 3, 1 gets service. Our newly designed scheduling policy serves 'n' packets at each time slot and also serves the packet with largest HOL delay hence this policy can achieve optimal delay and throughput with low complexity of O ($n^{2.5}$ log n).

CONCLUSION

In this paper we come across the hardness of designing a scheduling policy in multichannel multiuser wireless system that can perform optimally in terms of delay and throughput. Here we come across DWM and D-MWS policies that are delay and throughput optimal, we also made some of the assumptions on arrival process into each for achieving optimality in terms of delay and throughput. By intelligently combining these two policies we design a new scheduling policy that can be throughput and delay optimal with low complexity. Furthermore you can work on lowering delay, complexity and can think of designing new scheduling policy that can be even simpler than our scheduling policy.

V. ACKNOWLEDGMENT

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