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A Survey on Opportunistic Scheduling for Traffic Networks with Multiple Constraints

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ABSTRACT: Load balancing is a key method for improving internet performance. A good traffic distribution schemes are required for effective load balancing. Multipath routing split network's traffic among two or more paths in order to reduce latency and balance traffic loads. Once multiple paths are established, a policy is required to determine how to allocate individual packets to the paths. In this paper, we introduce Opportunistic Scheduling, a technique for exploiting short-term variation in path condition to maximize throughput and packet delivery ratio. In particular, Opportunistic Scheduler uses path conditions on time scales of up to several seconds to select low delay high bandwidth paths to maximize system overall throughput.

KEYWORDS: constraints, delay, Opportunistic Scheduler, multipath routing

I. INTRODUCTION

Multipath transmission establishes multiple network paths to provide effective load balancing and higher performance paths which can be fundamentally more efficient than unipath transmission. Once multiple paths are established Opportunistic Scheduling is used to allocate packets to the paths.

Opportunistic scheduling is inspired by an analogous wireless scheduling problem [1], [2]. In wireless networks, each user's channel condition is continuously varying due to fading, shadowing, and mobility. Opportunistic scheduling refers to the selection of the user with the best channel conditions while simultaneously ensuring that fairness constraints are satisfied over long time scales. Thus, algorithms such as developed in [3], [4], [5], [6] exploit high-quality channels when multiple channels are available, yet ensure that no user is starved due to poor channel conditions. Commonly adopted scheduling techniques operate regardless of path condition, e.g. a) First In First Out (FIFO) scheduler, the one who first entered into system is the one who first goes out b) Round Robin, that serves process for particular time quantum in circular manner c) Priority Schedulers, every process is processed according to priority. For good or efficient traffic networks, a scheduler is one which takes into account current path state to minimize the waiting time while operating within a set of resource and service related constraints [8], [9], [10].

Opportunistic Scheduler takes into account information such as channel condition that allows it to select the proper channel for each user. The idea behind exploiting the channel variation in a given network is to schedule a user having the best channel condition at a given time period. If the service requirement of all the users is flexible, such scheduling mechanism can result in higher packet delivery ratio and increased system throughput.

While selecting path scheduler consider some constraints such as maximum delay, minimum throughput, maximum response time, maximum latency and fairness must be imposed on the channel. So, a good scheduling algorithm should contain the characteristics such as maximum resource utilization, maximum throughput, minimum turnaround time, minimum waiting time, and minimum response time.

II. SIGNIFICANCE OF THE SURVEY

Opportunistic Scheduling solves the problem of scheduling with different aspects. These solutions are divided into five major categories: fairness, delay, QoS, throughput and distributed scheduling.

A. Fairness

Kushner *et al.* [1] proposed proportional-fair sharing which is one of the first opportunistic schedulers. It is based on the compromised base scheduling. It maintains the balance between two competing channels; trying to maximize total throughput while at the same time allowing all users at least a minimum level of service. It considers current channel rate and history of received throughput of the user. Yonghe Liu and Edward Knightly [2] proposed

Opportunistic fair scheduling over multiple wireless channels. This model uses adaptive control framework to develop opportunistic fair wireless schedulers. The framework guarantees that a throughput-optimal selection of users and a control-parameter-update problem that ensures that the fairness constraints are satisfied. This model develops a Multi-channel Fair Scheduler with Deterministic and Probabilistic fairness constraints.

Sunil Suresh Kulkarni and Catherine Rosenberg [3] proposed several opportunistic scheduling problems. First opportunistic scheduling problem includes multiple user QoS requirements and showed that the optimal solution is an index policy. Second scheduling problem is for multiple interface system with QoS impairments and physical impairments imposed by the system structure. This model proposed a heuristic opportunistic scheduling policy to guarantee short-term fairness. Simulations results showed that the throughput performance of the heuristic policy is comparable to that of the long- term optimal policy.

B. Delay

Michael J. Neely [4] proposed opportunistic scheduling that guarantees a bounded worst-case delay. It is important to provide stronger delay guarantees to network users because it specifies how long it takes for a bit of data to travel across the network. This is particularly challenging for a network which has time-varying channel condition. This model provides efficient throughput utility for a wireless network, a scheduling algorithm that is robust to general time- varying conditions. To provide a solution for the bounded delay this model uses Lyapunov optimization framework for stochastic network optimization.

Ahmed K. F. Khattab and Khaled M. F. Elsayed [5] proposed opportunistic scheduling for OFDMA based network for delay sensitive traffic. Implementing opportunistic scheduling techniques by using radio resource allocation in OFDMA can exploit multiuser diversity to increase system capacity. This model divides the scheduling decision into two sub-problems: the OFDMA subcarrier allocation and the subcarrier assignment. Both algorithms exploit multiuser diversity and provide fairness with respect to the realizable throughput per user, packet dropping ratios and packet delay distributions.

Vladimir Vukadinovic and Edouard Drogou [6] proposed opportunistic scheduling based on muti-user diversity effect. When there are many users which fade independently, at a particular time there is a high probability that some of the users will have a strong channel. By allowing only those users to transmit, the shared resources are used in an efficient manner and the total system throughput is maximized. If the requirement of all the users is flexible, this scheduling mechanism can result in higher spectrum utilization and increased system throughput.

C. Quality of Service

Xin Liu *et al.* [7] proposed a time slotted system where time is the resource to be shared among all users. They try to maximize the system performance stochastically under a certain resource allocation constraint by using time-varying channel condition. Given this resource allocation constraint, the problem is to determine which user should be scheduled to transmit at each time slot so that the network performance is optimized.

Xin Liu *et al.* [8] proposed a framework for opportunistic scheduling. This model uses a time-slotted system where time is the resource to be shared. Only one user can occupy a given channel or path but at any given time among more than one channel or path. Scheduling is used for only selected path. This model uses a stochastic model to capture the channel condition and time-varying dependent performance of each user. The better channels condition of a user, larger the value of the stochastic process. Here the stochastic process is either value of throughput or value of throughput minus cost of power consumption.

Konstantinos Gatsis *et al.* [9] proposed opportunistic scheduling over shared wireless channels. In network control system environment the available system resources need to be shared among different tasks. To meet desirable stability and control performance requirements efficient resource management is important. The scheduling mechanism is based on preventing from transmitting under adverse conditions. Here the objective is to maximize user utility measure, e.g., communication rate. Additionally this scheme provides efficient utilization of the available communication resources.

Abhijeet A. Bhorkar *et al.* [10] proposed opportunistic scheduling for the wireless multihop network when no knowledge of network topology and transmission success probability. They use reinforcement learning framework to design distributed adaptive opportunistic routing problem (d-AdaptOR). This scheme minimizes the average per packet cost for routing a packet from source to destination. This model requires initial knowledge about the network.

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D. Throughput

Jawad Rasool *et al.* [11] propose two simple and low complexity adaptive scheduling algorithms. This model develops an expression for the approximate throughput guarantee violation probability for users in time-slotted networks with the given statistics of the distribution of bit-rate in a time-slot, and a given distribution for the number of time-slots allocated within a time-window. They provide numerical results for identical throughput guarantee, Heterogeneous throughput guarantees, and effect of temporal correlation on throughput guarantee violation probability. Liu *et al.* [12] propose a simple algorithm for networks with short- lived flows. Using this algorithm, each flow keeps track of the best channel condition. Each flow whose current channel condition is equal to the best channel condition during its lifetime is eligible for transmission. It is shown that an algorithm which uniformly and randomly chooses a flow from this set of eligible flows for transmission is throughput- optimal. The algorithm is an opportunistic algorithm in that it selects users for transmission when they are in the best channel state that they have seen so far, without considering their backlogs.

Cetinkaya Coskun and Edward W. Knightly [13] proposed Opportunistic traffic scheduling over multiple network paths. Multipath routing uses multiple alternative paths in the network. Once multiple path are established a technique is required to efficiently distribute traffic among available paths. This model proposes Opportunistic Multipath Scheduling (OMS) to schedule a packet or traffic among the path. OMS minimize the delay and improves overall throughput.

E. Distributed Scheduling

Mao *et al.* [14] proposed distributed opportunistic scheduling with quality of service (QoS) constraints for a wireless network with hybrid links. Two types of links are considered. The first type of link has always a much lower transmission rate than the second type of link. These links are called as hybrid links. To avoid starvation of the first type of link i.e. secure links, a new opportunistic scheduling mechanism is proposed. A scheduler select high-quality path based on a link with highest transmission rate which maximizes system overall throughput.

The Ad-hoc network where many links contend for the channel using random access proposed using distributed opportunistic scheduling (DOS) under average delay constraint [15] from two different views. First one is, DOS with delay constraints, a network-centric view, with the objective to maximize the overall throughput. This model showed that the optimal DOS strategy under such delay constraint is a pure threshold policy. They consider critical time constant: the optimal threshold is a function of the critical time constant only if the imposed delay constraint is less than the critical time constant; otherwise, there is a no effect on the optimal scheduling and the optimal policy remains the same as if the delay constraint did not exist. Second, each individual link has its own average time constraint from the user-centric constraint. In this case, every link tries to maximize its throughput to its own individual delay constraint.

Andres Garcia-Saavedra *et al*. [16] proposed Distributed Opportunistic Scheduling (DOS) that have been used to improve throughput performance of the wireless network. With this model, each station contends for the channel with a certain access probability. If a contention is successful, the station checks the channel conditions and transmits in case the channel quality is above a certain threshold. Otherwise, the station or node does not use the transmission opportunity, allowing all stations or nodes to recontend. The model uses Homogeneous scenario with saturated stations, a heterogeneous scenario with saturated stations, a homogeneous scenario with non-saturated stations, a heterogeneous scenario with non-saturated stations for performance evaluation.

Table I compares various techniques used in Opportunistic Scheduling algorithms.

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Techniques	References															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Fairness	√	√	√					√								
Delay				√	√	√									√	
QoS	√		√				√	√	√	√				√		√
Throughput			√						√		√	√	√			
Distributed Scheduling														√	√	√

Table I: Techniques used for Opportunistic Scheduling

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III. REMARKS

Opportunistic Scheduling exploits the time-varying nature and the spatial diversity of the wireless channel to make an effective use of the available system resources to achieve fairness, maximization of throughput, QoS requirements. In this paper, opportunistic scheduling techniques are categorized based on the approach they took for formulating the problem of scheduling, i.e., capacity, QoS, fairness, distributed scheduling, throughput maximization.

The goal of opportunistic scheduling is throughput maximization subject to the fairness guarantee and resource constraints also to improve the system capacity and to achieve throughput optimality. QoS related opportunistic schedulers can also achieve throughput-optimal while maintaining the QoS constraints. Throughput gain obtained by these proposals depends on the number of QoS metrics and their desired values. We also observed that the unfairness issue which is caused by the greedy nature of opportunistic schedulers can be resolved at the cost of throughput reduction. Although these schedulers achieve fairness at the cost of throughput reduction, they still outperform the non-opportunistic schedulers. In order to reduce the complexity of opportunistic schedulers, some proposed opportunistic distributed scheduling.

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