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A Survey On Cross Layer Scheduling and Resource Allocation in Wireless Networks

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ABSTRACT
Cross-Layer Resource Allocation and scheduling approach allows optimisation of network resources and will enhance network utilization and increases the throughput. In this paper, we give a general idea of cross-layer design method, called opportunistic scheduling, which exploits the time varying nature of the environment and increases the overall system performance under certain fairness requirements of the users. Opportunistic scheduling advantages and costs are also discussed to identify possible research directions in the future. Various opportunistic scheduling schemes are also summarized, which exploits the time-varying nature of the environment to improve the efficiency of the spectrum while maintaining a certain level of user satisfaction.
Keywords:- Wireless Network, Cross-Layer Design, Opportunistic Scheduling, And Resource Allocation.

I. INTRODUCTION

Traditionally, strict layering principles are followed in protocol architectures, which is an attractive tool for fast deployment and efficient implementation of interoperable systems. The layering concept in the protocol design enables interoperability and improves the design of communication protocols. Additionally, a protocol describes the functionalities it offers within a given layer, while the internal parameters and implementation details are hidden to the remaining layers. This protocol architecture limits the performance due to the lack of coordination between the layers. Cross-layer design was proposed to overcome these limitations. The main idea of cross layer design is that the original layering functionalities to be maintained, but to allow interaction, coordination and joint optimization of protocols among different layers.

The management and allocation of resources are critical for wireless networks, because the resources are shared by multiple users. In the current dominated layered networking architecture, each layer is designed and operated independently to support transparency between layers.

Distributing resources among the users in the network is the responsibility of Scheduling algorithms. The scheduling algorithm's main goal is to utilize the network up to maximum extent and to achieve fairness among all the users.

Fairness is an interdisciplinary research topic which is usually related to resource allocation. Fairness in wireless networks is a measure of how equally the resources are allocated among the users. The resources can be time-slots, frequencies, code-sequences, or throughput.

The efficient utilization of the scarce resources in wireless networks is crucial for cross layer design approaches. To obtain better system performance, information exchanges across protocol layers can be used, which is not found in the traditional layered architecture.

This paper provides an overview of cross-layer design approaches for resource allocation in wireless networks, summarizes some of the opportunistic scheduling algorithms.

The network performance in a wireless network can be improved by using Cross-layer design. The traditional layered architecture is being violated by the cross-layer design approach, because creating new interfaces, adjacent layer merging, and sharing of key variables among multiple layers are required for cross layer design. Hence without altering the traditional layered architecture's current status, cross layer design approach must be selected [1].

II. CROSS-LAYER DESIGN

In wireless communications, direct communication between layers creating new interfaces for information sharing is the first implementation concern. The common entity acting as a mediator between layers is the second concern. A completely new abstraction is the third concern. The standard protocol stacks (TCP/IP) are being used by new wireless networks to ensure interoperability [2]. The cross-layer design may have the following possible implementations:

- **DIRECT COMMUNICATION BETWEEN LAYERS**

To allow runtime information sharing between layers to communicate with each other, direct communication between layers can be used as shown schematically in Fig. 1. This is applicable only when there is runtime information sharing between layers. Generally speaking, during runtime if the variables at one layer are visible to the other layer, then it is called direct communication between the layers. In a strictly layered architecture, every layer has its own variables, and other layer does not have any concern towards the variables[3][4].

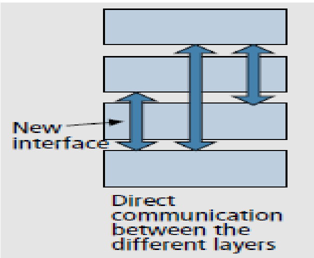

Fig. 1: Direct Communication

The different ways the layers can communicate with one another are as follows: Flow of information between layers can be done using protocol headers. Alternatively, extra information related to interlayer can be treated as internal packets.

- **A SHARED DATABASE ACROSS LAYERS**

The next class propose a common database which can be accessed by all layers, as depicted in Fig. 2. The common database is like a new layer, provides the service for storage and retrieval of information to all the layers. An optimization program can interface with the different layers at once through the shared database. Similarly, new interfaces between the layers can also be realized through the shared database. The main challenge here is the design of the interactions between the different layers and the shared database [3][4].

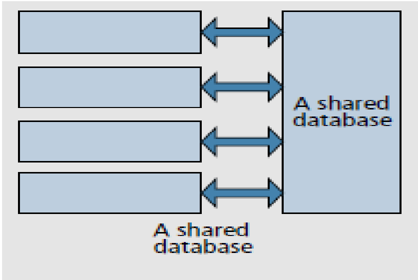

Fig. 2: Shared Database

- **COMPLETELY NEW ABSTRACTIONS**

The third proposal presents a completely new abstraction, which is illustrated in Fig.3. This proposal presents a new way to organize the protocols: in heaps, not in stacks as done by layering. Rich interactions between the protocol's building blocks are allowed in this organization of protocols, and hence it is appealing and also offers great flexibility, both during runtime as well as design. Completely new implementation is required because they change the way protocols have been organized [3][4].

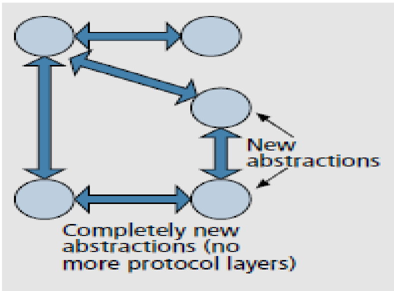

Fig. 3: Completely New Abstraction

The potential issues in cross-layer design are identified as follows[13]:

- Implementing cross layer interaction is complex because it requires modifications in the protocols at different layers. Cross-layer framework should be carefully designed to ensure minimal changes in the existing layered protocol stack. As discussed in [7], maintenance is difficult once cross layer design is adapted, because any change in protocols or upgradation in the protocol must be coordinated among different protocol layers. Hence, the design should ensure easy maintenance and upgrade.
- The modularity of the layered architecture should be preserved by the cross-layer design, so that uninterrupted operation it ensured to the layered stack and interoperability. However, Interoperability

between cross layer and non cross layer systems will be complex.

- The cross layer interactions not only affect the particular layer which executes cross layer adaptation but also other parts of the system are affected. Unintended consequences may arise during implementation on overall system performance due to unintended dependencies of system components [3].

III. RESOURCE ALLOCATION AND OPPORTUNISTIC SCHEDULING

Allocating resources to links when good channel conditions are experienced and avoiding allocating resources when poor channel conditions are experienced, thus utilizing the resources efficiently is the basic idea of "opportunistic scheduling", which is also referred to as channel-aware scheduling or exploiting multi-user diversity. Opportunistic scheduling algorithms primarily focus on exploiting the variability in channel conditions. The term ***opportunistic*** is used to denote the ability to schedule users based on favourable channel conditions [10].

This section focuses on the problems of opportunistic scheduling in wireless networks. The multi-user scheduling problem has received considerable attention over the past few years in both academia and industry. The unique feature which motivates the scheduling schemes in wireless networks are: scarce resources, mobile users, interference from other users in the network, and time-varying channel conditions. In order to exploit the channel conditions and to achieve higher network performance, good scheduling schemes in wireless networks should be opportunistically chosen.

Multi-user diversity gains can be achieved by Opportunistic scheduling because it enables the system to operate to its maximum performance rather than average performance when users experience good channel conditions [14].

In the literature, even though several scheduling algorithms have been proposed for wireless network, the challenge is the design of the algorithms to maintain different levels of services, fairness and implementation complexity. Different scheduling schemes and their proposals have been compared by many researchers, but there is no common, simple and standardized packet scheduling to make their comparisons with.

In this section, four cautiously chosen scheduling algorithms in wireless network are investigated. The most popular and dominant algorithms include Max-Min Fair Share (MMF), Proportional Fair Share (PF), Weighted-Fair Queuing (WFQ) and Opportunistic Round Robin (ORR).

OPPORTUNISTIC SCHEDULING ALGORITHMS

In this section, four basic and well-known opportunistic scheduling algorithms for cross layer design in wireless networks is presented. Many algorithms can be defined to solve the resource allocation problem by choosing different objective functions to be optimized and adopting different techniques to solve the optimization problem[10][11]. Few of them are:

1. Max-min fairness algorithm: For the poorly treated sessions, the algorithm maximizes the allocation, i.e., *maximize the minimum*, if no rates can be increased without decreasing an already smaller rate, then allocation is max-min fair.

The philosophy of this type of scheduling is to allocate the resources, such as channels and time slots, to the user with the minimal received QoS. The advantage of this type of scheduling scheme is the delivery of extreme fairness among the users with the same priority. However, this type of scheme does not consider the channel variances for different users and over different times, so the diversity, such as multiuser, time and frequency, cannot be exploited. Consequently the achieved performance is low.

Allocating the bandwidth equally to all contending users is the basic idea behind max-min fairness algorithm. If the bandwidth is not utilized by a user because of constraint elsewhere, then the residual bandwidth is distributed among others.

Thus no user is penalized excessively and a certain minimum QoS is guaranteed to all users. A bandwidth allocation is said to be max-min fair if it is not possible to increase the allocation of any user without hurting another user with a lower service rate. The purpose of maximizing minimal-value optimizations is to improve the resources of the individuals who get the least amount of resource.

2. Proportional Fair (PF) algorithms:

To maintain the benefits of multiuser diversity, proportional fair algorithm has been proposed and also to incorporate a certain level of fairness. The compromise based scheduling algorithm which maintains a balance between main challenging interests is the proportional fair algorithm.

The challenging interests are: allowing at least minimum level of service to all the users and trying to maximize their total throughput. This is done by assigning each data flow a data rate or a scheduling priority (depending on the implementation) that is inversely proportional to its anticipated resource consumption.

3. Weighted fair queuing (WFQ): is a data packet scheduling used by network schedulers. WFQ is both a packet based implementation of the generalized processor sharing policy (GPS), and a natural generalization of fair queuing (FQ), WFQ allows specifying, for each flow, which fraction of the capacity will be given. Weighted fair queuing (WFQ) is also known as Packet-by-Packet GPS (PGPS or P-GPS) since it approximates generalized processor sharing within one packet transmission time, regardless of the arrival patterns.

Weighted fair queuing (WFQ) is a method of automatically smoothing out the flow of data in packet switched communication networks by sorting packets to minimize the average latency and prevent exaggerated discrepancies between the transmission efficiency afforded.

4. Opportunistic Round Robin Scheduling (ORR)

To obtain the highest short term fairness, ORR algorithm is used. This algorithm uses the concept of time-slots, in which the time-slots are allocated in rounds depending up on the number of users participating. One time-slot will be assigned to all the users within a round, i.e., the time-slots are assigned opportunistically.

The users will be assigned the time-slots that maximize the total throughput within each round. The best user out of all the users is chosen and the first time-slot is assigned to that user. The best user out of the remaining user will be selected for the next time-slot not taking the previous user into account. For every new time-slot the previous user is not considered. Subsequently, only one user will participate in the competition for the last time-slot. This assures a maximum inter-access time of twice the number of users in time-slots, where inter-access time refers to the number of time slots between two consecutive servings of a user [12].

The theoretical performance of the above mentioned scheduling algorithms can lead to valuable insights that can be used for developing more advanced algorithms. These algorithms are mainly designed for networks where only one user is scheduled in each time-slot. Some of these scheduling algorithms provide some measure of fairness in the resource allocation between the different users. However, these scheduling algorithms assume that the users always have data to send and do not consider the QoS requirements of the different applications in the network and can therefore not provide exact QoS guarantees. Issues related to how opportunistic scheduling algorithms can be implemented in more complex wireless networks and issues related to how QoS guarantees can be promised to the different applications will be handled in Section V.

Cross-Layer Design Issues for Opportunistic Scheduling Algorithms

Traditionally, QoS and fairness for different QoS classes or different applications are the main research areas on packet scheduling, while opportunistic scheduling algorithm's main focus is to exploit the time-varying nature of the wireless channels and to provide fairness among the users. This leads to the segregation of packet scheduling and resource scheduling algorithms, which is not efficient because none of these types of scheduling algorithms focus both on (i) providing QoS for the applications and (ii) exploiting the time-varying characteristics of the wireless channel. Therefore it is necessary to combine both the packet scheduling and resource scheduling algorithms to design *cross-layer* scheduling algorithms [14].

An illustration of opportunistic scheduling schemes of the cross layer design in wireless systems is to exploit the time varying channel condition of the users in order to improve the system throughput. The costs and limitations involved in opportunistic scheduling are discussed as follows.

Decisions on scheduling mainly depend on the channel condition, hence opportunistic scheduling schemes involves signaling costs. The channel conditions must be constantly estimated by the users and reported to the base station. Thus signaling cost should be taken into account by the actual scheduling gain [10].

Because the channel conditions are estimated constantly, errors in estimation occur in all scheduling schemes. Some of the sources of errors in estimation are: estimation error in the channel, estimation error of the parameters involved in scheduling schemes, and the errors caused by various delays such as transmission delay, estimation delay, and restriction of time-slots, etc. Generally, slow is the variation of channel condition, good is the estimation.

The variation of channel conditions utilizes opportunistic scheduling and thus scheduling gain inherently depends on the amplitude of the variations of channels. Generally, the larger the variation of channel condition, the greater is the number of users, and the performance gain is better. The time scale of variation in opportunistic scheduling is another concern. The variation of channels should be slow enough for users to estimate and exploit it. On the other hand, the variation should be fast enough, so that users won't experience extreme long delays. Though many data users are delay-tolerant, extreme delays may cause upper-layer problems such as TCP timeout.

Generally, as the number of users increases, the scheduling gain also increases. But when the scheduling gain over the number of users is considered, the normalized scheduling gain decreases with the increase in the number of users and the signaling cost per user remains the same. Hence it is important to decide the number of users sharing the same channel.

The summary is, a new design approach is been presented by opportunistic scheduling for delay-tolerant traffic. The new design has its own advantages and limitations. Thus in order to avoid the negative impacts of the system, it is important for the system designer to take a comprehensive view of the cross-layer design [13].

IV. CONCLUSIONS

To improve the efficiency of the spectrum and to exploit channel condition variation, opportunistic scheduling is mainly used. The time domain diversity also called multi user diversity is an additional advantage to the system. And also the efficiency of the spectrum is improved, particularly for delay tolerant data transmissions. Various opportunistic scheduling schemes have been studied. The main objective is to improve system performance under various fairness constraints. The advantages of opportunistic scheduling schemes help us to work with resource management techniques. In summary, with its own advantages and limitations, opportunistic scheduling, is an excellent illustration of cross-layer design.

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