Joint Link Scheduling for Optimal Management of Radio Resources in Satellite Systems

Zhao Yang
1. Institute of Software, Chinese Academy of Science, Beijing, China
2. Huazhong University of Science and Technology, Wuhan, China
Email: skygloomer@gmail.com

***Abstract* — This paper mainly focuses on the solving of joint link scheduling, which is a major aspect of resource allocation in a wireless satellite communication system. A brief review of some early definitive schedulers are presented and evaluated first, then the prevailing heuristic scheduler, alongside with the most up-to-date intelligent optimal schedulers are further introduced. Some problems which still exist in current schedulers are brought forward and discussed at the end of this paper.**
***Keywords* — joint link scheduling, resource allocation, heuristic schedulers, intelligent optimal schedulers**

I. INTRODUCTION

Wireless communication systems utilizing geostationary satellites will gradually take over the market of the prevailing terrestrial wireless communication systems. Though satellite-based systems are currently available mainly for protected military communications, there is a high possibly, nearly a certainty, that such system is to prevail in daily usage in the nearby future.

Satellite communications possess great advantages over the conventional terrestrial wireless communication systems. For instance, in the current cellular wireless communication systems (e.g. the GSM system), cell coverage tend to be small irregular shaped areas normally a few kilometers in diameter, thus cell selection and reselection have to be done in short time intervals if the mobile station is in constant move [1]. However, satellite-based systems have large regional coverage area; those spot beams are regular shaped and typically have a radius of a few hundred kilometers [2], thus the coverage area which overlaps national boundaries and service areas will offer continuous high quality signals even if the mobile earth station is moving with a rapid pace.

An important feature of satellite-based systems is that they communicate via packet traffic, and packet-switched traffic has a bursty nature [3]. Therefore, dynamic allocation schemes have to be available to support such bursty traffic in order to maximize system capacity as well as to insure fair allocation of resources. Another noticeable difference between satellite-based and earth-bond systems is that the link quality varies more in a satellite communication system, for instance, weather acts as an important factor determining link quality along the propagation path, many decibels of additional attenuation can be resulted by a rain [4]. These variations in link quality, though occasional, must be accounted when proposing a certain allocation scheme.

As an overall approach, radio resource management plays an important role in maximizing throughput and ensuring a fair allocation of resources to all the terminals requiring services in a single satellite system. Resource allocation in a wireless satellite communication system involves the solving of joint link scheduling and ensuring proper power allocation [5]. In the following parts of this paper, we will assume that all nodes in the satellite-based network have fixed transmission power levels in order to simplify such a problem, a few scheduling methods are discussed and evaluated in the paper.

II. SOME EARLY SCHEDULERS

Technically, satellite data transmission scheduling problem refers to the allocation of sufficient radio resources in both satellite and earth terminals in order to successfully transmit the data required. Analysis of the scheduling problems consists of three major aspects, namely the study of system models, scheduling algorithms and practical application. The study of scheduling algorithms is the key aspect in solving such scheduling problems.

Prevailing allocation algorithms for terrestrial wireless systems during late 1970s are first applied to satellite-based systems, and without any doubt, all of such attempts had proven to be a failure. The difference of satellite-based and earth-bond systems in scheduling problems is that the satellite-based systems have epoch constraints, that is, system requirement indicates that time have to be allocated to individual terminals via the unit of epoch. In a satellite communication system, an epoch is an inseparable time unit used to accommodate the long propagation delay and reserve time for sufficient processing, an entire epoch has to be in the same mode, and in that sense, in a single epoch, which consists a integer number of timeslots (usually the number of time-slots in an epoch can be quite large, up to 300), the modulation format, coding rate and burst rate have to be exactly identical. So assuming that in a certain satellite communication system, a single epoch is divided into 300 time-slots, suppose that there are two terminals; terminal 1 has a queue length of 300 and terminal 2 has a queue length of 299, so when the system examines the terminals to minimize queue length during the allocation of time, terminal 1 will get a single epoch, with all the 300 time-slots assigned to it. But by common sense, we can well know that the optimal solution is allocating 150 time-slot each so that the queue length of both terminals are shorten and equalized.

In hope of obtaining better scheduling for satellite-based communication systems, dedicated solutions to satellite scheduling problem are being studied throughout the world. Studies of such algorithms started in early 1980s by IBM Company in hope to solve satellite range scheduling problems utilizing computer, certain week scheduling, day scheduling and real-time scheduling methods are obtained [6]. But it wasn’t until 1992 when Gooley, Schalck and Parish from Air Force Institute of Technology started investigating resource allocation schedulers for Air Force Satellite Control Network that a complete and well-oriented study of scheduling algorithm in satellite system is put on schedule [7]. Such studies led to the various schedulers that are available today, most schedulers can be classified into three distinctive groups, namely the definitive scheduler, the heuristic scheduler, and the most up-to-date intelligent optimal scheduler [8].

Definitive scheduler is the first available scheduler and it is born alongside with the practicalizing of satellite communication system for commercial use. In a definite scheduler, algorithms tend to be rather restricted to solving some pre-determined functions for optimal solution, these algorithms work well with small problems with a limited number of terminals, but as the number of terminals increases, the complexity of the problems becomes uncontrollably large [9][10]. Examples of such definite scheduler algorithms include the Strict Priority and Weighted Round Robin algorithm, mixed integer programming algorithm, dynamic programming algorithm, as well as the Depth First Branch and Bound algorithm. Strict Priority Round Robin algorithm examine queues in a strict priority order, it is obvious that such a rigid way of solving allocation problem is the easiest but, at the same time, the solution is also the farthest away from the optimal one, the Weighted Round Robin algorithm is slightly better since queue weights are considered [11]. The mixed integer programming algorithm [12][13] works best with small scheduling problems but worsen at the greatest rate when the number of terminals gets larger. The dynamic programming algorithm [14][15] is quite effective in solving satellite management and scheduling problem under terrestrial surveillance, but gets rather complex when dealing with complicated constraints. Depth First Branch and Bound algorithm [16] has proven to be able to obtain the optimal solution for management and scheduling problem of the SPOT satellite, but nonetheless, it is restricted to solving small problems, complexity of the problems varies much if the problem gets bigger.

III. HEURISTIC AND INTELLIGENT OPTIMAL SCHEDULERS

Heuristic scheduler refers to a group of related algorithms that solves such scheduling problems via closing in to the optimal solution by a heuristic function; such methods are regarded as a dynamic way of allocation. In conventional Earth-bond wireless systems, one way of solving potential contentions in resource management is the overprovision of resources, but this is not feasible in a satellite-based system. In terrestrial cellular systems, the path loss model can be characterized by an Ricean fading with a typical k-factor of between 7 and 9 [18], so fading can be rather evident even in short range. Due to the sharp fading characteristic in such terrestrial cellular systems, certain frequencies used in one cell can be reused by another outside its coverage, usually only a few kilometers away from the original cell. However, such frequency reuse is not viable in satellite-based systems, for a spot beam originates from a single satellite covering areas several hundreds of kilometers in diameter, besides, the signal propagate in a free space with an exponential loss factor of 2, so it won’t be a few hundred or even a few thousand kilometers before fading is complete and the frequencies can be reused. In general, resources are rather limited in satellite-based systems, so an efficient dynamic allocation algorithm has to be in place to solve such contentions in resource allocation.

Since the Strict Priority Round Robin scheduler in which queues are examined strictly in priority order had proven to be rather inefficient, an Equitable Weighted Queue Length Scheduler is presented, such an algorithm is based on the principle to ensure fair service to all terminals with identical priority within a single epoch. Hence the algorithm is designed in a way that the system allocates radio resources so as to equalize the weighted queue lengths at the end of each epoch. The proposed algorithms relies on a quadratic function with very few constraints, thus it would be relatively easy to solve the problem in a small scale. Such a scheduler is substantially dynamic in that it varies the allocation of resources according to the quality of the channel as well as the length of the queues, thus no queue is allowed to grow too long and similar services are provided to all queues with identical weights.

However, as the problem scale gets larger, difficulties arises when solving the scheduling algorithm of the Equitable Weighted Queue Length Scheduler, this is partially due to the nature of the quadratic function, as well as the integral nature of the values of variables. Therefore a typical heuristic allocation algorithm is further introduced; this method divides the process of solving the Equitable Weighted Queue Length function into two parts. Firstly, the maximum weight objective function is applied so as to maximize the sum of the weighted queue length of the users served, as solving such a function is only a linear program, we can easily obtain an integer value of the variable. After which, the mode of each terminal is fixed according to the results of the mixed integer linear program, in such a way variables can be continuous and the difficulty in solving the quadratic function is dramatically dropped. Such a scheduler is now commonly used in solving large-scaled satellite scheduling problems.

Based on the typical heuristic allocation algorithm described above, many practical schedulers are derived for military and commercial use. Marketization of heuristic schedulers can be dated back to 1996, when a hybrid scheduling algorithm is introduced by Gooley, Borsi and Moore in the AFSCN high orbit satellte resource scheduling problem, in which optimal time slot interval is obtained by limiting the adjustment time interval of the operation time [21]. Then in 2001, a heuristic biased stochastic sampling algorithm is introduced by Frank Jeremy, Ari J'onsson and Robert Morris, in this algorithm, preference function is combined with the heuristic information and random access technique to obtain an optimal solution [22]. To meet the demand of resource allocation in low orbit satellite, a greedy activity-selector algorithm is brought about, this is a simple technique and relatively less time-consuming than other heuristic schedulers, but it's weakness is also evident, this method needs simplification of allocation model and therefore does not provide precise solution, besides, it only provides solutions for satellite in low orbit [23][24].

The intelligent optimal scheduler is a novel allocation method derived from the typical heuristic allocation algorithm [25][26]. In the very beginning, such a scheduler is often based on some evolutionary intelligent algorithms [27][28], in which a group evolutionary operation is used in optimizing the solution to the allocation problem. A swarm intelligent algorithm [29][30][31] is then further introduced, such an algorithm obtains the optimal solution through the interaction between individuals, whereby acquiring a group intelligence behavior. An example of such algorithms includes the Ant Colony Optimization Algorithm, which is already in practical use in AFSCN but still requires further research [32].

Many problems still exists in the current resource allocation schedulers; for instance, most schedulers today still focus more on single-objective scheduling algorithms, which is far from efficient in the current satellite communication systems. In most circumstances, a few scheduling objectives have to be optimized simultaneously in order to obtain a compromised set of solutions, which is regarded as multi-objective scheduling algorithms [33][34]. Almost all algorithms mentioned above, whether it be opportunistic, or based in priority order or heuristic function, are all limited in solving single-objective scheduling problems.

The intelligent optimal scheduler is brought forward in hope of optimizing such multi-objective scheduling problems [35][36], but much research work has to be done yet to develop a fully operational multi-satellite resource allocation system. Besides, an ameliorated Greedy Activity-Selection Algorithm [37] has proven its effectiveness in multi-resources range scheduling, this greedy maximal scheduling model takes network geometry and the cumulative interference effect into account and therefore developes the optimal solution to multi-objective problems, but nonetheless, it still requires much further studies before applying for commercial use.

Another significant problem yet to be solved is the maximization of efficiency in those allocation algorithms. The time accounted for satellite data transmission includes both the operation time of the specific algorithm selected as well as the time needed for data transmission via the air radio interface. A balance between the two time factors has to be obtained in order to ensure the efficiency in a certain operation. Most advanced algorithms, though optimal in solution, tend to consume a larger amount of time in calculation. As more and more satellites are currently available and the amount of data transmission increase dramatically, many previous efficient algorithms started to be much too time-consuming, thus some allocation algorithms have to be re-evaluated and reselected, in order to reduce the time needed to come up with the desired solution.

IV. CONCLUSIONS

Satellite communication for commercial use start to prevail in recent years, and alongside with it reveals the problem of the urgent need for efficient resource allocation schemes. Through many years of research, certain joint link scheduling algorithms have aready proven its effectiveness in the current satellite communication systems and can well meet the need of practical use. However, the demand for multi-objective scheduling arises, which means that in the nearby future satellite communication systems are to meet the need of many bursty users with varying QoS requirements, thus the scheduling algorithms used should ensure fairness,as well as to maximize the overall system capacity under time-varying channel conditions and traffic loads. All these above requirements brought forward the need of finding new scheduling methods that can balance between all demanding criteria and acquiring the optimal solution to the allocation problem. Some intelligent optimal scheduler algorithms have already shown efficiency in solving such complicated resource allocation problems in satellite systems, but much more have to be done in ameliorating these present schedulers.

REFERENCES

[1] David Amzallag, Reuven Bar-Yehuda, Danny Raz, Gabriel Scalosub, Cell Selection in 4G Cellular Networks, INFOCOM 2008. The 27th Conference on Computer Communications. IEEE, 13-18 April 2008:700 – 708.

[2] GMR-1 01.202 (ETSI TS 101 376-1-3): "GEO-Mobile Radio Interface Specifications; Part 1: General specifications; Sub-part 3: General System Description".

[3] Jean-Paul M. G. Linnartz,On the performance of packet-switched cellular networks for wireless data communications, Wireless Networks, Volume 1, Number 2: 129-138.

[4] Aradhana Narula-Tam, Thomas Macdonald, Eytan Modiano, Leslie Servi. A Dynamic Resource Allocation Strategy for Satellite Communications, Military Communications Conference, 2004. MILCOM 2004. IEEE, 31 Oct.-3 Nov. 2004, Vol. 3: 1415 - 1421

[5] Hyang-Won Lee, Eytan Modiano and Long Bao Le, Distributed Throughput Maximization in Wireless Networks via Random Power Allocation, Mobile Computing, IEEE Transactions, Issue:99: 1-1

[6] Arbabi M.Range Scheduling Automation [J].IBM Technical Directions, 1984, 10(3):57-62.

[7] Parish D.A Genetic Algorithm Approch to Automating Satellite Range Scheduling [D].Masters Thesis.Patterson: Air Force Institute of Technology, USA, 1994.

[8] Yaxin Cao, Victor O. K. Li, Scheduling Algorithms in Broad-Band Wireless Networks，IEEE Proceedings of the IEEE, Vol. 89, No. 1, January 2001

[9] Barbulescu L., A.E.Howe, J.P.Watson, et al. Satellite Range Scheduling: A Comparison of Genetic, Heuristic and Local Search [C], Proceedings of the Seventh International Conference on Parallel Problem Solving from Nature (PPSNVII).Granada Spain: Springer Verlag, 2002:611-620.

[10] Globus Al,James Crawford,Jason Lohn,et al.A Comparison of Techniques for Scheduling Earth Observing Satellites[C], Proceedings of the Sixteenth Innovative Applications of Artificial Intelligence Conference(IAAI-04): AAAI(American Association for Artificial Intelligence)Press,2004:836-843.

[11] Mohammed Sabri Arhaif, Comparative Study of Scheduling Algorithms in WiMAX, International Journal of Scientific & Engineering Research, Volume 2, Issue 2, February-2011.

[12] Gooley T.D.Automating the Satellite Range Scheduling Process [D], Masters Thesis.Patterson: Air Force Institute of Technology, USA, 1993.

[13] Schalck.Automating Satellite Range Scheduling [D], Masters Thesis.Patterson: Air Force Institute of Technology, USA, 1993.

[14] Damiani Sylvain, Gerard Verfaillie, Marie-Claire Charmeau, A Continuous Anytime Planning Module for an Autonomous Earth Watching Satellite[C], Proc. of the 4th International Workshop on Planning and Scheduling for Space (IWPSS-04). Darmstadt, Germany, 2004.

[15] Damiani Sylvain, Gérard Verfaillie, Marie-Claire Charmeau. An Earth Watching Satellite Constellation: How to Manage a Team of Watching Agents with Limited Communications [C] , Proceedings of the fourth international joint conference on Autonomous agents and multiagent systems (AAMAS'05) .New York, USA: ACM (Association for Computing Machinery) Press, 2005:455-462.

[16] Bensana E.,G.Verfaillie,J.C.Agne`se,et al.Exact and Inexact Methods for The Daily Management of an Earth Observation Satellite[C], Proceedings of the Fourth International Symposium on Space Mission Operations and Ground Data Systems.Paris:European Space Agency,1996:507-514.

[17] GMR-1 01.202 (ETSI TS 101 376-1-2): "GEO-Mobile Radio Interface Specifications; Part 1: General specifications; Sub-part 3: General System Description; GMR-1 01.202"

[18] Gooley T.D., J.J.Borsi, J.T.Moore. Automating Air Force Satellite Control Network (AFSCN) Scheduling [J], Mathematical and Computer Modelling, 1996, 24(2):91-101.

[19] Frank Jeremy,Ari J′onsson,Robert Morris,et al.Planning and Scheduling for Fleets of Earth Observing Satellites[C], International Symposium on Artificial Intelligence Robotics, Automation Space, 2001.

[20] Burrowbridge Sarah E.Optimal Allocation of Satellite Network Resources [D], Masters Thesis.Virginia the Faculty of the Virginia Polytechnic Institute and State University, 1999.

[21] Barbulescu Laura,Jean-Paul Watson,L.Darrell Whitley,et al.Scheduling Space-Ground Communications for the Air Force Satellite Control Network[J], Journal of Scheduling, 2004, 7(1):7-34.

[22] Barbulescu L.,A.E.Howe,J.P.Watson,et al.Satellite Range Scheduling:A Comparison of Genetic,Heuristic and Local Search[C], Proceedings of the Seventh International Conference on Parallel Problem Solving from Nature (PPSNVII).Granada Spain:Springer Verlag, 2002:611-620.

[23] Barbulescu Laura, Adele Howe, Darrell Whitley.AFSCN Scheduling:How the Problem and Solution Have Evolved[J], Mathematical

and Computer Modelling, 2006,43(9-10):1023-1037.
[24] Burrowbridge Sarah E.Optimal Allocation of Satellite Network Resources [D], Masters Thesis.Virginia the Faculty of the Virginia Polytechnic Institute and State University, 1999.
[25] Barbulescu Laura, Adele E.Howe,L.Darrell Whitley,et al.Understanding Algorithm Performance on an Oversubscribed Scheduling Application [J], Journal of Artificial Intelligence Research, 2006, 27(11): 577-615.
[26] Chao Wang, Qiang Lin, Swarm intelligence optimization based routing algorithm for Wireless Sensor Networks, Neural Networks and Signal Processing, 2008 International Conference, 7-11 June 2008: 136 – 141
[27] T. Renk, C. Kloeck, D. Burgkhardt, F. K. Jondral, D. Grandblaise, S. Gault, JC. Dunat, Bio-Inspired Algorithms for Dynamic Resource Allocation in Cognitive Wireless Networks, Mobile Networks and Applications , Volume 13, Number 5, 431-441
[28] Dervis Karaboga, Bahriye Akay, A survey: algorithms simulating bee swarm intelligence, Artif Intell Rev (2009) 31:61–85
[29] Tiago Camilo1, Carlos Carreto2, Jorge Sá Silva1, Fernando Boavida1, An Energy-Efficient Ant-Based Routing Algorithm for Wireless Sensor Networks, Ant Colony Optimization and Swarm Intelligence, Lecture Notes in Computer Science, 2006, Volume 4150/2006: 49-59
[30] Nicola Bianchessi, Jean-François Cordeau, Jacques Desrosiers, Gilbert Laporte, Vincent Raymond, A heuristic for the multi-satellite, multi-orbit and multi-user management of Earth observation satellites, European Journal of Operational Research, Volume 177, Issue 2, 1 March 2007: 750-762.
[31] Erfu Yang, Ahmet T. Erdogan, Tughrul Arslan and Nick H. Barton, Multi-objective evolutionary optimizations of a space-based reconfigurable sensor network under hard constraints, Soft Computing - A Fusion of Foundations, Methodologies and Applications ,Volume 15, Number 1, 25-36
[32] Deming Lei, Multi-objective production scheduling: a survey, The International Journal of Advanced Manufacturing Technology ,Volume 43, Numbers 9-10, 926-938,
[33] Ajith Abraham, Hongbo Liu, Crina Grosan and Fatos Xhafa, Nature Inspired Meta-heuristics for Grid Scheduling: Single and Multi-objective Optimization Approaches, Metaheuristics for Scheduling in Distributed Computing Environments Studies in Computational Intelligence, 2008, Volume 146/2008, 247-272,
[34] Long Bao Le, Eytan Modiano, Changhee Joo, Longest-Queue-First Scheduling under SINR Interference Model, MobiHoc '10 Proceedings of the eleventh ACM international symposium on Mobile ad hoc networking and computing, Sep 2010.