Scheduling Multimedia Information Delivery Over Unicast Wireless Channels

B. Prabhakaran*
School of Computing, National University of Singapore, Singapore 117543
Email: prabha@comp.nus.edu.sg

Abstract

Wireless communication channels are generally characterized by availability of low bandwidth. Hence, exchange of multimedia information is normally done over a single or unicast channel. Multimedia information presentation can have certain constraints, such as precedence of one page of information with respect to another or the time of availability of information. Multimedia information delivery needs to be scheduled based on these constraints. In this paper, we model this scheduling problem using linear programming approach. We suggest the use of approximation algorithms proposed in [6] for this purpose. We have also presented the use of on-line approaximation algorithms for scheduling multimedia information delivery when their availability varies with time. We have presented our initial implementation experience also.

1 Introduction

Multimedia information typically comprises text, image, audio, and video. Information can be organized or presented in the form of pages, as shown in Figure 1. Presentation of multimedia information is typically done page by page. These presentations can have certain constraints. For example, one can have precedence constraints where a particular page of information needs to be presented ahead of another one. Alternatively, some of the pages may be available only after some point of time. In some cases, availability of these pages might vary with time.

*Supported in part by National University of Singapore Academic Research Fund Grant RP 981669.

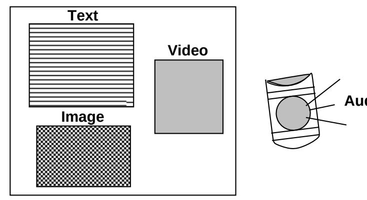

Figure 1: **Multimedia Pages Composition**

Wireless networks normally have low availability of network bandwidth. Exchange of multimedia information is, hence, done using unicast communication channels. Here, delivery of multimedia information pages is done one after another, as shown in Figure 2. We need to come up with a delivery schedule that identifies when a multimedia page can be delivered over the wireless network, based on the existing constraints (such as precedence relationships).

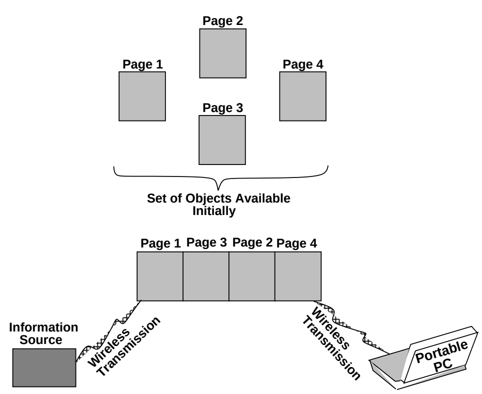

Figure 2: **Delivering Multimedia Pages Over Unicast Wireless Channels**

In this paper, we model this problem of scheduling the delivery of multimedia pages based on specified constraints, using linear programming approach.

0-7695-0559-7/00 $10.00 © 2000 IEEE

We suggest the use of approximation algorithms described in [6] for this purpose. We also outline the use of on-line approximation strategies for the case where the availability of multimedia pages vary with time. We then present our initial implementation experience in a simple wireless environment.

2 Delivery Schedule Based On Release Dates

In this section, we examine the applicability of a set of techniques for scheduling the delivery of multimedia objects based on precdence constraints. These techniques are based on a set of algorithms that have been designed to minimize average completion time of jobs based on certain constraints such as precedence and release dates [6]. These techniques are based on linear programming approach and help in scheduling jobs on single as well as parallel machines. The idea in using linear programming is as follows. There are n jobs that need to be scheduled. Each job j has a weight w_j and a non-negative processing time p_j, $j = 1, ..., n$. It is assumed that jobs will be processed without interruption, and a machine can process at most one job at a time. There might be precedence constraints among the jobs that need to be scheduled, i.e., there might be a partial order $j \prec k$, among any two jobs j and k. Each job j can also have a specified *release date*, r_j. Assuming C_j denote completion time for a job, the linear programming algorithm try to minimize $\sum_j w_j C_j$, or equivalently $(\sum_j w_j C_j)/n$ (i.e., the average completion cost for a job).

Based on this approach, we model delivery of multimedia pages as follows. Each multimedia page, as discussed earlier, is composed of various media objects such as text, image, audio, and video. One multimedia page is considered as a job that needs to be scheduled for completion. Processing time p_j for a multimedia page denotes the transfer time that might be needed for delivering all the objects composing the page. Processing time will be related to the sizes of the multimedia objects that compose a page and the network bandwidth. The weight w_j of a multimedia object denotes the importance of the object. In addition, pages j and k might be constrained by precededence relations, $j \prec k$.

Algorithm A1: Simple Schedule

1. Find the ratio of processing time to the weight of a multideia object (p_j/w_j).
2. Sequence the jobs in the non-decreasing order of p_j/w_j ratio.

This algorithm is proved to be optimal in [11]. However, it does not take into consideration other constraints such as precedence and release dates. Optimization of the average job completion time is a $NP-$hard problem when these (precedence, release) constraints are considered.

2.1 Constrained Schedule

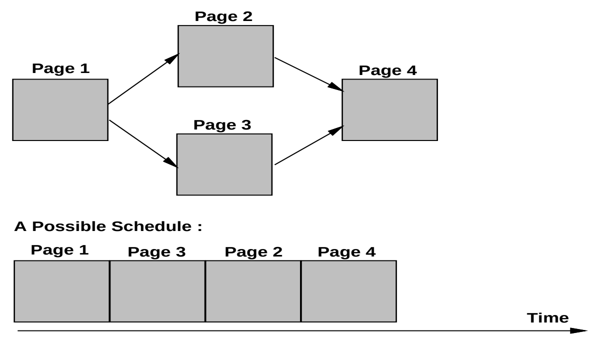

Figure 3: **Scheduling of Multimedia Pages Delivery with Precedence Constraints**

Here, we consider the problem of scheduling the delivery of multimedia pages taking into consideration precedence constraints. We consider an approximation algorithm proposed in [6] for scheduling multimedia pages with precedence constraints. Precedence relationship $j \prec k$ denotes that multimedia page j needs to be delivered (or presented) before page k. As an example, consider the presentation of multimedia pages shown in Figure 3. Here, page 1 needs to be presented before pages 2 and 3, Similarly, pages 2 and 3 are to be presented before page 4. Based on these precedence constraints, Figure 3 shows a possible schedule for delivery. In this schedule, it is assumed that w_3 is more than w_2, and hence page 3 is scheduled ahead of page 2. For this problem, the linear programming approach is again to minimize the average completion time :

minimize $\sum_{j=1}^{N} w_j C_j$. (1)

This minimization is done subject to the precedence

constraints among multimedia pages, expressed as below.
$C_k \geq C_j + p_k$, for each pair j, k such that $j \prec k$, where $C_j \geq r_j + p_j$ (2)
$C_k \geq C_j + p_k$ or $C_j \geq C_k + p_j$, for each pair j,k. (3)

The last constraint (3) is *disjunctive* in nature, and so it is not possible to model using linear inequalities. The last constraint can be rewritten as inequalities as follows [6].

If we set $w_j = p_j$ for all jobs j, then the sum $\sum_j w_j C_j = \sum_j p_j C_j$. For any schedule, the following is a valid constraint
$\sum_{j=1}^{n} p_j C_j \geq \sum_{j=1}^{n} p_j (\sum_{k=1}^{j} p_k) = \sum_{j=1}^{n} \sum_{k=1}^{j} p_k p_j = \frac{(p^2(N)+p(N)^2)}{2}$, (4)
where N denotes the entire set of jobs $1, ..n$. For each subset $S \subseteq N$, we can consider completion times C_j, $j \in S$. We can apply the previous inequality to each subset and derive the following valid inequalities :
$\sum_{j \in S} p_j C_j \geq \frac{(p^2(S)+p(S)^2)}{2}$, for each $S \subseteq N$. (5)

Algorithm A2: Constrained Schedule

1. Minimize $\sum_{j=1}^{n} w_j C_j$ subject to constraints (3) and (5).
2. Find optimal solution to the above linear program and obtain $C_1, .., C_n$.
3. Schedule the jobs in order of non-decreasing C_j. (In case of ties, precedence relations are used to sequence the jobs).

Scheduling With Pre-emption : Presentation of multimedia pages can be pre-empted by a client. As an example, a client may after viewing one of the objects composing a page may pre-empt the presentation by requesting the delivery of subsequent page. Here, the transfer time of the pre-empted page, p_j (job processing time), is reduced based on the time at which pre-emption is made. The constraint to be added for handling scheduling with pre-emption is:
$\sum_{j \in S} p_j C_j \geq l(S)$, for each $S \subseteq N$, where, $l(S) = r_{min}(S)p(S) + \frac{p^2(S)+p(S)^2)}{2}$. (6)

Algorithm A2.1: Constrained Schedule With Pre-emption

1. Minimize $\sum_{j=1}^{n} w_j C_j$ subject to constraints (3), (5), and (6).
2. Find optimal solution to the above linear program and obtain $C_1, .., C_n$.
3. Schedule a job j at time t such that t is the maximum of the following two: (a) all of j's predecessors have been scheduled, (b) time r_j, the release time for job j.
4. In case, a multimedia object's presentation is pre-empted by user. The next object is scheduled for delivery.

2.2 Constrained On-line Schedule

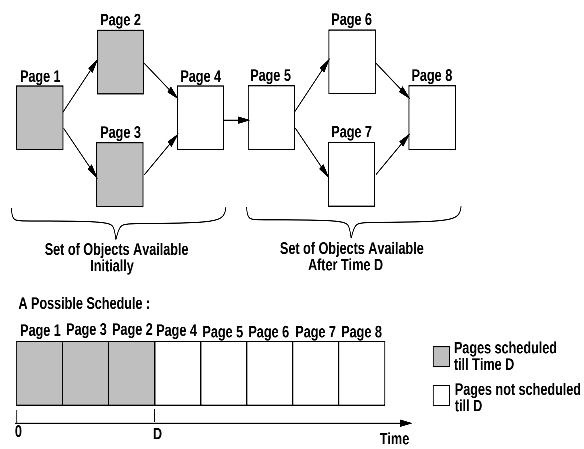

Figure 4: **Online Scheduling of Multimedia Pages Delivery with Precedence Constraints**

Here, we consider the problem of scheduling multimedia objects delivery in the following scenario. A set of objects are available at time 0 for scheduling. These objects are to be scheduled for delivery to the user till a time D. At time D, the objects delivery schedule is re-constructed based on the available objects, i.e., new objects might become available in the time interval [0,D]. This process is repeated till all objects are scheduled. We use a *greedy-interval* scheduling algorithm proposed in [6] for this purpose.

Algorithm A3: Constrained On-line Schedule

1. Consider the set of objects available at time τ_l. (Initially, $\tau_l = 0$).
2. Minimize $\sum_{j=1}^{n} w_j C_j$ subject to constraints (3) and (6).
3. Find optimal solution to the above linear program and obtain $C_1, .., C_n$.
4. Schedule the jobs in order of non-decreasing C_j till time D. (In case of ties, precedence relations are used to sequence the jobs).
5. At time D, consider the new set of jobs that are available for delivering. Repeat steps 1 through 5 after incrementing τ_l by D, till all objects are scheduled.

3 Implementation Experience

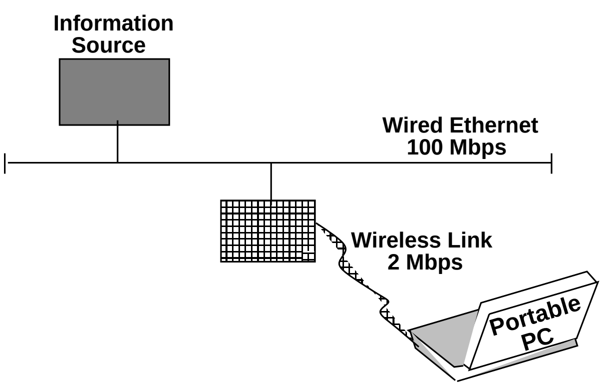

Figure 5: **Implementation Environment**

We implemented some of the techniques discussed above in an implementation environment as shown in Figure 5. Multimedia pages are stored in an Sun Ultra Sparc server that operates over a wired Ethernet at 100 Mbps. These pages, totalling around thirty in number, carries information about wild-life and the correspondig audio presents the sound made by each wild animal. Delivery of information was carried over a wireless network through a WavePoint wireless bridge operating at 2 Mbps. Client was a Pentium Laptop with WaveLan PCMCIA wireless network card. Each multimedia page is composed of objects such as text, image, and audio. We implemented Algorithm A2.1, i.e., constrained schedule of multimedia pages with pre-emption. Precedence constraints and weights for each page were assigned in an arbitrary manner among the thirty pages. We assigned about thirty constraints for the pages presentation. After identifying the delivery schedule, multimedia pages were delivered one after another over the wireless bridge to the laptop. Objects composing in one page (i.e., text, image, and audio) assigned three types of priorities: low, medium, and high. Presentation of a multimedia page can be pre-empted by clicking on a *link* object. Link object is one of the object (text or image) in a page. Links were assigned either based on object priorities or in a random manner. Time taken for identifying the delivery schedule was very negligible. Average sizes of text, image, and audio used im the multimedia pages were : . We measured the time taken for presentation with and without pre-emption. Without pre-emption, delivery of all the thirty pages were completed in seconds. For presentation with pre-emption, link objects were assigned based on priorities as well as randomly. Following table 1 summarizes the presentation times with pre-emption. Presentation of each page was pre-empted by clicking on a link object.

Links To object type	Ave. Page Time	Entire Presentation
High priority	26 ms	800 ms.
Medium priority	74 ms	2200 ms
Low priority	126 ms	3800 ms
Randomly assigned	90 ms	3200 ms

Table 1: **Presentation Times With Pre-emption**

We are in the process of implementing other algorithms outlined in this paper. We are also exploring techniques for structuring the delivery schedule based on the probability of page access. As an example, some of the multimedia pages may be popular and hence, performance might be improved by repeating the delivery of *popular* pages.

4 Related Work

Issues in wireless mobile computing environments are discussed in [4]. Management of data and querying aspects of databases are presented in [7, 8]. Issues and solutions for presentation of video objects in a mobile environment is described in [10]. Our work discussed in this paper is more general in that it deals with diverse media objects and also it deals with scheduling delivery of objects over a unicast wireless channel. Support for collaborative applications in mobile environments is outlined in [3]. Here, group coordinator services are provided in the International Standards Organization (ISO) Open Distributed Processing (ODP) environment and collaboration aware tools are designed using these services. We do not address the issue of collaborative nature of a presentation in this paper.

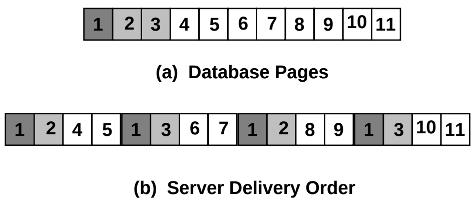

Figure 6: **Broadcast Scheduling of Disk Pages**

Techniques for indexing broadcast data have been investigated in [9]. Some of these techniques involve interleaving of index information with data. However, the paper does not address the organization of data objects based on precedence constraints or release dates. Use of repetitive broadcast as a way of augmenting the memory hierarchy of clients in an asymmetric, mobile communication environments is proposed in [1]. The technique, termed *Broadcast Disks*, helps in structuring broadcast data such that performance for non-uniformly accessed data is improved. As shown in Figure 6, the broadcast disk methodology repeats delivery of certain database pages depending on their frequency of access.

5 Summary

In this paper, we consider the problem of scheduling the delivery of multimedia pages over unicast wireless networks. Here, these multimedia pages might have constraints such as precedence relationships among pages or their time of availability. We have modeled this problem using linear programming approach. We have suggested the use of approximation algorithms suggested in [6] for scheduling the delivery of multimedia pages based on the existing constraints (such as precedence relationships). We have also outlined the use of on-line approximation algorithms for the case where the availability of multimedia pages varies with time. We carried out an initial implementation over a wireless bridge connected to a fast Ethernet.

References

[1] S. Acharya, R. Alonso, M. Franklin, and S. Zdonik, "Broadcast Disks: Data Management for Asymmetric Communication Environments", ACM SIGMOD'95, San Jose, CA, USA, 1995, pp. 199-210.

[2] Y.C. Chehadeh, A.R. Hurson, and M. Kavehrad, "Object Organization on a Single Broadcast Channel in the Mobile Computing Environment", Multimedia Tools and Applications, July 1999.

[3] N. Davies, G.S. Blair, K. Cheverst, and A. Friday, "Supporting Collaborative Applications in a Heterogeneous Mobile Environment", Special Issue of Computer Communications on Mobile Computing, 1995.

[4] D. Duchamp, "Issues in Wireless Mobile Computing", Proc. 3rd Workshop on Workstation Operating Systems (WW OS), Key Biscayne, Florida, US, IEEE Computer Society Press, 1992.

[5] A. Fiat, R. Karp, M. Luby, L. McGeoch, D. Sleator and N. Young, *Competitive paging algorithms*, Journal of Algorithms, Vol. 12, 1991, pp. 685-699.

[6] L.A. Hall, A.S. Schulz, D.R. Shmoys, and J. Wein, "Scheduling to Minimize Average Completion Time: Off-line and On-line Approximation Algorithms", Mathematics of Operations Research 22, 1997, pp. 513-544.

[7] T. Imielinski and B.R. Badrinath, "Querying in Highly Mobile Distributed Environment", Proc. of 18th VLDB Conference, Vancouver, Canada, 1992.

[8] T. Imielinski and B.R. Badrinath, "Data Management for Mobile Computing", SIGMOD Record, Vol. 22, No. 1, pp. 34-39, 1993.

[9] T. Imielinski, S. Viswanatha, and B.R. Badrinath, "Energy Efficient Indexing on Air", Proc. ACM SIGMOD'94, May 1994.

[10] B. Mah, S. Seshan, K. Keeton, R. Katz, and D. Ferrari, "Providing Network Video Services to Mobile Clients", Proc. 4th Workshop on Workstation Operating Systems (WW OS), Napa, US, Oct. 1993, pp. 48-54.

[11] W. Smith, *Various Optimizers For Single-Stage Production Problem*, Naval Research Logist. Quart. 3, 59-66.