Nonlinear Multidimensional Assignment Problems Efficient Conic Optimization Methods and Applications

Hans Mittelmann
ARIZONA STATE UNIVERSITY

06/24/2015
Final Report

DISTRIBUTION A: Distribution approved for public release.
14. ABSTRACT

The major goals of this project were completed: the exact solution of previously unsolved challenging combinatorial optimization problems. The size 16 three-dimensional quadratic assignment problem Q3AP from wireless communications was solved using a sophisticated approach with orbital shrinking and other techniques to exploit its symmetry. This problem has complexity (16!)^2 which is about 4.4*10^26. Another combinatorial optimization problem, the Directional Sensor Problem, was solved in two ways. First, heuristically in an engineering fashion and second, exactly after convexification. This had not been done before. While the Q3AP was solved in a linearized form leveraging the power of available MILP solvers, the sensor problem was solved as a nonlinear MINLP problem. Specifically, the information gain obtained was maximized in order to determine the optimal placement of the sensors. However, available MINLP solvers are not sufficiently effective, even in the convex case, and a hybrid Benders decomposition method was developed and applied. Results were published or submitted for publication and presented at several international conferences and a large number of research centers and universities around the world.

15. SUBJECT TERMS

combinatorial optimization, quadratic assignment, wireless communications, directional sensors, convexification, linearization, hybrid Benders decomposition
INSTRUCTIONS FOR COMPLETING SF 298

1. REPORT DATE. Full publication date, including day, month, if available. Must cite at least the year and be Year 2000 compliant, e.g. 30-06-1998; xx-06-1998; xx-xx-1998.

2. REPORT TYPE. State the type of report, such as final, technical, interim, memorandum, master's thesis, progress, quarterly, research, special, group study, etc.

3. DATES COVERED. Indicate the time during which the work was performed and the report was written, e.g., Jun 1997 - Jun 1998; 1-10 Jun 1996; May - Nov 1998; Nov 1998.

4. TITLE. Enter title and subtitle with volume number and part number, if applicable. On classified documents, enter the title classification in parentheses.

5a. CONTRACT NUMBER. Enter all contract numbers as they appear in the report, e.g. F33615-86-C-5169.

5b. GRANT NUMBER. Enter all grant numbers as they appear in the report, e.g. AFOSR-82-1234.

5c. PROGRAM ELEMENT NUMBER. Enter all program element numbers as they appear in the report, e.g. 61101A.

5d. PROJECT NUMBER. Enter all project numbers as they appear in the report, e.g. 1F665702D1257; ILIR.

5e. TASK NUMBER. Enter all task numbers as they appear in the report, e.g. 05; RF0330201; T4112.

5f. WORK UNIT NUMBER. Enter all work unit numbers as they appear in the report, e.g. 001; AFAPL30480105.

6. AUTHOR(S). Enter name(s) of person(s) responsible for writing the report, performing the research, or credited with the content of the report. The form of entry is the last name, first name, middle initial, and additional qualifiers separated by commas, e.g. Smith, Richard, J, Jr.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES). Self-explanatory.

8. PERFORMING ORGANIZATION REPORT NUMBER. Enter all unique alphanumeric report numbers assigned by the performing organization, e.g. BRL-1234; AFWL-TR-85-4017-Vol-21-PT-2.

9. SPONSOR/MONITOR'S ACRONYM(S). Enter, if available, e.g. BRL, ARDEC, NADC.

10. SPONSOR/MONITOR'S REPORT NUMBER(S). Enter report number as assigned by the sponsoring/monitoring agency, if available, e.g. BRL-TR-829; -215.

11. DISTRIBUTION/AVAILABILITY STATEMENT. Use agency-mandated availability statements to indicate the public availability or distribution limitations of the report. If additional limitations/ restrictions or special markings are indicated, follow agency authorization procedures, e.g. RD/FRD, PROPIN, ITAR, etc. Include copyright information.

12. SUPPLEMENTARY NOTES. Enter information not included elsewhere such as: prepared in cooperation with; translation of; report supersedes; old edition number, etc.

13. ABSTRACT. A brief (approximately 200 words) factual summary of the most significant information.

14. SUBJECT TERMS. Key words or phrases identifying major concepts in the report.

15. SECURITY CLASSIFICATION. Enter security classification in accordance with security classification regulations, e.g. U, C, S, etc. If this form contains classified information, stamp classification level on the top and bottom of this page.

16. LIMITATION OF ABSTRACT. This block must be completed to assign a distribution limitation to the abstract. Enter UU (Unclassified Unlimited) or SAR (Same as Report). An entry in this block is necessary if the abstract is to be limited.
In the second half of the grant period an emphasis was put on **distributing** the results of our funded research.

In 2014 we went on an extended travel to Australia and gave talks at the following universities:

- University of Newcastle, Newcastle, NSW
- University of New South Wales, Sydney, NSW
- Federation University, Ballarat, VIC
- University of Melbourne, VIC
- Curtin University, Perth, WA
- Flinders University, Adelaide, SA

Later in the same year we gave talks in Europe

- Aalto University, Helsinki, Finland
- Abo Akademi University, Turku, Finland
- Institute of Scientific Computing, University of Heidelberg, Germany
- Technical University Munich, Munich, Germany
- University of Erlangen-Nuremberg, Erlangen, Germany
- ZIB, Zuse Institute for Informatics, Berlin, Germany

We further gave talks in 2014 at the conferences

- Conference on PDEs; Novacella, Italy
- INFORMS Annual Meeting, San Francisco, CA

In early 2015 we went on an extended SE Asia trip and gave presentations at

- Chinese University of Hong Kong
- Hong Kong University of Science and Technology
- National Taiwan Normal University, Taipei, Taiwan
- National Taiwan University, Taipei, Taiwan

We further gave a talk at the conference **High Performance Scientific Computing 2015** in Hanoi, Vietnam.

All this in addition to numerous presentations earlier in the grant period, not listed here.

The final year of the grant period saw the attempt to address a number of challenging problems building on the earlier research and with the expectation that only a few could be finished within the grant period and most would have to be continued under a future grant. These problems include the exact solution of larger Q3AP problems and of still larger QAP problems.
An emphasis was here to avoid academic problems and instead work on real-life engineering problems. Some of these challenges were elusive on this first attempt, others were successful close to the end of the grant period.

The paper [1] had addressed a very specific three-dimensional assignment problem from wireless communications. This problem had been developed by the electrical communications engineer Zhi Ding, UC Davis, and his former student Harvind Samra. Peter Hahn et al [7] had attacked the problem for 8 and 16 bit assignments. They were only able to solve the smaller case exactly. Then in [1] we were able to do this for the size 16 problem, a major accomplishment. However, the modulation used in this work was special and in practice one often considers other methods. The modulation in [1] is phase-shift keying or PSK while in practice quadrature amplitude modulation or QAM is preferred. Further, there are several types of transmission channels in use. We collaborated with Zhi Ding and his current student Wenhao Wu and considered Q3AP problems for QAM modulation and sizes up to 64.

A first publication [5] addresses the 16 bit modulation Q3AP but for various channels. Our approach is to use the heuristic already successfully utilized in [1]. As can be seen from various graphs, our results are the best in a comparison with those of other typical methods.

However, an engineering ad hoc method (Seddik), came close in quality for this rather small bit number. In practice more frequently 32 and 64 bits are used. Since exact solution for size 32 is at present out of the range of computational power, we used heuristics again to solve realistic problems of these larger sizes through a sequence of two-dimensional QAPs, see [6].

As the graphs in [6] show, our method is giving by far the best results. The papers [5,6] will be finished in the near future.

While the number of publications produced in the grant period is moderate, the quality is partially substantial. Another reason is our delayed start due to vision problems during the entire year 2012 (5 eye surgeries up until late December).
References


1. Report Type

Final Report

Primary Contact E-mail

Contact email if there is a problem with the report.

mittelmann@asu.edu

Primary Contact Phone Number

Contact phone number if there is a problem with the report

480-965-6595

Organization / Institution name

Arizona State University

Grant/Contract Title

The full title of the funded effort.

Nonlinear Multidimensional Assignment Problems
Efficient Conic Optimization Methods and Applications

Grant/Contract Number

AFOSR assigned control number. It must begin with “FA9550” or “F49620” or “FA2386”.

FA9550-12-1-0153

Principal Investigator Name

The full name of the principal investigator on the grant or contract.

Hans Mittelmann

Program Manager

The AFOSR Program Manager currently assigned to the award

Fariba Faroo

Reporting Period Start Date

04/01/2012

Reporting Period End Date

03/31/2015

Abstract

The major goals of this project were completed: the exact solution of previously unsolved challenging combinatorial optimization problems. The size 16 three-dimensional quadratic assignment problem Q3AP from wireless communications was solved using a sophisticated approach with orbital shrinking and other techniques to exploit its symmetry. This problem has complexity (16!)^2 which is about 4.4*10^26. Another combinatorial optimization problem, the Directional Sensor Problem, was solved in two ways. First, heuristically in an engineering fashion and second, exactly after convexification. This had not been done before. While the Q3AP was solved in a linearized form leveraging the power of available MILP solvers, the sensor problem was solved as a nonlinear MINLP problem. Specifically, the information gain obtained was maximized in order to determine the optimal placement of the sensors. However, available MINLP solvers are not sufficiently effective, even in the convex case, and a hybrid Benders decomposition method was developed and applied. Results were published or submitted for publication and presented at several international conferences and a large number of research centers and universities around the world.

Distribution Statement

This is block 12 on the SF298 form.
Distribution A - Approved for Public Release

Explanation for Distribution Statement
If this is not approved for public release, please provide a short explanation. E.g., contains proprietary information.

SF298 Form
Please attach your SF298 form. A blank SF298 can be found here. Please do not password protect or secure the PDF. The maximum file size for an SF298 is 50MB.

SF298.pdf

Upload the Report Document. File must be a PDF. Please do not password protect or secure the PDF. The maximum file size for the Report Document is 50MB.

afosr_report_2015.pdf

Upload a Report Document, if any. The maximum file size for the Report Document is 50MB.

Archival Publications (published) during reporting period:

Changes in research objectives (if any):

Change in AFOSR Program Manager, if any:

Extensions granted or milestones slipped, if any:

AFOSR LRIR Number

LRIR Title

Reporting Period

Laboratory Task Manager

Program Officer

Research Objectives

Technical Summary

Funding Summary by Cost Category (by FY, $K)

<table>
<thead>
<tr>
<th></th>
<th>Starting FY</th>
<th>FY+1</th>
<th>FY+2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salary</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equipment/Facilities</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supplies</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Report Document

Report Document - Text Analysis

Report Document - Text Analysis

Appendix Documents

2. Thank You

E-mail user

Jun 14, 2015 05:01:44 Success: Email Sent to: mittelmann@asu.edu