Optimal Communications Systems and Network Design for Cargo Monitoring

[Extended Abstract]

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ABSTRACT

In the United States there is an emerging trend to ship goods by rail directly from ports to inland intermodal traffic terminals. However, for this trend to succeed shippers must have "visibility" into rail shipments. In this research we seek to provide visibility into shipments through optimal placement of sensor and communication technology. We formally define the notion of visibility and then highlight the objectives of our study. We also provide a generalized description of an optimization problem that has been developed to determine optimal sensor locations. Several problems must be solved to enable cost-effective visibility into rail shipments. We break down these problems into tasks and discuss how they can be addressed. The expected result of the proposed research includes a model (or models) that predicts the system cost given an assignment of sensors to rail-based containers. This model can be used to determine cost-effective scenarios for deploying sensors to containers on a train, as well as the system trade-offs.

Categories and Subject Descriptors

G.1.6 [**Numerical Analysis**]: Optimization

General Terms

Optimization theory

Keywords

sensor placement, cargo, trains, freight

1. INTRODUCTION

Various complex systems are used in the container transport industry resulting in a lack of visibility, accountability, efficiency and security into cargo shipments. Furthermore, cargo may be subject to hijack or theft [1] of goods, or contraband may be inserted into a shipment. Insufficiencies in these areas must be overcome to allow cost-effective transport over secure trade lanes. Sensors, networks and information technology offer the potential to address these insufficiencies. In the proposed research we will study the optimal design of the sensing and communications systems (e.g., radios, network, electronic seals, and seal readers) as one mechanism to provide cost-effective visibility (awareness) into a freight shipment.

To aid the development of a model suitable for analyzing a cargo monitoring system, assume that loads on a train are indexed by an integer j. Given a deployment of sensors and supporting communications infrastructure to a train, we can compute the cost of the system as well as the probability, P_{ϵ_j}, of detecting an event at a container, the probability, P_{α_j}, of having a false alarm at the container, the time τ_j taken to notify a decision maker of an event. For the decision maker to gain visibility into loads it is required that events are detected with a probability exceeding some threshold, P_{E_j}, the probability of false alarm must not exceed an upper bound P_{F_j}, and events are reported within a time interval bounded by T_{E_j}. We then define the visibility space as the set of system costs such that customer requirements for probability of detection, probability of false alarm and reporting deadline are met.

Our objectives in this study are:

1. Mapping and analyzing a "system" description of containers on railcars, train scenario[1] and associated communications infrastructure into the visibility space. Thus an appropriate system model needs to be developed.

2. Developing objective functions to assign a cost to every position in the visibility space.

3. Finding efficient mechanisms that use 1. and 2. to determine minimum "cost" systems for providing visibility into a rail shipment.

4. To use 1. and 2. to determine system trade-offs when seeking visibility into rail shipments.

The rest of this paper is laid out as follows: In Section 2 we present the expected contributions of this study. Sec-

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[1]This includes train speed and trips per time unit

tion 3 presents our proposed solution. Section 4 provides concluding remarks.

2. EXPECTED CONTRIBUTIONS

Some of the contributions of this study include:

- New definition of visibility. Cargo visibility provides the potential for:
  - Decreases in cargo insurance premiums
  - Increased customer confidence in the transportation chain
  - Increased efficiency in shipments
  - Better homeland security through reduced insertion risk for contraband
- Model to predict system cost, P_{ϵ_j}, P_{α_j} and τ_j and visibility of loads given an assignment of sensors and associated information systems.
- Optimization problem formulation
- Knowledge of whether an exact solution exists for the system design problem
- Identification of important system trade-offs

3. PROPOSED SOLUTION

The solution to provide visibility into shipments is under development. A prototype software package has been deployed to report events (intrusion detected, missing sensors, or low battery) at sensors. Our research focuses on how to find an optimal placement of sensors on containers assigned to a train. In this section we present our approach for addressing the sensor placement problem, followed by a high-level description of the tasks that we intend to complete in the course of this research.

3.1 Approach

Previous work [2] shows that placement of sensors is, in general, an NP-hard problem; however, approximation algorithms exist for sensor placement. Furthermore, others [3] have used Integer Linear Programming (ILP) techniques to place sensors in a field such that a desired amount of coverage is attained. Our objective in this research is to develop an extensible model(s) that can give the best (least expensive) system design. As a result, we resort to optimization theory. An optimization problem has been formulated with the following format: Given a list of parameter values $p_1, p_2, \ldots, p_n$ (such as the savings resulting from detecting events at containers, and container values) we define variables $x_1, x_2, \ldots, x_n$ (such as a variable that indicates if a sensor is placed on a certain container). We also define a function $f_o(\bar{x};\bar{p})$ that depends on the parameters and variables to return the system cost. Our goal in this research is to minimize this objective function subject to the constraints[2] specified by the system designer.

Concurrent with this study is the deployment of a prototype system to alert decision makers of events on an intermodal train. Some trials have already been conducted and statistics from those trials will be gleaned from log files and used to refine the optimization models that we develop.

[2]Some of these constraints specify valid placements for sensors and associated communications infrastructure. The constraints might also require that certain containers be visible.

3.2 Tasks

Thus far, two alternative system designs have been identified to compute the cost for cargo monitoring with the following deployment scenarios: 1) both the sensors and associated communications infrastructure are placed on the train, and 2) only the sensors are placed on the train while the associated communications infrastructure is placed at the trackside. The tasks that we intend to complete in this research effort include:

- **Task 1: Model Sufficiency** Are the models sufficient for describing the problem space?
- **Task 2: Model Tractability** Can we find an adequate solution for the system design problem in polynomial time?
- **Task 3: System Trade-offs** Which of the parameters in our model have the greatest effect on system cost? Given the large number of variables in our model formulation how do we carry out sensitivity analysis efficiently?
- **Task 4: Effect of Probability Distribution Functions on Model Results** Given that several variables in our model formulation are random variables, what is the effect of different probability distribution functions for these variables on our results?

4. CONCLUSIONS

In this paper we have provided a summary of a study to determine optimal communications systems and network design for cargo monitoring. Our study uses a new definition for visibility of containers in formulating an optimization problem to determine the best positions for sensors on a train. A prototype system has been developed to report events on a train to decision makers. This system has been used in a field trial, and statistics from this trial will be gleaned and used to refine our optimization model. The resulting model may then be used by train operators to monitor their cargo more efficiently as well as to identify important system trade-offs.

5. ACKNOWLEDGMENTS

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6. REFERENCES

[1] Federal Bureau of Investigation. (2006, July 21) Cargo Theft's High Cost. Headline. Federal Bureau of Investigation. [Online]. Available: http://www.fbi.gov/page2/july06/cargo_theft072106.htm

[2] A. Efrat, S. Har-peled, and J. S. B. Mitchell, "Approximation Algorithms for Two Optimal Location Problems in Sensor Networks," in *Second Int'l Conf. on Broadband Networks (BROADNETS 2005)*, Boston, MA, USA, Oct 2005, pp. 714–723.

[3] K. Chakrabarty, S. S. Iyengar, H. Qi, and E. Cho, "Grid Coverage for Surveillance and Target Location in Distributed Sensor Networks," *Computers, IEEE Transactions on*, vol. 51, no. 12, pp. 1448–1453, Dec 2002.