

Computational Mechanism Design for Multi-Sensor Information Fusion

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ABSTRACT

Conventional information fusion architectures are challenged by developments in sensor networks that allow individually-owned (and thereby selfish) sensors to interact and share data. Given this, we advocate the use of tools and techniques from computational mechanism design, a field at the intersection of computer science, game theory and economics, to address the challenges posed by these networks. These techniques allow us to engineer networks with desirable system-wide properties, in which sensors are represented as selfish rational agents, each attempting to fulfill their own individuals goals. In this paper, we present the work of the Argus II DARP project (<http://www.robots.ox.ac.uk/~argus/>) and we demonstrate the application of mechanism design within a real world information fusion sensor network scenario.

Categories and Subject Descriptors

H.4 [Information Systems Applications]: Miscellaneous

General Terms

Design, Theory

Keywords

computational mechanism design, sensor networks

1. INTRODUCTION

Multi-sensor networks (MSN) are being deployed in a wide variety of application areas ranging from military sensing to environmental monitoring and traffic control. Such networks consist of a number of sensors connected via a communication network. Each sensor is able to sense their local environment, but can also make use of data transmitted from neighbouring sensors in order to improve the accuracy of their own measurements (e.g. by combining their own noisy observation, with the observations from a number of other sensors, in order to reduce the final uncertainty).

To date, research in sensor networks has mainly concentrated on using cooperation among distributed sensors [3]. At its core, this approach involves determining the exchanges of observed data

between the sensors that results in the maximum gain in information across the whole sensor network. However, this approach overlooks the fact that in some applications each sensor may be individually-owned by different stakeholders. In such cases, the sensors are operating in a competitive rather than cooperative environment, and thus, they may attempt to optimise their own gain from the network, at a cost to the performance of the entire system.

To address the challenges of building sensor networks which exhibit desirable system-wide properties, despite the competitive behaviour of the constituent sensors, the Argus II DARP project (a collaboration between two academic partners: the University of Southampton and the University of Oxford, and three industrial partners: BAE SYSTEMS, QinetiQ and Rolls-Royce — see <http://www.robots.ox.ac.uk/~argus/> for more details) is exploring the application of computational mechanism design within information fusion scenarios.

2. INFORMATION FUSION SCENARIO

In this work, we consider a real world aerial surveillance scenario such as that posed in disaster relief contexts, where multiple emergency response agencies, with aerial vehicles of different capabilities, must interact in order to locate casualties. The sensor network is formed from sensors that are mounted onboard these aerial vehicles. Each sensor is provided with an imprecise estimate of its own location by the navigation system of the aerial vehicles to which it is mounted, and it is tasked with detecting and tracking multiple targets within a *region of observation* immediately surrounding itself. Within its region of observation, the sensor is able to estimate the position of each target by making noisy or imprecise measurements of the range and bearing of the target from itself. However, in order to better resolve the uncertainty in these position estimates, the sensors must acquire target observations from neighbouring sensors and then fuse these observations with their own.

The sensors are connected together via a communication network that has a limited bandwidth, and thus, there must be some coordination to determine which data should be sent to which sensors in order to make best use of this limited global resource. However, since each sensor is owned by a different stakeholder, it is thus selfishly seeking to maximise the accuracy of its own target position estimates. As a result, each sensor has a positive disinclination to share its observations since in doing so, it will occupy valuable bandwidth which may be used to receive observations from other agents. Thus, we use techniques from mechanism design to engineer a protocol that incentivises the sharing of observations, whilst also ensuring that the global resource of communication bandwidth is used effectively.

However, in order to apply the tools of mechanism design we

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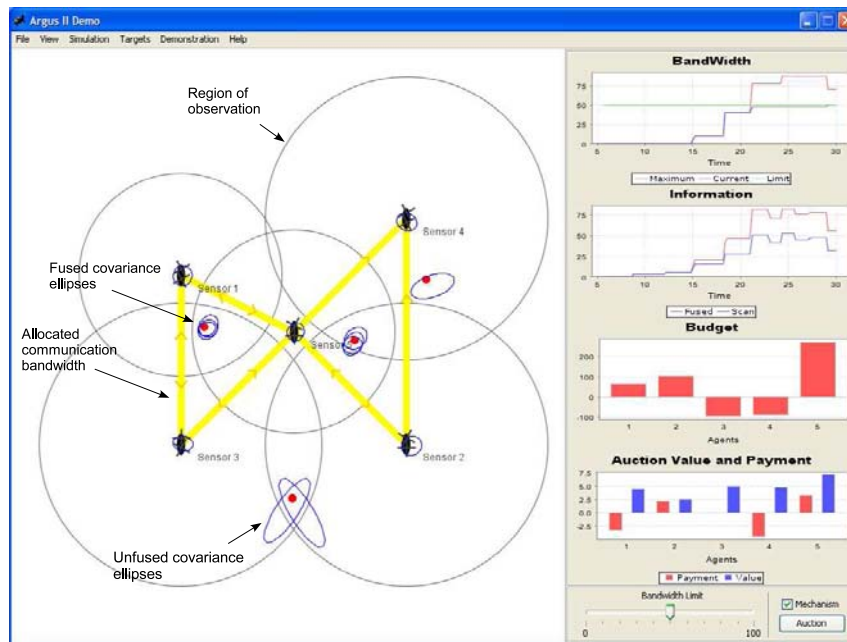


Figure 1: Example sensor network system showing the auction allocation in process and the resulting communication allocation.

require a metric that allows us to assign a value to the observations provided by each sensor. In our work, we have derived a metric based on the Fisher information of these observations [4]. This measure is related to the precision of the observations, and thus sensors that make range and bearing measurements with greater precision, generate observations with greater information content, and hence greater value. This metric is particularly attractive as when independent observations are fused, the information content of the fused observation, is simply equal to the sum of the two individual observations.

Adopting this measure allows us to develop a protocol, whereby an independent auctioneer allocates the communication bandwidth based on the valuations of observations supplied by the individual sensors. Thus far, we have focused our research onto a class of direct mechanisms that are said to be strategy-proof or incentive compatible [1, 2]. That is, the sensors have a dominant strategy to truthfully reveal the information content of their observations to the auctioneer (they thus have no incentive to engage in complex strategic behaviour). Such an outcome is achieved through the payments that the sensors must make (or collect) for receiving (or transmitting) observations. These payments are calculated by the auctioneer in order to align the individual goals of the sensors with the overall system-wide goals of the system designer. By incentivising truthful reporting of the information content of observations from the sensors, the auctioneer is then able to ensure that the bandwidth is allocated efficiently (i.e. to maximise the information gain of the entire network).

3. DEMONSTRATOR

To demonstrate the application of this mechanism, the information fusion scenario, the auction mechanism, and the individual sensors have been implemented within a fully asynchronous Java simulation environment. Figure 1 shows a screen shot of this simulator in operation. The main view shows the measurements and communication of the individual sensors that make up the sensor network. The graphs to the right record metrics of the entire system such as the total information gain of the network, the utilisation of the

available bandwidth, and the outputs of the auction process.

4. CONCLUSIONS

In this work, we have demonstrated an effective and efficient control mechanism for sensor networks, in which the constituent sensors are owned by different stakeholders that have their own goals and objectives. Our system has a principled valuation metric based on the Fisher information of a sensor's observations and uses computational mechanism design to engineer a sensor network with a particular desirable system-wide property (in this case, the efficient use of limited bandwidth capacity), despite the selfish goals and actions of the individual sensors. Whilst this research is ongoing, and is currently focusing on how the role of the auctioneer may be distributed amongst the sensors within the network, it is clear that computational mechanism design offers an invaluable and powerful set of tools and techniques to address the challenges posed by these scenarios.

5. ACKNOWLEDGMENTS

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