Efficient Information Spread Control in Cyber-Physical Systems

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1 Motivation

Networks play a vital role in cyber-physical systems (CPS) as they allow system components to communicate and cooperate. A typical network in future generation CPS would comprise millions of agents, i.e., sensors, computers, or people, with numerous connections. While high connectivity provides an unprecedented source of data, controlling the information flow over these networks is a tall order. A distinguishing feature of networked systems is that many global phenomena originate from local interactions of agents. This makes accounting for the effect of the surrounding neighborhood on an agent's behavior vital for performing any global task across the network. Motivated by this observation, our research is focused on addressing a fundamental issue: intervention in networks to control or impact the spread of information.

Studying the propagation of information in networks is important in and relevant to many fields including control, signal processing, and social sciences. Depending on the type of information, a network designer might be interested in accelerating or decelerating its spread over a network. In our recent work, we have considered two types of information spread control. In [1], we derived optimal defence and attack strategies for controlling information diffusion over a network of agents operating under linear dynamics. In [2], we studied the problem of epidemics control in networks with low curing rates. In both papers, the controllers we designed were centralized and were assumed to know the network topology; to better cope with the surge in network sizes in CPS, our proposed research will revolve around the following main themes:

- Exploring the fundamental limits of network controllability using a limited number of controllers.
- Constructing distributed controllers that operate in the presence of failures and large uncertainties.

Keywords: *Multi-Agent Systems, Game Theory, Network Control, Diffusion Dynamics, Epidemics.*

2 Proposed Research

Information spread control techniques must be *scalable*. Controlling each and every node quickly becomes a prohibitive task in a network with millions of nodes. Nonetheless, it is a common theme in current research to assume that the network designer can control all the nodes. In reality, such freedom in placing controllers may not be possible. Therefore, a question we plan to address and answer is: *for a given network, what is the minimum number of nodes one should control to drive the network state to a desired* *point or trajectory? Which nodes should be controlled?* We presented a partial answer to this question in [2] for the specific example of virus spread control where we proposed a framework for considerably reducing the number of controllers required to stabilize the network to the all-healthy state. Constructing search algorithms to find a near-optimal set of control nodes while providing performance guarantees is another potential direction.

Another limitation arises through the assumption that a network designer knows the types of each and every node in the network. Propagation of messages in a network depends on whether the agents at the individual nodes are leaders, followers, stubborn, or adversarial. From a network designer standpoint, it is important to be able to control the flow of information in the presence of such a variety of types, and if possible without requiring precise knowledge on the types of a large subset of the nodes. A promising framework within which to study problems with various node types is provided by game theory as it allows for modelling nodes of various types. Moreover, it is rich in tools that enable designing strategic controllers that operate in the presence of unknown parameters.

Evidently, studying the entire network at once can incur increasing complexity. Nonetheless, viewing the network as a dynamical system with components consisting of a manageable subset of nodes, and designing controllers for the smaller components first, is advantageous in two ways: 1) nodes' interaction within smaller components can offer insights about the global behavior of the network; and 2) feedback control theory becomes useful to understand the effect of one component on the other.

3 Potential Impact to CPS

Constructing controllers that overcome the above challenges will provide economical solutions for future CPS technologies. Examples of where our controllers can be used include:

- Directing traffic in a transportation network: Place few distributed controllers across the network which manage to produce a global re-routing pattern.
- Quarantining a set of nodes in an infected network: Limit the spread of a disease by surrounding the highly infectious nodes with a limited number of curing nodes.
- Regulating spam spread in a network: Offer incentives to a set of users to report suspicious messages and regulate a subset of the messages they forward.

Our treatment of the control of information spread problem utilizes a dynamical optimization framework and focuses on establishing connections between dynamical systems and game theory. This approach would yield strategies that are robust to adversarial intervention and are well suited to large-scale CPS.

References

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