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Response Essay: Dr. Fatemah Afghah

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Wireless Communication and Cognitive Processing: Applications of Game Theory

**Research Topic Overview**

The architecture of our communication networks has evolved substantially over the short history of digital communication, incorporating advanced methods for processing and relaying signals throughout vast network infrastructures. Dr. Afghah’s research is focused on how these (wireless) communication networks interact and can be optimized using game theory and specifically the concept of Nash equilibrium. Distinguishing the most effective communication strategies given a known a set of known variables, in this case a given infrastructure and the physical properties of the wireless spectrum, is a central tenet to modern signal processing and also modern society.

As it stands, the wireless spectrum is first and foremost limited by physics and the resulting properties of the electromagnetic spectrum. The International Telecommunications Union, the world’s governments, and their regulatory agencies have developed an organizational framework housed under the practice of spectrum management and specific frequency allocations that governs the use of the available radio/wireless spectrum and is something that all users must legally adhere to. This being said, it would seem that the realm of wireless communication management is signed, sealed, and delivered. However, with the advancement of wireless technology and increased demand on a limited system, novel approaches to the management of existing resources has become a central focus of wireless communication strategy. In response to this, Dr. Afghah’s research and presentation is centered on the application of complex theoretical concepts, like cooperative game theory, to the current inefficiencies in our wireless communication networks. Using such an approach to uncover alternative methods for wireless communication networks will greatly enhance the capabilities of our wireless infrastructure.

The application of game theory to communication network optimization is rooted in the concept that an ideal stable-state can be achieved if the parameters of the game, the network in this instance, and the players, the users in this instance, are better managed through game design and informed prediction. A stable state for wireless communication can be envisioned as all available bandwidth/spectrum being utilized at all times, eliminating any unused bandwidth that is usually reserved. More specifically, this is a scenario in which any user can occupy a specific channel based on its momentary availability regardless their priority status, all occurring under the assumption that security and privacy remain a top concern.This is the point in which the concept of cooperative game theory is being incorporated into the algorithm development outlined in Dr. Afghah’s presentation.

Expanding on traditional game theory concepts, cooperative game theory considers the integrity of the players, the future, decision history, and time as factors to be considered. Ultimately, cooperative game theory trends towards an outcome that will be the best for all the players involved. By design, a game’s rules can incentivize coalitions between players and award payoffs for continuingly successful outcomes. As this relates to communication networks, Dr. Afghah explained that by designing the game and the player protocol to make relatively minimal sacrifices for the greater good (i.e. most efficient outcome) the most effective network communication strategy will be possible. Player protocol and coalitions are accounted for with incentives rewarding players who share their available connectivity with the wireless infrastructure and punish those who actively refuse to share. In essence, establishing a network of users who are incentivized by sharing their connectivity and position within the available spectrum will create a deeper, broader, and more resilient network.

**Research questions**

-How can the available network spectrum be optimized through novel algorithms based on cooperative game theory and more specifically the goal of nash equilibrium?

-How can all network users actively cooperate and share the available spectrum without compromising their privacy and by causing a prohibitive amount of interference?

-What combination of strategies will yield the most effective decentralized wireless network?

**Research Purpose**

As discussed previously, Dr. Afghah’s research seeks to optimize wireless communication network functioning by applying cooperative game theory based algorithms to existing infrastructure and users. This can be generalized as the establishment of a secure, efficient, and complete interconnectedness of users, an advanced internet of things. As she discussed, there are some significant challenges to be addressed before this concept will become realized and users can mutually benefit from being continually interconnected. Some of the challenges are maintaining a high-level of security and privacy between users, establishing viable power management and distribution protocol, and accounting for users’ characteristics (e.g. history of collaboration and reputation). The issues of security and privacy are especially pertinent because without guaranteeing the privacy of users, expecting users to share information and their piece of the wireless network infrastructure is not responsible or rational given the percentage of people's’ lives contained in the digital realm. More practically, the issues of power management and distribution are based on the power requirements of an individual when they are acting as a network node for other users.

**Research Tools and Techniques**

To enable the optimization of wireless networks, different methods of multiple-input and multiple-output network capacity building were discussed in the assigned literature. Specifically, dynamic spectrum management/access and opportunistic spectrum access were highlighted as some of the most current methods for most effectively populating a wireless network. The practice of dynamic spectrum management refers to strategies that can govern the allocation of available spectrum based on network demand. Doing so makes use of previously idle portions of the spectrum, spectrum holes, mainly portions of the spectrum that were always reserved for certain users. Drawing the somewhat coarse analogy to a neighborhood municipal sewer pipe, it is most efficient for all households to share the same main pipe because establishing individual sewer pipes for each household to the destination would greatly increase the costs as well as increase the idle time of each pipe. While this analogy doesn’t address the ideas of signal interference or privacy, the ideas of available space and appropriate timing of the resource can be inferred. Being able to detect or sense this idle space and time across a network and utilize it is how Dr. Afghah proposes to insert cooperative game theory concepts into algorithm development. If availability can be accurately sensed, both spatially and temporally, then it can re-allocate users depending on demand. When users take a complex series of factors into account and play according to the predetermined rules of the game (e.g. sharing channels in a more fluid manner) the outcome for all players is improved.

**Research Connections**

I was able to distinguish some key connections between my proposed research and that of Dr. Afghah’s. First, since a significant portion of my research will be focused on applications of UAV technology, understanding space/time-based algorithms to determine a UAVs flight and behavior could be of vital importance once movement was incorporated. More specifically, the evolution of sense-and-avoid technologies could essentially emulate applications of a cooperative game theory in that what is best for a single UAV will likely be the best for all given a specific set of minimal sacrifices. This is best illustrated as a scenario in which there are multiple UAVs (all under autonomous flight) who are having to make small sacrifices in battey power (i.e. flight time) to avoid one another, but in doing so catastrophic crashes are avoided. Adding to this example, current technologies are being developed as an aid for manned aircraft in detecting UAVs and alerting the pilot of the best course of action to take to avoid collision, which could evolve into a cooperative relationship between players achieved by a wireless communication channels.

Another connection between mine and Dr. Afghah’s research is the utilization of UAVs as nodes/players in a next generation wireless network communications infrastructure. While this is already being used in certain military applications, expansion into the civilian domain is not far off (see Google). Having a semi-stationary UAV, perhaps tethered to a power source, act as a relay in a high traffic or geographically stretched wireless network can help the resiliency, capacity, and efficiency of that network. That becomes especially true if a network of interconnected UAVs are all sharing the same algorithmic protocol over a large area. After a brief review, this concept is being actively tested and refined in the scientific literature and also rapidly evolving the ways in which UAVs are being considered as useful.