A Game-theoretic Approach to Device and Resource Discovery in Internet of Battle Things

Shahab Tayeb, Adrian Ruiz, and Shahram Latifi
Department of Electrical and Computer Engineering, University of Nevada, Las Vegas, 89154, USA
Email: Shahab.Tayeb@unlv.edu; ruiza12@unlv.nevada.edu; Shahram.Latifi@unlv.edu

Abstract **—**This paper investigates the problem of optimizing automated supply support operations in the Internet of Battle Things. Such networks have highly dynamic environments and decision making in hindered by the big data volume, velocity, and variety. The literature for automation in the Internet of Battle Things lacks a decision-making model for this crucial logistic task. A solution is proposed based on coalition game theory. The problem of responding to supply support requests is formulated as a coalition game of selecting the best group of cargo supply vehicles, to respond to supply support requests in a region of the battlefront. Through the principles of coalition formation, a coalition selection and region assignment algorithm are designed to form coalitions for optimizing resource allocation and maintaining a high level of request satisfaction.

Index Terms**—**Device discovery, coalition games, game theory, internet of things, wireless sensor network

I. Introduction

Infrastructures are becoming increasingly complex in the sense of having components form a highly complex system. With Internet of Things (IoT), operation of infrastructures becomes more efficient. An IoT system can gather information from multiple sources which in turn could be used to improve the efficiency of planning. With the advancements in IoT applications, the idea of an Internet of Battle Things (IoBT) for a military setting is sought after. With the development of IoT, the military applications of an IoT can account for reconnaissance, environment surveillance, supply lines, and so on. However, the military has failed to equip such a system [1]. This paper proposes a game-theoretic framework and Device to Device (D2D) communication to improve upon the implementation of IoBT.

The concept of IoBT has given rise to the possibility of automating a wide number of operations in the military. In modern day, decisions for supply support operations are ultimately made by a commander. This method is constrained by the human component which is limited in its ability to consider numerous variables. Autonomous cargo vehicles in the IoBT can be leveraged for this operation to increase satisfaction from requesting units, and optimize resource allocation for an increased chance of mission success.

While there have been many proposed ideas on how to implement and improve IoBT, security should be one of the major priorities for an IoBT system. With critical information having to be sent, information should not be compromised. While there has been many advancements and proposals in the other aspects of IoBT, little has been proposed about security or about using collected data. In a warzone, an enemy can attack and gain information from the IoBT which could endanger the lives of the soldiers. Also, an enemy could upload malware to the IoBT which could lead to the system crashing. Because the dynamic nature of a warzone, it would be beneficial to implement a task assignment feature to an IoBT. However, the dynamic nature of a war zone means that it soldiers, and other units move around, so the problems are finding the location of a unit. This is where the discovery protocol finds the units and knows the location of them. When assigning a task to a located unit, a game-theoretic framework helps with assigning different tasks to different units. This could allow for better supply lines, better infantry communication, and many more.

Infantry units in an IoBT are equipped with multiple sensors which could be used to model Wireless Sensor Networks (WSN). Due to the dynamic nature of humans, infantry needs are simplified based on the information that their sensors gather. We wish to improve upon the medical responses on the battlefield, and any relevant information is sent to the different medical centers in which they use game theory to calculate which center should fulfill the request.

This paper proposes a game-theoretic framework to secure the IoBT system while also be used to perform task assignment. Because of the dynamic nature of a warzone, D2D communication is used to help with task assignment. Game theory is proposed to create energy efficient networks. A coalition game is proposed in Liu *et al.* [2] to handle assigned tasks and picking the best coalition for the task. Similarly, Massin *et al.* [3] formulate a coalition game which fills in the gaps in ad hoc network clusters. Pillai *et al.* [4] also use a coalition game used for resource allocation

With regards to D2D discovery, there are various proposed solutions. A common solution is using a slotted wake-up and sleep schedule usually with the purpose of energy efficiency. In Sun *et al.* [5] the wake-up and sleep schedule uses combinatorial block design to create a duty cycle, while Zhang *et al.* [6] use a probability to

Manuscript received August 12, 2018; revised April 25, 2019.
Corresponding author email: Shahab.Tayeb@unlv.edu
doi:10.12720/jcm.14.6.484-489

determine the duty cycle. Other solutions include using a probing interval algorithm such as in Wang *et al.* [7] where the probing interval alternates.

However, there are limitations to these approaches. With D2D discovery in the wake up and contact probing schedules, if two nodes are waiting to receive a message, the nodes do not discover one another. Also, many D2D discovery algorithms attempt to find nodes, but after a node is discovered, not much is done. With a game-theoretic framework, most studies assume that all the communication information is received, but there are times when information exchange could be incomplete. There is also no order in tasks if tasks needed to be handled in a certain order.

Our proposed method is to use D2D discovery along with a game-theoretic framework to create a dynamic network. Game theory and D2D have not been used yet for task assignment. Medical units on warzone need to get to a request as quickly as possible. Decisions need to be made quickly and accurately in order not to miss a request. A game would handle task assignments, but due to the dynamic nature of a warzone, node positions could change. With a D2D discovery algorithm, node locations are identified and updated regularly. If a node is discovered that is close to the request, it is assigned to that task. This allows the nodes to be used after being discovered.

For our proposed approach to work, there are several cases that need to be studied. It is hypothesized that a sink node acting as a rendezvous station might facilitate task assignment and reduce communication overhead. Nodes need to find the shortest path to the request; however, if something happens to the path, a node needs to find a new optimal path. With multiple discovery protocols, an optimal protocol should be selected. Moreover, node communication should be evaluated in a noisy environment.

II. Literature Review

Several discovery protocols have been proposed over the years with many focusing on energy efficiency. In Wang's study [8], a framework is proposed to characterize the tradeoff between a contact probing interval and a contact missing probability. It could estimate arrival rates and adapt the contract-probing interval based on an estimate. Similarly, Li *et al*. propose [9], a framework that also uses contact-probing and missing probability is proposed. It instead would limit the number of discovered peers and not change the interval. Both frameworks used data gathered from experiments to be used in the adapting process.

Many protocols that have been proposed have been for infrastructure that follows a topology. Many of the proposed protocols' goals are to limit traffic and energy consumption while not compromising the discovery of nodes. In [10], the proposal involved a wake- up and sleep schedule using combinatorial block design and a multiple of two algorithms. By combining two designs and overlapping them with each other, the new design could use in a duty cycle. Using the multiple of two algorithms allowed an asymmetric operation to become symmetric which then come used for combinational design. Other proposed solutions involving using IPv6 and LLDP to reduce traffic. Lee [11] proposed a solution by piggybacking MAC address messages with neighbor solicitation messages to reduce traffic. Khan *et al*. [12] surveyed the current topology discovery methods along with the threats and security issues in an SDN. The SDN mentioned is a three-layer architecture, including the controller, with hosts, switches and links. Nodes are found by using OFDP, LLDP, switches, and packets. However, the architecture of the SDN leaves vulnerabilities for attacks, but a few solutions have been proposed to increase the security.

Other solutions on device discovery have been proposed depending on the problem that needed to be solved. Doukha *et al*. [13] proposed road segmentation to synchronize beaconing problem in VANETs. The paper also tested that it was possible to have the beaconing happen in one interval. In [14], network-assisted D2D discovery is used to develop a framework that estimates the probability of two tagged devices in a proximity. Another approach [6], developed a protocol in which nodes sleep during unlikely times of activity and awaken when the probability is high.

Coalition game theory is a well-known approach to these types of resource allocation and optimization problems. In [2], energy consumption in WSANs was balanced to improve the life-time of the network, [4] derived near-optimal strategies for maximizing resource allocation in cloud services by using service requirement tuples, and [11] reduces transmission times for video surveillance footage with a Bayesian coalition game. There have been no previous studies on optimizing supply support operations with game theory.

III. The Proposed Method

A. Background and Settings

The supply support problem is framed as a coalition game on the battlefront. A temporary supply point has been established at an entry location to the battlefront where the cargo vehicle fleet is initially stationed. The battlefront is partitioned into regions with several properties. An authority vehicle is present in the fleet named the Commanding Vehicle (CV) which has the power to form coalitions and assign those coalitions to a region to carryout supply support requests. The goal of the CV is to optimize the coalitions formed for each region. Coalition forming decisions are based on analyzing the supplies each region is requesting, which vehicles can provide those supplies best, and the importance of each region to the overall mission success.

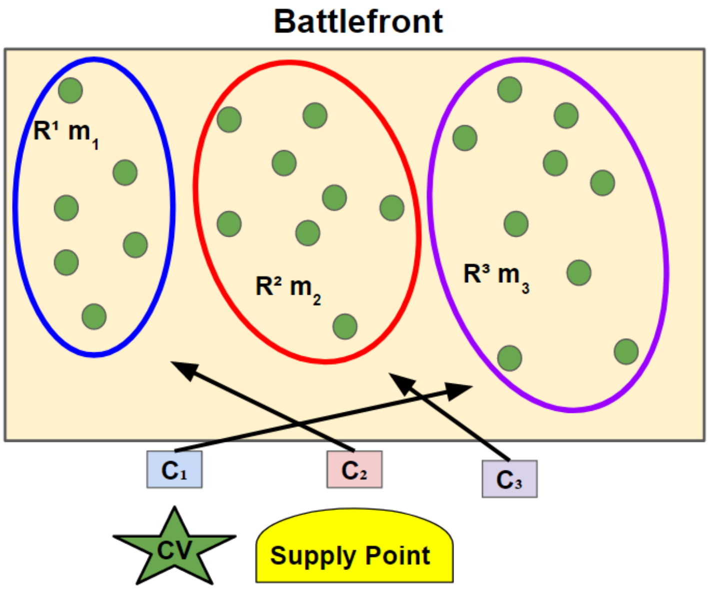

Fig. 1. Note how the caption is centered in the column.

B. Regions and Supply Requests

1) Let S be a 10-tuple (S_1, S_2,…S_{10}) where Sn represents an amount of class-n supplies, $0 \leqslant S_n \leqslant 10$.

2) Let I be the number of requests in a region. Requests are defined by tuple S where R_i^j (S_n) denotes the amount of class-n supplies needed by the i^{th} request in the j^{th} region.

3) Let J be the number of regions. Regions are defined by tuple S where $K^j(S)$ denotes the total amount of supplies needed by the j^{th} region. This is computed by the following equation:

$$K^j(S) = \sum_{i=0}^{I}\left[\sum_{n=1}^{10} R_i^j(S_n)\right]$$

The agents that form the possible coalitions are autonomous cargo vehicles with communication to the CV via Vehicle-to-Vehicle (V2V) communication in the IoBT network.

1) Let M be the number of vehicles in the vehicle cargo fleet where V_m denotes the m^{th} vehicle.

2) The supply capabilities of Vm are represented by tuple S, where $V_m(S_n)$ represents the amount value of class-n supplies V_m is capable of supplying.

C. Payoff Functions

The max payoff for a request is the total sum of the amount of supplies it needs. The expected payoff for a vehicle is proportional to the max reward, and the similarity between a vehicle's capabilities and a request's needs. A vehicle will receive the most payoff be responding to the request whose needs most matches its capabilities.

1) Vehicle: The payoff, P, for request R_i^j fulfilled by vehicle V_m is computed by:

$$P(R_i^j, V_m) = S(R_i^j)\left[1 - \Delta(R_i^j, V_m)\right]$$

where Δ (R_i^j ; V_m) is the mean difference from a paired difference analysis computed by:

$$\Delta(R_i^j, V_m) = \frac{1}{100}\sum_{n=1}^{10} |V_m(S_n) - R_i^j(S_n)|$$

2) Coalition: The total payoff, v, available from region K^j for C_j is computed by:

$$v(C_j) = \sum_{i=1}^{W} U(R_i^j, V_m)$$

where W is the number of vehicles in the coalition.

D. Utility Functions

To increase overall decision-making time, a distributed Payoff Computation Algorithm (PCA) is proposed. In summary, each vehicle will compute its payoff for each supply request and transmit the payoff matrix to the CV for coalition forming.

Algorithm 1 Payoff Computation Algorithm

Input: List of all requests
Output: i x j payoff matrix for V_m

for each region K^j **do**
  for each request R_i^j **do**
    Compute $P(R_i^j, V_m)$
    Occupy matrix cell [i,j] with payoff value
  end for
end for
Transmit payoff matrix to CV

E. Coalition Formation

Once each vehicle has computed its individual payoffs for each request, the CV will form coalitions by assigning vehicles to different regions depending on the vehicle payoff for the requests in that region.

Algorithm 2 CFRAA

Input: Payoff matrices for all vehicles

Output: Optimal coalitions for each region

for each region K^j **do**
  for each request R_i^j **do**
    Find **max**(matrix cell [i,j]) $\forall V_m$
    Assign V_m to coalition C^j
  end for
end for

IV. Experiments

Scenario 1: If a signal came, car one had to decide whether to drive to the location or stay on patrol. Then car who must decide followed by car three. Fixed payoffs were assigned to each end of the branches. However, the outcome was not the desired result. We want each car to act independently of each other, and not act after a car has decided. We also wanted to add probability to the car's decisions at first. We wanted to set the car's decisions to fifty-fifty initially, and have the probability change over the course of multiple games. The results showed that all the cars made the same decision every time.

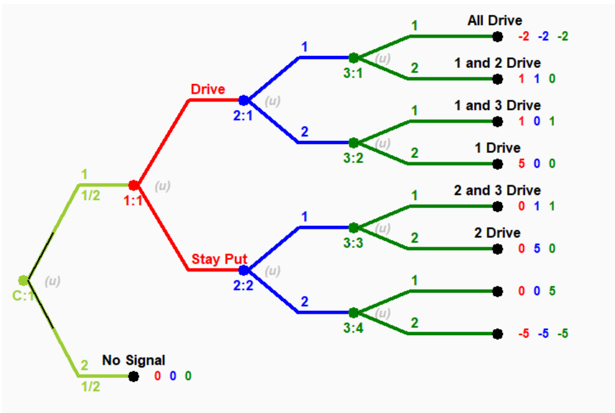

Fig. 2. Game setup (Scenario 1)

Scenario 2: The goal was trying to add some probability to the game. Each of the light green branches was our attempts to adding probability to the car's decisions. It is still not exactly what we want since the car's decisions are always 100 percent. Our problem is trying to figure out how make the cars make decisions at same time, and how to add initial probability to the car's decisions.

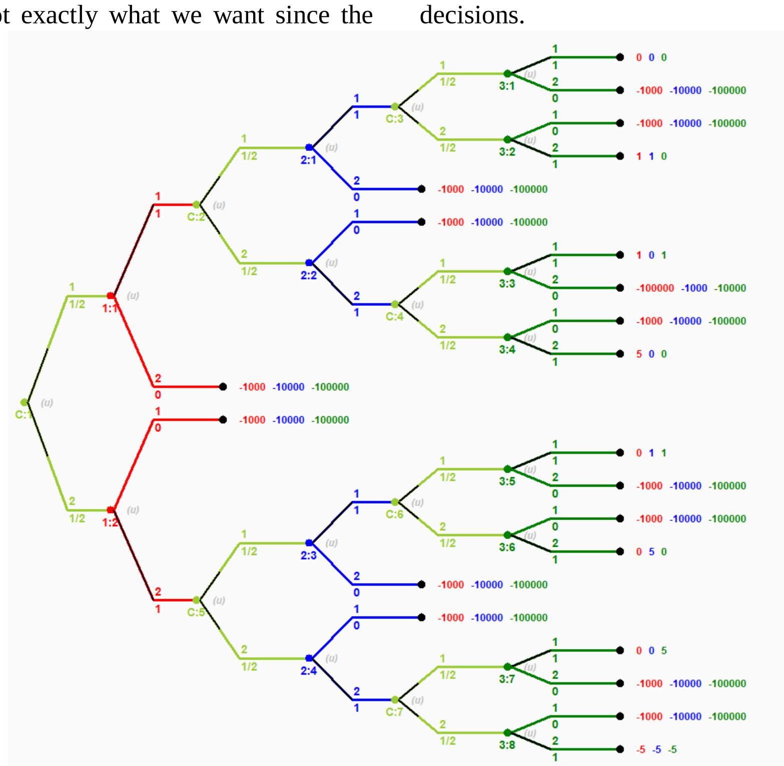

Fig. 3. Extended game setup (Scenario 2)

V. Conclusions

We make the first effort to formulate device discovery and resource assignment in a military IoT setting as a coalition game. The regions, supply requests, utility and payoff functions were modelled as mathematical functions and the game was implemented in Gambit to visualize the possibilities.

Acknowledgment

This material is based upon work supported in part by the National Science Foundation under Grant No. IIA-1301726 and in part by UNLV Graduate College Rebel Research and Mentorship Program (RAMP). The authors also wish to acknowledge Mr. Alvaro Pintado's involvement in part of the study.

References

[1] D. E. Zheng and W. A. Carter, "Leveraging the internet of things for a more efficient and effective military," *Rowman & Littlefield*, 2015.

[2] Q. Liu, S. Yang, L. Zhang, and L. Ji, "Game-theory-based coordination in wireless sensor and actor networks," *IET Wireless Sensor Systems*, vol. 6, no. 5, pp. 166-172, 10 2016.

[3] R. Massin, C. J. Le Martret, and P. Ciblat, "A coalition formation game for distributed node clustering in mobile ad hoc networks," *IEEE Transactions on Wireless Communications*, vol. 16, no. 6, pp. 3940-3952, June 2017.

[4] P. S. Pillai and S. Rao, "Resource allocation in cloud computing using the uncertainty principle of game theory," *IEEE Systems Journal*, vol. 10, no. 2, pp. 637-648, June 2016.

[5] W. Sun, Z. Yang, X. Zhang, and Y. Liu, "Energy-Efficient neighbor discovery in mobile ad hoc and wireless sensor networks: A survey," *IEEE Communications Surveys & Tutorials*, vol. 16, no. 3, pp. 1448-1459, Third Quarter 2014.

[6] B. Zhang, Y. Li, D. Jin, and Z. Han, "Network science approach for device discovery in mobile device-to-device communications," *IEEE Transactions on Vehicular Technology*, vol. 65, no. 7, pp. 5665-5679, July 2016.

[7] W. Wang, M. Motani, and V. Srinivasan, "Opportunistic energy-efficient contact probing in delay-tolerant applications," *IEEE/ACM Transactions on Networking*, vol. 17, no. 5, pp. 1592-1605, Oct. 2009.

[8] C. Wang, J. Li, F. Ye, and Y. Yang, "A mobile data gathering framework for wireless rechargeable sensor networks with vehicle movement costs and capacity constraints," *IEEE Transactions on Computers*, vol. 65, no. 8, pp. 2411-2427, 2016.

[9] B. Han, J. Li, and A. Srinivasan, "On the energy efficiency of device discovery in mobile opportunistic networks: A systematic approach," *IEEE Transactions on Mobile Computing*, vol. 14, no. 4, pp. 786-799, April 1, 2015.

[10] R. Massin, C. J. Le Martret, and P. Ciblat, "A coalition formation game for distributed node clustering in mobile ad hoc networks," *IEEE Transactions on Wireless Communications*, vol. 16, no. 6, pp. 3940-3952, June 2017.

[11] N. Kumar, J. H. Lee, and J. J. Rodrigues, "Intelligent mobile video surveillance system as a Bayesian coalition game in vehicular sensor networks: Learning automata approach," *IEEE Transactions on Intelligent Transportation Systems*, vol. 16, no. 3, pp. 1148-1161, 2015.

[12] S. Khan, A. Gani, A. W. A. Wahab, M. Guizani, and M. K. Khan, "Topology discovery in software defined networks: Threats, taxonomy, and state-of-the-art," *IEEE Communications Surveys & Tutorials*, vol. 19, no. 1, pp. 303-324, 2017.

[13] Z. Doukha and S. Moussaoui, "An SDMA-based mechanism for accurate and efficient neighborhood-discovery link-layer service," *IEEE Transactions on Vehicular Technology*, vol. 65, no. 2, pp. 603-613, Feb. 2016.

[14] D. Xenakis, M. Kountouris, L. Merakos, N. Passas, and C. Verikoukis, "On the performance of network-assisted device-to-device discovery," in *Proc. IEEE Global Communications Conference*, San Diego, CA, 2015, pp. 1-7.

Shahab Tayeb (Ph.D. '18 expected, M.S. with Distinction'12, B.S. Maxima Cum Laude '10) is a doctoral candidate at the College of Engineering, University of Nevada-Las Vegas, where he has been awarded numerous national and international scholarships. Prior to joining the Ph.D. program, he was the managing director at Cisco Networking Academy where he taught various entry, associate, professional, and expert-level courses. He has authored/co-authored 20+ refereed research papers over the past three years and his research findings have been highlighted by the National Science Foundation. His research interests span the areas of Cybersecurity, Internet of Things, and Cyber-Physical Systems utilizing Big Data Analytics, Deep Learning, and Game Theory.

Adrian Ruiz (Ph.D. '18 expected, M.S. with Distinction'12, B.S. Maxima Cum Laude '10) was born in Las Vegas, Nevada. He is currently an undergraduate student at the University of Nevada Las Vegas pursuing a B.S degree in computer engineering. He started his research as part of the UNLV Graduate College Rebel Research and Mentorship Program (RAMP) and his research interests include IoT and device discovery.

Shahram Latifi, an IEEE Fellow, received the Master of Science degree in Electrical Engineering from Fanni, Teheran University, Iran in 1980. He received the Master of Science and the Ph.D. degrees both in Electrical and Computer Engineering from Louisiana State University, Baton Rouge, in 1986 and 1989, respectively. He is currently a Professor of Electrical Engineering at the University of Nevada, Las Vegas. Dr. Latifi is the co-director of the Center for Information Technology and Algorithms (CITA) at UNLV. He has designed and taught undergraduate and graduate courses in the broad spectrum of Computer Science and Engineering in the past three decades. He has given seminars on cyber-related topics all over the world. He has authored over 250 technical articles in the areas of networking, cybersecurity, image processing, biosurveillance, biometrics, document analysis, fault tolerant computing, parallel processing, and data compression. His research has been funded by NSF, NASA, DOE, DoD, Boeing, Lockheed and Cray Inc. Dr. Latifi was an Associate Editor of the IEEE Transactions on Computers (1999–2006), an IEEE Distinguished Speaker (1997–2000), and Co-founder and General Chair of the IEEE Int'l Conf. on Information Technology (2004–2015). Dr. Latifi is the recipient of several research awards, the most recent being the Silver State Research Award (2014). He is also a Registered Professional Engineer in the State of Nevada.