ENERGY EFFICIENT WSN SYSTEM OF INTER-SATELLITE COMMUNICATION FOR SPACE DEBRIS BY USING COOPERATIVE GAME THEORY

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Abstract- Energy efficiency in an important part of leading design principles for the current deployment of satellite networks for countries. With this way, space debris removal approaches are as important as it, too. Space debris pollution is similar to other international environment problems. Countries glory with the space satellite rates, however when the situation is removal space debris, they lag behind in their mission because of the cost. Cooperation between the countries can be effective way to clean the space. In this paper, a cooperative game theoretic approach is proposed to allocate the costs or gains between players taken the space satellite rate, space debris demand, and energy efficient as values.

Keywords- energy efficient, routing, wireless sensor networks, cooperative game theory, allocation rules, space debris.

I. INTRODUCTION

A wireless sensor network (WSN) is a network of thousands of resource-constrained sensors whose communications with a central station are conveyed by means of wireless signals. A sensor node is generally comprised of four basic elements, including a sensing unit, a processing unit, a transceiver unit, and a power unit. The WSN is frequently deployed for sensing the area of interest where data captured encompass light, pressure, sound, and others [11, 17, 30, 32].

Energy supply, limited computing power, and limited bandwidth of the wireless links connecting sensor nodes. One of the main design goals of WSNs is to carry out data communication while trying to prolong the lifetime of the network and prevent connectivity degradation by employing aggressive energy management techniques. The design of routing protocols in WSNs is influenced by many challenging factors [2]. In WSNs where nodes operate on limited battery energy, the efficient utilization of the energy is very important. The energy efficiency has been considered in wireless ad hoc network routing, but the conventional routing objective was to minimize the total consumed energy in reaching the destination [4,9].

Al-Karaki and Kamal [3] summarized recent research results on data routing in WSNs in a comprehensive manner. Their table shows how different routing protocols fit under different category and also compare different routing techniques according to many metrics.

In this paper, we use the energy-aware routing which introduced by Shah and Rabaey [26] to use a set of sub-optimal paths occasionally to increase the lifetime of the network. These paths are chosen by means of a probability function depending on the energy consumption of each path. Network survivability is the main metric that the approach is concerned with. The approach argues that using the minimum energy path all the time will deplete the energy of nodes on that path. Instead, one of the multiple paths is used with a certain probability so that the whole network lifetime increases. The protocol assumes that each node is addressable through a class-based addressing which includes the location and types of the nodes.

In this paper we give some basic information and notions from Game Theory in Section 2. In Section 3, an application on space debris by the cooperative game theoretical approach is given finally, we give concluding remarks on future works in Section 4.

II. GAME THEORY

In order to obtain a practical and feasible WSN and due to the operation nature of the network, Game Theory (GT) is regarded as an attractive and suitable basis to accomplish the design goal. Game theory is a branch of mathematics and can be used to analyze system operations in decentralized and self-organizing networks. GT describes the behavior of players in a game. Players may be either cooperate or non-cooperative while striving to maximize their outcomes from the game. In this regard, sensors manage their operations in terms of power resources devoted to sensing and communicating among themselves and with a global controller such that the assigned task could be completed effectively as desired [15,27,30].

Game theory becomes especially relevant when one wants to assume that the environment of the wireless terminals is structured, otherwise classical optimization tools may suffice. Game-theoretic approaches may lead to more efficient network states than the worst-case approach, where structural elements are ignored or not accounted for. Remarkably, considering a terminal as an intelligent entity which is capable of observing a structured environment and reacting sufficiently rapidly, has become an increasingly realistic assumption with the significant progress in signal processing (e.g., spectrum sensing algorithms and dramatic increase of admissible computational complexity). For a long time, game theory was used quite marginally and more like an analysis tool in communication problems. With recent technological progress and the arrival of new wireless paradigms, the era of using game theory for design has come. Multiuser information theory has inspired researchers and engineers, and led them to invent important concepts such as successive interference cancellation, cooperative diversity, and multiuser diversity [19].

2.1. Cooperative Game Theory

To reduce the whole WSN's energy consumption and prolong its lifetime, some nodes will cooperate and form a coalition. Coalitional Game Theory is one of the most important cooperative game theory, thus, cooperative game theory is sometimes denoted as coalitional game theory [6]. For a WSN obeying the CGT, cooperating groups are formed and players choose strategies to maximize their own groups' utility. CGT allows a reduction of power consumption in WSN by forming coalitions.

The real-life networking scenario that we illustrate is a situation, which involves multiple access networks cooperating to support a particular anticipated service demand for a certain period (e.g., supporting a multiparty multimedia service), and which none of the participating networks is prepared to handle on its own [22]. For example, in the case that increased service demand exists, which none of the access networks is capable or willing to support on its own, this requires the participating access networks to cooperate in order to form appropriate coalitions that can serve the particular demand. In this case, an appropriate coalition formation game theoretic framework is developed to direct the selection and formation of the most appropriate coalition [6].

Coalitional games deal with the situation in which interactions occur between groups of players (coalitions), and thus actions are assigned to coalitions even though individual entities may consider their own preferences, especially when selecting a particular coalition in which to participate. Therefore, a coalitional model is characterized by its focus on what groups of players can achieve rather than on what individual players can achieve [20]. In order to determine the solution to a coalitional game, we must first define the way payoffs are assigned to the various coalitions; such assignment can occur per group as a whole, or per group using a particular division arrangement within the group for its members. When payoffs are assigned per group, the players that participate in the same group are associated with the group's payoff and it is not defined how this payoff may be further partitioned among its members. This case of payoff assignment is referred to as transferrable payoff coalitional game. The alternative is known as non-transferrable payoff coalitional game, and in such model there exists a rule on how group payoffs are divided among participating players [6,20].

A cooperative n-person game in coalitional form is an ordered pair $< N, v >$, where $N = \{1, 2, \dots, n\}$ (the set of players) and $v : 2^N \rightarrow \mathcal{R}$ is a map, assigning to each coalition $S \in 2^N$ a real number, such that $v(\emptyset) = 0$. This function v is called the characteristic function of the game, $v(S)$ is called the worth (or value) of coalition S. Often we identify a game $< N, v >$ with its characteristic function.

In this paper, we have proposed a cooperative game to improve the energy efficient WSN System of Inter Satellite Communication and give a scenario on Space Debris.

2.2. The Shapley Value

Each player in coalition must receive a fraction of the coalition value, that we call the payoff of player in coalition. Our game is conceived in such a way to form coalitions in which players get payoffs as maximum/minimum as possible, without violating the fairness requirement, so that stability is achieved. For this reason, a payoff allocation rule must be specified in order to compute the payoffs of each coalition member in such a way to ensure fairness in the division of payoffs.

To this end, we studied the cooperative game theoretic properties for the proposed game model and compared the cost/savings allocations obtained with the optimal solution and one well-known game theoretic cost allocation, namely the Shapley value.

The Shapley value is a payoff allocation rule based on the concept of marginal contribution of players in CGT. The marginal contributions show the change in the worth of a coalition when a player joins to that coalition. The larger is the contribution provided by a player to a coalition, the higher is the payoff allocated to it. This means, in a given coalition, some more-contributing players will be rewarded by other less-contributing players to encourage them to join the coalition. More specifically,

Let $\pi(N)$ be the set of all permutations $\sigma : N \rightarrow N$. The set $P^\sigma(i) = \{r \in N | \sigma^{-1}(r) < \sigma^{-1}(i)\}$ consists of all predecessors of i with respect to the permutation σ.

Let $v \in G^N$ and $\sigma \in \pi(N)$. The marginal vector $m^\sigma(v) \epsilon \mathcal{R}^n$ with respect to σ and v has as ith coordinate $m_i^\sigma(v) = v(P^\sigma(i) \cup \{i\}) - v(P^\sigma(i))$ for each $i \in N$.

The Shapley value [28] is one of the most interesting one-point solution concepts in classical cooperative game theory. The Shapley value associates to each n-person game one (payoff) vector in $\mathcal{R}^n$.

The Shapley value $\Phi(v)$ of a game $v \in G^N$ is the average of the marginal vectors of the game, i.e.

$$\Phi(v) = \frac{1}{n!} \sum_{\sigma \epsilon \pi(N)} m^\sigma(v)$$

2.3. The Allocation Rule PROP

An allocation informs the players, before starting cooperation within the grand coalition, about the individual payoffs obtainable via cooperation. We notice that the players' agreement on a particular allocation $(J_1, \dots, J_n)$ based on a solution concept merely says that the payoff x_i that player i will receive when the outcome of the grand coalition is known belongs to the J_i. This is a very weak contract to settle cooperation. An important issue the players have still to agree upon in order to settle cooperation within the grand coalition is how to transform an allocation, obtained by a chosen solution, into a (real-valued) payoff vector. In this paper we apply one stage procedure which transforms an allocation into a payoff vector when the value of the grand coalition becomes known. The one-stage procedure (in the case when the value of the grand coalition becomes known at once) uses as input data an allocation $(J_1, \dots, J_n)$, the realized value of the grand coalition, R, and function(s) specifying the division rule(s) for distributing the amount R over the players [8].

Recall that a bankruptcy situation with set of claimants N is a pair (E, d), where $E \geq 0$ is the estate to be divided and $d \in \mathbb{R}_+^N$ is the vector of claims such that $\sum_{i \in N} d_i \geq E$.

A bankruptcy rule is a function assigning to each bankruptcy situation (E, d) a payoff vector $f(E, d) \in \mathbb{R}^N$ such that $0 \leq f(E, d) \leq d$ (reasonability) and $\sum_{i \in N} f_i(E, d) = E$ (efficiency). In this paper we use a bankruptcy rule namely and it is the proportional rule (PROP).

The rule PROP is defined by $PROP_i(E, d) = {d_i}/{\sum_{i \in N} d_i}\, E$ for each bankruptcy problem (E, d) and all $i \in N$.

As expected, the cooperative game theoretic solutions offer a more fair distribution of the cost/savings among the cooperating players with all WSNs having some benefits from the cooperative approach. Moreover, the proposed solution guarantees the allocations to be stable as well in the sense that all players have a personnel advantage and are interested in being part of the coalition. Since these features are not guaranteed with the optimal cost allocation, we believe the proposed model will help in driving the application of WSNs of inter satellite communication cooperation in real scenarios.

III. AN APPLICATION: THE COOPERATIVE GAME MODEL ON SPACE DEBRIS

Satellite communication plays a vital role in the area of telecommunication. The satellite system becomes more vulnerable to failure due to various factors, such as space debris. Space debris are by definition non-functional, man-made objects in space, including large objects of several meters in size like defunct satellites and spent upper stages, but also including all sort of centimeter and millimeter-sized debris created by explosions and collisions, and even very small particles like paint flakes, and solid rocket motor slag or dust [18,29]. These objects are populating the same regions in near-Earth space, which are used for operating satellites. Space debris are thus mostly found in geocentric orbits with altitudes ranging from 300 to 40,000 km [24]. There are many sources of space debris, including satellites that are no longer functional; mission related objects, such as tools lost by astronauts during extravehicular activities; and fragmentation events, which can be either accidental or intentional [5]. Fragmentation debris is the largest source of space debris. Three countries in particular are responsible for roughly 95 percent of the fragmentation debris currently in Earth’s orbit: China (42 percent), the United States (27.5 percent), and Russia (25.5 percent) [23]. Although this distribution of responsibility suggests that these countries should contribute more to cleaning up the near-Earth space environment than others, the fact that many nations will benefit from remediation results in a classic free rider problem that complicates the situation. Similar to the political challenges associated with an effective multilateral response to climate change, this uneven distribution of historic responsibility threatens to prevent or stall much-needed action [5,29].

Heiner Klinkrad, head of ESA’s space debris office, said the conference delegates, representing 26 nations with substantial Russian and Chinese presence — because of U.S. budget issues NASA was not there, but NASA data was front and center — said there is an “urgent need to undertake active debris removal.” See more at [1,12,13].

Unless nations reduce the amount of orbital debris they produce, future space activities could suffer loss of capability, destruction of spacecraft, and perhaps even loss of life as a result of collisions between spacecraft and debris [16,31].

This study is aimed to investigate optimal active space debris removal strategies of players in the space sector and we hope that our model will provide an understanding of how some parties want to get involved in clearing pace debris to reduce the costs.

Over the years, researchers have come up with several hypothetical methods to clear space debris. Proposals have included everything from snagging it with robotic arms and harpoons, using the power of electricity to slow down its movement, and deploying the drag of a solar sail to push orbiting space debris into lower orbits. There are several fundamental realities about removing space debris and some debris removal approaches can be seen from [14,16,25]. Additionally, some projects on space debris cleaning also are available and can be examined from [1,7,10,12,13]

Since governments of space-faring nations would benefit by allowing a private-sector company to remove debris, it is likely that grants, low-interest loans or guarantees might be made available to assist in capitalizing the venture. Such assistance might be viewed as risky, but this approach avoids the otherwise inevitable taxing of every satellite launched to pay for debris clean up [10,14,21,31].

3.1. The Model

We consider 3 countries that aim space debris removal as the USA, Russia, China (Fig. 1). They use energy aware routing in their own WSNs and the space satellite rates are 35%, 25%, 42%, respectively.

The Inter-Agency Space Debris Coordination Committee (IADC) is an international governmental forum for the worldwide coordination of activities related to the issues of man-made and natural debris in space. The primary purposes of the IADC are to exchange information on space debris research activities between member space agencies, to facilitate opportunities for cooperation in space debris research, to review the progress of ongoing cooperative activities, and to identify debris mitigation options.

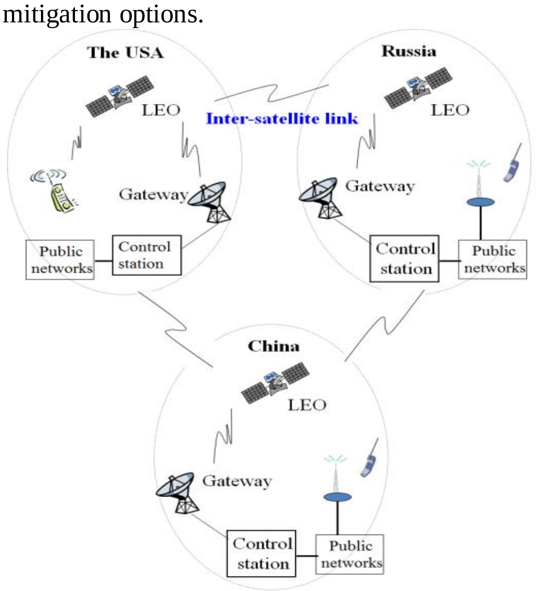

Fig.1. The Model

Countries are demanding payment for space debris from IADS. The USA is demanding $ 8 million; Russia and China are demanding $ 6 million. Whereas, the IADC's annual budget for the space debris removal operation is just $ 15 million.

When we examine the energy efficiencies of routing algorithms used in WSNs, we see that the countries as the USA, Russia, China reached %50, %70, %40 energy efficiency, respectively (Table 1).

Table1: The Values of Scenarios

Countries	Space Satellite Rates (%)	Demand for Space Debris ($ m)	Energy Efficient (%)
The USA	35	8	50
Russia	25	6	70
China	42	6	40

3.2. The Bankruptcy Situations

In a classical bankruptcy, a certain amount of money E has to be divided among some people, $N = \{1, 2, \ldots, n\}$, who have individual claims $d_i, i \in N$ on the state, and the total claim is larger than the state.

For each coalition, the corresponding bankruptcy game is defined as follows:

$$v_{E,d}(S) = \max\{E - \sum_{i \in N \setminus S} d_i\}$$

a) **Scenario 1**

Our first situation is based on space satellite rates as $(E, d) = (100; 35, 25, 42)$. The coalitional payoffs are given in Table 2 and calculated by using (1).

The RUN rule (Run To the Bank) for bankruptcy situations coincides with the Shapley value and can thus be expressed as

$$RUB\,(N, E, d) = \frac{1}{n!} \sum_{\sigma \epsilon \pi(N)} m^{\sigma}(v_{E,d})$$

The coalitional payoffs of the bankruptcy game in space satellite rates are given in Table 3. Table 4 reports the Shapley values as well as the detail on each country's marginal contributions (columns).

Table 2: Coalitional Payoffs of Scenario 1

(S)	{∅}	{(1)}	{(2)}	{(3)}	{(1,2)}	{(1,3)}	{(2,3)}	{(1,2,3)}
$v_{E,d}(S)$	0	33	23	40	58	75	65	100

Table 3: Run Rule Computation

π(N)	1	2	3
123	33	25	42
132	33	25	42
213	35	23	42
231	35	23	42
312	0	60	40
321	35	25	40
RUB	28.	30.1	41.3
	5	7	3

Table 4: Shapley Value Computation

π(N)	1	2	3
123	33	25	42
132	33	25	42
213	35	23	42
231	35	23	42
312	0	60	40
321	35	25	40
Φ	28.	30.1	41.3
	5	7	3

b) **Scenario 2**

Our second situation is based on space satellite rates as $(E, d) = (15; 8, 6, 6)$. The coalitional payoffs are given in Table 5.

Table 5: Coalitional Payoffs of Scenario 2

(S)	{∅}	{(1)}	{(2)}	{(3)}	{(1,2)}	{(1,3)}	{(2,3)}	{(1,2,3)}
$v_{E,d}(S)$	0	3	1	1	9	9	7	15

The RUN rule and the Shapley value are the same as follows:

$RUB(N, E, d) = \Phi(v) = (6.34, 4.33, 4.33)$.

c) **Scenario 3**

Our last situation is based on space satellite rates as $(E, d) = (100; 50, 70, 40)$. The coalitional payoffs are given in Table 6.

Table 6: Coalitional Payoffs of Scenario 3

(S)	$\{\emptyset\}$	$\{(1)\}$	$\{(2)\}$	$\{(3)\}$	$\{(1,2)\}$	$\{(1,3)\}$	$\{(2,3)\}$	$\{(1,2,3)\}$
$v_{E,d}(S)$	0	0	10	0	60	30	50	100

The RUN rule and the Shapley value are the same as follows:

$RUN(N, E, d) = \Phi(v) = (30, 45, 25)$.

3.3. The PROP Rule Solutions

In this section, we propose a one point solution by using our solutions.

We assume that the realization of $v(N)$ are $R_1 = 80, R_2 = 10, R_3 = 75$ in scenarios, respectively and consider that cooperation within the grand coalition is settled based on the use of the Shapley value and the RUN rule (Table 7).

The claims of each country on the realization R_1, R_2, R_3 in scenarios are the payoffs of each country of the Shapley value and the RUN rule.

Table 7: The Prop Rule Solutions Of The Shapley Value And The Run Rule

	Scenario 1	*Scenario 2*	*Scenario 3*
	$R_1 = 80$	$R_2 = 10$	$R_3 = 75$
Φ	(22.8,22.14,33.06)	(4.22,2.89,2.89)	(22.5,33.75,18.75)
RUN	(22.47,19.47,33.06)	(4.28,2.86,2.86)	(22.5,33.75,18.75)

CONCLUSION AND OUTLOOK

In this paper, we study on the energy efficient routing in WSNs, and propose a cooperative game theoretical approach to space debris removal. We give some solutions of cooperative game theory. Cooperation between countries has been considered as an effective way to reduce space debris. We give three scenarios on space satellite rates, space debris demands and used energy efficient techniques.

In order to make such a solution more attractive in real implementation scenarios where profit-driven countries acs as players. Using this approach of this study, countries or special firms can meet the payoff allocation rules in order to reduce/increase their own payoffs. Moreover, the proposed solution guarantees the allocations to be stable as well in the sense that all players have a personal advantage and are interested in being part of the coalition.

In future, after the required modification, hardware and software optimization in the sensor nodes with the approach of cooperative game theory, WSN of inter satellite system would be economical and effective in space debris removal systems for space environment.

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