УДК 004.414.22/004.051/519.687.5

V. M. VARTANJAN, V. V. TURKINA

National Aerospace University "Kharkov Aviation Institute", Kharkov, Ukraine

GAME THEORETICAL APPROACH TO COOPERATION IN AUTONOMOUS WIRELESS NETWORKS

The principles of construction of wireless Ad-hoc networks are discussed. It is shown that improved quality of service in the mobile Ad-hoc net-works achieved by integration of heterogeneous wireless access technologies. The analysis of publications, using game-theoretic approach to the problems of constructing networks Ad-hoc, is performed. The problem of formation of cooperative games is based on the principles of coalition theory of interaction of mobile subscribers in the Ad-hoc networks. It is proposed to use the Shapley value as a method of distribution of the winning.

Keywords*: wireless networks, the Shapley value. quality of service, cooperative game, the mobile subscriber, network resources.*

Introduction

Mobile broadband traffic has surpassed voice and is continuing to grow rapidly. This trend is set to continue, with global traffic figures expected to double annually over the next five years [1]. This traffic growth, driven by new services and terminal capabilities, is accompanied by user expectations for data rates similar to those of fixed broadband.

Improving capacity and coverage is one of the main issues in next-generation wireless communication. Heterogeneous networks (HetNets), which is currently investigated in LTE-Advanced standard, now is a promising solution to enhance capacity and eliminate coverage holes in a cost-efficient manner. A HetNet consists of two levels of base stations (BS): Macro-Cellular BSs (MCBSs) and underlying Small-Cell BSs (SCBSs); these can use the same technology (e.g. LTE) or different technologies (LTE and WiFi). It is well known that a HetNet not only increases the network capacity, but also provides better coverage and enhances the user's experience. These benefits are achieved by offloading data traffic dynamically from MCBSs to SCBSs using an algorithm based on several parameters such as the characteristics of the traffic, the required quality of service (QoS) and network congestion.

By deploying small cells into the existing network, operators enhance the users' quality of service which is suffering from severe signal degradation at cell edges or coverage holes. Nevertheless, there are numerous challenges in integrating small cells into the existing cellular network due to the characteristics: unplanned deployment, intercell interference, economic potential, etc.

With the development of intelligent wireless devices such as cognitive radios, the network users' capability has been largely increased. It becomes important to analyze and understand the network users' intelligent behaviors, especially selfish behaviors. Recently, game theory has been shown to be a powerful tool for investigating the challenges in HetNets. Cooperation has been indentified as an effective technique to enhance the performance of HetNets networks [2].

1. Related work

Beginning from the work [3], devoted undivided traffic, routing games are not only the most advanced, but also a very progressive net games direction today.

There are many publications, where problem of network selection, which arises when wireless mobile users can choose among multiple available wireless access networks to connect, is study. In particular, authors [4] investigate the dynamics of the competition among different selfish mobile users which operate the network selection with the goal of minimizing their own selection cost. This problem is formalized as a non-cooperative game, and the corresponding Nash equilibrium is studied under three expressions for the users' selection cost.

As non-cooperative game the authors of paper [5] investigate the situation, when an uplink cellular network shared by a finite number of mobile users with limited batteries. Whenever the battery drains out, the user pays a fixed price to recharge the battery. The novelty of this model is in considering the dynamic game in which the transmission power of a player may depend on the amount of energy left in its battery with various types of constraints and derive for each one the structure of the equilibrium.

Hierarchy in the classical non-cooperative game,

© V. M. Vartanjan, V. V. Turkina

where the users choose their best power control strategy in order to selfishly maximize their energy-efficiency, is introduced in two ways [6]:

– in Stackelberg formulation of the game where one user is the leader;

– assuming neither leader nor followers among the users, hierarchy is introduced by using successive interference cancelation at the receiver.

The authors of the paper [7] propose dynamic channel allocation strategy based on game theory along with the concept of primary–secondary users. A hybrid access policy is to be adopted along with self-organizing power control scheme. For proposed scheme there is no need of using different access policy for different purposes. By adopting the proposed scheme, system throughput, capacity as well as revenue of operators can be increased considering optimal price for consumers.

Most of the current research in the coalitional game theory for communication networks is restricted to applying standard coalitional game models and techniques to study very limited aspects of cooperation in networks [8].

A special case of the game on the wireless network, consisting only of the transceiver pairs, reviewed in paper [9], where game model is constructed on the basis of the network model with utility functions which are selected so that the game transforms to the potential. In the paper [10] the task of choosing by the mobile user access point wireless network from several available was solved based on non-cooperative game with Nash equilibrium and selfish behavior of players, the analysis of the "price of anarchy" and the sustainability of such a game are given also. The task of forming the topology of the wireless Ad-hoc network in which the nodes are arranged in a plane, is considered in the article [11] as a non-cooperative game. Main goal of this game is minimizing the total power consumption with providing network connectivity by means of assign required power to transmitters. Two algorithms form a network, using the method of double best responses suggested to solve the problem.

The problem of data transferring in a simple wireless network is considered in article [12]. This process is modeled using stochastic (Markov) game. This paper proposes a system of penalties and rewards to network users to control data transfer. Unfortunately, the cooperative solution, resulting in the work, is applicable only for the reduced structure of the network. When the network structure is changed, the matrix of transition probabilities and the vector of the players wins must be redefined. There is also a computational difficulties in finding the inverse matrix in the equations defining the expectations of the players revenues.

In the monograph [13] several game-theoretic approaches have been proposed to modeling the distributed deployment and self-organization feature of HetNets. The authors first give an overview of the challenges in HetNets and illustrate how game theory can be applied to solve issues related to HetNets:

– game theory based uplink power control and downlink power allocation strategies for the interference mitigation are investigated;

– two kinds of game models, namely the non-cooperative Stackelberg and the cooperative coalition, are introduced to optimize the radio resource allocation;

– comparison of the centralized and distributed coverage optimization methods based on game theory are performed;

– a heterogeneous network consisting of macrocell networks overlaid with cognitive small cells that opportunistically access the available spectrum is considered ets.

For achievement seamless handover capability, Quality of Service (QoS), self-organizing features in autonomous wireless networks the game theoretical approach to cooperation in the modern theory is considered in the following areas:

– non-cooperative and cooperative games;

– one step and repeated games;

– static and dynamic games;

– auction games.

The developing of the mechanism of the mobile users interaction in the wireless self-organizing Ad-hoc networks, based on the theory of cooperative games, is the purpose of this article.

2. Mobile users interaction in Ad-hoc networks as cooperative game

We consider autonomous Ad-hoc networks where nodes belong to different authorities and have different goals. Assume all nodes are selfish and rational, that is, their objectives are to maximize their own payoff, not to cause damage to other nodes. Each node may act as a service provider: packets are scheduled to be generated and delivered to certain destinations; or act as a relay: forward packets for other nodes. The sender will get some payoffs if the packets are successfully delivered to the destination and the forwarding effort of relay nodes will also introduce certain costs.

Figure 1 illustrates system model by showing a network snapshot of one-hop packet forwarding between two users. In this figure, there are two source-destination pairs (S_1-D_1) and (S_2-D_2). S_1 and S_2 need to help each other to forward packets to the destination nodes.

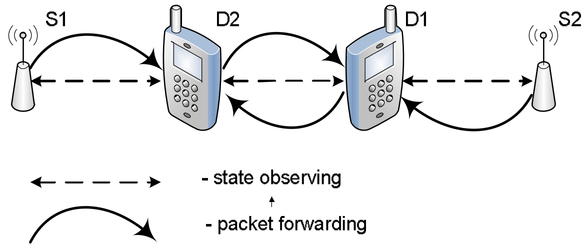

Fig. 1. Packet forwarding in autonomous Ad-hoc networks

The solving task is formulated as follows: if there are profitable for all subscribers of the radio resource sharing scheme, where each subscriber gain access to the new channel exceeds the costs necessary for the organization of interaction between users?

The solving task belongs to the class of cooperative games, which are considered in cases where the players (the mobile subscribers in the problem) are to increase the winnings of each player to combine their efforts to agree among themselves on joint actions and thus form a single coalition.

In cooperative games, the users are able to make enforceable outcomes through centralized authorities. Thus, for cooperative games, the interests lie in that how good the game outcome can be or how to define and choose the optimality criteria in cooperative scenarios. Cooperative game theory may not directly help us solve the cooperation issue in autonomous wireless networks, but it is useful to measure the efficiency of the solution that we obtain from non-cooperative game study on autonomous wireless networks.

Let N - the set of all players, N = {1, 2, ..., n}, and the coalition S - any subset. Each player can participate in any of the possible coalitions. The set S of players, which belong to a coalition, acts as a single player against the other players (coalitions), and the prize of this coalition depends on the strategies used by each of the n-players. Obviously, the total number of coalition consisting of exactly r count equal to the number of combinations of n on r:

$$C_n^r = \frac{n!}{r!\cdot(n-r)!}, \tag{1}$$

and the total number of possible coalitions, including single-player coalitions, is equal:

$$\sum_{r=1}^{n} C_n^r = 2^n - 1. \tag{2}$$

Therefore, for the analysis of interaction of mobile subscribers in a wireless Ad-hoc networks possible number of the coalitions exponentially increases with the number of players in this game. In the analysis of cooperative play is necessary to take into account all the possible coalitions, so complexity increases exponentially with n.

The characteristic function of the game is a function $\upsilon(S)$, that assigns to each coalition S greatest confidently produced her winnings. The characteristic function is called simple, if it takes only two values: 0 and 1. If the characteristic function is simple, the S coalition, which = 1, called the winner, and the S coalition, for which = 0 – the loser.

If a simple characteristic feature wins are those and only those of the coalition, which contain a fixed non-empty coalition of R, then the characteristic function $\upsilon_R(S)$ is called elementary.

The principle of optimal allocation of the winning coalition between the parties is based on Shapley value [14]. According to this principle, if the gain of each player is equal to its average contribution to the total well-being of the coalition with a certain mechanism of its formation.

Let K_i – is subset from player set N containing i first players in some ordering. The contribution of the i-th on the player's account is the value $\upsilon(K_i) - \upsilon(K_{i-1})$.

Shapley value of cooperative games is called a payoff distribution in which each player receives the expectation of their contribution to the relevant coalition of the K_i, with equally probable occurrence of ordering:

$$\Phi(\upsilon) = \frac{1}{n!}\sum_{\tau \in T} x_\tau, \tag{3}$$

where n - the number of players,

T - set of orderings of N players,

x_τ - winning distribution, in which the player standing on the place i in the ordering, receives your contribution to the coalition K_i.

The formula can be interpreted as follows: imagine the coalition being formed one actor at a time, with each actor demanding their contribution $\upsilon(K_i) - \upsilon(K_{i-1})$ as a fair compensation, and then for each actor take the average of this contribution over the possible different permutations in which the coalition can be formed.

Example. Assume that:

– at the initial time two mobile unit in the Ad-hoc network have a quality of service equal to (0,3; 0,5).

– after the unification of these devices into a coalition of service quality indicators are equal desired.

Then the answer to the question of a fair proportion of resources spent on the devices that the coalition is determined by taking into account the Shapley value (fig. 2).

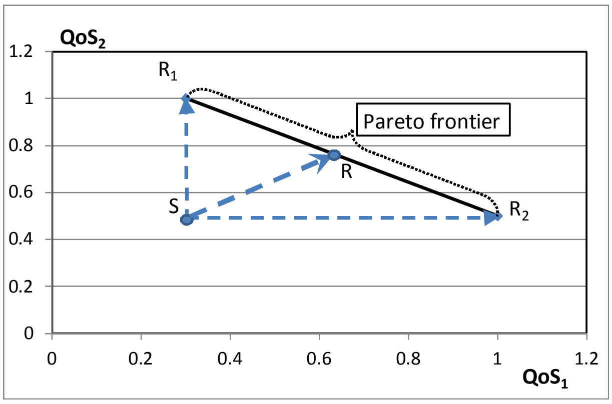

Fig. 2. Shapley value of cooperative games with 2 network players

The kernel of a cooperative game (A,v) with respect to a given coalition structure is the set of so-called K-stable configurations (S,u) in which all coalitions in S are in equilibrium. Coalition C is in such an equilibrium if each pair of agents in C is in equilibrium, i.e., any pair of agents in C is balanced, that is, none of both agents can outweigh the other in (S,u) by having the option to get a better payoff in coalition(s) not in S excluding the opponent agent. Obviously, the kernel of a game is exponentially hard to compute unless, for example, the size of the coalition is limited by a constant. The kernel appears to be attractive due to the following features: The kernel K is unique for any 3-agent game (A,v), assigns symmetric agents of some coalition in a given coalition structure for (A,v) equal payoff, and is locally Pareto-optimal in K.

Conclusion

With the development of intelligent wireless devices such as cognitive radios, the network users' capability has been largely increased. Cooperation has been identified as an effective technique to enhance the performance of HetNets networks. Efficient resource allocation is one of the key concerns of implementing cognitive radio networks. Game theory has been extensively used to study the strategic interactions between users for effective resource allocation. In this article we discussed how cooperative games theory may be applied to form mobile units coalition for share their resources and to reduce their spending resources. The use of game theoretical approach to cooperation in autonomous wireless networks has played a vital role for improving the energy efficiency of mobile users.

References (GOST 7.1:2006)

1. Heterogeneous networks – increasing cellular capacity [Electronic resource] / S. Landström, A. FuruskÃr, K. Johanss et al // Ericssonreview 1. – 2011. – Access mode: http://www.ericsson.com/res/thecompany/docs/publications/ericsson_review/2011/heterogeneous_networks.pdf. -15.01.15.

2. Radwan, A. Energy Efficient Smart Phones for 5G Networks [Text] / A. Radwan, J. Rodriguez. - 2014. – 267 p.

3. Papadimitriou, D. Worst-Case Equilibria [Text] / D. Papadimitriou, E. Koutsoupias // Proceedings of the 16th Annual Symposium on Theoretical Aspects of Computer Science, Trier, Germany, 1999. Lecture Notes in Computer Sciences, Springer, Berlin. – P. 404-413.

4. Cesana, M. Game theoretic analysis of wireless access network selection: models, inefficiency bounds, and algorithms [Text] / M. Cesana, N. Gatti, I. Malanchini // Proceedings of the 3rd International Conference on Performance Evaluation Methodologies and Tools (ValueTools '08). ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering), ICST, Brussels, Belgium, Article 6. – 10 p. DOI: 10.4108/ICST.VALUETOOLS2008.4341.

5. Menache, I. Battery-state dependent power control as a dynamic game [Text] / I. Menache, E. Altman // Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks and Workshops, 2008. WiOPT 2008. 6th International Symposium. 1-3 April 2008, pp.242-250.

6. Lasaulce, S. Introducing hierarchy in energy games [Text] / S. Lasaulce, Y. Hayel, R. El Azouzi, M. Debbah // Wireless Communications, IEEE Transactions on July 2009. – vol. 8, no. 7. – P. 3833-3843.

7. Alshamrani, A. She,X. Xie,L-L. QoS Provisioning for Heterogeneous Services in Cooperative Cognitive Radio Networks [Text] / A. Alshamrani, X. She, L-L. Xie // Selected Areas in Communications, IEEE Journal. – 2011. – Vol. 29, № 4. – P. 819-830.

8. Walid, S. Coalitional game theory for communication networks [Text] / S. Walid, H. Zhu, D. Merouane, H. Are, B. Tamer // IEEE Signal Processing Magazine. – 2009. – P. 77–97.

9. Ошмарин, Д. В. Распределение канальных ресурсов в сетях когнитивного радио на основе теории игр [Текст] / Д. В. Ошмарин // Бизнес-информатика. – 2010. – №4. – С. 38–45.

10. Cesana, M. Game Theoretic Analysis of Wireless Access Network Selection: Models, Inefficiency Bounds, and Algorithms [Text] / Matteo Cesana, Nicola Gatti, Ilaria Malanchini // Proceedings *of the 3rd International Conference on Performance Evaluation Methodologies and Tools, October 20-24 2008, Athens, Greece. ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering). – October 2008. – 6 p.*

11. Bazenkov, N. I. Double best response dynamics in topology formation game for ad hoc networks [Text] / N. I.Bazenkov // Large Scale Systems Control. Automation and Remote Control. – 2015. – Vol. 76, Issue 2. – P. 323-335.

12. Парилина, Е. М. Кооперативная игра передачи данных в беспроводной сети [Текст] / Е. М. Парилина // Математическая теория игр и её приложения.– 2009. – Т. 1, № 4.- С. 93-110.

13. Chungang, Y. Game Theory Framework Applied to Wireless Communication Networks [Text] / Y. Chungang, L. Jiandong. – China : Xidian University, 2016. – 502 p.

14. Efficient Computation of the Shapley Value for Game-Theoretic Network Centrality [Text] / T. P. Michalak, K. V. Aadithya, P. L. Szczepański et al. // Journal of Artificial Intelligence Research. – 2013. – № 46. – P. 607–650.

References (BSI)

1. Landström, S., FuruskÃr, K., Johanss, A., Falconetti, L., Kronestedt, F. Heterogeneous networks – increasing cellular capacity. *Ericssonreview*, no. 1, 2011. Available at: http://www.ericsson.com/res/thecompany/docs/publications/ericsson_review/2011/heterogeneous_networks.pdf. (accessed 15 Jan 2016)

2. Radwan, A., Rodriguez, J. *Energy Efficient Smart Phones for 5G Networks*, 2014. 267 p.

3. Koutsoupias, E., Papadimitriou, D. Worst-Case Equilibria. *Proc. of the 16th Annual Symposium on Theoretical Aspects of Computer Science*, Trier, Germany, Lecture Notes in Computer Sciences, Springer, Berlin. 1999, pp 404-413.

4. Cesana, M. Gatti, N. Malanchini, I. (2008) Game theoretic analysis of wireless access network selection: models, inefficiency bounds, and algorithms. *Proc. of the 3rd International Conference on Performance Evaluation Methodologies and Tools (ValueTools '08).* ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering), ICST, Brussels, Belgium, Article 6. 10 p. doi: 10.4108/ICST.VALUETOOLS2008.4341.

5. Menache, I. Altman, E. Battery-state dependent power control as a dynamic game. *Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks and Workshops*, 2008. WiOPT 2008. 6th International Symposium, 1-3 April 2008, pp. 242-250. doi: 10.1109/WIOPT.2008.4586072.

6. Lasaulce, S., Hayel, Y., Azouzi, R. El, Debbah, M. Introducing hierarchy in energy games. *Wireless Communications*, IEEE Transactions, 2009, vol. 8, no.7, pp. 3833-3843.

7. Alshamrani, A. She, X. Xie, L-L. QoS Provisioning for Heterogeneous Services in Cooperative Cognitive Radio Networks. *IEEE Journal in Selected Areas in Communications,* April 2011, vol. 29, no. 4, pp. 819-830.

8. Walid, S., Zhu, H., Merouane, D., Are, H., Tamer, B. Coalitional game theory for communication networks. *IEEE Signal Processing Magazine*. 2009, pp. 77–97.

9. Oshmarin, D. V. Raspredelenie kanal'nykh resursov v setyakh kognitivnogo radio na osnove teorii igr [Distribution channel resources to cognitive radio networks based on game theory] *Biznes-informatika,* 2010, no. 4 (14), pp. 38-45.

10. Cesana, M., Gatti, N., Malanchini, I. Game Theoretic Analysis of Wireless Access Network Selection: Models, Inefficiency Bounds, and Algorithms *Proc. of the 3rd International Conference on Performance Evaluation Methodologies and Tools,* October 20-24 2008, Athens, Greece. ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering), 2008. 6 p.

11. Bazenkov, N. I. Double best response dynamics in topology formation game for ad hoc networks. *Large Scale Systems Control. Automation and Remote Control*, 2015, vol. 76, Issue 2, pp 323-335.

12. Parilina, E. M. Kooperativnaya igra peredachi dannykh v besprovodnoi seti [Cooperative transmission game in wireless network]. *Managing large systems. Special Edition 31.1 "Mathematical game theory and its applications,* 2009, t. 1, vol. 4, pp. 93-110.

13. Chungang, Y., Jiandong, L. *Game Theory Framework Applied to Wireless Communication Networks*, China, Xidian University, 2016. 502 p.

14. Michalak, T. P., Aadithya, K. V., Szczepański, P. L., Ravindran, B., Jennings, N. Efficient Computation of the Shapley Value for Game-Theoretic Network Centrality. *Journal of Artificial Intelligence Research*, 2013, no. 46, pp. 607–650.

Поступила в редакцию 3.02.2016, рассмотрена на редколлегии 14.04.2016

ТЕОРЕТИКО-ІГРОВИЙ ПІДХІД ДО КООПЕРАЦІЇ В АВТОНОМНИХ БЕЗДРОТОВИХ МЕРЕЖАХ

В. М. Вартанян, В. В. Туркіна

Розглядаються принципи побудови бездротових Ad-hoc мереж. Показано, що поліпшення якості обслуговування в мобільних Ad-hoc мережах досягається шляхом інтеграції різнорідних бездротових технологій доступу. Виконано аналіз публікацій щодо використання теоретико-ігрового підходу до проблем побудови Ad-hoc мереж. Проблема формування кооперативних ігор ґрунтується на принципах теорії коаліційної взаємодії абонентів мобільного зв'язку в тимчасових мережах. Пропонується використовувати вектор Шеплі як спосіб розподілення виграшу.

Ключові слова: бездротові мережі,вектор Шеплі, якість обслуговування, кооперативна гра, мобільний абонент, ресурси мережі.

ТЕОРЕТИКО-ИГРОВОЙ ПОДХОД К КООПЕРАЦИИ В АВТОНОМНЫХ БЕСПРОВОДНЫХ СЕТЯХ

В. М. Вартанян, В. В. Туркина

Рассматриваются принципы построения беспроводных Ad-hoc сетей. Показано, что улучшение качества обслуживания в мобильных Ad-hoc сетях достигается путем интеграции разнородных беспроводных технологий доступа. Выполнен анализ публикаций об использовании теоретико-игрового подхода к проблемам построения Ad-hoc сетей. Проблема формирования кооперативных игр основывается на принципах теории коалиционного взаимодействия абонентов мобильной связи в одноранговых сетях. Предлагается использовать вектор Шепли в качестве способа распределения выигрыша.

Ключевые слова: беспроводные сети, вектор Шепли, качество обслуживания, кооперативная игра, сетевые ресурсы, абонент мобильной связи.

Вартанян Василий Михайлович – д-р техн. наук, проф., зав. каф. маркетинга, Национальный аэрокосмический университет им. Н. Е. Жуковского «Харьковский авиационный институт», Харьков, Украина, e-mail: vartanyan_vm@ukr.net.

Туркина Виктория Валентиновна – аспирант каф. маркетинга, Национальный аэрокосмический университет им. Н. Е. Жуковского «Харьковский авиационный институт», Харьков, Украина, e-mail: viki1361@mail.ru.

Vartanian Vasily Mikhailovich - Dr. Sc. in Engineering, Prof., Head of Dep. of Marketing, National Aerospace University " Kharkiv Aviation Institute ", Kharkiv, Ukraine, e-mail: vartanyan_vm@ukr.net.

Turkina Victoria Valentinovna - PhD student of Dep. of Marketing, National Aerospace University "Kharkiv Aviation Institute", Kharkiv, Ukraine, e-mail: viki1361@mail.ru.