MULTIAGENT COORDINATION IN AD-HOC NETWORKS BASED ON COALITION FORMATION

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Abstract: This research investigates the problems of agent coordination when deployed in highly dynamic environments such as MANETs (Mobile Ad-hoc NETworks). Several difficulties arise in these infrastructures especially when the devices with limited resources are used. All the constraints of agents' development must thus be reexamined in order to deal with such situations, especially due to the opportunistic mobility of nodes. In this paper, we thus propose a new multiagent coordination mechanism through agent coalition formation for such an environment. In order to validate it, evaluation performance tests have been conducted on an application devoted for the assistance of hospital patients and their results are also presented in the paper.

1 INTRODUCTION

This paper addresses the problem of dynamic coalition formation in multiagent systems deployed on ad-hoc networks. Several intrinsic difficulties arise in using these original infrastructures, which require reexamining in depth agent coordination issues. Indeed ad-hoc networks (Akyildiz, 2009) or mobile ad-hoc networks (MANET), comprise a set of mobile, autonomous nodes, which are interconnected using wireless links. The adaptive behavior of MANETS allows a network quickly reorganize itself even under the most unfavorable conditions. The topology in MANETs is dynamic, and to coordinate, nodes need sophisticated protocols that can cope with topology changing problems.

On the other hand, the main purpose of using multiagent systems (MAS) is to collectively reach goals that are difficult to achieve by an individual agent or in other words to achieve coordination (Hsieh, 2009)(Jennings, 1994) amongst the agents. In systems composed of multiple autonomous agents, coordination is a key form of interaction that enables groups of agents to arrive at a mutual agreement regarding some beliefs, goals or plans. However due to resource constraints, agents are generally selfish and try to maximize their benefits. In this paper, we study agent coordination based on coalitions. An attractive question is the way in which these coalitions are formed in these specific infrastructures. Furthermore, one of the central problems is the study of the agents' payoffs whether the proposed solution is efficient.

For coordination between the agents in traditional wired networks such as *Ethernet*, *ADSL*, there already exist several mechanisms like contract net and its extensions (Hsieh, 2009), coalition formation (Tsvetova, 2001), etc. However, such protocols are not suitable to MANET since they do not handle the dynamics of this networks where nodes can move, join or live the network. In fact, some related research on this problem is done in (Wang, 2005)(Christine, 2004), but these works don't really address the problems of mobility of nodes i.e. nodes leaving and joining the environment. In this paper, we propose a new mechanism which handles the problem of nodes mobility and agent coalition formation.

The novelty in our work is the introduction of dynamic coalition formation mechanism for solving nodes' mobility problem in MANET. We show that this mechanism is time efficient and it provides better payoff for the nodes in much sophisticated and generalized way. The rest of the paper is structured as follows: Next section presents the review of the existing solutions. Section 3 describes our context with the help of an example. Section 4

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focuses on the proposed mechanism and section 5 and 6 delineate the implementation results, and a conclusion respectively.

2 RELATED WORK

One of the approaches used for object oriented coordination in ad-hoc networks is presented in (Cutsem, 2007). This work considers a loosely coupled object-oriented coordination abstraction, named as an *ambient reference (AR)*. *AR* initiates a service discovery request for a remote object exported as a music player and whenever a node leaves the environment, the *AR* is rebounded to point to another principal object in the network. A similar sort of solution is proposed in (Christine, 2004), where the concept of *Egospace* (which is a kind of middleware for addressing the specific needs of the agents) is explored. All the available data in the network is stored in a common data structure and whenever the agents move within their communication range their local data structure is merged to form a *global view*. Some other related solutions based on the common data structure for handling nodes' inaccessibility in an ad-hoc network are considered in (Cao, 2006) and (Sislak, 2005).

The above mentioned solutions fulfill few of their results by handling some aspects related to mobility, but still there exists a problem of agents' shallow knowledge which does not represent their preferences, intentions and allocation of resources. To address this issue, Advertising on Mobile phones ADOMO (which is a partially agents' coordination approach) is proposed in (Carabelea, 2005). ADOMO uses sending and receiving of agents' messages to address mobility issues. Another ad-hoc coordination approach has been proposed in (Wang, 2005), where the concept of agent based Peer-to-Peer (P2P) fostering is used for handling the problems like nodes dropping out and mobility.

Other then ad-hoc networks, work done by *Soh et al*, related to MAS learning via coalition formation is also worth mentioning here. In (Soh, 2006), they have proposed a computer-supported cooperative learning system in education and the results of its deployment. The system consists of a set of teacher, group, and student agents. Specifically, their appraoch uses a Vickrey auction-based and learning-enabled algorithm called *VALCAM* to form student groups in a structured cooperative learning setting. The approach has the traditional limitation of Vickrey auctions which does not allow agents for *price discovery*, that is, discovery of the market price if the agents are unsure of their own valuations, without sequential auctions.

Nevertheless, all the aforementioned coordination solutions do not behave well on environment with highly dynamics where agents need to have both the capabilities of coordination and device failure handling, these approaches fall short of giving a generalized solution.

3 PROBLEM DESCRIPTION

This section explains the mobility arising problem and presents an example to illustrate our approach. We are considering here the example of a hospital where software agents are deployed on several devices (figure. 1). In this figure, the chargers *(Cr_1, Cr_2... Cr_i)*, patients' wheelchairs *(W_1, W_2... W_j)*, laptops *(L_1, L_2 ... L_k)*, cardiac monitors *(M_1, M_2... M_l), etc.*, are mobile in a sense that the staff or the patients can move them from one place to another, according to their requirements of use or charging.

For the purpose of coordination and for exchanging energy (charge) between the devices, agents are deployed at each of them. Agents need coordination if they require more energy in their devices or if they need to remain connected with other agents in the MANET. Each agent a_i has its payoff function F_i, which is maximized by its charge consumption and the rewards it gets after performing its tasks. Deployed agents start coordination if they consider that there is not enough energy left to move further and to achieve their tasks or if they require multi-hop communications with other agents in their environment.

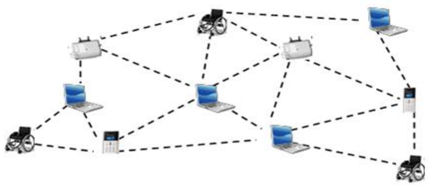

Figure 1: Agents' connections in ad-hoc infrastructure.

To give an example, let's consider a wheelchair, a cardiac monitors, and a charger which have agreed upon communication and charge sharing using some protocols, and suddenly a staff member comes and takes the charger away for giving charge to some other wheelchairs, at a different place. One node of this MANET can tell the other nodes by using some sort of routing protocols e.g. *ADODV* and *DSR* or by using agent communication approaches, that it is leaving the environment. However the problems of charge losing and communication breakage still remain there, since current approaches and protocols do not guarantee the resolution of such problems under these conditions.

4 METHOD OF RESOLUTION

As mentioned in previous sections, the main concern of our work are to handle the mobility of nodes in a MANET, so that the agents deployed on them can still communicate and coordinate effectively and their energy sharing continues without any breakage. In this section, we present our solutions to the mentioned problem mainly based on coalition formation.

4.1 Notations and Definitions

Before going further in the presentation of our mechanism, let's introduce some definitions. Let A be a set of agents. The payoff function F_i of each agent a_i measures the expected achiveable payoff of a_i for each proposal p_j. Every agent a_i knows its reference state r_i for which the expected payoff is minimal and tries to maximize F_i. We assume that each a_i of A is selfish and has a set of goals $G_i = \{g_1, g_2, ..., g_m\}$ which it aims to achieve. There is one agent per node and agents communicate through message passing. Every agent a_i of A holds in its *view*, $v(a_i)$, a list of agents it can contact, as well as the communication cost for contacting them. This cost varies depending on the type of communication used (either single or multi-hop communication). H is the function that measures the cost of these communication hops. However, as nodes can leave or join the system, the view of an agent changes dynamically. By periodically checking the aliveness of its neighbors, an agent can update its *view* and exclude those agents that do not belong to the system anymore. In this model:

*A **coalition** is a tuple* $C = <A_c, G_c>$ *where* $A_c = \{a_1, a_2 ... a_k\}$ *is a set of agents of A that agreed to perform a set of goals* G_c.

Every agent might simultaneously belong to several coalitions in order to reach its own goals. We consider then that:

*A **coalition structure**, CS, is a set of coalitions* $\{c_1, c_2 ... c_k\}$ *such that* $\cup A_c(c_i) \subset A$, *and* $\cup G_c(c_i) \subset G$ *where* $c_i \in CS$.

As the system is deployed on an ad-hoc infrastructure and the agents are selfish, a coalition formation process does not necessarily search to satisfy all goals of every agent in A. Mainly, each agent a_i approves the coalition structures that satisfy its own payoff function F_i. Hence:

*An **approved coalition structure** CS is considered by each agent* a_j *of CS to be either a complete solution, if all* a_j*'s goals in* G_j *are satisfied by CS, or a partial solution, if some of its goals are not considered by CS.*

An agent a_i that has approved some partial solutions $\aleph_k$ is totally satisfied if $\cup_k \aleph_k$ deals with all its constraints on its goals in G_i.

4.2 Coalition Formation Mechanism

Before defining our protocol, let's introduce other concepts:

Coalition agreement. An agent participating in a coalition formation process approves a coalition structure or a coalition (*i.e.* singleton coalition structure) either because this structure represents a partial solution or a complete solution for it.

An agreement on a coalition structure, CS, is reached if all the agents of the CS have approved this structure, i.e. $\forall a_i \in CS$, $F_i(a_i)$ *is higher for the CS when compared to its reference state* r_i.

Coalition concessions. Making concessions is certainly the best way to reach agreements on a coalition formation. A *trivial concession* is the one where an agent a_i approves a coalition structure CS^* for which $F_i(a_i)$ is inferior to another previously approved structure CS. Moreover, an agent can make *Pareto concessions* where the payoff of at least one participant agent can be improved with a new approved coalition structure without deteriorating the payoff of others. Other kinds of concessions can also be considered, such as egalitarian measurements of agents' utilities, etc. It is worth noting that in economic theory, we can find several sorts of concessions that an agent can make within a negotiation. In the proposed mechanism, agents focus on different forms of concessions.

In our *pessimistic ad-hoc coordination protocol* which is proposed for solving the mobility problem by the means of coordination, each of the nodes maintains a cache for saving temporary data about its mobility. The agents deployed on them update this cache with the latest probability information about their movements or stability *(*$Prob_{mins}$*)*. In the coalition formation problem, each agent makes its proposals of coalition structures and must reach with others agreements on those which will be adopted such that the following conditions are satisfied: (1) validity: if an agent adopts a CS then this CS have been agreed on by its forming agents; (2) Agreement: no agent reaches an incoherent state after deciding; and (3) termination: every agent eventually decides.

Let us now present the steps of the protocol:

(1) *In the first round each agent a_i, which has some goals G_i to achieve, initiates a coalition formation process, p_i, by contacting some or all the agents of its view, i.e., its neighbors within its one-hop communication range. a_i builds proposals to submit to these agents using the information provided on their goals and resources. Just before starting it, the initiator agent (a_i) sets a timer with a timeout value which is an upper bound estimation of the time delay that the coalition formation will take.*

(2) *Each agent $a_j \in v(a_i)$, interested in the coalition p, seeks to make proposals either just based on its own goals, resources and its $Prob_{mins}$, or initiates one or more sub-coalition formation processes, p_i^k, with its other one-hop neighbors in order to be able to make further proposals to a_i in the current coalition process p_i.*

(3) *In each subsequent round, each agent can keep its previous proposals, or make some concessions, or even make a new proposal. For an agent a_j, if its $Prob_{mins}$ is lower than an acceptable threshold, a_j initiates a sub-coalition formation process, p_j^-, with its one-hop neighbors. The process p_j^- allows that the commitments of a_j with a_i will not be withdrawn since at least one agent of p_j^- will perform them if a_i's node moves and $F_i(a_i)$ has decreased due to multi-hop communications with a_j.*

(4) *An agent ends its negotiation phase of a given coalition formation process in one of the following cases: (a) a complete solution which handles all its goals is found; (b) an agreement is reached on a partial solution which comprises some of its goals; (c) a conflict arises and no agent's concession is possible (d) the timeout delay for the coalition formation expired.*

(5) *For each negotiation that successfully ended, the agents involved in the agreed coalitions apply an atomic commitment phase in order to validate or give up the negotiation phase. The latter takes place either because one or more of the involved agents can not keep their agreements or because the nodes have moved.*

5 PERFORMANCE EVALUATION

We present in this section our results and experiments where all the agents are in operation together in a coordinated way under the supervision of the proposed coalition formation model. For the results to be efficient, the agents must provide better payoffs of each requester which asks for its goals to be performed. Also, total number of goals achieved (number of successful charge sharing agreements) and negotiation time (i.e. the total time for communication and goal solving measured in minutes) are the other two important parameters. The parameters are chosen as they will testify our approach in terms of its feasibility, efficiency, accuracy and scalability.

The whole scenario is simulated based on the hospital example. The simulation starts with a set of agents in which any random agents a_i, have some goals G_i to achieve (or to get charged). They initiate a coalition formation process, p_i, by firstly searching and then contacting some or all the agents in their view. After contacting, a_i sends these agents the information about the charge they need, setting a timeout for reciving response. Each of the interested agents $a_j \in v(a_i)$, make their proposals based on their goal solving abilities (or charging capabilities). The factor of $Prob_{mins}$ is considered for sending proposals. Necessary sub-coalitions are also formed in case the value of $Prob_{mins}$ < threshold. The main purpose of these experiments is to show the improvement with the required payoff (the charge needed in the beginning) of agents and their achieved goals or tasks (the number of charge sharing agreements successfully completed).

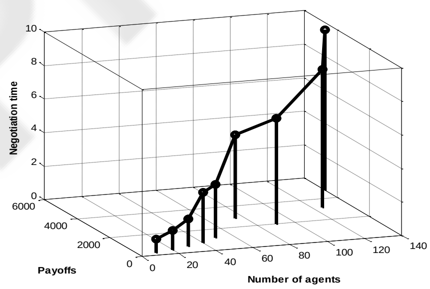

Figure 2: Comparison of achieved payoffs and negotiation time.

Figure 2 shows a graph of several values of achieved payoffs in relation to time by running the simulation with varying number of agents. The maximum time taken for negotiation and goal solving is not more than 9.59 minutes with the highest payoff value of 4725. Figure 3 depicts the number of messages exchanged between the agents when both the values of agents and their achieved payoffs increase.

One of our objectives is to evaluate the different values of payoffs of agents in terms of number of messages required to achieve these values.

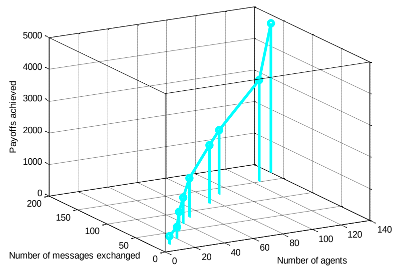

Figure 3: Achieved payoffs with number of messages exchanged.

Relating this aspect, two experimental graphs have been set up. A first experiment (Figure 4) has been conceived to compare the initial required values of agents' payoffs (blue lines) and the values of payoffs they have achieved at the end (black lines). Here, by required payoffs, we mean the sum of various amounts of charge needed by the participating wheelchairs, while the achieved values of payoffs are the several amounts of charge gained at the end. Thus, different random sets of agents (from 10 up to 140) are generated and represented in a 2D form. The achieved payoffs are at maximum of 1211 (over a total of 1350) when the number of agents is in the range from 0 to 50 and exhibits less variability on the average. Beyond 50 agents, there is a rapid boost in the achieved payoffs reaching to a peak value of 4725 (over total of 4800). Thus, it is clear that almost 90-95% of the total required payoffs have been achieved efficiently. Figure 5 depicts the number of messages exchanged between agents, that grows with increasing values of the achieved payoffs.

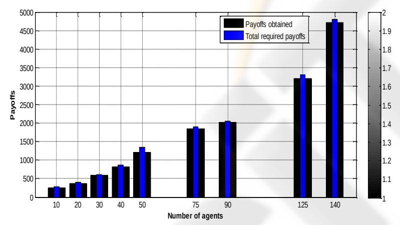

Figure 4: A graph comparison: Total required payoffs versus achieved payoffs.

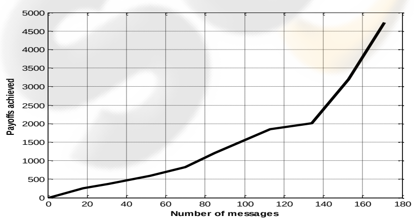

Figure 5: Achieved payoffs with number of messages exchanged.

Next we present three different results that illustrate the agents loss which they have caused in terms of the unachieved goals (or failed tasks), time and number of messages. In figure 6, a graph is given with the achieved payoffs and the number of unachieved goals. By unachieved goals we refer to as the number of unsuccessful agreements. This difficulty arrives when charger agents become mobile and later they cannot find their replacements in case of mobility. It is clear that the values of unachieved goals are not even in the double figures, while the achieved values of payoffs are at their maximum peak range. Thus the flow of achieved payoffs is higher and there are not much goal losses when running the simulation with increased values of agents. The experiment of Figure 7 determines different values of unachieved goals with regard to the number of message loss. In the figure, the losses in terms of tasks and messages are almost leveled off for various sets of agents (from 10 to 140) and exhibits less fluctuating pattern on average. Even with maximum of 140 agents the values of tasks and message losses are 5 and 11 respectively.

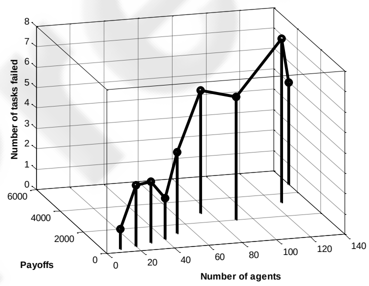

Figure 6: A graph with the achieved payoffs and number of unachieved goals (failed tasks).

Figure 8 is drawn to compare the values of achieved goals with their associated time values respectively. In the figure, there is a continuous boost in terms of achieved goals. For example if with 10 agents, the numbers of achieved goals are 5 (out of 6), then this phenomenon continues up till maximum of 140 agents where the achieved goals are 67 (over 72 initiated goals). Thus a climbing percentage of efficient results is maintained continuously. Similarly the total time taken for 10 and 140 agents is 0.68 and 8.92 respectively, which can also be considered as continuous.

Briefly, we studied in this section, how the increased values of achieved goals can influence the efficiency of our agents. Since, with the increase in number of agents, the results are more efficient, we expected to find that the higher the values of agents, the higher the average values of achieved payoffs.

Thus when using bigger scenarios (with huge number of agents) where time is not a highly concerned issue, with the main focus on achieving higher values of goals and payoffs, our ad-hoc coalition formation approach seems still an efficient solution.

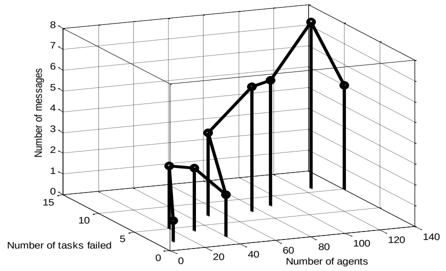

Figure 7: Number of unachieved goals (failed tasks) with the messages lost.

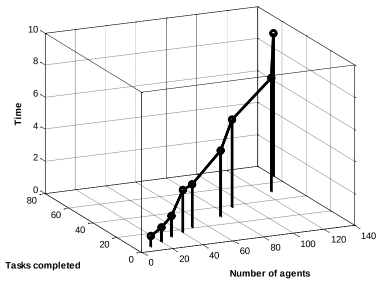

Figure 8: Number of achieved goals (successful tasks) with their associated time.

6 CONCLUSIONS

This paper addresses the problem of nodes mobility and the communication breakage costs, in MANET using coalition formation through MAS coordination. Several difficulties arise in these infrastructures especially when devices with limited resources are used. In order to cope with those problems, we have developed a new coalition formation mechanism, which addresses these issues in an efficient manner and increases the payoffs of each node according to its needs. In essence, the implementation and test results have shown that our approach can form coalition structures in a regular and effective manner in highly mobile conditions. The simulation results are based on several parameters including: payoff, coordination time, number of achieved and unachieved goals, number of messages. Our approach converges to an efficient position with the increase in number of agents, reaching to even better coordination and payoff at higher stages.

REFERENCES

Hsieh, F.-S., 2009. Developing cooperation mechanism for multi-agent systems with Petri nets. In, *International Journal of Engineering Applications of Artificial Intelligence.* ACM Press.

Akyildiz, I. F., Lee, W-Y., and Chowdhury, K. R,, 2009. TP-CRAHN: A transport protocol for cognitive radio ad-hoc networks. In. *INFOCOM'09, 29th Conference on Computer Communications*. IEEE Press.

Cutsem, T. V., Dedecker, J., and Meuter, W. D., 2007. Object oriented coordination in mobile ad-hoc networks. In. *9th International Conference on Coordination Models and Languages*. Springer Press.

Soh, L-K., Khandaker, N., and Jiang, H., 2006. Multiagent coalition formation for computer-supported cooperative learning. In. *AAAI'06, 21st International Conference on Artificial Intelligence*. AAAI Press.

Cao, W., Bian, C- G., and Hartvigsen, G., 2006. Achieving efficient cooperation in a multiagent system: the twin-base modeling. In. *WCIA'06, Ist International Workshop on Cooperative Information Agents*. Springer/ACM Press.

Carabelea, C., and Berger, M., 2005. Agent negotiation in ad-hoc networks. In. *MOBIQUITOUS'05, Second Annual International Conference on Mobile and Ubiquitous Systems*. ACM/IEEE Press.

Sislak, D., Pechoucek, M., and Rehak, M., et al, 2005. Solving inaccessibility in multi-agent systems by mobile middle-agents. In. *International Journal on Multiagent and Grid Systems*. ACM Press.

Wang, M., Wolf, H. and Purvis, M., et al, 2005. An agent-based approach to assist collaborations in a framework for mobile p2p applications. In. *AAMAS'05, Autonomous Agents and MultiAgent Systems*. Springer Press.

Christine, J., and Catalin, R.G., 2004. Active coordination in ad-hoc networks. In. *6th International Conference on Coordination Models and Languages*. Springer Press.

Tsvetova, M., Sycara, K., and Chen, Y., et al, 2001. Customer coalitions in electronic markets. In. *AMC'01, Agent-Mediated Electronic Commerce III*. Springer/ACM Press.

Jennings, N. R., 1994. Cooperation in industrial multiagent systems. World Scientific Publishing, London, 2nd edition.