A Proposal for Exploring Data Mule Based Weak Rendezvous for Communication between Loosely Coupled Convoys

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ABSTRACT

The goal of the project presented in this paper is to study a system of *weak rendezvous* that we introduce to support data mule based communication between two loosely coupled convoys. We will define distributed algorithms to deal with this situation, analyze the behavior of the system and derive upper and lower bounds on the time needed to move information from one convoy to the other. Our approach relies on dynamic graphs relabeling as previously studied in our research group. We will also, as far as possible, develop a prototype using the swarms of robots and UAVs that we have deployed at LaBRI. The approach proposed here is original in that it makes extremely weak assumptions on the network and focuses on the computation of lower bound values - for inter-convoy information exchange - and possibility results, depending on variations of these assumptions. **The project described in this paper is sponsored by the Department of the Navy, Office of Naval Research, under grant / award N62909 - 13 - 1 - N193.**

Categories and Subject Descriptors

C.2.4 [**Computer Communication Networks**]: Distributed Systems – *distributed applications.*

General Terms

Algorithms, Performance, Reliability, Experimentation, Theory.

Keywords

Swarms, Unmanned Systems, Dynamic Networks, Degraded Mode of Operation, Data Mule, Inter-Convoy Communication

1. INTRODUCTION

During the past few years, the MUSE (Mobility, Ubiquity, Security) research group at LaBRI (Bordeaux Computer Science Research Laboratory), has gained significant expertise in Mobile Ad Hoc Networks and especially in UAVs. We have set up a swarm of UAVs and ported to this platform distributed collaborative applications that assume unsafe asynchronous communications. These applications are modeled with a formal model based on a graph relabeling approach (local computations), which we call ADAGRS (Asynchronous Dynamicity Aware Graph Relabeling System). This model not only makes it possible to express algorithms but also makes it easier to provide necessary and/or sufficient conditions on the dynamics of the underlying communication graph to guarantee the success of an algorithm (possibility/impossibility results). Beyond the theoretical contributions, this work led to the development of the CARUS demonstrator [5] in which five UAVs share the supervision of a grid of fifteen points of potential ground incidents (see http://muse.labri.fr/scual/carus/). When a UAV detects an incident, it comes close to it (the mobility of the nodes is controlled) in order to deal with it. The rest of the swarm must then take care of the points that this UAV no longer visits. The necessary reorganizations of the swarm (retasking) are done in total autonomy with respect to the ground and under the hypothesis of possible loss of UAVs and messages. Each UAV takes its decisions locally, according to its local estimation of the global situation, which is built by consecutive merges of the estimations of its neighbors in the swarm.

Based on this expertise and background, we have begun exploring data mule based communication between loosely coupled convoys.

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2. PROBLEM STATEMENT

In communication networks dedicated to support decision making, the fundamental problem of the provision of information is a research topic that has already been the subject of numerous studies. It raises a number of issues, especially when the network is unstable (loss of entities - also called units, or nodes - and communication links, unsecure boundaries, etc.). The goal of the project described in this paper is to contribute to this domain by addressing the problem of information circulation in these harsh conditions. We focus on configurations where the entities of the network are not only mobile but have some decisional autonomy and for some of them can be remotely controlled (we are addressing convoys composed of troops, ground/air vehicles/robots/UAVs).

Data mules have been identified as an option for circulating information in these situations where the network is not (always) fully connected and can be composed of disjoint islets (because the entities are spread over a possibly large geographical area and because of the potential mobility of the entities) [1, 2]. In these configurations a set of data mules coming from the different islets cooperate so as to circulate the information within the network.

To support the communications required to insure the above cooperation, it is possible to organize rendezvous, instead of waiting for the (opportunistic) meeting of two (or more) nodes (mules and/or simple entities). Each node involved then knows when and where it has to be located in order to be able to share information with the others. They can thus optimize the usage of their resources still maximizing their ability to exchange. The rendezvous can be planned, or when the mobility of the nodes can be controlled, they can be decided on the flight.

Indeed, in some cases, the movements of the data mules introduced above can be controlled, and this is achieved either dynamically or planned in advance. This is for instance the case in the SUAAVE [3] or RECUV [4] projects, to cite but a few. Adapting the movements (or mobility patterns) of the mules can then be used to optimize the circulation of information between the involved entities or the revisit frequency of any of these entities by a mule. This control feature is clearly considered as a plus to support systems that show a high level of mobility among the entities they are composed of.

3. ISSUES WITH EXISTING SYSTEMS

Among the major characteristics of the existing systems, we have identified three issues which, even though not always present altogether in each of the approaches, individually constitute a real limitation to the context we want to address. These are the facts that: (i) a single authority is considered, (ii) the possible disappearance of mules is not considered and (iii) the rendezvous between the mules can be somehow planed. These are described and commented in more details below.

(i) The existence of a single authority. This assumption makes mules in some sense most often interchangeable: a mule can integrate any islet and be replaced by another entity of the network (that thus becomes a mule), i.e. they do not have any preferred islet they need to get back to, once they have delivered their information. This of course does not apply to a military scenario where the islets can depend on different authorities (different members of NATO for instance), or the mules (possibly a UAV) have been specifically affected to one of the islets.

(ii) The stability of mules, even though a hypothesis that makes things easier to cope with, is not always realistic, especially in a military scenario. Furthermore, the stability of mules often makes it possible to assume that some of them have a partial shared knowledge of the network status (for instance they can share a lower bound of the number of mules in the network and use it to achieve their mission). This also does not hold in the configurations that we consider.

(iii) The knowledge of the rendezvous to come in terms of space and time is also an assumption that makes things much easier. When such rendezvous are scheduled, they are known either in advance (before the beginning of the mission), or provided during the previous rendezvous. Once again, this cannot hold in the kind of dynamic networks and environments that we consider, in which the evolution of the situation cannot by nature be foreseen. We will thus have to weaken the notion of rendezvous to fit the context.

4. THE WEAK RENDEZVOUS APPROACH

Our approach does not rely on any of the assumptions described in the previous section. We wish to study a system in which mules can belong to different authorities, we have no expectation about their stability, and there is no scheduled rendezvous between mules. The usual rendezvous is replaced by a waiting period at the rendezvous point (we call it *weak rendezvous*) to wait for the possible arrival of the other mule. Of course a maximum waiting time is decided upon.

The problem we propose to tackle during this project is the delivery by a system of data mules, of a piece of information (I) available in a convoy (C^1) to another convoy (C^2). The architecture we consider relies on a weak rendezvous between a mule coming from convoy C^1 and a mule coming from convoy C^2. The whole operation cannot be achieved by a single mule; there are a number of reasons why we do not want any entity from C^1 (resp. C^2) to approach C^2 (resp. C^1), among which: we hope to minimize the length of the path of the mule of each convoy (equal load for each mule); we intend to guarantee a minimum security distance between the two convoys; the mules must remain in their own territory (borders); a convoy must be able to leave at any time without having to inform the other convoy (weak commitment between the convoys).

The ideal is for each convoy to have at least one UAV at any time that endorses the data mule role. When a piece of information has to be delivered to a remote convoy, it is given to the local mule which carries it to a predefined (delivery) point. Two configurations are then possible: the mule delivers the information to a fix ground node that will later pass it to a mule coming from the other convoy – this a simplified scenario - ; the mule waits until a mule coming from the other convoy also reaches the delivery point, and the former mule then delivers the information to the latter mule. Once the second mule has received the information, it delivers it back to its convoy.

5. CONCLUSION

The goal of the project described in this paper is to study this global system, the decentralized and cooperative algorithms that we can set up and the guarantees (possibility/impossibility results) that we can offer to the convoys (and the resulting situation management support). The main concern of this kind of system is the delivery time of information from one convoy to the other. Among the metrics that we will study are the lower bound, the upper bound, the mean, etc. of this delivery time. These results will depend on the assumptions made on the context (possible loss of messages, of UAVs, one loss at a time or several at the same time, etc.). We will initially consider a simple case with basic, standard assumptions and then elaborate on the associated results to study more complex configurations.

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