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# Smart Green Communication Protocols Based on Several-Fold Messages Extracted from Common Sequential Patterns in UAVs

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## Abstract

Green communications can be crucial for saving energy in UAVs and enhancing their autonomy. The current work proposes to extract common sequential patterns of communications to gather each common pattern into a single several-fold message with a high-level compression. Since the messages of a pattern are elapsed from each other in time, the current approach performs a machine learning approach for estimating the elapsed times using off-line training. The learned predictive model is applied by each UAV during flight when receiving a several-fold compressed message. We have explored neural networks, linear regression and correlation analyses among others. The current approach has been tested in the domain of surveillance. In specific-purpose fleets of UAVs, the number of transmissions was reduced by 13.9 percent.


## Introduction

The energy consumption of communications can be crucial in some contexts. For example, Unmanned Aerial Vehicles (UAVs) may depend on energy for either flying or controlling this flight. Thus, lowering the consumption of communications may improve autonomy of UAVs. This tutorial article will guide users in how the extraction of sequential patterns can be used for compressing information of communications. In addition, we present a mechanism for using off-line data mining techniques for properly estimating timing information for properly interpreting blended messages.

In order to reach a broader audience, a daily example of most families' lives can help readers to understand the concept of blended messages extracted from sequential patterns. This mechanism is based on detecting common patterns in communications for avoiding redundancy in these communications. For example, a mother could tell their children "come to the kitchen to have dinner;" after they have dinner, she would tell them "wash your teeth;" and after this she would tell them "go to sleep." Imagine that every day the mother would ask her children these same three orders in the same sequence with similar time intervals. Following this metaphor, the current approach would detect a communication pattern and will instruct the mother and her children to learn the "night" communication pattern. This would include the compression of these three orders in just one word referring to this pattern. Thus, the mother would only need to tell their children once the "night" pattern, and children would perform the activities of having dinner, brushing their teeth and going to sleep separated with time intervals similar to the ones elapsed between the original different orders. The technical details of how to extract sequential patterns from communications can be observed in our previous work about extraction of sequential execution communication patterns in multi-agent systems [1]. However, the novelty of the current approach is to use these sequential patterns for compressing the communications with blended messages.

In order to apply sequential patterns for performing blended messages regarding actions separated in time, the next problem is to estimate the appropriate elapsed times between the activities of a pattern. Following with the metaphor of communication between the mother and her children, the questions could be, for example, how much time their children usually spend having dinner. A raw common estimation could be the average time that they usually spend having dinner. However, one could perform a more accurate estimation based on different kinds of information. For example, the food may influence time. Kids may eat meat faster than fish, since they need to cautiously remove the fish bones in the latter case. The day of the week may also influence time, as eating may be more relaxed on evenings before a weekend day without of the pressure of getting up early the next day.

With the advent of big data and the need to analyze it, data mining techniques have improved in their estimation of unknown data. For this purpose, all these techniques usually need a training phase. In this phase, the predictor learns from cases in which the input parameters and the real output are known. For instance, following the metaphor of the mother and children, the predictor would need to observe the time elapsed in having dinner, the meal, the day of the week and so on. Then, the predictor is able to perform estimations. Normally, the accuracy of its predictions is assessed by estimating and comparing the results in cases different from the ones used in the training phase. There are several mechanisms for making predictions such as artificial neural networks (NN), K-nearest neighbors, and support vector machines. Readers can understand better about these machine learning methods in the

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existing literature [2]. In the current approach, the novelty is its application to off-line training of predictors for later making inline predictions of the time intervals between the requests belonging to several-fold pattern communications.

The effectiveness of the current approach for green communications is illustrated with a case study about UAVs, since these are one of the most energy-dependent vehicles.

While most green-communication works focus on communication levels such as the selection of relays for establishing the most energy-efficient paths [3] and, more specifically in UAVs, the efficient update of neighbors information in flying ad hoc networks [4], the literature still lacks green-communication contributions in a more abstract communication level. In this gap of the literature, the current work fosters a new paradigm of green communication based on the gathering of messages into several-fold messages based on the learning from specific-domain UAV interactions, reducing the total number of interchanged messages and consequently the energy consumption.

This article is organized as follows. The next section introduces some related works for highlighting the relevance of the current approach. We then propose a novel technique for achieving smart communication protocols by means of the analysis of sequential patterns of messages for defining several-fold messages. Following that we describe how to use big data analytics in the current approach mainly for estimating the elapsed time between actions when following the requests of several-fold messages. The final section provides the conclusions and mentions some future research lines.

## Related Work

Several approaches have been proposed for achieving green communication. In the case of 5G networks, the most popular approach is to use small cells for improving energy efficiency, as reported in the survey in [3]. This survey analyzed the ten most relevant works in this field, and these were focused on improving the energy efficiency of relays (intermediate local nodes in communications). One common approach was to send the signal to the vicinity relays instead of to the base station if the two communication ends were close enough to each other. Another common approach was to reduce the number of long-distance or high-consuming communications between the base station and relays, by using other lower energy consumption paths involving more intermediate relays.

In the specific applications of green communication in UAVs, [4] proposed to improve the energy consumption by properly regulating the frequency of hello messages to maintain the flying ad hoc network. While long intervals are not enough to properly keep the neighbors information updated, short intervals require much energy consumption. This approach regulated the frequency based on features such as volume of the allowed airspace, number of UAVs, UAV transmission range, and UAV speed. Their results showed a reduction of 25 percent of energy consumed in hello messages.

The innovation of all the aforementioned approaches belonged to the communication levels related with in the selection of relays for transmitting messages or maintaining the UAV neighbors information updated. By contrast, the innovation of the current approach belongs to a higher abstraction level in communication, and is the coordination of autonomous automated entities based on gathering messages into patterns, decreasing the total number of interchanged messages and consequently reducing the energy consumption.

Another research line is the UAV networks, in which UAVs temporary support the communications of an area by providing drone small cells. This has been applied for military purposes, but also for civilian purposes such as improving the connectivity in events such as festivals, sport activities or seminars or replacing damaged communication infrastructures after disasters. In this line, green communications are really relevant due to the limited energy in UAV batteries. For instance, [5] focused on the scheduling of beaconing periods, and investigated structural properties with a game perspective. They used a learning algorithm for ensuring that the target area was covered using a Nash-equilibrium approach. However, to the best of our knowledge, the works of this research line have not proposed to gather messages into several-fold messages for reducing their number, as the current work does.

In some scenarios, UAVs operate in groups and need to coordinate among each other [6]. UAVs need coordinated motion to cover certain space, to follow some target, or surround some element. For example, AR Drones can cooperate with mobile devices with Android and Linux OS for focusing on and locating certain targets and then transferring HD videos about this [7]. Most of these coordination mechanisms require explicit communications, which usually carry a non-negligible energy consumption. In these scenarios, the current approach can help in compressing and reducing communications with little loss in coordination capacity The following sections present a novel approach for making UAV communication more energy efficient in this context.

## Technique for Including Green Communications in UAVs

This technique for conforming green communications focuses on improving some previous existing coordination among UAVs. The current approach aims at reducing the amount of information and the number of communications. Figure 1 shows an overview of the current technique, indicating the order of the tasks with numbers. In the top part of the figure, one can observe the analysis of the communications of the existing previous coordination. This technique analyzes the messages among UAVs in order to extract sequential patterns. Then, this technique performs the training phase of the data mining for assessing the time intervals between messages. The bottom part of the figure shows the coordination with green communications and the relation of each component with the analysis of the previous coordination. The green coordination uses several-fold messages based on common sequential patterns, and the messages are compressed according to the specific domain. All the UAVs of a fleet share the dictionary of sequential patterns and incorporate the trained data model for estimating the time intervals between the requested actions concerning each sequential pattern.

The diagram of Fig. 2 introduces the steps of the current approach. The steps have been classified into the categories of: pre-processing of messages (represented as blue in the diagram), the extraction of sequential patterns (represented as red), and the learning of elapsed time intervals between messages of each pattern (represented as green). These steps are described below:

1. *Analysis of the ontology of messages:* In this step, the designer analyzes all the possible commands that UAVs can transfer and the number of given parameters.
2. *Lightweight encoding of messages:* Given the certain number of message types, this step assigns the minimum number of bits for representing this specific number of messages. All the UAVs of a fleet will use this encoding for both encoding and decoding the messages interchanged among each other.
3. *Analysis of sequential patterns:* A tool automatically analyzes the existing data from previous communications, to detect common sequential patterns of messages.
4. *Selection of several-fold messages:* A several-fold message will be defined for each of the most common sequential patterns. In this manner, a several-fold message will mean the same as the group of messages.
5. *Sequential patterns with reciprocal communications:* In some cases, one communication from one UAV to another may imply a reciprocal communication of the latter to the former. In these cases, one UAV can estimate when it would receive the reciprocal message so the receiver can save this communication.
6. *Lightweight encoding of several-fold messages:* A encoding will be selected for the new group of several-fold messages.
7. *Analysis of the elapsed time intervals:* The elapsed intervals between actions of several-fold messages may be known beforehand or not. In the former cases, these elapsed times should be transmitted alongside the message. In the later cases, if the receptor has the same prediction capacity over these intervals, then the prediction is performed in the receptor to save the corresponding transmission.
8. *Data mining for estimating elapsed time intervals:* In the necessary cases, the estimation will use data mining by training with the previous coordination information. This approach recommends performing the training before taking off. In this way, for example in the case of using a NN, then this should be trained before departing assigning the weights to the neurons, and then these neuron weights will be used for estimating elapsed times.

Each message contains the following information:

- Bit for determining whether the message is atom or several-folded
- The lightweight encoding of the message for both atom and several-folded ones
- Parameters of the commands if any
- Elapsed time between actions regarding a several-folded message if known.

An example of a message follows:

*1, 01, 27.3, 38.4, 80*

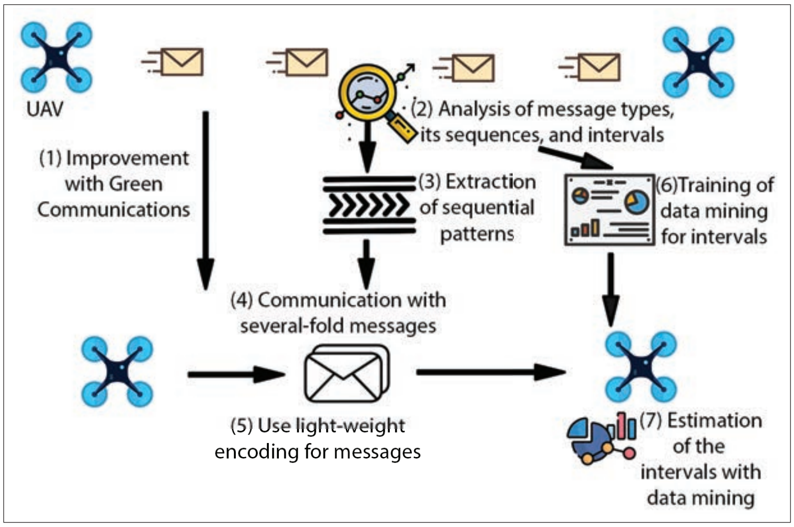



FIGURE 1. Overview of the approach for using green communications in UAVs.

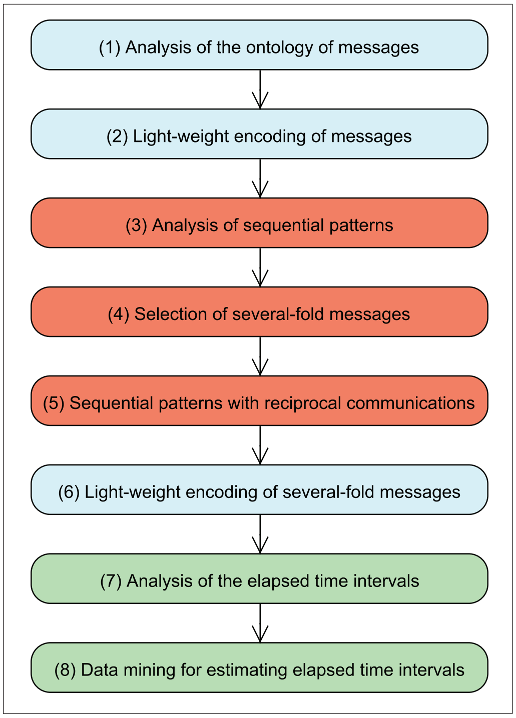



FIGURE 2. Steps of the current approach for achieving green communications.

In this example, the first bit indicates it is a several-fold message, "01" is the lightweight binary encoding of the several-fold message "a person has been detected," 27.3 and 38.4 are the coordinates of the current location of the person in the local reference system in meters, and 80 is the estimated elapsed time in seconds for the second action concerning "the guards are arriving."

Initially, a person could do most of the aforementioned steps. However, the proposal is aimed at achieving automation for most of the previous steps.

## Big Data Analytics

The big data field usually involves the management and analysis of massive amounts of data. The relevance of data mining techniques is now increasing steeply with the increasing prevalence of big data. Data mining [8] usually has several

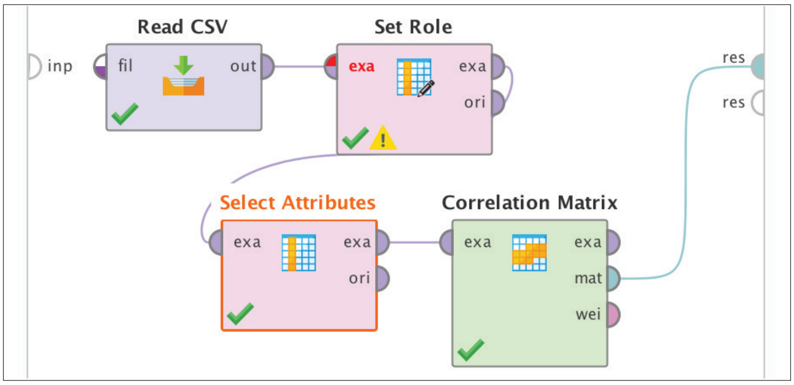



FIGURE 3. Visual process design for obtaining a correlation matrix in RapidMiner.

phases. First, there are some pre-mining tasks, then the data mining tasks are executed, and finally there are some post-mining tasks.

In the pre-mining tasks, the data are cleaned by removing incoherent data. In some cases, the dimensionality can be reduced by selecting the most relevant features. These could be features with the highest correlation with the target variable, features with the most variability, or some other definition of relevance.

In the current approach, the designer should also perform these pre-mining tasks. It should establish the time intervals as the target dependent variable that is studied given a certain sequential pattern. These time intervals refer to the times elapsed between each original message and the following one in the sequential pattern. Then, one should determine which features are more related with this information. For instance, in the case study presented later, the local time (e.g., during daylight or night) was related with the speed of people moving, and consequently it was also related with time intervals between messages of a sequential pattern. We also propose to standardize the values of the features so that all these use similar data ranges of values and are comparable. One can assign different weights regarding its relevance.

For applying the data mining techniques, we propose to consider the most common mechanisms. The k-nearest neighbor selects the K most similar cases given the input features and certain weights for features [9]. In addition, we recommend to use multi-layer perceptron (MLP) regressor [10], which is a kind of artificial NN. Artificial NNs use a representation of biological neurons. Each of these neurons has several input connections from other neurons or inputs from which an output is calculated. The neurons are distributed in several layers for obtaining outputs given certain inputs. Other simpler systems can be used like linear regressors. Although this regressor can only fit domains with linear dependencies, it has the advantages of having good performance in terms of time response.

Once the designer has found the most reliable combination of pre-mining and application of the data mining technique, these are trained with the existing data. The trained data mining model is incorporated in the UAVs, so that these can be applied for using green communications.

In order to rapidly prototype all these aforementioned options among others, RapidMiner [11] allows one to easily process data from excel files, by visually designing the process model. In this way, in the current approach, designers can easily test all these techniques and determine which one they would like to incorporate.

Figure 3 shows an example of a visual process design with RapidMiner for analyzing communication data to obtain a correlation matrix from several features, including the time interval between messages. This correlation matrix can be useful for the pre-mining task of selecting which features might be more relevant for prediction during the flight. In particular, the most relevant will have correlation values closer to 1 or –1 with the time interval.

In some cases, for applying some specific predictors, this approach recommends using the Scikit-learn [12] library in Python programming language. This library allows one to apply different predictors such as the MLP regressor, KNN and linear regressor.

In order to extract sequential patterns, we recommend to use WUM (a tool for Web Utilization Analysis) [13]. Although this tool was initially designed for analyzing web utilization, it can also be used for analyzing sequential patterns of communications. In particular, a communication is represented as a transition from one UAV to another, and then the tool discovers sequential patterns. Among these, the designer should select the most frequent patterns after following the processes described earlier.

## Case Study

In this case study, we applied the current approach for using green communications for the surveillance of a border. It departs from a previous protocol communication inspired by blockchain principles. In this case, the flying pattern was changed so the communications were more predictable, and consequently easier to be transformed into green communications. Instead of flying randomly, the UAVs were designed so each one was in charge of flying over a specific area.

In this case study, the purpose was to keep track of any person going across a border. For that purpose, each UAV alerted the ones in the neighbor areas to catch images of the neighbor areas.

We used the WUM tool to extract the common sequential patterns in this case study. We simulated the surveillance of a border with UAVs, and these UAVs alerted their neighbors when they detected a person, so that each person was tracked. For the simulations, we used an initial version of the simulator ABS-GreenComUAV (later presented in this section) that did not include the proposed optimization for green communication. The UAVs were associated with identifiers. We programmed a module within this simulator to log all the messages into a file indicating the timestamp, the sender identifier and the receiver identifier of each message, following the input file format of the WUM tool. We performed 100 simulations with different numbers of areas ranging from 4 x 6 to 10 x 24 and with different probabilities of appearing people ranging from 0.1 to 0.5. WUM processed this file containing all the logs, and presented the most common sequential patterns.

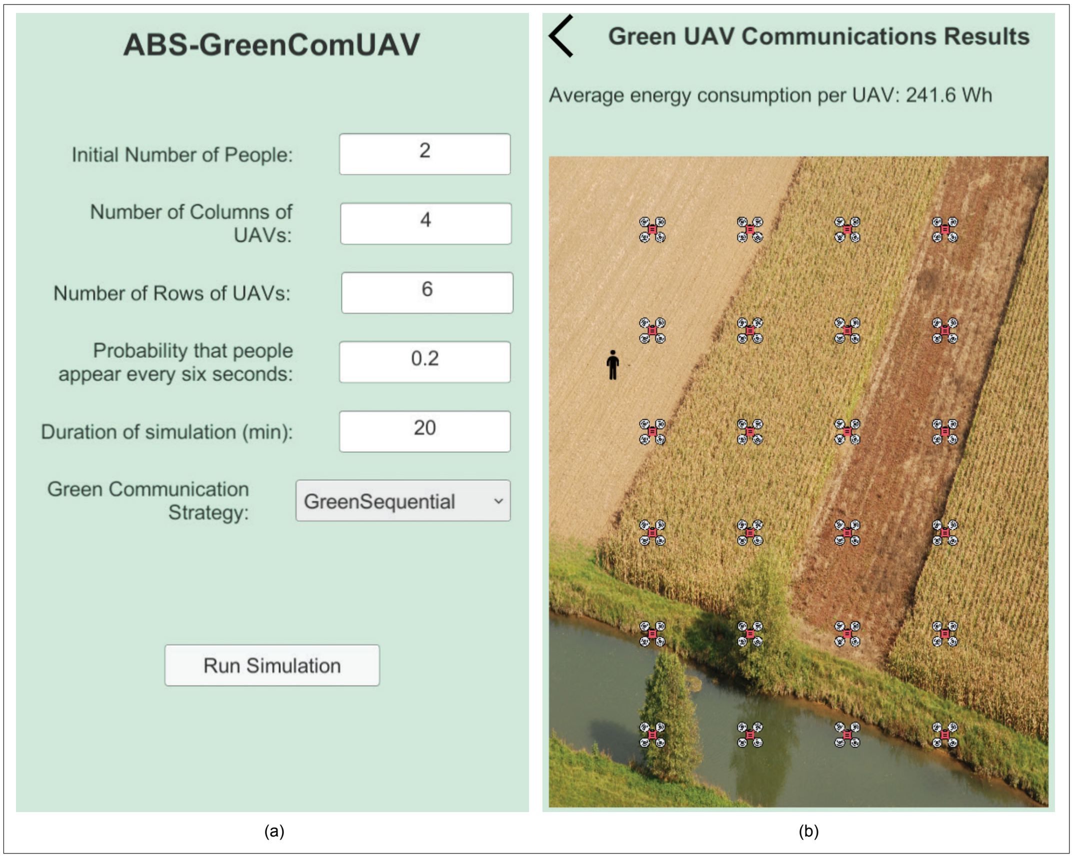



FIGURE 4. Screens of the ABS-GreenComUAV for: a) entering input parameters; b) presenting simulation results.

When we analyzed the sequential patterns, we observed that in some cases one communication was followed by a reciprocal communication (e.g., when the target went backwards). This sequential pattern was reduced by assuming a possible reciprocal message. In this way, the sender did not need to receive this reciprocal communication.

In the pre-mining task, the time of the day was related with time interval. In this scenario, the time interval was normally related with the speed of the person, since this speed was related with the time it takes for going from one area to another.

To test the current approach, we have developed a novel agent-based simulator (ABS) called ABS-GreenComUAV. This ABS allows one to test different green communications strategies. In particular, we used this ABS to include the strategy based on the analysis of the sequential patterns. Figure 4 shows the user interface of this simulator. More concretely, Fig. 4a shows the screen where the user enters the input parameters of the simulation. These parameters are:
- The initial number of people
- The size of the grid of UAVs determined by the numbers of columns and rows, respectively
- The probability that people appear for trespassing the border
- The duration of simulation in minutes
- The green communication strategy.

Programmers can define tailored green communication strategies with C# programming language by including a new file in the application folder. Figure 4b shows the simulation output of the ABS-GreenComUAV. This provides a graphical representation of the final state of the simulation, where users can observe the people in the border controlled area and the UAVs. This output also provides the average energy consumption per UAV during the simulation. In addition to this outputted information, this application also keeps track of the evolution of the average energy consumption per UAV during the simulation. We developed this ABS following TABSAOND (a technique for developing ABS apps and online tools with nondeterministic decisions) [14], so that we were able to simulate the common nondeterministic behaviors of people when trying to trespass a controlled border area.

In order to test the current approach, we simulated the surveillance of a border distributed with 8 x 20 areas. Each of these areas was controlled with an UAV. Initially there was one person. After 20 s of proper tracking, this person was assumed to be captured. We simulated five minutes. Every six seconds, the probability of a new person appearing was 0.2. This simulation was simulated respectively using the previous communications protocols (referred to as control communications), and with the green communications using the presented approach. Figure 5a compares the results between both types of communications. To obtain more representative results, we executed again this scenario for simulating 25 min, and Fig. 5b presents the results. As one can observe in both comparisons, the current approach decreased the energy consumption of UAVs when applying the conversion to green communications.

We applied big data analytics for conforming a prediction of the estimated elapsed interval between messages of sequential patterns. For this

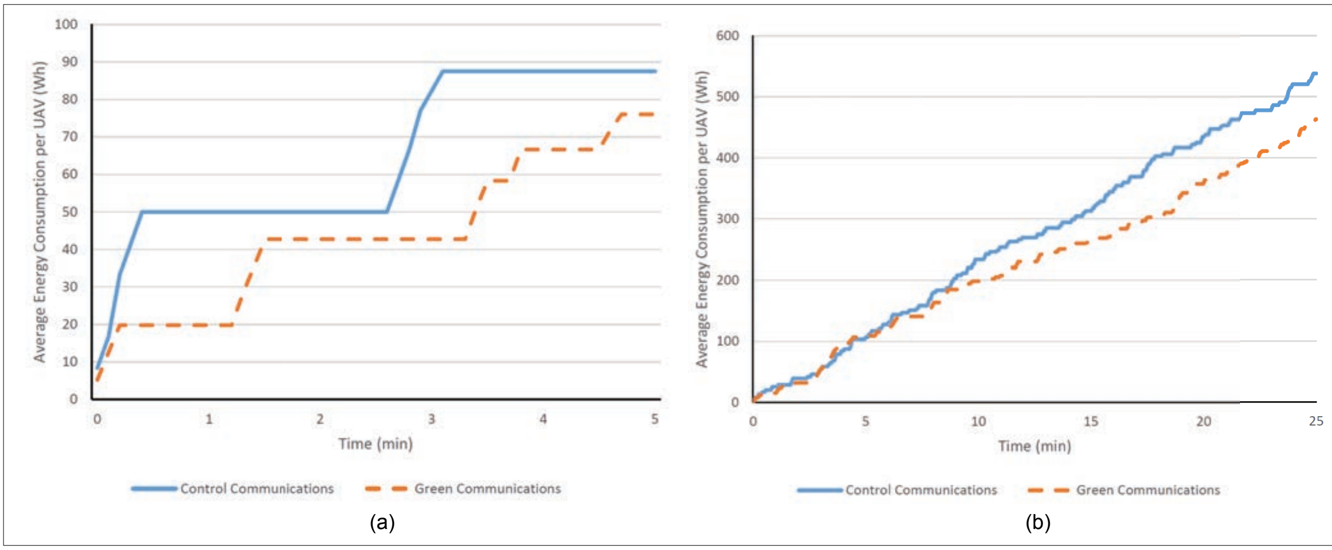
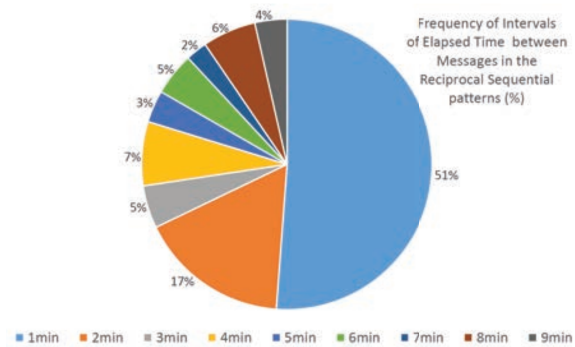



FIGURE 5. Simulated energy consumption: a) for 5 min; b) for 25 min.

| Attributes | Time | Sender | Receiver | Sender is Border | Receiver is Border | Time Pattern |
|---|---|---|---|---|---|---|
| Time | 1 | 0.189 | −0.041 | 0.226 | −0.004 | −0.130 |
| Sender | 0.189 | 1 | 0.433 | −0.166 | −0.047 | 0.170 |
| Receiver | −0.041 | 0.433 | 1 | −0.226 | 0.014 | −0.017 |
| Sender is Border | 0.226 | −0.166 | −0.226 | 1 | 0.098 | 0.055 |
| Receiver is Border | −0.004 | −0.047 | 0.014 | 0.098 | 1 | 0.001 |
| Time Pattern | −0.130 | 0.170 | −0.017 | 0.055 | 0.001 | 1 |

(a)




(b)

FIGURE 6. Analytics for analyzing time between messages of sequential patterns: a) results of correlation-matrix analysis; b) frequency of time ranges.

purpose, we applied RapidMiner for analyzing the list of all the messages interchanged among UAVs in a simulation. We used a simulation of 20 min over a 4 × 6 area, and the simulator recorded all the messages interchanged in a log file. In particular, we first used the correlation matrix analysis, and we obtained the results presented in Fig. 6a. The time pattern column refers to the time elapsed between the two messages conforming the sequential patterns. The senders and receivers refer to the ones of the second message of the sequential patterns. We considered the position of each UAV and whether it was in the border of the controlled area. As one can observe, senders were more related with the pattern times than receivers, when considering both their positions and whether they were in the border of the controlled area. In addition, Fig. 6b shows the frequency of the different time ranges in the reciprocal sequential patterns. We considered the time durations in the ranges for respectively from one to nine minutes, since larger duration intervals may be due to non-related events. More than half of these patterns (51 percent) had a duration range of only one minute, and 17 percent of these patterns had a duration range of two minutes. The other time ranges were less frequent, and had frequencies between 2 percent and 7 percent.

Furthermore, we scanned the communications, and we observed that there were no undesirable communications in terms of undesirable unbalanced overloading communication patterns as described in [15].

In other words, the communications were properly distributed, and there were no UAVs overloaded because of receiving an excessive amount of communications from other UAVs. Mainly, the communications were between neighbors, and these mainly depended on the positions of people crossing the borders, which were balanced.

Considering the simulation of 25 min as the most representative, we calculated the reduction of energy consumption. The energy reduction was 13.92 percent.

## Conclusion

The current work has presented a technique for incorporating green communications in UAVs. This technique uses the analysis of sequential patterns for defining several-fold messages with lightweight encoding. It also uses data mining techniques for estimating the intervals among communications. In this way, fewer communications are necessary for obtaining similar behaviors. Our case study concerning surveillance and tracking of people with UAVs shows the benefits of the current approach in terms of energy consumption reduction.The simulated experimental results showed a reduction of 13.92 percent in energy consumption in communication. These results advocate that the proposed approach based on sequential patterns in specific-purpose UAV fleets can reduce the number of interchanged messages by using several-fold messages, fostering a new paradigm in UAV green communication.

The current approach is planned to be applied to different domains in messenger companies, ad hoc networks with UAVs and mobile devices, and underwater vehicle networks, to further confirm its utility. Moreover, we plan to extend the current approach with a new research line about intelligent identification of sequential patterns and estimation of their properties with the principles of human-centric artificial intelligence (HAI). In particular, the future HAI approach will test different techniques such as NNs, K-nearest neighbors, support vector machines and random forests, and will automatically select the most appropriate one based on the accuracy results. After training with HAI, this approach will not only provide the learned model but also some auto-generated explanations about this model. In this way, engineers will be able to rapidly assess whether the learned model is trustworthy in the corresponding specific domain, fastening and improving the supervision process.

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## Biographies

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