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Dans ce papier, nous considérons le problème d'enregistrement d'un événement sportif (par exemple un match de foot) par un couple de drones. Pour effectuer ce travail, les drones doivent se positionner sur le terrain de jeu et suivre les mouvements des joueurs et du ballon afin de fournir aux spectateurs de l'événement des données vidéo de haute qualité, tout en tenant compte des contraintes de communication entre les deux drones. Pour atteindre cet objectif, on propose un ensemble d'algorithmes distribués pour le déplacement des drones, basés sur les fonctions de potentiel artificiel et sans aucune connaissance prèalable sur la séquence d'action de jeu. Afin d'évaluer les performances de notre approche par rapport à la satisfaction de l'utilisateur, au coût de la solution et au comportement du réseau on a simulé et testé de nombreux scenarii.

Mots-clefs : Rseaux, Potentiels Artificiels, UAVs

1 Introduction

In this paper, we envision the usage of Unmanned Aerial Vehicles (UAV) for filming a sporting event and streaming images and replays to the spectators within the stadium. The main issues to face for implementers of sport filming systems are summarized in a set of requirements, for the communication infrastructure, that include *high throughput* and *delay-intolerance*. After the technology was ready [1], the first systems that used drones for filming sport events appeared [2, 3, 4]. The *Sport Event Filming* (SEF) problem, recently introduced in [2], consists of finding the best positions for a fleet of UAVs in order to maximize the satisfaction of the event's spectators and minimize the UAVs' traveled distance. The UAVs move timely over the current position of the ball and film the action. In the original formulation of the SEF problem, no attention has been paid to the communication and connectivity constraints required to deliver a High Definition (HD) stream to the spectators. In this paper, we extend the formulation of the SEF problem by including communications and connectivity constraints for a scenario with two UAVs, which are used respectively as filming and supporting nodes. In the rest of this paper, we will refer to this new problem as *Sport Event Filming with Communications and Connectivity Constraints* (SEF-C^3). Different than existing works, the work presented in this paper proposes a meta-heuristic approach directly implementable on the UAVs. Our work is inspired by the one in [2]. We aim at maximizing network performance in a realistic communications environment, using distributed techniques that are based on Artificial Potentials methods. These can be summarized in the application of virtual or artificial forces, which are set among mobile devices and obstacles by creating potential fields that can attract or repulse the devices towards each other [5] and towards a goal. Actual movements are executed by following the gradient descent of the potential function. Most of artificial potential literature is focused on coverage problems [6] or higher-level mobility [7].

[†]This work has been carried out in the framework of the DIVINA Challenge Team, which is funded under the Labex MS2T program. Labex MS2T is supported by the French Government, through the program ≪ Investments for the future ≫ managed by the National Agency for Research (Reference: ANR-11-IDEX-0004-02).

2 A model for the SEF-C^3 problem

We assume that the stadium is structured as a set of two concentric rectangles : the internal one has the average soccer field dimensions, $110 \times 80[m]$, and the external one, which contains also the spectators space, is $210 \times 160[m]$, as in Figure 1. Two UAVs move over the field to film the event and relay the video streaming to all the spectators within the stadium. Points (P_1) and (P_2) represent the farthest of these on a side (*corner points* in the rest of the paper). We will refer to the two UAVs as *filming* (P_3) and *supporting* UAV (P_4) in the rest of the paper. According to the measurements presented in [8], for a soccer game field, two drones are sufficient. With reference to Figure1, we define as 1-Hop the shaded area at the center of the field. When the action (and the filming UAV) is in this area, there is no need of a supporting UAV to deliver HD video to the whole stadium. On the contrary, when the action occurs in one of the filled corners of the field, the farthest sectors of the stadium in respect to this corner (filled in the same way) will not be provided with the HD video by using a single UAV. For readability issues, the figure illustrates the behavior for actions on the right-side of the field only. By assuming a uniform distribution of spectators in the stadium and simple geometric relationships, it is possible to compute the set U_{HD} of spectators who would be provided with HD video. By using the following notation : $C_1 : t^f_{arr,i} < t_{start,i}$, where N_i is the position of the i^{th} action, filmed by the f UAV and relayed (if necessary) by the s UAV. The values $t_{start,i}$ and $t_{stop,i}$ represent the start and stop times of an action of interest (i.e. a sprint or a goal) ; $t^f_{arr,i}$ is the arrival time of the filming UAV at the position of action i. We can define set U_{HD} of spectators who are provided with high definition video, and their satisfaction : $VS^k_{i,HD} = (1 - (\neg C_1) \cdot \frac{t^f_{arr,i} - t_{start,i}}{t_{stop,i} - t_{start,i}}) \cdot (VS_{maxHD})$,

3 A TLC system to film sport events

For the rest of this paper, we consider the data to transfer as a standard MPEG-4 Part 14 stream. For the video to be deemed as HD, the stream has to be composed by either a H.264 High Profile (HiP, 100) or a MPEG-4 Part 2 with an Advanced Simple Profile (ASP) alone (no audio track). Their transmission requirements can be upper-bounded by published specifications to $500 \sim 600$ Mbps [9]. Thus, we devise the filming UAV as continuously broadcasting its video stream using a dedicated IEEE 802.11ad-capable [10] wireless interface.

Broadcasting on a dedicated channel permits data to be correctly decoded by all the devices (spectators and other UAVs), which are close enough to the transmission source to receive the stream with a Bit-Error-Rate below the 802.11ad higher-bandwidth modes threshold. We define as $R_{HD,i}$ the communication range associated with this transmission threshold for the receiving node i.

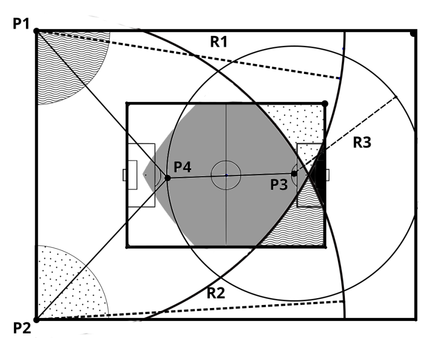

FIGURE 1: Model of stadium and game field

Using this configuration, for the remainder of this paper we consider all the users belonging to the U_{HD} set and, accordingly, we consider the viewer satisfaction composed by $VS^k_{i,HD}$.

The filming UAV : (i) always follows the actions (i.e. the ball) and (ii) broadcasts the video stream to both the spectators in his half-field and the other UAV. The supporting UAV, in turn, has to : (i) re-broadcast the data as received by the filming UAV and (ii) use a movement strategy that keeps it always inside the R_{HD} of all the spectators (R_1 and R_2) of its half-field and keep the filming UAV inside its own R_{HD} (R_3).

4 Movement Schemes for the SEF-C^3 problem

By applying virtual attractive and repulsive forces on the UAVs' control model, the supporting UAV will move away from the filming UAV in order to relay the HD video stream to the farthest spectators within the stadium. Considering that the filming UAV tries to follow the actions, in the following, we describe a control model specified in the following formula, capable of dynamically driving the supporting node.

$$\dot{x}(t) = v(t)$$
$$\dot{v}(t) = \begin{cases} u(t, x_4, v_4, x_3, v_3) \\ f(t) \end{cases}$$

where $x(t)$, $v(t) \in \mathbb{R}^2$ and $u(t,x_4,v_4,x_3,v_3) : [0,+\infty[\times\mathbb{R}^{2(n+1)} \to \mathbb{R}^2$ are, respectively, the position, velocity and control input associated with the supporting UAV, and $f(t) : [0,+\infty[\to \mathbb{R}^2$ is a signal describing the filming UAV velocity. Exploiting the Artificial Potentials, we can set : $u = -\nabla V_{x,y} + \gamma(v_i - v_4)$ where $\gamma(v_i - v_4)$ represents a velocity coupling. This function will be further specified in Section 5. In this paper, we assume the presence of an absolute positioning system for each UAV.

5 Performance Evaluation

We have implemented the control model for the movement techniques of Section 4 and a selected set of techniques from [2]. Specifically, the *Ball-Movement-Interception with Specular Repositioning* (BMI-SR) and the version of *Ball-Movement-Interception with Quasi-Specular Repositioning* (BMI-QSR) with the optimal *detour factor* of 0.6 : BMI-QSR$_{0.6}$ are used in our comparison. Note that these techniques have been proposed in [2] only to optimize the event coverage.

5.1 Simulation Scenario

The Artificial Potential method of this proposal is driven by the following set of functions, as described in Section 4 as our $f(t)$. The HPF (Hyperbolic Potential Function) $f(t) = \frac{1}{R^2_{HD,i} - ||d_{i,j}||^2}$ is characterized by a repulsive stimulus when a UAV approaches the R_{HD} boundary and the other two functions (Hyperbolic Cosine Potential Function $f(t) = cosh\left(R^2_{HD,i} - ||d_{i,j}||^2\right)$ and Binomial HCPF $f(t) = cosh\left((R_{HD,i} - ||d_{i,j}||)^2\right)$, instead, try to keep the UAV in the proximity of that value, albeit with different intensities. The simulated UAVs in NS3 [11] are equipped with a single wireless interface and an Ad-Hoc MAC protocol to simulate a IEEE 802.11ac stack. As the UAVs are always within line of sight of each other, we consider a Ricean fading model, where the signal components coming from secondary paths are disregarded. To model the data to deliver, we use a set of traces coming from actual HD video decomposition into packets, whose MTU is below the maximum allowance for a 802.11ac system. For all the simulations, we use the following parameters : Speed of Drones 15 $[m/s]$; Ball Min and Max Speed $= \{1 \div 40\}$ $[m/s]$. For each simulation scenario we created a set of 20 actions (equal to the number of simulation runs) whose positions and durations are uniformly and non-overlapping distributed (in space and time). The space is represented by the game field and the time is varied in order to have an action duration between a minimum of 2 [s] and a maximum variable between 6, 8, 10 and 12 [s]. In respect to previos approaches, the movements followed by the UAVs, using the proposed approach, are smoother and tend to maintain the same distances between them. This behavior is visible in Figure 2. For this set of measurements, the proposed solutions are designed to maximize the networking performance and thus, keeping the UAVs at the correct distances all the time makes it possible to minimize the packet loss and increase the transmission quality. In the same situation, the results coming from BMI techniques show that they were not designed to consider telecommunications features. For instance, as the BMI-DF approach completely disregards the communications constraints, the performance of the packet loss is unconstrained.

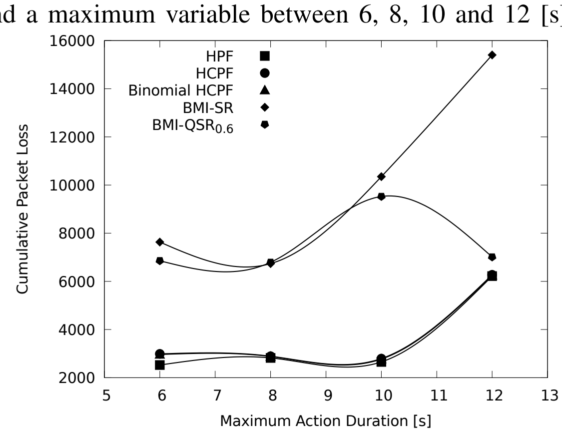

FIGURE 2: Cumulative Packet Loss over varying Maximum Action Duration.

6 Conclusion

In the context of coordination schemes for UAV networks, we have introduced the *Sport Event Filming* problem with communication and connectivity constraints (SEF-C^3), where the spectators of a sport event within a stadium receive on their personal devices a video stream, taken from two UAVs that fly over the sport field.

To coordinate the movements of the two UAVs, we have introduced three variations of a distributed technique. These schemes have no knowledge of the sequence of actions and use Artificial Potential methods to keep the connectivity of the two UAVs with the farthest spectators within the stadium.

Future works will consider the creation of a mathematical model and the proposed schemes to unbounded fields (as for bicycle races).

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