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COMMUNICATION ASPECTS IN USING UNMANNED AERIAL VEHICLES FOR EARLY DETECTION OF FOREST FIRES

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Abstract. In this paper, we introduce a novel approach in using drones (Unmanned Aerial Vehicles, UAV) for early detection of forest fires in rural areas (national parks). A special emphasize we give to the communication aspects between the UAV and the Crisis Management Centers (CMC), including the transmission of pictures and/or streaming video of the thermal and video cameras, and the fire alarm itself. In our approach, the UAV will implement a basic algorithm for autonomously forest fire detection. Most important, these alarms and the data associated with them should be transmitted as soon as possible to the CMC without human intervention. Because of the bad and sometimes missing communication connectivity in the rural areas, we will present our ideas for developing delay-tolerant network solutions and gossip protocols for hop-by-hop spreading of urgent sensor data and fire alarms.

Keywords*: forest fire, fire detection systems, drones, delay tolerant networking, persistent communication, and sliding window protocol.*

ACM Classification Keywords*: A.0 General Literature – Conference proceedings; C.2.4 Distributed Systems – Distributed applications.*

Introduction

Systems for early detection of forest fires using Unmanned Aerial Vehicles (UAV) have been proposed in several recent papers [Yuan, et al., 2016], [Yuan et al. 2015], [Skorput et al.,2016], [Ghamry and Zhang, 2016]. However, those papers do not deal with the possible missing connectivity or network coverage. That is, given the timely and reliable detecting the forest fire, in some situations the alarm signal and the multimedia information associated with it, cannot be forwarded quickly to the CMC. In our opinion, it is crucial to deliver the information about the forest fire as soon as possible to the responsible persons and authorities in order to take an action. However, in rural areas (e.g. national parks) the network coverage (like GPRS, 3G, 4G) is missing and even the UAV (flying at 1000 meters and more) has a better chance to get connected, than the person on the ground does. Furthermore, the UAV has the chance to connect to alternative network provider, or even to other ground facilities using alternative communication channels, like 433 MHz radio, LoRa, WiFi, or WiMAX.

The goal of this paper is to develop concepts for the detection of possible forest fires using UAV, and in case of a fire alarm to ensure on time delivery of the alarm together with the multimedia content to the CMC cloud.

Obstacles

In order to ensure on time delivery of the alarm data, the following communication problems should be solved:

1. **Network switching.** The UAV should search for the best connection via different networks in order to get quick access to the Crisis Management Center (CMC), e.g. via GPRS/UMTS/4G, WLAN, LoRa, WiMAX, etc. Even when already connected and started with the transmission, suddenly deteriorated quality of the communication, or transmission stalling can be the reason to switch

from one network to another. As a result, all ongoing transmission sessions will be disconnected.

2. **Frequent disconnection**. The communications over the wireless interface can temporary deteriorate, or even are interrupted. The communication paradigm, the so-called Delay Tolerant Networking (DTN) describes this behavior. The corresponding routing protocols are called store-carry-and-forward, expressing that the sender can store the message, carry it for a long period, and forward it, when the connectivity is restored [Krifa et al., 2008].
3. **Quick changes in the wireless throughput**. The Quality of Service parameters to streaming media include throughput, error bursts, delay, jitter, etc. Layered streaming coding has become a subject of research in wireless systems also [Chakareski, et al., 2003], [Rejaie and Ortega, 2003]. According to those ideas, the basic media stream is first encoded into a base layer providing the minimum quality and therefore requiring the minimum bandwidth. The enhancement layers are encoded separately into special packets, where each additional layer contributes to the improving the quality of the media played. In our system, we plan to use the concept of Peer Ports [Stainov, 2009] so that the interrupted delivery will be automatically restored, even over different communication channels and networks.

Solutions

For the solution of these problems, we are going to use the concept of the Peer Port [Stainov, 2009], [Stainov, 2010]. In contrast of the Peer Port usage in those papers, the Peer Port will be located on the UAV itself and will initiate the communication with the receiver, or with his proxy over an appropriate communication network. We call this kind of Peer Port the Active Peer Port. The Active Peer Port has the following characteristics:

1. **Delay Tolerant Networking (DTN).** The Peer Ports will be implemented on the UAV, and will be used for back-up during normal operation and as add-on persistent communication in case of interruption. The corresponding routing protocols are called *store-carry-and-forward*, expressing that a Peer Port can store a data message, carry it for an arbitrary amount of time, and forward it when connectivity is restored [Krifa et al., 2008].
2. **Low cost recovery after interruption.** Usually, when both the sending and receiving sites are online, they behave like a traditional end-to-end system with the Active Peer Port as a proxy. The Peer Port initiates a Sliding Window Protocol with the receiving site. When the sending site loses connectivity, the Active Peer Port will save the Sliding Window session and will restore it, when the connectivity, even over a new network, is restored. Thus, the communication between the CMC cloud and the Active Peer Port will be a "low cost" one, because no packets have to be resent for the new session.
3. **Network independent recovery.** Sending processes push the data into the Active Peer Port. The Active Peer Port initiates a Sliding Window session with the receiving cloud. In case of interruption, this session will be restored, causing two main advantages: (1) the receiver doesn't have to reconnect to the sending Active Peer Port in order to resume the communication, and the already sent packets do not have to be resent; (2) after reconnection, when the sender appears in a different network with a different IP-address, it can simply connect to old sliding window session and resend the missing data.
4. **Layered streaming.** Real-time communication like video are encoded into a basic layer, providing the minimum quality of the media stream, and one or more enhancement layers, with each one improving the media stream quality. This concept introduces

the distinction of Base and Enhancement packets. However, this very idea is not part of the prototype and is not being implemented for now.

Main Principles

An Active Peer Port can be understood as an ordered message buffer for urgent persistent fire alarm communication. From the point of view of the sending process on the UAV, the Active Peer Port is just the receiving process for fire alarms and alarm data, belonging to the same operating system. From the point of view of the receiving CMC cloud, the Active Peer Port represents another overlay and offers a back-up of urgent or sent data to be transmitted quickly. Thus, a change of the sending IP address does not affect the possibility to pull missing data from the Active Peer Port.

The procedure can be summarized as follows:

1. **Active Peer Port registration.** When a UAV registers with the cloud (CMS), it creates an Active Peer Port process, defines its buffer size and validity duration (set to 24 hours by default), sets up a unique sequence number for data packets, and creates a ticket for accessing it.
2. **Normal Operation**. A copy of all sent data is pushed to the Active Peer Port message buffer. The pair {Active Peer Port ID, message sequence number} identifies every message.

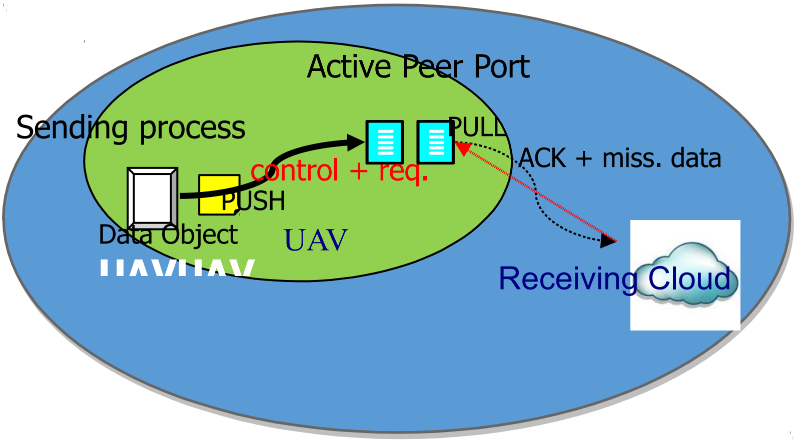

Figure 1 Operation with buffering at the Active Peer Port

3. **Sliding Window Protocol**. The protocol for maintaining data consistency will be explained in detail in the following section.
4. **Persistent communication in case of interruption**. In case of no connectivity, lost messages, or a change of the network, the receiving cloud pulls the missing data from the Active Peer Port when the connectivity is restored. In order to initialize, or restore the Sliding Window session, it uses the ticket associated with it, and the control messages specify the sequence numbers of the data packets to be retransmitted (Fig.1). It is obvious that continuously requesting lost messages introduces overhead to the communication so that the receiving peer gives up transient communication after not getting any message from the sender for a certain amount of time (e.g. 1 minute) and sends the request to the Active Peer Port to continue pushing all received data, without being requested. At this point, we get a persistent communication and the Active Peer Port functions as a proxy.

5. **Active Peer Port deletion**. After transmission has finished, the receiving peer resets the message sequence number and deletes the message buffer.

Sliding Window Protocol

The classical sliding window protocol is used for flow control in communication protocols, preventing the receiver's buffer to overflow, and to ensure the selective repeat of missing data. However, in case of interruption of the communication between the Active Peer Port and the receiving cloud, the sliding window protocol will ensure the selective transmission of delayed or lost messages. Furthermore, the Sliding Window Protocol includes the acknowledgment of already received data at the receiving cloud, so that this data can be removed from the Active Peer Port buffer. (see Fig. 2)

Practically, this means that when a connectivity is restored, the receiving peer sends a control message to the Peer Port confirming the last received consecutive data packet and, if applicable, the missing data packets to be selectively sent. The Peer Port's reply includes an acknowledgment and/or the data requested (called "piggybacking").

The buffer management at the Peer Port is organized in a queue data structure, inserting new data at one end and either deleting or sending old data at the other end.

System Architecture

The system architecture includes the following modules (Fig.3):

1. Forest fire detection system based on thermal and video camera. They are several papers describing forest fire detection using thermal camera [Shixing et al., 2010]. In our system, we are going to develop a thermal picture analyzing module based on neural networks. The main idea in this module is to allow learning from

typical patterns in order to detect a possible forest fire. [Shixing et al., 2010].

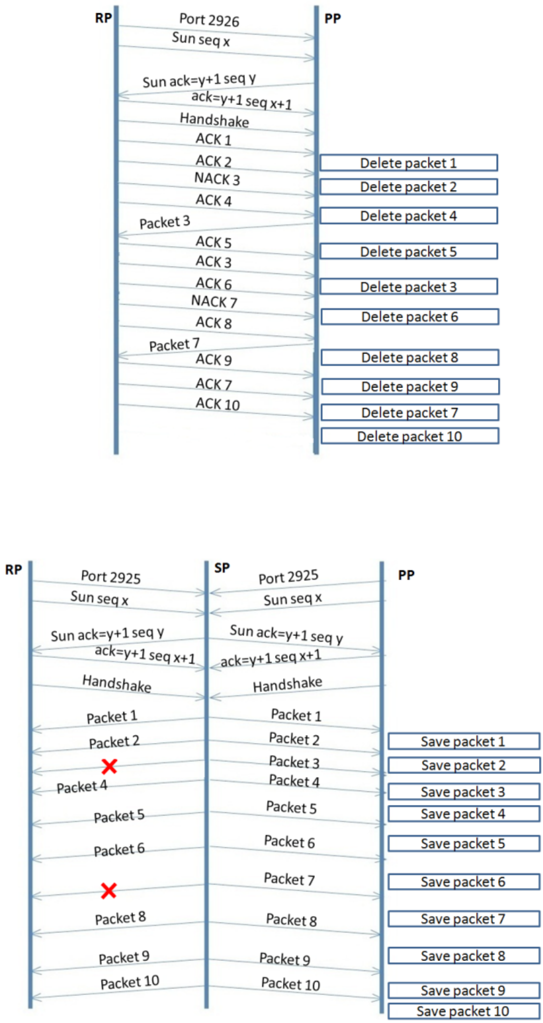

Figure 2 Sequence diagram of selected repeat protocol

Once a potential forest fire is detected, this module will send a fire alarm signal (including GPS coordinates) to the Active Peer Port

Active Peer Port

and will include the sensitive data. The sensitive data consist on thermal, as well as of video pictures or/and streaming video of the suspected forest fire. (Fig.3)

2. System for mapping the thermal pictures to video, and to google maps. In order to make a decision, a specialist needs not only the thermal and video pictures, and streaming media, but also the exact location of the forest fire, expressed in terms of google maps. Figure 3 gives an idea of this module which will be implemented on the CMC cloud. In this paper, we will not describe it in detail.

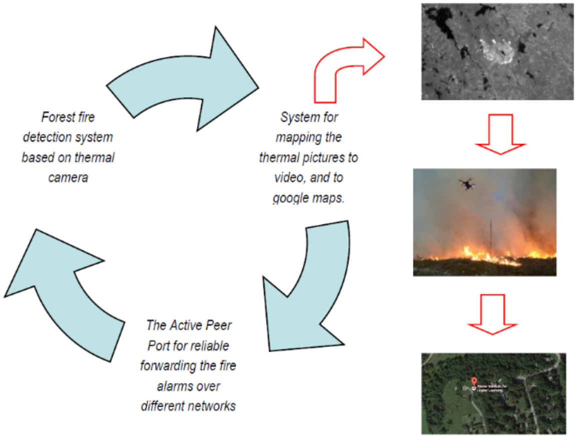

Figure 3 System Architecture on the UAV (left) and mapping of the thermal pictures to the video pictures, and to Google maps on the CMC cloud (right).

3. The Active Peer Port. As already described, it provides reliable delay tolerant delivery of the fire alarms and the associated data over different parallel wireless networks. The idea is to forward those data, while the UAV is flying in order to discover the best connectivity to the CMC cloud. Even, when the transmission is interrupted, or stalled, the Active Peer Port will restore it over a different communication channel using the Sliding Window Protocol described above.

Implementation

A drone from Erle Robotics has been selected and we started with the implementation of the basic communication alternatives. First, we tried to use the native drone processor, the so-called Erle-Brain, running Linux and providing USB interfaces for HSPA+3GPP, and other sticks. Because of the limited memory and processing capacity of the Erle-Brain, we decided to experiment in parallel with the idea to use an Android Smart Phone on the drone for communication, and for image processing. Our feeling is that the Smart Phone will provide a better platform for our implementation, because of his effective and compact technology, and more important, because of his low power consumption. Figure 4 shows our experimental set-up.

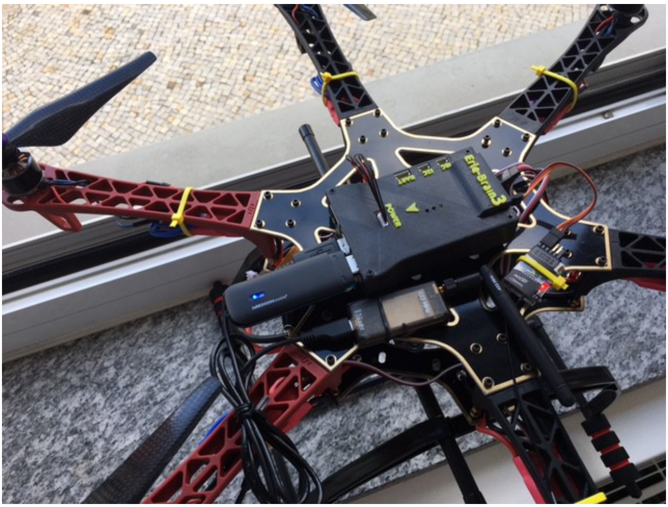

Figure 4 The experimental UAV allowing communication over HSPA+3GPP, WiFi, 433 MHz radio, and Bluetooth.

Conclusion

The main application that we are now experimenting with is data messages and file transfer. But the development of the

Active Peer Port prototype is currently in incipiency and there is research yet to be conducted as some questions are still unanswered. Especially the performance, though different wireless networks (GPRS, 3G, 4G, WiFi, WiMax, 433 MHz radio, LoRa) in rural areas have been partially tested and evaluated yet.

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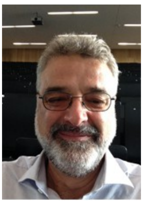

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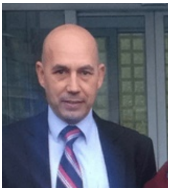

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