UAV system assistance in hazardous materials transport applications

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***Abstract* — Prevention of traffic accidents in transport using new technical achievements is one of the main topics in academic and industrial circles, especially due to the accelerated development of autonomous vehicles. Special attention is paid to the safety of transport of hazardous substances, such as hazardous waste. This paper describes one of the methods to improve communication between vehicles and vehicles and infrastructure in order to reduce traffic accidents during the transport of explosives and toxic substances. The possibility of complete monitoring of the transport of dangerous goods using Unmanned Aerial Vehicles (UAVs), which also enable communication between vehicles in areas of poor or no network signal coverage, is discussed. Simulation results indicate the reduced interrupt probability of communication in the network with UAVs.**

I. INTRODUCTION

Transport and storage of dangerous goods are processes of vital economic importance for any advanced and technologically oriented society. All goods that pose a risk to any human being's health, and whose properties may endanger the environment, are classified as dangerous goods. Despite the fact that society and the economy are making great efforts to improve the level of safety of transport of dangerous goods with technical and procedural measures, accidents happen. Unlike the transport of ordinary goods, accidents during the transport of dangerous substances can cause severe consequences for human health, the environment and property. Accidents during this kind of transport result in uncontrolled release of dangerous and harmful goods into the environment. Fires, explosions, high pressure and sudden release of contaminants lead to great casualties, injuries, destruction, material damage and environmental degradation for a long time with unforeseeable consequences. In particular, the impact of hazardous materials on the environment, in practice so far, has occurred at times when these transports were not monitored [1].

Having in mind the importance of that problem, it is necessary to introduce monitoring of the transport of dangerous goods by road, railways, water and air. This, among other things, fulfills the legal obligation prescribed by the states on whose territory the transport is performed. Moreover, continuous monitoring is required all the time during the transport. The basic type of monitoring can be provided by physical and technical monitoring in the form of accompanying vehicles with crews. But the use of advanced telegeomatic technologies has become substantial nowadays [2]. The development of modern technology has enabled the use of Global Positioning System - GPS locators, i.e. a special satellite vehicle tracking system allowing the tracking of vehicles by supplying their geographic position, so it is possible to track its movement in real time. Moreover, the transport could be equipped with a series of real time intelligent sensors that are able to detect conditions under which the transport is performed [3]. For example an accelerometer, a moving body acceleration measurement device, is used for various purposes: drop or load indication, the inclined angle in relation to the ground (slope), detection and measurement of vibration strength, etc. Likewise, a record of temperature and pressure changes, as well as attempts to unauthorized handling, on valves for example, can be monitored additionally.

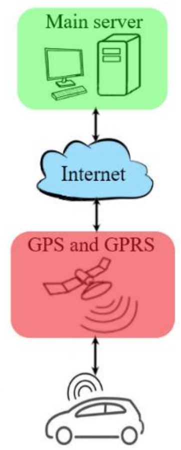

Figure 1. The components of the proposed architecture

Currently developed systems for transport monitoring of dangerous goods mainly consist of two main parts. The first part represents sets of hardware devices and software embedded into the vehicles, while the second part is a system responsible for receiving and processing data [4]. According to the Figure 1, the on-board system capture vehicle’s circumstances (temperature, pressure, speed, GPS coordinates, acceleration and so on) transmitting data wirelessly by a General Packet Radio Service - GPRS through Global System for Mobile – GSM, and finally connecting over the Internet to the main application server.

However, the main problem arises when a monitored hazardous substances transport comes to areas with low network or generally without network coverage, because in such cases it is exposed to additional risks. With the advent of Unmanned Aerial Vehicle - UAVs, commonly known as drones - aircrafts without any human pilot, crew or passengers on board, network coverage might be exceptionally improved and the way of communication in any part of the world could be facilitated [5].

II. UNMANNED AERIAL VEHICLES

Unmanned Aerial Vehicles have recently received significant attention by the civilian and military community, mostly due to the fast growth of UAV technologies supported by wireless communications and networking. The Federal Aviation Administration - FAA has released forecasts consistent with the emerging trends and structural changes. Aerospace Forecast predicted that the number of small UAVs in the U.S. commercial fleet would attain its peak over the next 5 years, from the present 1.44 million units to around 1.55 million units by 2025. This is possible because of decreasing equipment prices, improved technology and relatively easy maneuvering [6]. Namely, UAVs can be deployed quickly whenever and wherever required, which makes them ideal candidates to assist terrestrial networks when they suffer from poor connectivity. In cases like that, monitoring operations become easier with Wireless ad-hoc networks (WANET) in place. Wireless ad-hoc networks (WANET) are used for transport monitoring without using physical cables, where cooperation between WANET and flying objects provide better signal coverage.

A. Classification of wireless ad-hoc networks

WANETs being persistent and economical can be widely used in emergency situations because of their minimal configuration requirements and setup. They can link a small number of devices, so they become more practical than a traditional based network, offering an effective, low-cost way to communicate with nearby devices.

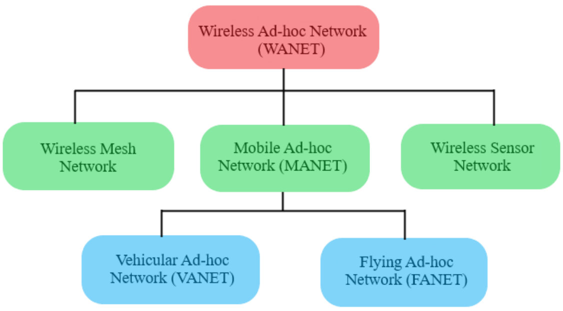

Figure 2. Hierarchy of wireless ad hoc networks

They are divided into three subcategories according to their use in various applications as shown in Figure 2. The categories are: Wireless Mesh Networks (WMNs), Mobile Ad-hoc Networks (MANETs) and Wireless Sensor Networks (WSNs). MANET is an infrastructure-less and self-configuring network of mobile nodes coupled through wireless links. Due to the movement of vehicles and drones as well as the frequent changes connection between nodes in the network, MANETs are used for transport monitoring.

Both VANET (Vehicular Ad-hoc Network) and FANET (Flying Ad-hoc Network) are subclasses of MANET. VANET is formed with vehicles as nodes in contrast to FANET where nodes are Unmanned Aircraft Systems [8]. The combination of these two networks allows complete control of the areas without a predefined network infrastructure, and it is discussed further in the paper.

B. FANET

Until recently, drones were operated individually, but today a large number of coordinated drones can work together, such as in low-coverage areas, where drone communication is of paramount importance. Different types of network protocols are used in drone communications, so the design of the network is determined by their application. In FANET, the movements of drones are very fast, which results in a very fast change in the topology of the network. Therefore, routing data among drones is challenging. Routing protocols should be able to dynamically update routing tables. FANET can also collect information from the environment, as in wireless sensor networks, which would be another traffic configuration [8].

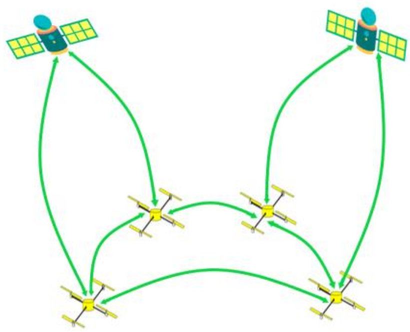

Figure 3. Communication between satellites and drones

When it comes to surveillance, safety reasons, or more broad outreach activities, satellite communication is also an excellent option to expand network with drones due to reliability and the guarantee of security of the wireless communication channels (Figure 3.) [9].

UAVs are envisioned to be used as flying aerial vehicles to both provide cost-effective wireless communications to selected areas and support the connectivity of terrestrial wireless networks and for ensuring long-term coverage to specific zones.

C. VANET

There are a lot of services provided by VANET but the most important among all is the road safety services for the reduction of road accidents by data sharing through the internet. There are two sorts of communication in VANET that is Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) characterized by high mobility and frequent topology changes as shown on Figure 4.

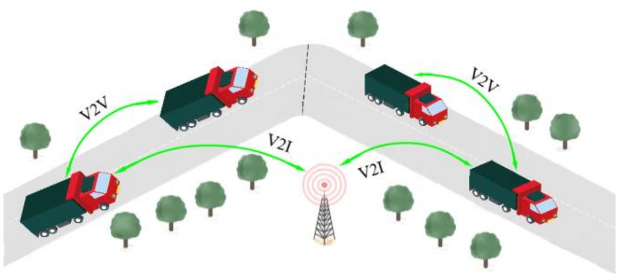

Figure 4. VANET communication

Wireless technology is advancing rapidly with time, and VANET is one of the most growing research areas. With the advancement and maturity of the VANET, there will be a great revolution in the field of wireless communication in terms of fast handovers, network availability, security, safety with the use of advanced applications etc.

In VANET, each vehicle can accept and transfer the messages with other vehicles or road infrastructure through the wireless medium. All participating vehicles can be considered as a wireless nodes or routers, allowing them to connect and communicate with each other in defined range.

When a vehicle falls out of the signal range, it will be dropped out of the network. That or any other vehicles can rejoin the network, when it comes in the signal range of the existing vehicles in the network. When it comes to safety, the requirement of safety messages is that they must be delivered to each neighboring node without delay within limited time. If a single event-driven message is lost or a safety message is delayed, it could end with dangerous circumstances.

Intelligent Transportation Systems have a standard for reducing inconvenience and avoiding danger situations like prevention and/or detection of various accidents. ITS can also be used for distributing information and data about the road maintenance, weather forecasts and road conditions along with emergency notifications [10].

III. THE USE OF UNMANNED AERIAL VEHICLES IN AREAS OF LOW NETWORK COVERAGE

Deployment of drones over the ground networks of vehicles is very important for overcoming the limitations of communication between vehicles. UAVs are deployed to assist VANETs as relays and forward data packets between vehicles when communication between vehicles on the ground is not possible.

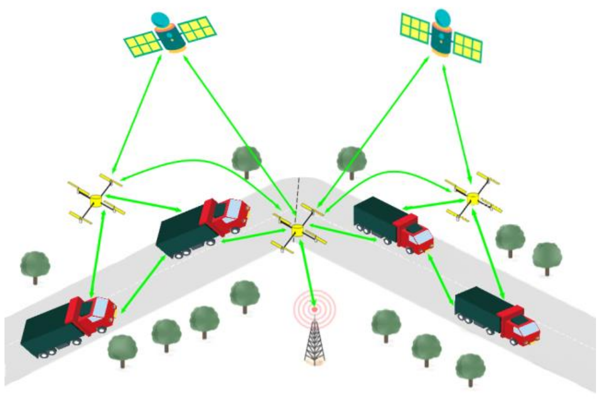

Figure 5. A completely covered area with network

A set of drones equipped with cameras and various other sensors placed in the sky, monitor a given geographical area and cooperate with land entities in the form of vehicles and road infrastructure in real time [5]. They are being set up to play the key role in case there is no connected route between the nodes and satellites to establish alternative solution.

However, the adjustable mobility of drones could be further optimized for placement in appropriate locations in accordance with ground outages [10]. In order to fully cover the area (Figure 5.), the number, distribution and connectivity of drones, the speed of movement to increase coverage, as well as the possibility of collecting, processing and storing large amounts of data should be taken into account. The use of drones over terrestrial networks, especially VANET, is becoming more common to overcome the limitations of communication between vehicles [5].

IV. PROBABILITY OF INTERRUPTION IN THE NETWORK

Communication between vehicles carrying hazardous materials on roads where signal coverage is poor, and when conditions between vehicles are not in Line of Sight (LOS) can be improved by using drones. We consider scenario presented in Fig 6. where communication between two vehicles is supported via UAV. The channel conditions between vehicles (V2V) are poor and without LOS, which leads to the fact that the channel gain can be modeled by exponential distribution. The drone would allow the better channel conditions on the formed links between UAV and vehicles, enabling LOS. Therefore, Rice distribution is used for simulation of V-UAV gain links.

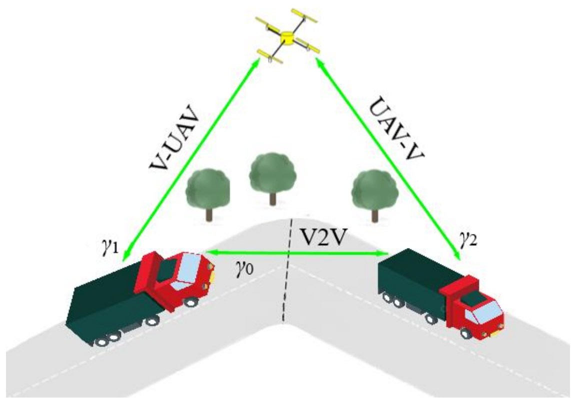

Figure 6. Internal communication between the drone and the vehicle

The outage probability of system consisting of two vehicles (without a drone), and in a system when the drone is used for relaying information between vehicles is shown in the Figure 7.

Simulation results for the probability of interruption are obtained for the case in which the gain of the channel between the vehicles is modeled by an exponential distribution, for a certain average signal-to-noise ratio (SNR), γ_0. The drone allows the conditions on the links it forms with the vehicles to be better than the direct link between the vehicles. In the simulation it is used that the average SNR on the drone and reception is $\gamma_1 = \gamma_2 = 4\gamma_0$ (Figure 7.). The use of drones allows the creation of a wireless channel with LOS between the drone and the vehicle. The results shown in the Figure 7. represent different cases, when K = 2, 5 and 7dB (where K is the ratio of the power of the LOS component to the diffuse component).

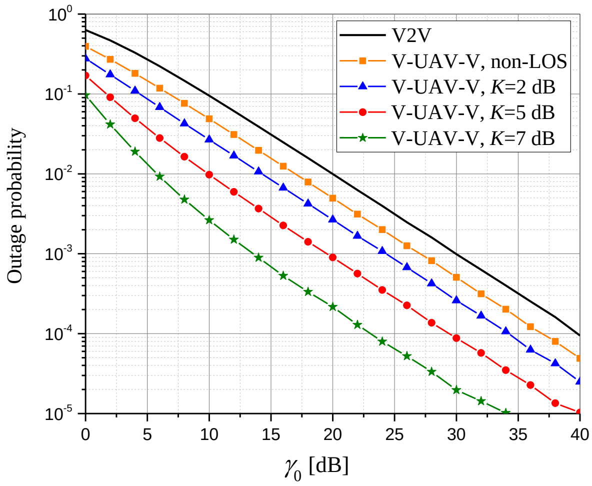

Figure 7. Outage probability of considered system

Analyzing the results it can be concluded that for an interruption probability of 10-3, it should be ensured that the signal strength on the receiving vehicle is 1000 times higher than the noise power, while in a system with a drone, i.e. this ratio is equal to 400 when K = 5dB. In the scenario where the drone is used to provide the LOS component in the connection between the UAV and the vehicle, in order to achieve the mentioned probability of interruption, less transmission power is required compared to the system without its use.

V. Conclusion

The problem of communication between vehicles in the transport of hazardous materials, in environments without good quality of service, can be significantly improved by using UAVs. For these purposes, FANETs are also convenient due to their low latency and high reliability of communications. Drones are used in communication system as relays or base stations for information transmission, but at the same time for monitoring the environment. Scenarios with drones in transport of hazardous materials are presented while the solutions for overcoming the problem of communication reliability are investigated. The outage probability, which depends on the characteristics of the wireless channel formed between the vehicle and the drones, was examined. A comparison of the probability of interruption when communication between vehicles is poor due to environment obstruction and when drones are included in the network is given. In order to overcome the problem of low signal network, communication based on UAVs in transport of hazardous materials can be vitally important to give alert about conditions on the roads or to prevent possible traffic accidents.

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