UAV-Enabled Intelligent Transportation Systems for the Smart City: Applications and Challenges

Hamid Menouar, Ismail Güvenc, Kemal Akkaya, A. Selcuk Uluagac, Abdullah Kadri, and Adem Tuncer

Due to their mobility, autonomous operation, and communication/processing capabilities, UAVs are envisaged in many ITS application domains. The authors describe the possible ITS applications that can use UAVs, and highlight the potential and challenges for UAV-enabled ITS for next-generation smart cities.

ABSTRACT

There could be no smart city without a reliable and efficient transportation system. This necessity makes the ITS a key component of any smart city concept. While legacy ITS technologies are deployed worldwide in smart cities, enabling the next generation of ITS relies on effective integration of connected and autonomous vehicles, the two technologies that are under wide field testing in many cities around the world. Even though these two emerging technologies are crucial in enabling fully automated transportation systems, there is still a significant need to automate other road and transportation components. To this end, due to their mobility, autonomous operation, and communication/processing capabilities, UAVs are envisaged in many ITS application domains. This article describes the possible ITS applications that can use UAVs, and highlights the potential and challenges for UAV-enabled ITS for next-generation smart cities.

INTRODUCTION

Intelligent transport systems (ITSs) are considered to be one of the major building blocks of any smart city [1]. Indeed, road infrastructures have been benefiting from information and communication technologies (ICT) for decades. Despite the advanced level of the presently deployed ITS solutions, the technology is continuously evolving. Next generation ITS technologies, such as connected and autonomous vehicles, are finishing their last phase toward large-scale worldwide deployment. Testing of both technologies on public roads has already started in many countries around the world, and serious efforts are ongoing to regulate and mandate such near-future technologies. As the autonomous and inter-connected vehicle penetration in traffic increases, many new services and applications will be enabled.

Unmanned aerial vehicles (UAVs), a.k.a. drones, have been used in the military for many years. Recently, there has been a drastic increase in the use of UAVs in other fields such as precision agriculture, security and surveillance, and delivery of goods and services [2]. For instance, Amazon and Walmart have been working on a new platform that uses UAVs to deliver shipments to customers over the air (http: //www.amazon.com/b?node=8037720011). Similarly, DHL of Germany and China's largest mailing company have started their experiments with a fleet of UAVs that could deliver around 500 parcels every day. Use of UAVs for daily consumer-oriented services is expanding and becoming a reality.

Automation of the overall transportation system cannot be achieved through only automating the vehicles. Indeed, other components of the road and the end-to-end transportation system, such as the field support team, traffic police, road surveys, and rescue teams, also need to be automated. Automation of those components can be achieved by using smart and reliable UAVs, as shown in Fig. 1. For example, a road support team can be replaced or supported by a set of UAVs that could fly around the location of an incident to provide basic support, or at least to send back a survey report about the situation. Moreover, a traffic police officer can also be replaced or supported by UAVs, which can fly over vehicles on a highway to monitor and report possible traffic violations.

ITS UAVs can provide an efficient means not only to enforce traffic rules and support traffic police on the ground, but also to provide road users with efficient information on traffic (i.e., intelligent traffic management). The ITS UAVs can be enabled with a dedicated short-range communication (DSRC) interface, which will be included in future vehicle models providing vehicle-to-vehicle and vehicle-to-infrastructure (V2X) communications (http://www.its.dot.gov/DSRC/dsrcfaq.htm). Such technology will allow the ITS UAVs to communicate through a direct wireless link with vehicles in proximity to better enforce road safety and support traffic efficiency.

Some of the applications that can be enabled by ITS UAVs include, but are not limited to, flying accident report agents, flying roadside units (RSUs), flying speed cameras, flying police eyes, and flying dynamic traffic signals. These examples require multiple UAVs to fly together, collaborate, and coordinate to execute a specific mission. When acting in a group, UAVs could overcome the limitation of their energy efficiency if optimal coordination algorithms are used, for example, to perfectly share the tasks among all UAVs. In the case of a flying accident report agent, as shown in Fig. 1, one UAV could fly to the accident location and issue a report/alarm (e.g., video), then

---

Hamid Menouar and Abdullah Kadri are with Qatar Mobility Innovations Center, Qatar University; Ismail Guvenc, Kemal Akkaya, A. Selcuk Uluaga, and Adem Tuncer are with Florida International University; Adem Tuncer is also with Yalova University.

Digital Object Identifier:
10.1109/MCOM.2017.1600238CM

0163-6804/17/$25.00 © 2017 IEEE

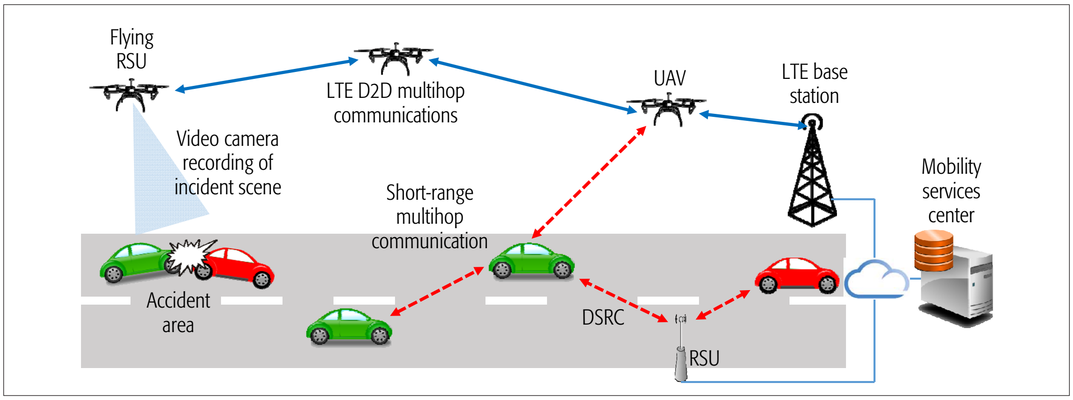


Figure 1. Example usecase scenario for UAV-enabled ITS: UAVs can be used as flying RSUs to capture video recordings of the incident scene and then relay them to a mobility services center.

Vehicles automation is one step forward toward the fully automated transportation networks as there will be still a need to automate other actors of the transport network such as traffic police agents, highway maintenance, and support teams.

land and transmit its report/alarm through other UAVs via device-to-device (D2D) multihop communications. Another nearby UAV or an RSU that has access to the network (e.g., 4G LTE) can then forward the report to the relevant entity. Designing optimal coordination algorithms is one of the challenges that need to be tackled to enable ITS UAVs.

Efficient data routing over flying UAVs, vehicles, and roadside infrastructure is another new research area that should be considered for enabling UAV-enabled ITSs. For example, flying communication nodes (i.e., UAVs) are free to move in a 3D space without restriction to road topology such as in a vehicular network. This brings some flexibility from the data routing point of view, as a flying node can fly to a specific location to strengthen a weak link or fix a broken one. Finally, security and privacy pose serious challenges to UAV-enabled ITS infrastructures within a smart city environment. One particular challenge stems from quick and efficient communication decisions that need to be made among the participants of the UAV-enabled smart city ITS infrastructure. As such, it is difficult to accommodate strong security and privacy mechanisms that are often hungry in terms of processing time. Another pertinent challenge is to preserve the privacy of sensitive information (e.g., location) from vehicles and other drones. Hence, both efficient security and privacy preserving technologies need to be adapted for the UAV-enabled ITS infrastructure in smart cities.

The rest of this article provides an overview of the potential of integrating UAVs with connected and autonomous vehicles to enable fully automated ITSs and discusses related challenges in further detail.

ITS FOR SMART CITIES

Thanks to the advancements in computer engineering and proliferation of ICT, smart cities have recently been transitioning from concept to reality. Smart cities offer improved quality of life for their citizens by providing fully or semi-automated management systems for the assets that exist in the city, such as transportation systems, the electricity network, residential homes, and offices. In future smart cities, almost every object around us will be connected to the the Internet via the Internet of Things (IoT) technology [3].

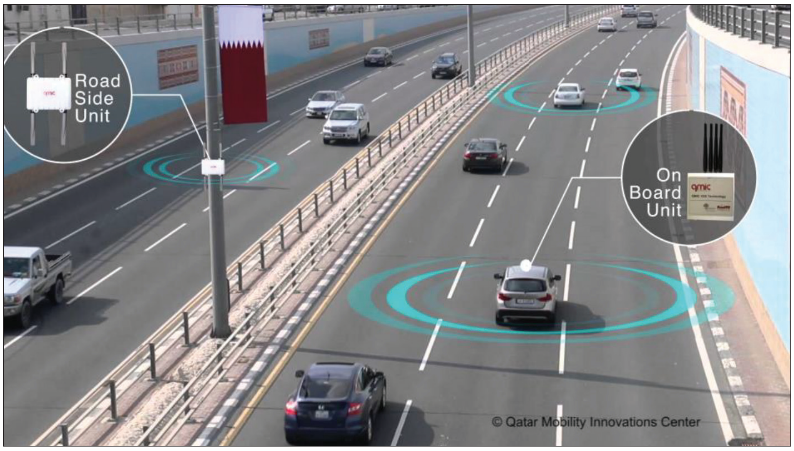
The ITS constitutes one of the oldest smart city technologies, and it has been deployed in many cities around the world. For example, in Madrid, Spain, all the public transportation systems and components, including train, tramway, buses, and bus stops, are connected to a central control room where data are collected and processed in a real-time manner to provide the end users with smart and efficient services and applications. As a user of public transportation, you can be informed about the bus arrival time at the stop next to your home, which is accurately calculated based on the real-time traffic on the bus route.

The next generation of ITS technology will be enabled by the proliferation of connected and autonomous vehicles. Connected vehicles technology provides vehicles on the same road the means to communicate and exchange real-time data that can be used to improve the safety functionalities and therefore improve road safety. Along with other sensing technologies, connected vehicles can be used to enable driverless vehicles, which will completely change the way we travel. For example, there will be no need to own a car as you could schedule an automatic pickup by an automated car every time you need a ride. Also, there will be no need to waste time searching for a parking spot at the final destination; the automated car can drop you off and go look for a parking spot. Such applications of connected vehicles are already being tested around the world. A large-scale pilot project for connected vehicles in the city of Doha, Qatar, is illustrated in Fig. 2.

Vehicle automation is one step forward toward fully automated transportation networks, but there will still be a need to automate other actors of the transport network such as traffic police agents, highway maintenance, and support teams. The last mile toward fully automated end-to-end transportation systems can be enabled by using automated UAVs.

APPLICATIONS OF UAVS IN SMART CITIES

As explained earlier, there is high potential for UAVs to complement autonomous driving and enable fully automated roads. Many new ITS-related applications could be enabled by using automated UAVs to either help improve traffic, bring better safety and security on the road, or enhance the comfort of the driver. Before being able to utilize UAVs in such applications, there are still some serious issues to tackle. These issues include limited energy, processing capabilities, and signal



© Qatar Mobility Innovations Center

Figure 2. Deployment of RSUs and onboard units (OBUs) in Doha, Qatar, to enable testing of vehicle-to-roadside-unit and vehicle-to-vehicle communications.

transmission range. Taking into account the technology revolution in the past decades, there is great potential that the above limitations in UAV utilization will be cleared in the near future. In the following sections we list and describe only a few of these applications.

Flying Accident Report Agent

When a traffic accident occurs, the lives of the involved persons depend on the rescue team efficiency, which directly relies on how fast the rescue team can reach the accident scene. When the closest rescue team terminal is located too far from the accident location, the time for the rescue team to reach the scene can be too long. In some cities, the rescue team uses helicopters to reach accidents located in isolated and rural areas. Such a solution has high related cost, making it unsuitable for many cities and scenarios. Traffic congestion on the way to or around the accident location, which can also be caused by the reported accident, is another crucial factor that can delay the rescue team.

In this context, UAVs might be a good complementary solution to help the rescue team reach the accident scene within the shortest time. Indeed, as shown in Fig. 3a, the rescue team can be equipped with an automated UAV that can quickly fly over the traffic until reaching the accident location. It is also possible to have a number of UAV stations deployed around the city from which UAVs can take-off for a mission. In that case, it is required to have some intelligence to select the right UAV station for a specific mission. This selection can be made based on the distance between the accident location and available UAV stations, number of available UAVs at each UAV station, and so on. When the UAV reaches the accident location, it can send a detailed report about the situation, for example, the number of involved persons and their situation along with their profiles, which can be supported by photos and videos. The UAV can also be used to establish a real-time communication channel (voice and video if possible) between the accident site and the rescue team still on their way (and also the team in the control center). Such a communication channel can help the rescue team to provide remote instructions if needed as well. The Flying Accident Report Agent can also be used to provide the accident site with a first aid kit while waiting for the rescue team to arrive.

Flying Roadside Unit

In the near future, our cars will be equipped with DSRC technology to let the vehicles communicate through a DSRC channel (similar to WiFi) with other vehicles and road infrastructure in the surrounding environment. Such an emerging technology becomes efficient when the number of equipped vehicles on the road reaches a certain threshold. At the same time, there will be a need for RSUs to be installed on the road to support the communication among vehicles. Additionally, the RSUs are needed in some places such as intersections to support the DSRC communication, which cannot go through obstacles like nearby buildings. In fact, DSRC operates over 5.9 GHz, which is known to be weak in penetrating obstacles. Most of the RSUs will be installed on the roadside at static locations along with a few mobile RSUs. For example, road operators can equip their maintenance and field service vehicles with RSUs that can operate in both static and mobile modes. If an RSU is installed on a highway maintenance vehicle, it will be in static mode when the maintenance vehicle is parked and then can switch to mobile mode when the vehicle starts driving on the highway.

Similar to a highway maintenance vehicle, a UAV can be equipped with DSRC to enable a flying RSU, as shown in Fig. 3b. The flying RSU can fly to a predefined location to execute a specific application. For example, consider an incident on the highway at a section that is not equipped with any RSU. Then the highway operator in the control center can actuate a UAV to fly to the incident site and land at the appropriate location to broadcast the information over the air and inform all approaching vehicles about the incident.

Flying Police Eye

Traffic police are getting more equipped with the latest technologies to enable safer traffic on the roads. Speed and CCTV cameras remain the most used technologies to enforce traffic rules. If a driver exceeds the speed limit, he/she can be caught by either a static or mobile speed camera, and if a driver runs a stop sign, he/she can be caught by a nearby CCTV camera. As time goes by, the static cameras become less efficient as drivers get to know about them and adjust their driving behaviors when approaching the area under the angles of those cameras. This motivated the adoption of mobile cameras that can be installed at different locations (sometimes unknown locations) to surprise drivers.

Indeed, the latest technologies enable speed cameras to be fully mobile and can be operated while moving. These state-of-the-art mobile speed cameras are usually embedded on police vehicles that drive on the road to catch vehicles violating the traffic rules in the surrounding areas. The same technology can be embedded on a UAV, as in Fig. 3c, to enable a flying speed camera or for other traffic enforcement applications. We can think about fully automated UAVs that are able to execute all or specific tasks of traffic police agents. For example, a UAV can fly over a road and stop a specific vehicle for identity and a regular driving license check. The UAV can stop a vehicle by holding a traffic light that can be turned to red in front of the vehicle. The same UAV can fly over a highway and catch any vehicles for speeding or breaking traffic rules. Here may arise the issue of the limitation in the maximum speed of a UAV vs. a fast vehicle driving on a highway. This limitation can be overcome by letting the UAV fly at high altitude to get an overview, which compensates the limitation in the speed.

USE OF UAVS FOR ITSS IN SMART CITIES

Use of UAVs for ITS applications, such as roadside condition surveys or counting vehicles in traffic, has recently been getting more attention in the literature [4, 5]. In this section, we study three different aspects for ITS applications of UAV deployment optimization, data routing, and cybersecurity and privacy.

UAV LOCATION DEPLOYMENT AND PATH PLANNING

Deployment of RSUs for vehicular ad hoc network scenarios has been studied in earlier works [6, 7]. On the other hand, the use of UAVs as mobile aerial RSUs has not been considered to the best of our knowledge. As shown in Fig. 4a, we envision future ITS deployments that not only consist of ground RSUs, but also flying RSUs that are carried at UAVs. Such flying RSUs will bring the capability of dynamically and optimally placing them using UAVs, considering various cost functions and other criteria. For example, in the case of an accident, UAVs may quickly arrive at the incident scene and collect critical information from nearby vehicles. In order for UAVs to be used for longer time periods in ITS applications, the use of recharge stations will be critical. To solve such an issue, we may either charge UAVs while they are not actively serving, or swap their empty batteries with charged ones to minimize interruptions in UAV utilization. To this end, joint deployment of UAVs, recharge stations, and ground RSUs becomes an intricate optimization problem, as outlined in Fig. 4a.

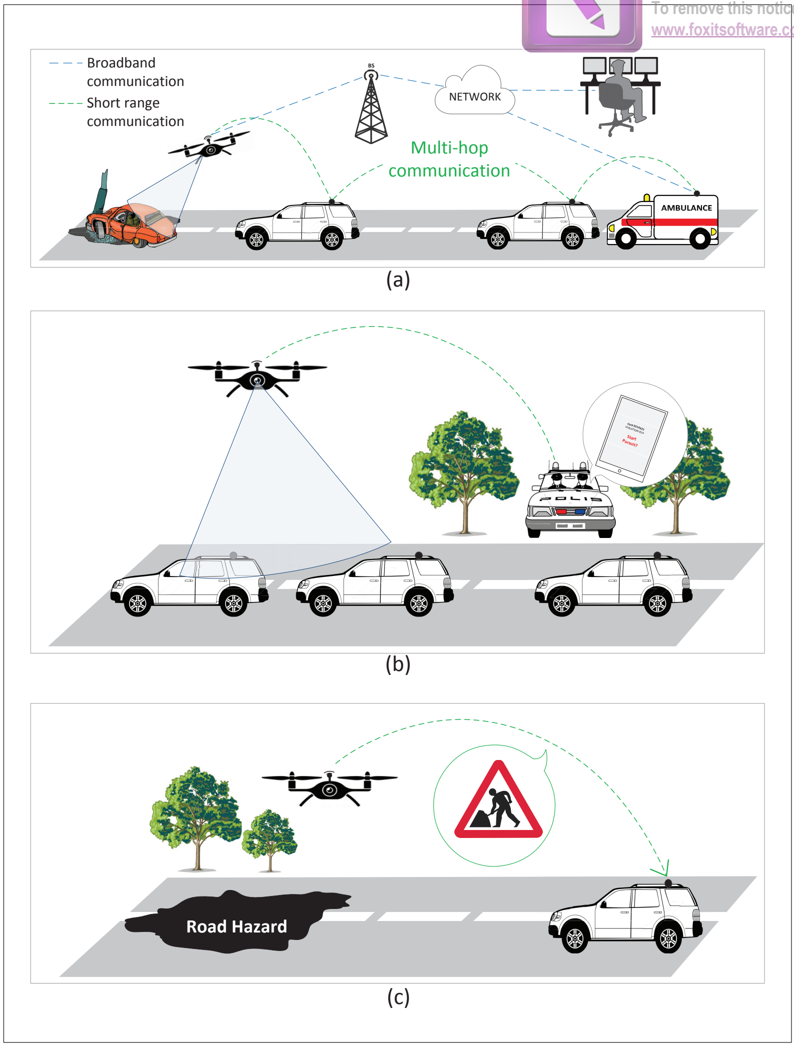


Figure 3. Examples of UAV applications in ITS: a) a UAV is used to provide the rescue team an advance report prior to reaching the incident scene; b) a UAV is used by police to catch traffic violations; c) a UAV is used as a flying RSU that broadcasts a warning about road hazards that have been detected in an area not pre-equipped with an RSU.

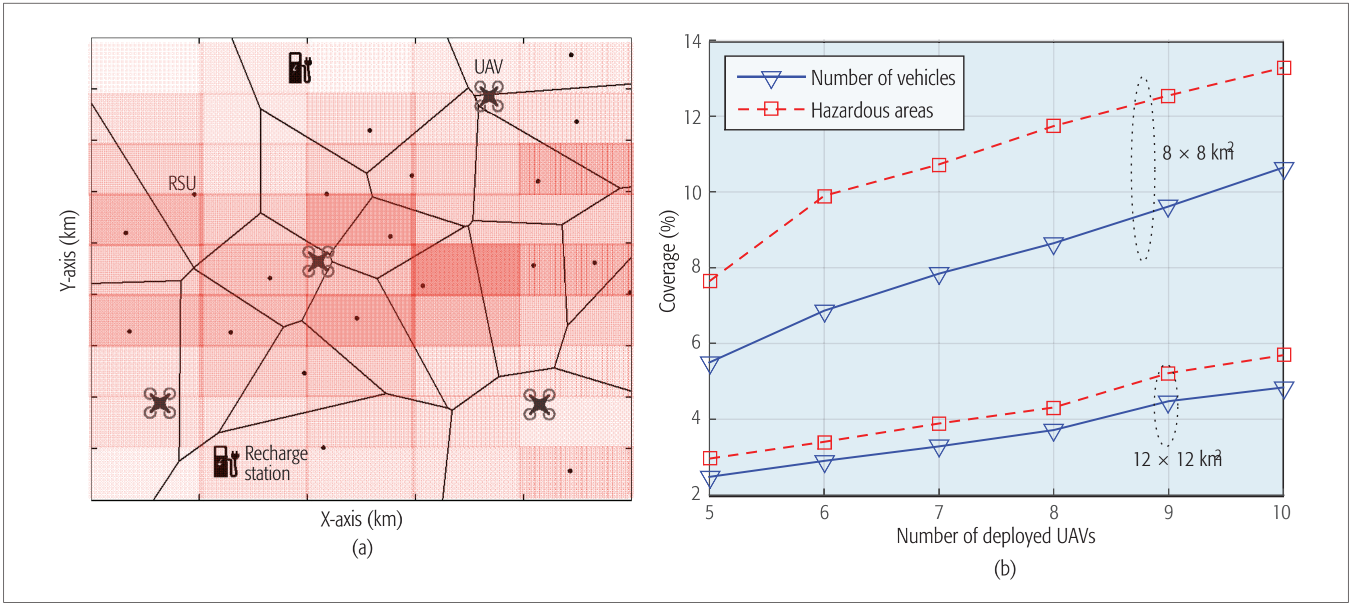


Figure 4. a) Placement of RSUs, UAVs, and recharge stations for ITS scenarios; b) coverage percentage in terms of number of vehicles and hazardous area, due to deployment of varying numbers of UAVs.

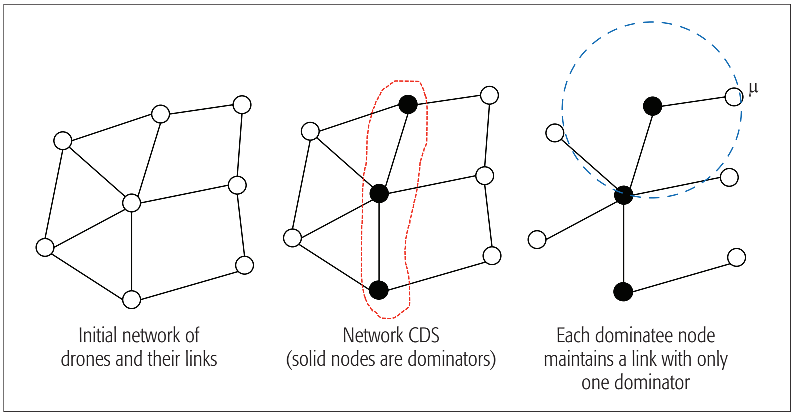


Figure 5. CDS formation for an ad hoc network of UAVs in ITS. The links among black nodes (e.g., dominators) are maintained all the time. The white nodes can have flexibility of moving further as long as they maintain their links with their dominator nodes within their transmission ranges (blue circle).}

Here, we introduce a preliminary framework for deployment optimization of UAVs in ITS scenarios. Let $\mathcal{I}$ and $\mathcal{R}$ denote the set of intersections and set of road segments, respectively, in a road network.

Then UAVs can alleviate deployment costs of RSUs with minimal degradation in performance. More formally, under the given deployment budget constraint B_{tot}, we can define the following optimization problem for joint RSU and UAV emplacement:

$$\max \sum_{j=1}^{N_R} \sum_{k=1}^{N_{SS}(R_j)} W_{SS}(j,k) I_{RSU}(j,k) I_{UAV}(j,k) + \sum_{i=1}^{N_I} W_I(i) I_{RSU}(i) I_{UAV}(i), \qquad (1)$$

where N_R and N_{SS} are the total number of road segments and the total number of road sub-segments, respectively, while I_{RSU} and I_{UAV} are indicator functions that are 1 if a sub-segment or intersection is covered by a RSU/UAV and 0 otherwise. Moreover, the weight $W_{SS}(i, j)$ of each sub-segment in road R_i can be written as a function of accident frequency, vehicle count frequency, and connection time for RSU location optimization. A similar metric $W_I(i)$ can also be defined for the intersections. Given this optimization framework, various algorithms, such as genetic algorithms, ant colony optimization, bee colony optimization, and particle swarm optimization, can be used to find the optimum RSU and UAV locations. In [7], a related and simpler problem of deploying only the RSUs has been studied at QMIC, Qatar, without the involvement of UAVs. Among the Knapsack and PageRank algorithms investigated in the article, Knapsack is observed to yield better performance in terms of covering hazardous zones as well as the connectivity of the vehicles for large-scale deployment.

We performed Matlab computer simulations for deployment optimization of UAVs for a representative scenario, and the simulation results are shown in Fig. 4b. We implemented an ITS deployment framework similar to the ITS scenario in [7] where no UAVs have been considered but optimization of RSU placement has been evaluated. Simulations are carried out for urban areas with two different sizes, 8 × 8 km^2 and 12 × 12 km^2. The communication coverage area of UAVs is considered to span a circle with a radius of 500 m (see, e.g., [8]). For simplicity, it is assumed that each sub-segment length is equal to the communication coverage of UAVs. Therefore, dividing roads into sub-segments can better approximate the real map [9] and also provide more UAV deployment choices. For distributing the accidents and vehicles, we consider a distribution where the likelihood of an accident and number of vehicles change from one road/intersection to another. This is a more realistic scenario where accidents are more likely to happen around intersections than in the sub-segments [6]. Numbers of vehicles and accidents are modeled as Poisson distributions.

The results in Fig. 4b show the coverage percentage for the number of vehicles and coverage of hazardous areas under different numbers of UAVs, which are placed in such a way as to maximize Eq. 1. For simplicity, the impact and optimization of RSUs and recharge station placement is not included in the results, and they are left for future work. Hazardous areas have been considered as areas with more traffic accidents. Results show that coverage percentage of hazardous areas is always larger than that of the number of vehicles. For example, if the number of deployed UAVs is increased from 5 to 10 for an 8 × 8 km^2 area, coverage percentage for vehicles can be improved from 5.6 to 10.6 percent, while the coverage percentage for hazardous areas is improved from 7.8 to 13.4 percent. Moreover, using the same number of UAVs in a larger 12 × 12 km^2 area significantly reduces the coverage percentages in both scenarios, with a larger degradation in the coverage percentage of hazardous areas. Further work is needed to study different spatial distributions of hazards and traffic densities and deployment optimization techniques of UAVs for different scenarios.

DYNAMIC COORDINATION AND DATA ROUTING

UAVs may act as relaying nodes or traffic monitoring tools in ITS applications for smart cities. In such cases, UAVs need to coordinate the tasks with each other and with the vehicles on the ground. This coordination needs to rely on the ability to maintain communications, in particular among the swarm of UAVs. In other words, the connectivity of the UAV network needs to be maintained at all times. Assuming that the network is modeled as a unit disk graph in 3D, we can maintain such connectivity by building a backbone of the UAV network and keeping it connected at all times.

To enable this, we propose using the notion of a connected dominating set (CDS) from graph theory. The UAVs that will be part of the CDS will need to follow a group-based mobility model based on the destination location. The UAVs that are not part of the CDS will have the flexibility to be connected to the core network (i.e., CDS) via a single link. Their movement will be constrained by their transmission range, as seen in Fig. 5. For safety applications, real-time communication is crucial, and thus, UAV u may only move within the transmission range of its dominator to maintain its connection with the rest of the network. For other application scenarios where real-time communication is not crucial, UAV u may leave that range, collect data, store it, and then come back to forward the data to its *dominator* when it is within the communication range of its dominator.

In terms of end-to-end data routing among UAVs and other vehicles, there is a need for a routing protocol since multiple hops can be exploited due to the limited radio ranges. While vehicular communications plan to rely on the IEEE 802.11p and DSRC standards [10] as the underlying link-layer communication protocol for UAVs, this will not be enough in the case of multiple hops to reach an RSU or other UAVs. There has been extensive research on routing for this type of network in 2D, referred to as mobile ad hoc networks (MANETs). Some of the ideas can be applicable in this context. However, the challenges of 3D environments and mobility patterns need to be taken into account. Despite a large number of works, there are not many standards used today for such multihop routing. IEEE 802.11s is one of the standards that are IP-based and can be used with different MAC layer protocols [11]. The nice feature of this standard is that it can be used with IEEE 802.11p and thus can be interoperable with the upcoming DSRC standards. IEEE 802.11s mesh standard can form a mesh among the UAVs to provide multihop routes to certain destinations. In this case, there will be an RSU acting as the gateway and the remaining UAVs will be the wireless mesh nodes in terms of the 802.11s standard naming conventions. The vehicles will then be able to connect any of these mesh nodes as clients.

Cybersecurity and Privacy

The provision of security and privacy for any UAV-enabled smart city ITS infrastructure and its applications in smart cities is extremely important. As future ITS and road safety systems will consist of interconnected systems of heterogeneous systems including UAVs, vehicles, and roadside infrastructure, the UAVs will carry, generate, and hand over valuable sensitive information about the users of these systems among themselves. For instance, vehicle location and speed information can be tracked and leaked to adversaries for malicious purposes. Even benign UAVs can be manipulated to perpetrate attacks on sensitive ITSs and road safety data. Hence, any sensitive data needs to be protected properly against third parties [12].

One promising technique for providing privacy is to utilize the emerging privacy preserving technologies [13, 14] (e.g., homomorphic encryption schemes). A typical scenario of fully homomorphic encryption (FHE) is illustrated in Fig. 6. The user sends the information encrypted with public key *pk* by function *Encrypt* to the server. The encryption scheme ε has an algorithm $Evaluate_\varepsilon$ that, given plaintext $\pi_1, \pi_2, ... \pi_t$, for any valid ε, private, public key pair (*sk*, *pk*), any circuit *C*, and any ciphertext $\psi_i \leftarrow Encrypt_\varepsilon(pk, \pi_i)$, yields $\psi \leftarrow Evaluate_\varepsilon(pk, C, \psi_1 ... \psi_t)$ such that $Decrypt_\varepsilon(sk, \psi) = C(\pi_1, \pi_2 ... \pi_t)$. The server in the cloud does operations on the encrypted numbers by function *Evaluate* with public key *pk* and outputs ψ. The server sends □ back to the user. The user then decrypts ψ by function *Decrypt* with his/her private key *sk* and obtains the result of $C(\pi_1, \pi_2 ... \pi_t)$. In this way, the server conducts the desired operation for the user without acquiring any plaintext. For example, a vehicle or UAV can authenticate themselves to a particular UAV or roadside infrastructure unit, which should be oblivious to sensitive data such as IDs, locations, and other pertinent data.

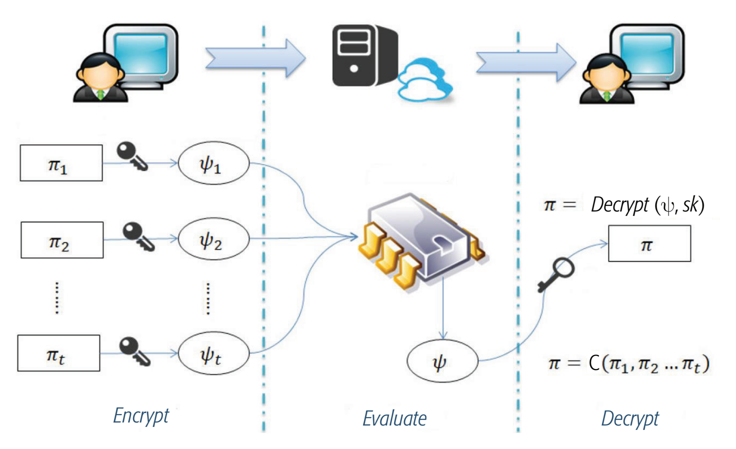


Figure 6. An illustration of Fully Homomorphic Encryption: The user (left) (e.g., UAV, vehicle), the server (right) (e.g., UAV, road-side infrastructure), and fully homomorphic operation ($\psi \leftarrow Evaluate_\varepsilon(pk, C, \psi_1 ... \psi_t)$).

Although FHE systems are becoming a viable technology with recent developments on their practicality, specific aspects of UAVs such as swarm, mobility, and autonomy should also be carefully considered in adapting the privacy-preserving technologies.

In addition to privacy, another challenge is to provide flexible and configurable security that can accommodate the needs of different road safety and UAV-enabled ITS applications swiftly. In other words, the fact that decisions need to be made very quickly among the UAVs, RSUs, and vehicles to meet the delay requirements of the ITS applications pose a specific challenge to accommodate strong security and privacy mechanisms that are often hungry in terms of processing time.

Deployment Issues and Challenges

There may be several deployment challenges in the utilization of UAVs for ITS applications. Regulations related to operation of UAVs may restrict how UAVs can be used for ITS scenarios. As noted in [15], integration of UAVs into national airspace requires that "UAVs function as if there were a human pilot onboard," and this is ensured through regulations by national authorities. For example, the Federal Aviation Authority (FAA) in the United States requires small UAVs to fly under 400 ft with no obstacles around, maintaining a line of sight between the pilot and the UAV at all times, not flying UAVs within 5 mi from an airport (unless permission is received from the airport and control tower), avoiding endangerment of people or aircraft, and not flying near people and stadiums. On the other hand, there may be the possibility of receiving a Certificate of Waiver or Authorization (COA) from the FAA for getting an exemption on the use of UAVs for ITS applications.

Energy limitation is another challenge. Indeed, the battery life of typical UAVs is usually less than half an hour, which introduces challenges for ITS operations with UAVs due to limited flight time. On the other hand, recent developments in battery technologies such as enhanced lithium-ion batteries and hydrogen fuel cells, more energy-efficient designs of UAVs, and the use of alternative

While UAVs have a potential to be one of the major components of future smart cities, there are also several research and implementation challenges ranging from battery limitations to UAV flight regulations. We expect that academic and industrial research and development activities will pave the way toward effective integration of UAVs into future smart cities.

energy sources such as solar energy to extend flight missions, UAVs may fly on the order of several hours in the future.

Another challenge is linked to the maximum speed a typical UAV can reach when compared to the speed of a vehicle driving on a highway. This can cause issues to some applications like the Flying Police Eye, as the ground speed of a UAV may be less than the speed of a tracked vehicle. Such a challenge can be overcome by letting the UAV fly at a high altitude, benefiting from a high view that can compensate the limitation in the speed.

Similar to any other connected network of nodes, when enabling a network of UAVs we need to be careful about security and privacy. This is obviously another serious challenge when applying UAVs to ITS. Indeed, the consequences may be high if such UAV-based ITS systems or applications are hacked. Finally, truly autonomous operation of UAVs in an ITS scenario is a big challenge, since it requires sensing of humans and obstacles to avoid collisions. In a large-scale ITS scenario with many UAVs, a human supervisor may control a swarm of UAVs that may simultaneously operate in different parts of a city. Since the attention span of a supervisor may be limited, there should be a balance between supervisor intervention and autonomous operation of UAVs. This trade-off is referred to as autonomy spectrum in [16], which provides 10 different levels of UAV swarm control ranging between fully autonomous and fully supervisor-controlled operation.

CONCLUSION

The concept of ITS is expected to move into reality in emerging smart cities. In this article, we study the applications, deployment optimization, and security/privacy challenges for the use of UAVs in ITS scenarios. While UAVs have the potential to be one of the major components of future smart cities, there are also several research and implementation challenges ranging from battery limitations to UAV flight regulations. We expect that academic and industrial research and development activities will pave the way toward effective integration of UAVs into future smart cities.