

Research Article

A Dual-Mode Medium Access Control Mechanism for UAV-Enabled Intelligent Transportation System

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With the exponential growth in technologies for the vehicular Internet of things applications and high demands for autonomous road vehicles, future transportation systems are projected to be revolutionized on a global scale. This new landscape requires a stable, flexible, and business-friendly base of connectivity, networking, and computing technology, in which Unmanned Aerial Vehicles (UAVs) can play an important role. A UAV-enabled Intelligent Transportation System (ITS) can provide a cost-effective communication solution to improve the safety and efficiency of the transportation system, particularly if the data traffic is nonhomogeneous and nonstationary. Typically, wireless is the communication medium between vehicles and UAVs in an ITS setting, which is based on the IEEE802.11p MAC protocol adopted by car manufactures. However, the IEEE 802.11p MAC protocol is modified solely for omnidirectional antennas, which restricts network coverage, delay, and throughput. In comparison, the directional antenna has greater network coverage, spatial reuse, and bandwidth. In addition, a multiaccess edge computing (MEC) facility at the backhaul link will provide ultralow latency and high bandwidth services to meet the increasingly growing demand for latency-sensitive vehicle applications such as vehicular video data analytics, autonomous driving, and intelligent navigation. Therefore, this article aims to propose a novel dual-mode MAC protocol that can work in two antenna modes, i.e., directional and omnidirectional. For modeling and simulation purposes, we use the Optimized Network Engineering Tool (OPNET) and aim to seek an evaluation with respect to throughput, media access delay, and retransmission attempts. The results obtained demonstrate the effectiveness of the proposed scheme.

1. Introduction

Technical advances are underway exponentially in the automotive market, with the focus of progress turning towards ubiquitous connectivity and fully autonomous vehicles. When independent, autonomous vehicles become connected with each other and with Vehicle-to-Everything (V2X) communications, the potential of such a transformation will be completely disclosed. Based on shared planned movements from nearby vehicles, V2X will create a collective understanding of the surrounding environment

and help make more informed decisions for the vehicles. To achieve this, connected and automated vehicles require continuous access to sensory data from which vehicles can carry out advanced trajectory planning and more complicated high-speed maneuvers [1]. The vehicle can use onboard sensor information for short-term trajectory decisions, but for long-term decisions, the car requires data and information from other nearby vehicles. The sharing of sensor data is, therefore, an essential factor requiring a stable connection between vehicles that are subjected to the strict quality of service (QoS) guidelines [2, 3]. This new

paradigm of fully autonomous connected vehicles will pave the way for an Intelligent Transport System (ITS), an important part of which will be UAVs. Integrating UAVs into ITS provides enormous opportunities for new applications and services to be developed [4] as they provide on-the-fly communication facilities in a cost-effective way. In addition, due to their high mobility, autonomous operation, three-dimensional (3D) movement, and communication/processing capabilities, UAVs can play a key role in the Intelligent Transportation System (ITS). As the number of vehicles grows, the existing communication framework does not satisfy the data transmission demands, especially when there are hot spots (e.g., road intersections) during rush hours. A UAV-enabled ITS has several advantages over the traditional transportation system. Firstly, since the UAV can fly closer to vehicles compared to stationary base stations, the path loss will be much lower. Secondly, the UAV is versatile in changing the transmission control depending on the mobility of the vehicle. Thirdly, the performance of UAV-to-Vehicle connections is typically better than that of terrestrial links due to the line-of-sight (LoS) communication.

Automation of the entire transportation infrastructure cannot be done by merely automating road vehicles [5]. It is also important to automate other components of the road and end-to-end transport infrastructures, such as the field support unit, the traffic police, road surveys, and rescue teams. Figure 1 illustrates the sample network architecture of UAVs-enabled ITS. A road support team, for example, may be supplemented or supported by a set of UAVs that may fly around an incident site and provide basic support, or at least bring back an incident survey report. In addition, UAVs that can fly over vehicles on a highway to track and record potential traffic violations may also be substituted or assisted by a traffic police officer. On the one hand, UAV-enabled ITS can provide an effective means not to implement traffic rules and help on-the-ground traffic officers only but also to provide efficient traffic information (i.e., intelligent traffic management) to road users. On the other hand, it suffers from limited onboard energy, restricted computing capability, insufficient bandwidth, and other issues that preclude UAVs from being the prevalent part of the ITS network.

IEEE 802.11p is the typical wireless MAC standard, which is an enhancement to 802.11 (the basis of devices sold as Wi-Fi) adopted by car manufacturers to support applications for Intelligent Transportation Systems (ITS) [6]. By default, the IEEE 802.11p standard has been optimized for low-delay and small-bandwidth wireless communication applications. In addition, the IEEE 802.11p is designed with omnidirectional antenna settings in mind. It assumes that all packets, i.e., RTS/CTS/DATA/ACK, are sent and received as omnidirectional signals. However, with an omnidirectional antenna, network coverage, delay, and throughput, etc., will remain limited. In comparison, directional antennas deliver several advantages over omnidirectional antennas, such as greater coverage, spatial reuse, and high bandwidth, due to the concentration of total RF energy in one direction. Nonetheless, these advantages pose some unique challenges for the MAC layer. The primary challenge with the directional antenna is the error in location estimation for high-speed UAVs and road vehicles [7, 8]. For this reason, the

combination of multiple navigation systems is the central requirement for the practical solution of error reduction in the position estimation. Therefore, the UAVs must be fitted with a GPS-based Inertial Measurement Unit (IMU) device so that other UAVs can be placed accurately at any time. IMU can be rated by GPS signal and therefore, can provide position and angle at a faster rate [9].

1.1. Authors' Motivation and Contributions. Designing an appropriate MAC protocol for UAV-enabled ITS is very necessary for achieving high throughput, low latency, and fewer retransmission attempts, etc., for efficient communication. The primary objective of this MAC protocol is to overcome data packet transmission collisions, provide reduced channel access delay, and allow numerous UAVs to share a common medium efficiently with improved data transfer rate and network coverage. Therefore, in this article, we present the MAC protocol based on the IEEE 802.11p standard, which consists of two antenna modes: directional and omnidirectional. Under the 3D terrain model, network density, coverage area, routing protocols, and speed of both UAVs and ground vehicles are considered to check the performance of the proposed protocol. Some of the highlights of our research contribution in this article can be summarized as follows:

- (i) We propose a dual-mode Medium Access Control (MAC) protocol. The protocol is based on the IEEE 802.11p standard, which consists of two antenna modes: directional and omnidirectional.
- (ii) We assume a 3D terrain model, where each of the UAVs flies at different altitudes in order to achieve realistic results.
- (iii) The proposed scheme is modeled and implemented using Optimized Network Engineering Tool (OPNET) and deployed on Intelligent Transportation System (ITS) as a case study.
- (iv) We compare the proposed protocol in terms of throughput, media access delay, data dropped, and retransmission attempts to its existing counterpart, i.e., omnidirectional antenna-based MAC protocol.
- (v) The findings from the comparison results demonstrated the superiority of the proposed scheme over conventional omnidirectional based MAC protocol.

1.2. Organization of the Paper. The rest of the article is structured as follows. In section 2, we address the related work. An overview of the IEEE 802.11p specification is provided in section 3. In section 4, the proposed MAC dual-mode protocol is presented. Section 5 describes the simulation environment using the OPNET tool. Section 6 includes the results and analysis followed by concluding remarks in section 7.

2. Literature Review

In the literature, very few research studies are found in the field of directional antennas focusing on the UAVs network. In 2004, Ulukan and Gürbüz [10] presented a MAC angular

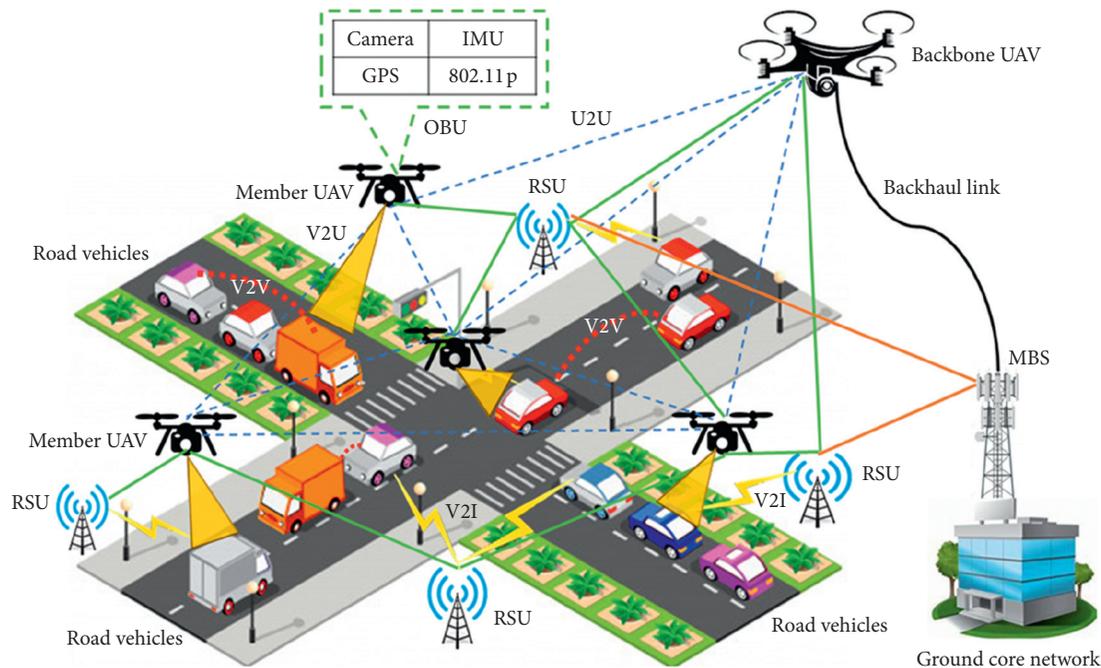


FIGURE 1: Sample architecture of UAV-enabled ITS.

protocol (AN-MAC) to improve the network's performance with directional beams. The proposed protocol allows stations to classify busy sectors with a location-based scheduler to prevent collisions and congestion on the network. The authors intend to check the performance analysis of AN-MAC on different topologies with an increased number of antennas per node. In [11], the authors introduced an Adaptive Medium Access Control (AMAC) protocol in which two directional antennas and two omnidirectional antennas were mounted on each UAV. It is observed that the performance of UAVs network with directional antennas in terms of bandwidth, range, and delay is comparatively better than omnidirectional antennas. However, this scheme can be further improved for transmitting and receiving packets using multiple directional antennas mounted on UAVs. Huba and Shenoy [12] presented an aerial network in which UAVs are mounted with directional antennas. The proposed approach combines scheduling and clustering with a single algorithm in the MAC layer, providing a robust and scalable solution. Temel and Bekmezci [13] researched various flight scenarios and used directional antennas to demonstrate the effect of the distance between the operating UAVs and the main beam angles. The authors have not, however, focused on improving network efficiency in terms of both data rate and latency.

Biomo et al. [14] researched the efficiency of current routing protocols using FANET directional antennas. The proposed mechanism for this scheme will result in improved performance of the network in terms of packet delivery ratio (PDR) and latency. The authors further examined the fact that the directional antenna offers a wider coverage with the same number of nodes. However, the authors used only one flow in 2D sight. In 2019, Khan et al. [15] directional antenna-based medium access control (MAC) protocol using

multiple directional antennas for FANETs. The proposed scheme was modeled and implemented in the OPNET Modeler. It has been shown that major improvements can be made in terms of end-to-end delay and retransmission attempts using directionally based MAC. However, in the proposed scheme all the six antennas were active without any on/off mechanism. Finally, in 2020, the authors introduced a dual channel MAC protocol based on a directional antenna for the underwater acoustic sensor networks [16]. However, the switching time between the omnidirectional directional and directional antenna modes has been ignored, and in real-world scenarios, it cannot be ignored. To this end, in our work, the promising results have inspired us for the extended version of the same scheme, as [14, 15] adopted a similar approach for the UAVs network.

For ITS, analysis of the research works is provided using IEEE 802.11p [17] for MAC and PHY layers [18–23]. Arena et al. [6] presented an overview of IEEE 802.11p, with a special emphasis on its adoption in an ITS environment. They studied both MAC and PHY layers explicitly in a dedicated short-range communication (DSRC) environment.

3. Overview of IEEE 802.11p

The IEEE 802.11p protocol has a series of specifications that are useful to allow connectivity in the vehicle environment, i.e., in the environment where sudden changes take place. The operating frequency of the 802.11p band, which is set in the DSRC, is 5.850–5.925 GHz. IEEE 802.11p uses a physical (PHY) layer based on OFDM (Orthogonal Frequency Division Multiplexing). In modulation and coding strategies with data rates from 3 to 27 Mbps, the IEEE 802.11p standard is identical to IEEE 802.11a. The basic medium access

method known as CSMA/CA is often used for IEEE 802.11p (Carrier Sense Multiple Access with Collision Avoidance). In CSMA/CA, a node has to sense the channel before it sends a message. The node will not transmit in events if the channel is being used by another node. If the channel is detected to be idle, the nodes will only initiate their transmission and postpone the transmission until the completion of the ongoing transmission if the channel is detected to be busy. When the received power intensity of the signal is higher than the Clear Channel Assessment (CCA) threshold, the radio channel is interpreted as busy. The CCA threshold is expected to be greater than the receiver's sensitivity level, i.e., the threshold of sensing power. After the channel is observed busy, the node waits for a backoff period to eliminate collisions during contention with other nodes that have already postponed their transmission. The time of the channel is separated into synchronization intervals of a fixed period of 100 ms. It consists of intervals of equal duration, which varies between the CCH (Control Channel) and the SCH (Signaling Channel). For safety-related messaging and device control data exchange, all nodes must tune in to the CCH frequency during the CCH interval. A guard time of 4 ms is set at the beginning of each interval so that the delay in radio switching and timing inaccuracies in the systems can be taken into account.

Seven 10 MHz channels are arranged in the DSRC spectrum, in which 5 MHz is the guard band, as seen in Figure 2. Channel 178 is intended for safety-related communications only and is known as the control channel (CCH). It has the most important beacons and alarms. Both networks are used at the edge of the spectrum for future uses and specific employment, such as automated collision prevention and the use of public protection. For residual applications and routine correspondence, the remaining channels are service channels (SCH). It is also possible to merge pairs of these neighboring channels into a 20 MHz channel.

As seen in Figure 3, each layer practices various protocols in the DSRC architecture. IEEE standards 1609.2, 1609.3, and 1609.4 are incorporated in the upper layers for special services, such as security services (1609.2), network services (1609.3), and channel switching (1609.4). The IEEE 802.11p is deployed for the PHY and MAC layers. The WAVE Short Message Protocol (WSMP) also operates on the network layer, but it is also acceptable to use other protocols such as IPv6.

4. Proposed Dual-Mode MAC Protocol

By default, the directional antenna in the OPNET simulator is not available on any node. Therefore, we need to design our own directional antenna, which enables users to define the representation of antenna patterns using an antenna pattern editor. The antenna pattern can be connected with a radio transmitter and/or receiver using a node editor antenna module to give the gain defined by the pattern. We implemented the standard 802.11p DCF

MAC for designing the proposed protocol. Typically, the IEEE 802.11p protocol uses 10 MHz bandwidth. It operates in the frequency band of 5.9 GHz ranging from 5.850 to 5.925 GHz and adopts OFDM. It is offering fast data speeds between 3 Mbps and 27 Mbps. This protocol uses CSMA/CA, an important technique in the WLAN MAC layer with Distributed Coordination Function (DCF) as ITS performance decreases with a variety of factors such as high speed, 3D movement, regular distance changes between UAVs and road vehicles, and link quality fluctuations. Thus, the distance between connected UAVs and vehicles in the proposed scheme will not reach the transmission limit of the directional antenna. A medium access table is set up with the help of RTS/CTS messages to know the destination location information and adjacent UAVs. More information on the proposed MAC protocol can be found below.

4.1. Station Model. UAV station model is designed so that each UAV is fitted with four directional antennas covering an area of 360. The proposed model also has mounted external GPS, IMU, and altimeter pod (radar, lidar, and others) to track and update the neighboring UAV's position, altitude, and distance. The standard 802.11p uses RTS/CTS packets to book medium-to-exchange packages.

4.2. Terrain Model. We assume a 3D terrain model, where each UAV would fly at different heights to achieve more realistic results. To achieve the desired results, each UAV is fitted with an altimeter pod (consisting of radar, lidar, and others) that retains its height relative to the terrain to which it flies. Therefore, it is evident that the geographical characteristics of the regions will affect UAV communication.

4.3. Antenna Model. The proposed scheme uses a switched-beam directional antenna with $N=4$ separate antenna beams. All four beams can cover an area of 360° in total, as shown in Figure 4. The beamwidth of each antenna is 90° . Thus, to design the proposed mechanism as shown in Figure 5, four separate RF modules with a single MAC chip are required. We used the Friis transmission equation in the proposed system to get parameters for the antenna.

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi R)^2}, \quad (1)$$

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi R} \right)^2. \quad (2)$$

In equation (2), P represents power and G denotes gain; respectively, subscript t and r stand for transmitted and received. In addition, λ is the wavelength and R is determining the range of transmission.

For omnidirectional antennas, setting the parameters in the OPNET simulator as follows will provide the transmission of 1000 meters: $P_r = -95$ dBm, $P_t = -196$ dBm, Frequency = 5.885 GHz and $G_r = G_t = 0$ dB:

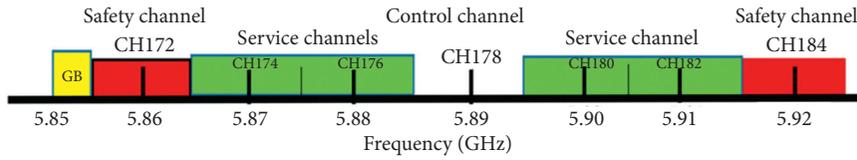


FIGURE 2: DSRC spectrum.

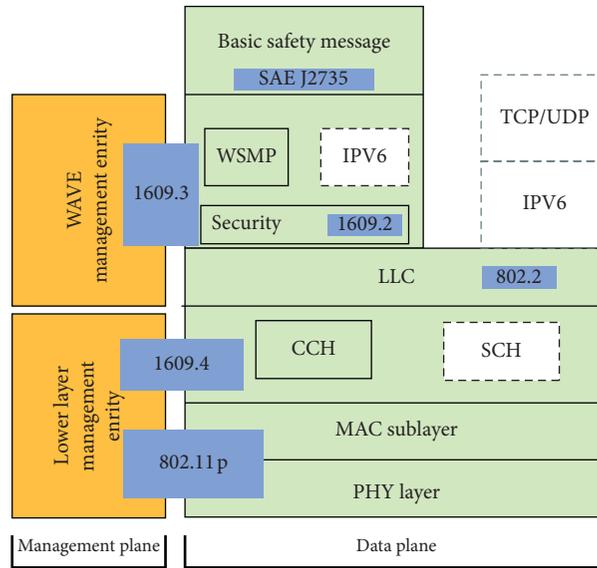


FIGURE 3: DSRC architecture.

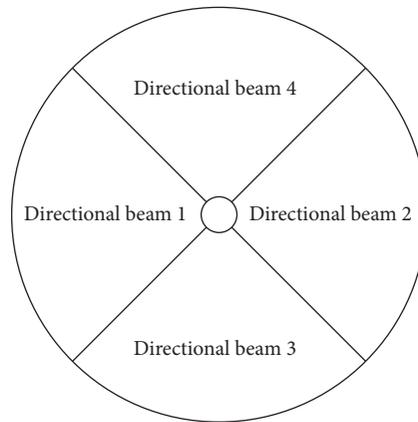


FIGURE 4: Beams configuration for directional and omnidirectional modes.

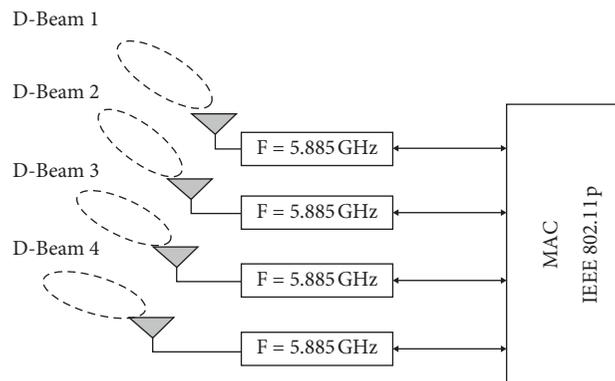


FIGURE 5: Single MAC chip integrated with directional and omnidirectional beams.

$$\frac{60}{360} \pi r^2 = \pi R^2, \quad (3)$$

$$r = R\sqrt{4} \implies 1000\sqrt{4} \approx 2000m.$$

In the case of a 4-beam directional antenna, with the same transmission range, i.e., 2000 m, we will have $P_t \approx -200$ dBm.

4.4. Interference Model. In a directional antenna, some power is still radiating in the side lobes, although most of the power is directed towards the central beam. This power is considered an interference among the remaining UAVs. The interference zone between directional antennas is illustrated in Figure 6. The maximum transmission range of the main lobe beam R_m , side lobe beam R_s and guard zone R_g is defined as follows [13]:

$$\begin{aligned} R_m &= \sqrt[4]{P_t/P_r}, \\ R_s &= \sqrt[4]{R_m + G_s}, \\ R_g &= \sqrt[4]{R_s G_s}. \end{aligned} \quad (4)$$

P_t , P_r , and G_s are the transmitted power, received power, and side lobe gain, respectively, as mentioned in equation (4).

UAVs in the Indirect Interference Zone (IIZ) will concentrate their antennas beyond beam N. The total volume of IIZ expressed in m^3 is the sum of the conic zone linked to the receiver antenna and the sphere connected to the sidelobe gain of the receiver. The probability distribution function (PDF) is used for the deployment of K number of UAVs with their initial locations over a terrain. The volume of the spherical zone V_c and the side lobe sphere V_s is determined from equations (5) and (6). Moreover, in equations (7) and (8), the total volume of IIZ, VIIZ, and the volume of DIZ, VDIZ, are determined.

$$V_c = \frac{\theta}{2\pi} \left(\frac{4}{3} \pi R_m^3 \right), \quad (5)$$

$$V_s = \left(\frac{4}{3} \pi R_s^3 \right), \quad (6)$$

$$V_{IIZ} = V_c + V_s = \frac{\theta}{2\pi} \left(\frac{4}{3} \pi R_s^3 \right), \quad (7)$$

$$V_{DIZ} = V - V_{IIZ}. \quad (8)$$

The total interference (I_t) and SIR experienced by all the UAVs can be measured from equations (9) and (10) as follows:

$$I_t = \frac{P_t G_s G_m}{I_d^\alpha}, \quad (9)$$

$$SIR = \frac{P_t G_m G_m}{I_d^\alpha}. \quad (10)$$

The maximum number of UAVs without affecting the ongoing communication in the field can be expressed as in the following equation:

$$UAV_{act} = \frac{SIR}{SIR_{th}}. \quad (11)$$

4.5. Mobility Model. In the UAV-enabled ITS, due to the agile motion of the UAVs, it is necessary to select the appropriate model of mobility to achieve maximum accuracy in the simulation results. There are many circumstances in which a group of UAVs is tasked with acting against a common point to patrol a particular area. Therefore, in the proposed scheme, we used Reference Point Group Mobility (RPGM) [24] for the simulation of a UAVs group. In the RPGM model, in order to achieve collective work, UAVs are grouped around a centralized node, called a group head (backbone UAV). The movement pattern of the reference point describes the movement of the whole group, including position, altitude, velocity, and direction. The group head follows a random viewpoint (RWP) mobility model, and the rest of the UAVs revolves around the center with their movement patterns (see Figures 7(a) and 7(b)) [25]. There are several types of mobility models, such as columns (CLMN) [25], nomadic community (NC) [25], and purse (PRS).

4.6. Protocol Operation. The proposed MAC protocol consists of two antenna modes, namely directional and omnidirectional. In the directional mode of operation, only one antenna beam will be active at a time. The beam can only be deactivated by settings its gain up to -200 dB that results in 0 linear gain. We have set an active sector gain of 7.8 dB. The entire process is well presented in [14, 26]. By comparison, in the case of omnidirectional mode, all four sectors are active with a gain of 0 dB resulting in linear gain 1. UAVs will remain in this mode if there is no RTS-CTS-Data-ACK exchange. In the proposed scheme, initially, each UAV with pending data sends an RTS frame using N beams in all directions. By default, these RTS messages are sent using a traditional CSMA/CA algorithm. All the connected UAVs that are idle or in a backoff state hear the channel omnidirectionally. When the intended UAV receives the RTS packet, it disables all other beams with the maximum power except the one receiving the signal. The UAV in question then sends a CTS packet through the maximum signal strength beam. Similarly, the transmitting UAV also selects the beam with maximum power that receives the CTS. Using the beam, it will then send data in the same direction. Also, ACK packets are sent in a directional pattern. The flowchart of the proposed dual-mode MAC protocol is illustrated in Figure 8.

5. Simulation Environment

Modeling and simulation of the proposed scheme are achieved using OPNET Modeler 14.5 [27]. OPNET consists of an antenna pattern editor where an antenna directionality is modeled and an antenna gain is set. We made changes to the IEEE 802.11a standard due to the unavailability of IEEE 802.11p in the OPNET modeler as shown in Figure 9. We

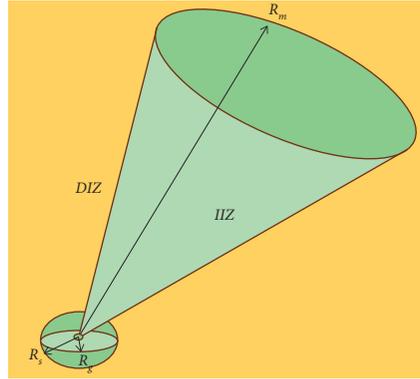


FIGURE 6: The maximum transmission ranges of DIZ and IIZ zones.

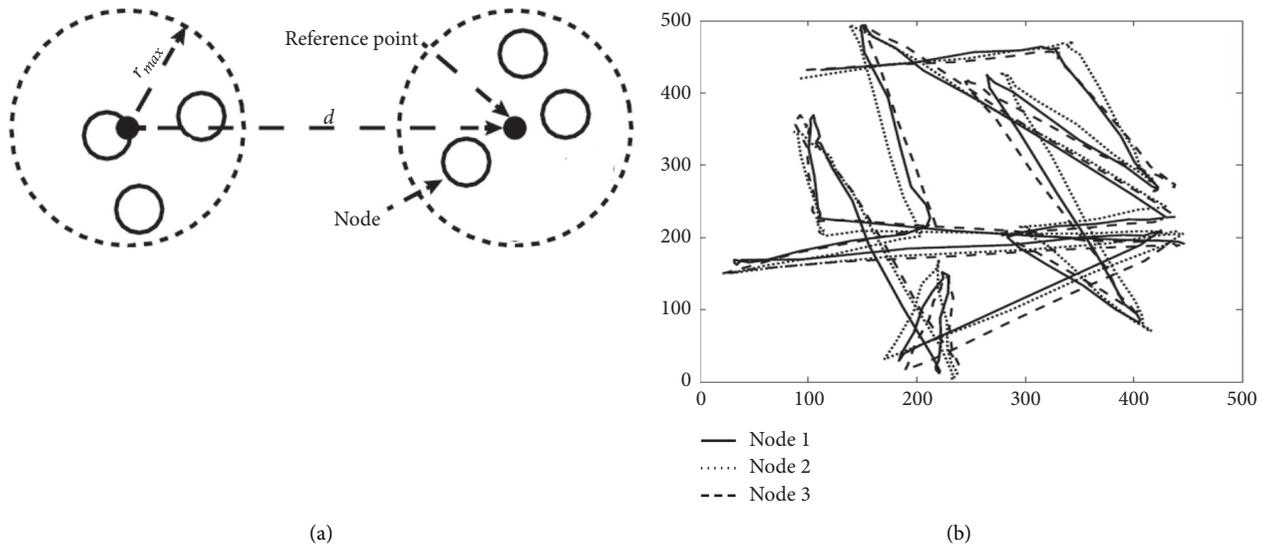


FIGURE 7: Mobility models: (a) Nomadic community (NC) with three UAVs. (b) Mobility pattern of one group (i.e., three UAVs) using RPGM.

also made modifications in the MANET node model according to which the proposed MAC protocol for both directional and omnidirectional antennas can be implemented. As shown from Figures 10 and 11, the UAV and vehicle node model consist of three main parts: the lower part (physical layer), the middle part (data link layer), and the upper part (upper layer). The transmitter, receiver, and antenna module are part of the physical layer. Wireless connectivity between the associated nodes is the duty of these modules. The middle part, i.e., the data link layer, consists of the MAC module using the IEEE 802.11p standard. By default, it is primarily designed to work with omnidirectional antennas. This module is designed to run collectively to support the proposed scheme. The TRAF SRC, UDP, MANET RTE MGR, DHCP, IP ENCAP, ARP, IP, and CPU modules are included in the upper layers, i.e., the top part.

The directional antenna node model provides all of the compulsory interfaces that are set in each antenna for working with four separate beams. In the proposed model, each UAV has a 60° beam width that enables them to cover

an area of 360° with the help of four directional antennas. For all beams, the UAV will sense the signal intensity and mark the beam with maximum signal strength for data communication. The UAV can also block all other beams except the one with maximum signal strength. We choose all the suitable parameters. For more detailed information, further parameters are summarized in Table 1.

When the UAVs start flying, along with height sensors, IMU, GPS units, and other embedded equipment such as flight controllers, the network formation starts. We presume that UAVs are well aware of the zone ID, position, altitude, and velocity of their neighbors when network creation begins. The performance of the proposed MAC protocol is evaluated on the basis of throughput, media access delay, data dropped, and retransmission attempts.

6. Results and Discussion

Figures 12–14 show the performance of the proposed dual-mode MAC protocol with the default omnidirectional based IEEE 802.11p protocol in terms of throughput, media

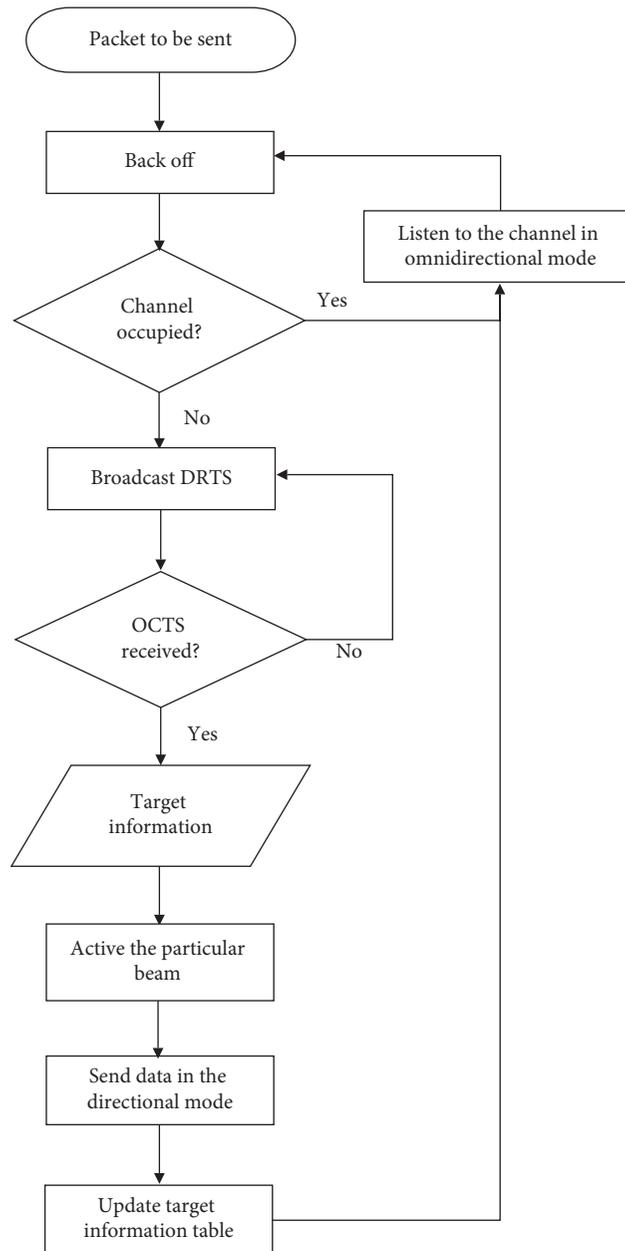


FIGURE 8: Flowchart of the proposed dual-mode MAC protocol (UAV side).

access delay, and retransmission attempts, respectively. In the graphs, the x-axis specifies simulation time and the y-axis stipulates the throughput in bits, media access delay in seconds, data dropped in bits, and retransmission attempts in packets, respectively. The proposed scheme is tested under the area of $2000\text{ m} \times 2000\text{ m}$ composed of 60 nodes. The simulation using the OPNET simulator is performed for two different scenarios, i.e., proposed dual-mode MAC protocol with and default IEEE 802.11p, respectively, under the RPGM mobility model. We chose the RPGM model because, under the RPGM model, the movement of UAVs is controlled by a reference point, which is the group head in a particular zone. That way, the network stays fully connected all the time. The results of the simulation authenticate that the proposed dual-mode MAC

protocol meets the desired QoS requirements. That is, the use of directional antenna in terms of throughput, media access delay, data dropped, and retransmission attempts provides better performance than that of the default MAC protocol using omnidirectional antennas. Using an omnidirectional antenna, the distance between the nodes increases and network performance deteriorates. For this purpose, each UAV in the same Basic Service Set (BSS) assumes that other UAVs will terminate communication before transmitting frames if the MAC protocol is based on the use of an omnidirectional antenna. Each UAV that is available in the same BSS must, therefore, wait until the other UAV completes its transmission by the same protocol. In comparison, the proposed dual-mode MAC protocol, which uses directional antennas, allows each

(wireless_lan_mac) Attributes	
Attribute	Value
Access Point Functionality	Disabled
Physical Characteristics	OFDM (802.11a)
Data Rate (bps)	24 Mbps
Channel Settings	(...)
Bandwidth (MHz)	10
Min Frequency (MHz)	5.855
Transmit Power (W)	0.005
Packet Reception-Power Threshold...	-95
Rts Threshold (bytes)	None
Fragmentation Threshold (bytes)	None
CTS-to-self Option	Enabled
Short Retry Limit	7
Long Retry Limit	4
AP Beacon Interval (secs)	0.02
Max Receive Lifetime (secs)	0.5

FIGURE 9: Setting parameters for IEEE 802.11p applied to the nodes in OPNET.

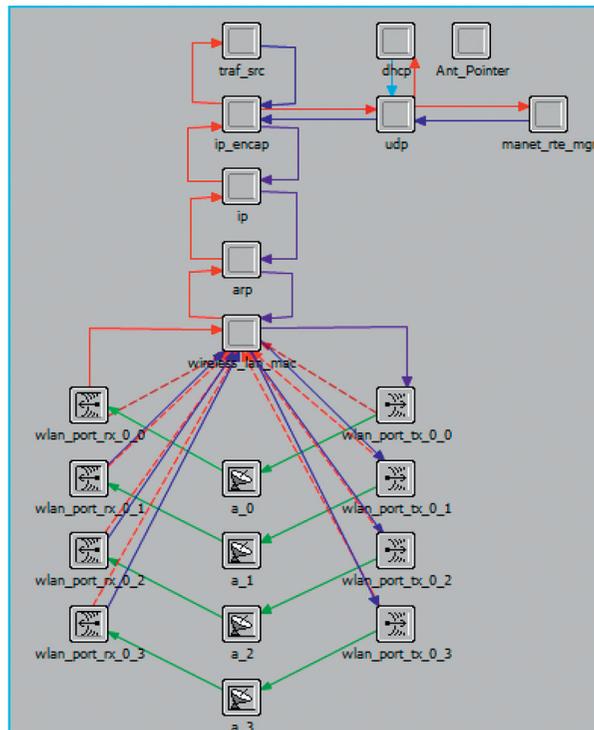


FIGURE 10: Designing of node model for UAV in OPNET.

UAV to concurrently use the same channel for transmitting data with other UAVs over the same BSS. Moreover, the proposed scheme would require retransmission of each

UAV against any transmission that fails. They will continue to transmit until the receiving UAV sent an ACK frame or up to the maximum retransmission limit. Therefore, the

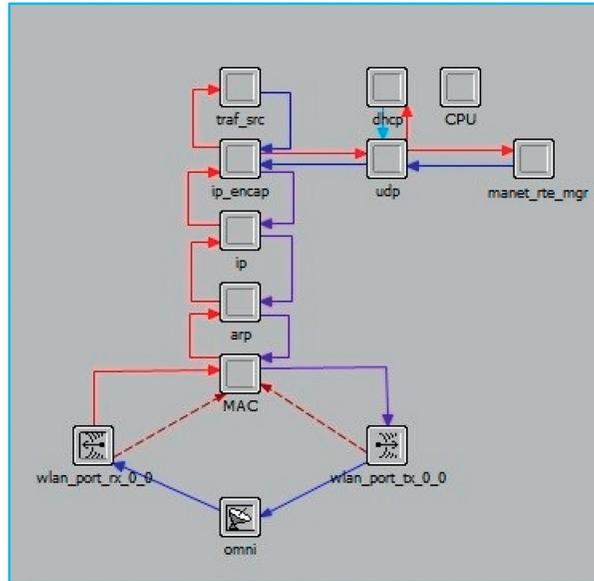


FIGURE 11: Node model for vehicle in OPNET.

TABLE 1: Simulation parameters.

Parameter	Value
Dimensions	2000 m × 2000 m
Number of UAVs	30
Number of vehicles	30
Mobility model	Random point group mobility (RPGM)
Frequency	5.885 GHz
Application	Simple source
Packet interval	Exponential (1) sec
Packet size	1024 byte
Simulation time	1800 sec
Road vehicles	Mobile
UAVs type	Mobile
UAVs altitude	25 m
Speed of UAVs	50 m/s
Speed of vehicles	30 m/s
CTS-to-self option	Enabled

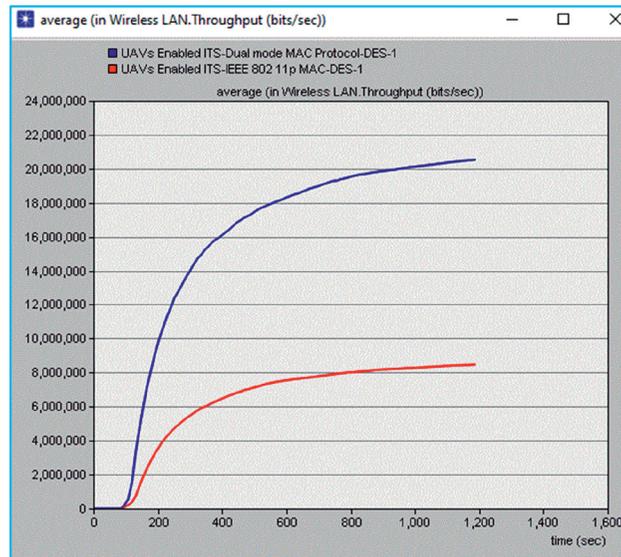


FIGURE 12: Throughput (in bits/sec).

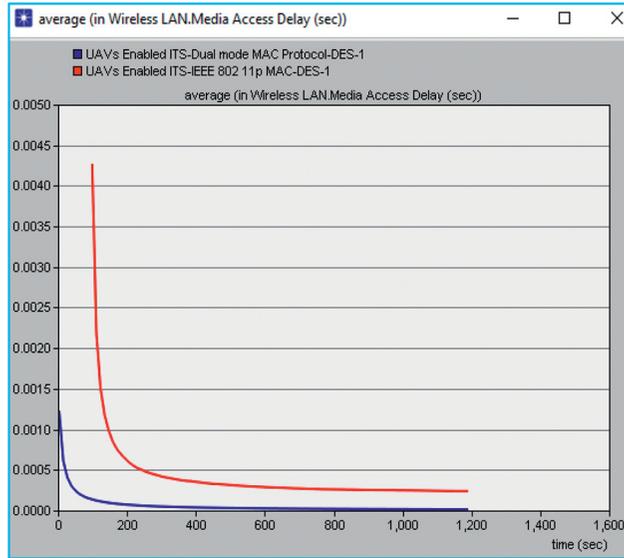


FIGURE 13: Media access delay (in sec).

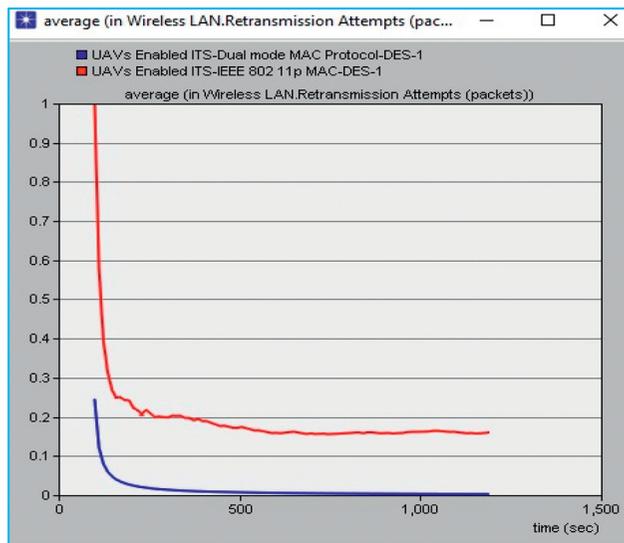


FIGURE 14: Retransmission attempts (in packets).

results show that the proposed dual-mode MAC has a better performance than that of default IEEE 802.11p in all three evaluation metrics.

7. Conclusions

In this article, a dual-mode Medium Access Control (MAC) protocol is proposed, which is based on the IEEE 802.11p standard. It consists of two antenna modes: directional and omnidirectional. The proposed MAC mechanism integrates

the antenna’s directivity with CSMA and SDMA, allowing each UAV to share bandwidth simultaneously with other UAVs and road vehicles in the same BSS becomes fair. Moreover, the proposed scheme overcomes the unique challenges associated with a MAC protocol based on directional antennas. The proposed scheme is modeled and implemented using Optimized Network Engineering Tool (OPNET) and deployed on Intelligent Transportation System (ITS) as a case study. The simulation results in terms of the throughput, media access delay, data dropped, and

retransmission attempts confirm that the proposed scheme is better than the default IEEE 802.11p omnidirectional antenna-based MAC protocol.

Data Availability

All the data generated or analyzed during this study are included in this article.

Conflicts of Interest

The authors declare no conflicts of interest with respect to the research, authorship, and/or publication of this article.

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