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Procedia Computer Science 159 (2019) 2384–2393

Procedia Computer Science

www.elsevier.com/locate/procedia

23rd International Conference on Knowledge-Based and Intelligent Information & Engineering Systems

Bio-Inspired Routing Protocol in VANET Networks- A Case Study

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Abstract

Vehicular Ad-Hoc NETworks (VANETs) have received considerable attention in recent years, due to its unique characteristics, which are different from Mobile Ad-Hoc NETworks (MANETs) such as rapid topology change, frequent link failure, and high vehicle mobility. VANET will provide several applications and services such as cooperative collision avoidance, emergency warning messages, cooperative intersection collision avoidance, and traffic management. VANET's routing objective is to conduct packets through a path in the network to their final destinations. Currently, most of the proposed VANET routing protocols focus on urban or highway environments. The contribution of the paper falls within the study of VANET routing protocol in extreme and complex environments such as underground mines. This paper addresses the need for a bio-inspired adaptive routing protocol in VANETs which can tolerate low-density network traffic with little throughput and delay variation.

Keywords: VANET networks; vehicle to vehicle communication; bio-inspired routing protocol; ant colony routing; throughput, delay.

1. Introduction

Mining is essential to the global economy and societal development that has so far exhibited a slow uptake of

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1877-0509
10.1016/j.procs.2019.09.413

automation technology — but this is beginning to change. In today's economy, it is essential that the mines stay as productive as possible to remain economically viable. To date, productivity increase has been achieved through mechanization, moving from human and animal power early last century to present-day electric and diesel-powered machines [1]-[2].

While the increased levels of mechanization have led to improved productivity, it has also lead to safety concerns. Machines and underground mines vehicles have become progressively more significant and more powerful. Therefore, there is an increased risk of serious injury caused by humans having to work in such confined spaces with heavy machinery [3]. Automation and the use of emerging technologies have been identified as the most likely means to attain the next jump in productivity and safety since sensing, control and computing technologies are advancing rapidly [1].

To maintain the safety of mining workers, a robust and reliable communication system should be established during all working process although it is important to note that this system should be combined with all other security mechanisms [4]. These communication systems will allow exchanging data between employees, interaction with machines, environment monitoring and provide an updated miners position (i.e., localization and tracking).

Furthermore, it is vital that operators are continuously aware of underground conditions and risk profiles. On the other hand, the large number of machines and vehicles circulating in an underground mine gallery makes the location, the path travelled by these vehicles, collision warning, automated emergency braking systems and up-to-date traffic a piece of crucial information.

Vehicular Ad Hoc Network (VANET) is a type of Mobile Ad Hoc Networks (MANET). VANET communication has recently become an increasingly popular research topic in the area of wireless networking as well as the automobile industries. The goal of VANET research is to create a vehicular communication system to enable quick and cost-efficient distribution of data for passengers' safety and comfort [5].

VANET will provide several applications and services such as cooperative collision avoidance, emergency warning messages, cooperative intersection collision avoidance, and traffic management.

However, because of the limited transmission range of the vehicle node, the communication traffic must be routed to final destinations through one or more intermediate nodes (i.e., vehicle). Each intermediate node is then considered as a router that contributes and cooperates in transferring data and therefore be part of the whole routing mechanism.

The contribution of the paper falls within the study of VANET routing protocol in extreme and complex environments such as underground mines. To the best of our knowledge, this is the first study of its kind. For this propose we evaluated an adapted ant colony routing for VANET in underground mines. In addition, the performance will be analysed using the OPNET Modeler ™ and adapted to the underground mining environment. Furthermore, the performance of the proposed routing protocol will be compared to a routing protocol used in ad-hoc and VANET networks.

The paper is organized as follows: In the next section, we give a brief overview of the use of wireless communication in underground mines. The advantages of using VANET technology in helping the mining industry is given in Section 3. Bio-inspired and adapted ant colony routing protocol, called V-Ant, is described in Section 4. The simulation results are provided in Section 5. Section 6 will contain a summary and some suggestions for future research.

2. Wireless Communication in Underground Mines

Communication is an activity related to the transmission of data from two separate geographic locations for the sake of information exchange.

Working conditions in underground mining are associated with a considerable number of health risk factors, such as a high physical workload, fire, high temperature, and humidity conditions and exposure to dust and gas phase hazardous substances. Figure 1 shows a photograph of an underground mine gallery.

Fig.1. A picture was taken from an underground mine gallery [7].

Reliable communication system not only save the machine break down time but also help in quick passing of a message from the vicinity of the underground working area to the surface for a fast rescue operation. Therefore, a reliable communication system is also an essential requisite for safety in underground mines [6]-[7].

In the interests of mine safety and productivity, it is vital that operators are continuously aware of underground conditions and risk profiles. They must always be able to locate and communicate with mine workers, particularly in the event of fires, roof falls or other life-threatening situations.

In mining, infrastructure cost is essential thus, a communication system should be integrated as a multipurpose system capable of transferring all types of information as data, voice and video.

Researchers from both industrial and academics have been made for improving the technology from the beginning of the 20th century. Underground communication methods are lagging the surface level communication which is now crowned with fifth generation (5G) networks and Internet of Things (IoT).

The existing systems in underground mines are based on two networks — wireline communication (wired) and wireless communication. Figure 2 illustrates the main wireline technologies deployed in underground mines such as Data Over Cable Service Interface Specification (DOCSIS) standards, Cable Modem Termination System (CMTS), optical fiber, coaxial cables, and leaky feeder.

The leaky feeder communication system is a hybrid system that was first developed in the 1970s. It employs both wired and wireless communication features to provide robust and flexible communication in challenging mine environments [8]. The leaky feeder operates for analog voice communications in half-duplex (i.e., talkie-walkie) have been used for more than thirty years in the mining industry.

During the last two decades, several emerging technologies are being deployed in the mining industry. Examples include Wireless Local Area Networks (WLAN), also known commercially as WIFI networks, wireless sensor networks [9], Zigbee [10]-[11], RFID tag network [6].

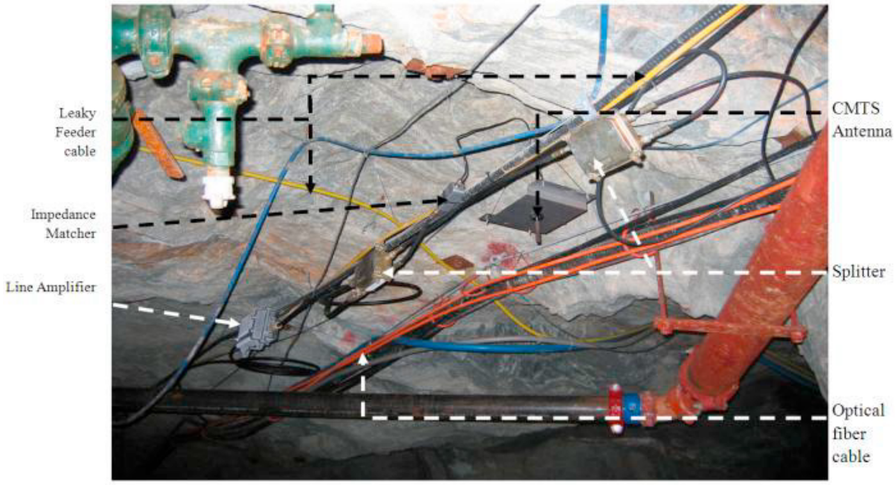

Fig. 2. Wireline technologies deployed in underground mine (from CANMET Underground mine, QC Canada).

3. VANET technology helping the mining industry

Wireless communication technologies in mining will have a significant impact on mine operations in the coming decades, giving mine managers and staff much greater understanding and control over mining processes in under to monitor and optimize mining operations [7]. Whereas, wireless network system deals with WiFi (IEEE 802.11), Bluetooth (IEEE 802.15) and WiMax technologies. Ultra-Wide Band system is another radio system for short-range communication with low power at a very high data rate [12]-[13].

Vehicular ad hoc networks (VANETs) have been studied intensively due to their wide variety of applications and services.

This type of network benefits from the movement of vehicles. Since the nodes are equipped with a wireless communication ability, this might allow increasing the capacity of the primary communication system (i.e., other networks than VANET) and the extension of its coverage. The main idea is to exploit a collaboration between the moving vehicles to exchange data and reach zone beyond the reach of the primary communications system. It will also provide the necessary redundancy to address a possible fault in the central communication system.

As an example, figure 3 shows a scenario where a vehicle is located close to a hazardous area. This vehicle needs immediately to inform the gateway about this threatening situation. Furthermore, if the primary communication system is down, the vehicle could transmit this information using the intermediate nodes as part of a local VANET network.

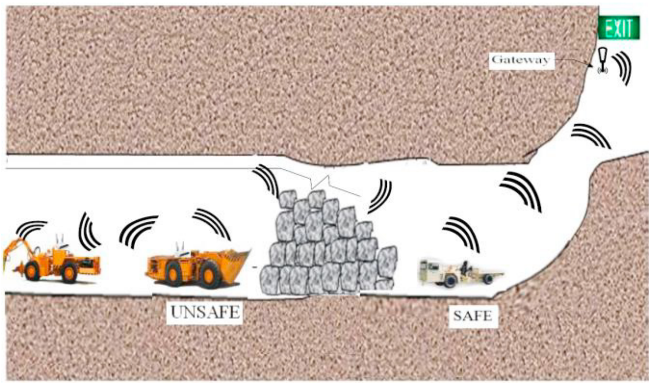

Fig. 3. The application of VANET in underground mining environments.

In addition to the classic routing, VANET can use flooding for forwarding the data. The decentralized nature of VANET makes them suitable for a variety of applications where central nodes can't be relied on and may improve the scalability of wireless ad hoc networks compared to wireless managed networks, through theoretical and practical limits to the overall capacity of such systems have been identified [14]. Minimal configuration and quick deployment make VANET networks suitable for emergencies like underground mines disasters. The presence of dynamic and adaptive routing protocols enables ad hoc networks to be formed quickly.

Regardless of its progress in the research field, large-scale deployments of VANETs are still missing. Therefore, when VANETs are fully deployed in underground mines, they might encounter situations where the technology limitations become a challenge.

4. Bio-Inspired Routing in VANET Networks

In the previous section, some VANET characteristics were introduced as a function of routing. An exciting solution will be the design of a routing protocol that will take advantage of the cooperation between nodes (vehicles) adapted to VANETs networks. This approach is inspired by this concept of collaborative control routing, is based on the ant colony optimization technique.

Ant colony optimization is a stochastic metaheuristic based on the iterative improvement of a population of solutions and is inspired by the intelligence that ants can show when moving foraging, and the process path discovery and dissemination of information on the different paths found [15].

Ants (individuals) communicate indirectly through the environment through the deposit of pheromone trace. This communication generates a movement guided by the traces. The pheromone is put with a quantity which reflects several parameters (quality of the path, time traveled), one then attends a situation in which all the mobile individuals tend to use the / the most runways. The system then moves from a state where all paths are random to a state of best available routes, based on individual-specific information, in addition to the global information generated by the pheromone deposits.

4.1. V-Ant Algorithm

The description of the proposed algorithm is as follows. In regular time intervals, $\boldsymbol{\Delta t}$ from each node $\boldsymbol{s}$ of the network, a mobile agent (forward ant: FA) $\boldsymbol{F_{s\rightarrow d}}$ is launched to a destination node d to discover a feasible path at the least cost to this node. The mobile agent will examine the state of change of the network. The FAs share the same queues as the data packets, so they experience the same load of the system. The destination nodes are chosen locally depending on the traffic load models and the local function cost. If $\boldsymbol{f_{sd}}$ is a measure (in bits or number of packets) of the data flow $\boldsymbol{s} \rightarrow \boldsymbol{d}$, then the probability for a node to create an FA agent with $\boldsymbol{d}$ as the destination is:

$$p_d = \frac{f_{sd}}{\sum_{d'=1}^{N} f_{sd'}} \tag{1}$$

When traveling to different destinations, agents keep track of the routes traveled and the traffic conditions. The elapsed time from the start until the arrival to each visited node k are stored in a memory stack $\boldsymbol{S_{s\rightarrow d}(k)}$.

For each visited node $\boldsymbol{k}$, each traveling agent to its destination d will select next nodes ($\boldsymbol{n_s}$) to which it will move, and which has not yet visited, or to all neighboring nodes in case, they were all visited. These neighbor $\boldsymbol{n_s}$ is selected with a probability $\boldsymbol{P'_{nd}}$ computed as the normalized sum of the probabilistic entry $\boldsymbol{P_{nd}}$ of the routing table with a heuristic correction factor ln taking into account the state (the length) of the $n - th$ link queue of the current node $\boldsymbol{k}$:

$$P'_{nd} = \frac{P_{nd} + \alpha l_n}{1 + \alpha(|N_k| - 1)} \tag{2}$$

The heuristic correction $\boldsymbol{l_n}$ is a normalized value in the range [0,1] which is proportional to the value $\boldsymbol{d_n}$ which represents and gives an idea of the transmission delay in the queues that connects the node k with its neighbor $\boldsymbol{n}$:

$$l_n = 1 - \frac{d_n}{\sum_{n'=1}^{|N_k|} d_{n'}} \tag{3}$$

The value of $\boldsymbol{\alpha}$ measures the importance of the heuristic correction while respecting the probability values stored in the routing table. The value of $\boldsymbol{l_n}$ reflects the instantaneous state of the node queues, assuming that the queue's consuming process is almost stationary or slowly varying, $\boldsymbol{l_n}$ gives a quantitative measure associated with the queue waiting time. On the other hand, the values in the routing tables are the result of a continuous learning process and capture both the current and past state of the entire network, as seen from a local node. The system is more "reactive" after these values are corrected by the values of $\boldsymbol{l}$ while avoiding the fluctuations of the network. The combination of the long-term learning process and instantaneous heuristic prediction allows agents to make decisions [15].

If a cycle is detected the ant is forced to return to an already visited node, the cycle's nodes are popped from the ant's stack $\boldsymbol{F_{s\to d}}$ then all memory about them is cleared. If the cycle has a long time compared to the lifetime of the ant before entering the cycle, $\boldsymbol{F_{s\to d}}$, or in other words, if the cycle has lasted more than twice the ant's age, then the Ant is destroyed.

When the destination node $\boldsymbol{d}$ is reached, the agent $\boldsymbol{F_{s\to d}}$ is transformed to another agent (Backward Ant) $\boldsymbol{B_{d\to s}}$ while keeping his memory.

Agent $\boldsymbol{B_{d\to s}}$ takes the same path as the corresponding $\boldsymbol{F_{s\to d}}$, but in the opposite direction. In each node $\boldsymbol{k}$, of the path, the agent uses his stack $\boldsymbol{S_{s\to d}(k)}$ to know the next hop node. Backward ants $\boldsymbol{B_{d\to s}}$ do not share the same link queues as the data packets, so they use queues with higher priority because their task is to quickly update the routing table by the information collected by the forward ants $\boldsymbol{F_{s\to d}}$.

When the packet $\boldsymbol{B_{d\to s}}$ arrives at a node $\boldsymbol{k}$, and this node is different from the destination $\boldsymbol{d}$, the backward ant updates two primary data structures of the node: (1) the local model of the traffic $\mathbf{M_k}$ and (2) the routing table $\mathbf{T_k}$, for all the entries corresponding to the (forward ant) destination node $\boldsymbol{d}$.

The update is done based on the quality of the path that has been traversed by the agent $\boldsymbol{F_{s\to d}}$. The evaluation is done by comparing the real-time of travel with the estimated time, according to the local model of the delay.

Once agent $\boldsymbol{B_{d\to s}}$ arrives at its destination, it is then destroyed and removed from the network. Figure 4 illustrates a simple example of the algorithm behavior.

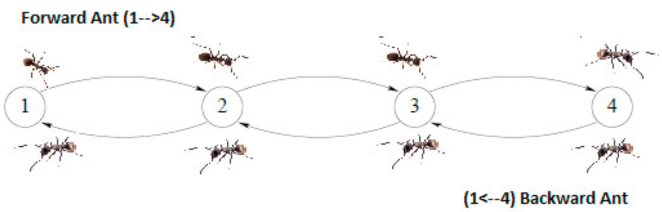

Figure 4: illustration of the V-Ant behavior.

5. Performance Analysis

We started by considering an environment consisting of an underground mining tunnel 1200 meters long.

Now, let us consider the following assumptions: a) the lower layer technology used in VANETs will be a variant of IEEE 802.11 technology [16] and b) there will be only one control channel, for the exchange of both types of safety messages. Carrier Sensing Multiple Access with Collision Avoidance (CSMA/CA), i.e., 802.11 Link Layer protocol, is a totally asynchronous approach. Furthermore, each vehicle (nodes) run the IEEE 802.11 in the ad-hoc mode, that is, without infrastructure, and all the experiments are conducted using the IPV4 protocol.

We assume that some communication parameters (e.g., transmission range, packet generation rate) can be appropriately set. Furthermore, each node can control its transmission range within 60 ± 5 meters, so the average number of hops from each node was always higher than two nodes.

We focus on simulating VANET network in underground mines using IEEE 802.11 technology. The model was first simulated without mobility, and then with powerful mobility simulator designed mainly for VANETs: VanetMobiSim [17]. An example of VanetMobiSim is shown in figure 5.

In OPNET, simulation models are organized in a hierarchy that consists of different levels. We then implemented our new model, at each different level [18].

The use of 3600 sec as simulation time allows us to observe the transition zones in the graphs. The parameters of the simulation are presented in Table 1.

Tab. 1. The parameters of the simulation.

Length of the underground gallery	1200 meters
Radio coverage	60 ± 5 meters
Network packet generator	Exponential distribution with $\lambda = 1$ (1 package / sec)
Number of nodes	Up to 30 vehicles
Data rate	11 Mb/sec
Speed of vehicles	5 – 10 Km/h
Access Method	IEEE 802.11 Standard
Simulation tool	OPNET Modeler ™ 15.0
Simulated time	3600 sec

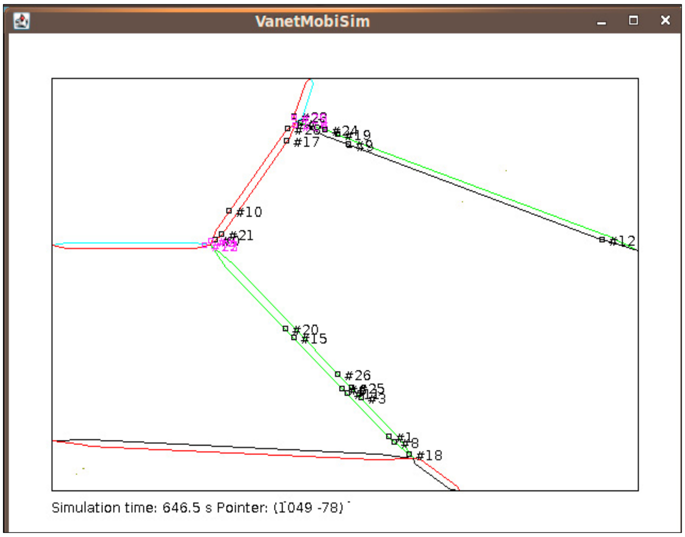

Fig.5. Simulation environment on VanetMobiSim.

5.1. Effective Throughput

The measured throughput between the source node and the gateway (destination node) is presented in figure 6. We can observe that the V-Ant protocol has a better delivery capacity than the standard flood technique. V-Ant reduces the network load by using the cooperation advantage between the nodes and maximize throughput. Both algorithms, including V-ant, flood the network until around time $t = 50\,sec$. From the instant $t = 250\,sec$, the V-Ant overcame the flooding protocol; we observe a gain of 20 % of the successful delivery rate.

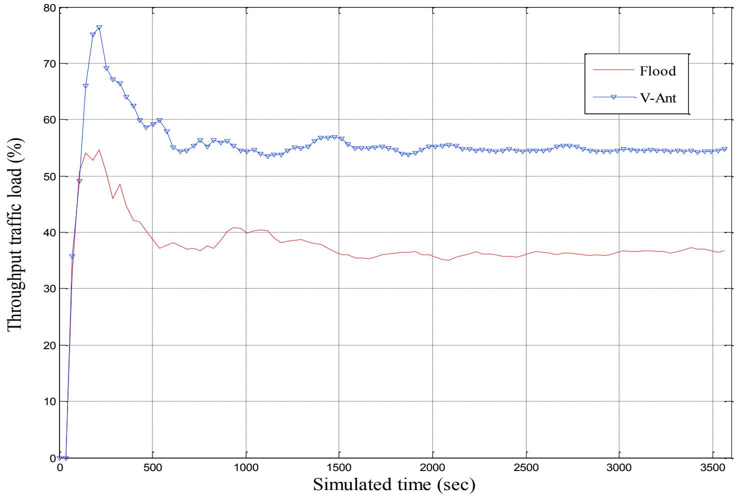

Figure 6. Comparison between V-Ant and flooding technique.

5.2. End-to-end delay:

Figure 7 shows the comparison between V-Ant and flooding protocol in term of end-to-end delay between the source node and the gateway. The vertical axis is the unit packet delay while the horizontal axis is the time delay. We can notice that the information on the states of the route provided by the V-Ant helps the nodes to choose the path with minimum delay and efficiently compared to flood routing.

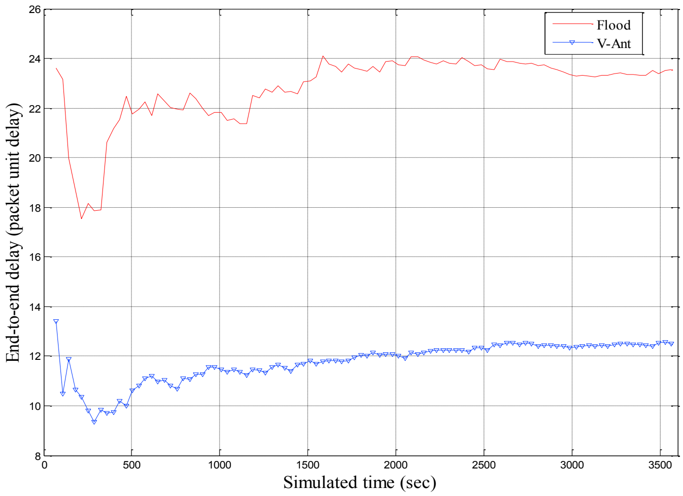

Figure 7. Comparison of end-to-end delay between V-Ant and the flood protocols.

5.3. Effect of the change in traffic transmitted on the amount of traffic received

In this part of the performance study, we will use the three V-Ant, Optimized Link State Routing Protocol (OLSR), and Geographic Routing Protocol (GRP) to deliver the maximum amount of data to the destination.

We will still change the amount of traffic flowing through the network to see the trend of the three algorithms to support this change. Figure 8 presents a comparison between the three routing algorithms from the point of view the amount of received traffic.

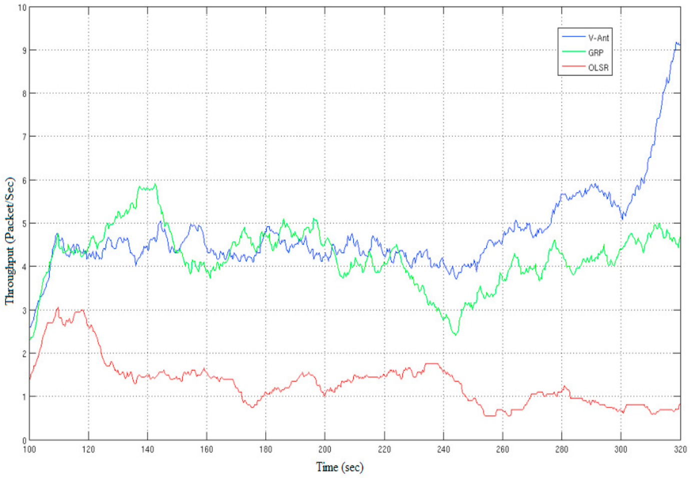

Figure 8. Comparison of the traffic received between V-Ant, GRP, and OLSR.

Figure 9 presents a comparison of the amounts of traffic received in the case of V-Ant, GRP, and OLSR. V-Ant once has a better delivery capacity than OLSR and GRP, which comes from better adaptability to network mobility.

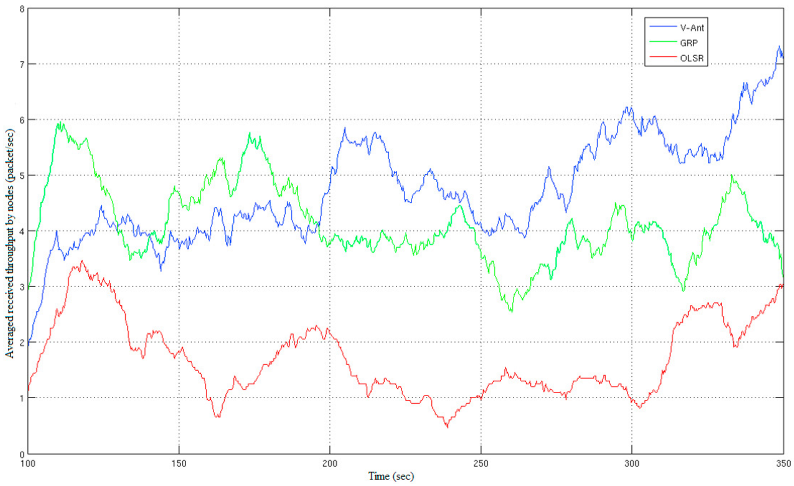

Figure 9. Comparison of traffic volumes received between V-Ant, GRP and OLSR for average speed = 60 km/h.

6. Conclusion

We have witnessed a wide spread of mobile technologies during the last two decades. This paper presented a VANET routing protocol in extreme and complex environments such as underground mines. We have proposed an adapted ant colony routing for VANET networks. Our evaluation of the V-ant protocol, implemented using OPNET Modeler, shows an improvement of the throughput performance of approximately 20% of gain compared to the traditional and well-known flooding protocol. Furthermore, our scheme can also reduce the end-to-end delay by 50 %

compared to flooding protocol.

Several possible improvements are in our plans. First, we intend to extend our scheme to handle a different number of vehicles, different speeds for various underground topologies. Second, we plan to complete a comprehensive study and comparison of the adapted ant colony routing to more efficient routing protocols such as Ad Hoc On-Demand Distance Vector (AODV) and Optimized Link State Routing Protocol (OLSR).

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