Application of Rate Adaptation Algorithm on Road Safety in Vehicular Networks

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Abstract **- Vehicular communications occur when two or more vehicles come into range with one another, to share data over wireless media. The applications of vehicular communication are far-reaching, from toll collection to collision avoidance. One of the goals of rate adaptation is to maximize throughput by exploiting the multiple transmission rates available for 802.11 devices by adjusting their transmission rates dynamically, based on to the time-varying and location dependent wireless channel conditions.**

In this paper, we present and study in detail Adaptive Context-Aware Rate Selection (ACARS) algorithm that is efficient in data transfer, energy utilization and road safety applications. The goal of ACARS is to select the rate that will yield a good throughput performance, with transmit power control and access point (AP) coordination to improve data transfer performance and safety application in Dedicated Short Range Communication (DSRC). From results obtained, ACARS is able to minimize the total transmit power in the presence of propagation processes and mobility of vehicles, by adapting to the rapidly varying channels conditions compared to other rate adaptation algorithms.

Keywords- DSRC; Vehicular Communication; IEEE802.11p; Rate Adaptation; Road Safety.

I. INTRODUCTION

Safety of lives is one of the primary concerns for the evolution of Dedicated Short Range Communication (DSRC) technology in vehicular networks. The rate at which accidents occur on our roads increase proportionately, especially as the number of vehicles on the road is on the increase. According to recent news, the number of connected cars is expected to grow from 45 million at the end of 2011 to 210 million by 2016 [17]. Carelessness from drivers, inexperience, mal-function of vehicles and the 'act of god' are some popular reasons for cause of road accidents, which leads to death due to its regular occurrences. For this reason, DSRC has proposed a technology to be built into every vehicle [1] since safety in vehicular communication is inevitable. DSRC is designed to offer complete solution for mobile data broadcast, and also to active Wireless Access to Vehicular Environment (WAVE) protocol. It is a short to medium range communication service that supports applications like: electronic toll collection, Collision Avoidance (CA), Quality of Service (QoS) and public safety etc.

The focus of DSRC for any Rate Adaptation Algorithm (RAA) is low latency and high data rate, experienced due to the fast varying condition of vehicles as they change speed and environments. DSRC supports both safety (control channel) and non-safety (service channel) to enable its effectiveness. Vehicles must be able to switch between Control Channel (CCH) and Service Channels (SCHs) several times a second. Both of these share the limited resources of DSRC. Control Channel Interval (CCHI) has direct impact on reliability; the larger CCHI, the lower collision probability.

The rest of the paper is organized as follows: Section 2 is review of literature, while Section 3 deals with vehicular communication, Section 4 is an overview of ACARS, Section 5 presents the network concept and the results and discussions are presented in Section 6. Finally, Section 7 concludes the paper.

II. REVIEW OF LITERATURE

Auto Rate Fallback (ARF) [18] was first proposed in 1996, as the simplest and first rate adaptation algorithm. Other popular existing RAAs in wireless networks are Adaptive Auto Rate Fallback (AARF) [16] (ACARS) [11], Channel-Aware Rate Adaptation (CARA) [13], Context-Aware Rate Adaptation Algorithm (CARA) [15], Robust Rate Adaptation Algorithm (RRAA) [16] etc.

In ARF the decision whether to increase or decrease the transmission rate is based on the number of consecutive successfully or unsuccessfully transmission attempts. This algorithm is widely adopted because it is simple. In this algorithm, the sender tries to send a packet at a higher rate after a fixed number of continuously successful transmissions at a given rate. The sender decreases the rate after one or two consecutive failures. If the probe packet is successful, the next packet will be sent at higher rate and if not, the sender will immediately lower the rate. The sender also lowers the rate after two consecutive failures.

In [2]11]15][16], AARF was implemented with mobility concept. From these references, some of the implementations were with context- information [2] [11], while others implemented with power control in analysing the performance of rate adaptation algorithm.

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ONOE [16] is a very slowly adapting algorithm whose implementation is available in the MADWifi driver code [5]. It tries to change the rate after one second interval. ONOE is a credit-based algorithm that maintains the credit score of the current rate for every destination and after the end of a second; it calculates the credit and makes the rate change decision. This rate selection scheme has also been implemented with mobility and power control in [2][11] [15] where performances of various rate schemes were analysed.

In [4], SampleRate algorithm was proposed in order to maximise throughput in wireless networks. It is based on transmission statistics over cycles. In every tenth packet data, it picks a random rate that may do better than the current one to send the data packet. If it occurs that the selected rate provides smaller transmission time, it will switch to this rate. The performance of this rate selection scheme was evaluated in [2], with different performance metrics for various RAAs.

Furthermore, in [2] another RAA was proposed known as Context-Aware Rate Selection (CARS). This algorithm performs better in stressful scenarios, since it adapts its bit-rate faster in varying conditions. From [2], results show that CARS performs better than ONOE and SampleRate by using optimum higher data rates which allows CARS scheme to reduce network load. The limitation in this scheme is that, it lacks the ability to dynamically tune the estimation window size using the context-information, and it is not robust to adapt to shadowing effect available in wireless and mobile environments and detecting channel errors.

In [12] [13] [14] , another rate selection scheme known as Context-Aware Rate Algorithm (CARA), also considered other RAAs by implemented mobility in existing RAAs and CARA itself., but there was no implementation of power control scheme to enable existing RAAs estimate Signal-to-Noise Ratio (SNR) from the Physical (PHY) layer.

Adaptive Context-Aware Rate Selection (ACARS) algorithm is a SNR-based rate selection scheme that relies on the Request-To-Send/Clear-To-Send (RTS/CTS) mechanism to provide instantaneous receiver-side Signal-to-Interference Noise Ratio (SINR) information to the transmitter. With the knowledge of the SINR at the receiver, the transmitter directly sets the transmission rate without wasting time to probe. But the trade-off in a SNR-based rate selection scheme is that in trying to solve the hidden node problem using RTS/CTS mechanisms, introduces significant overhead because of the time it takes in communicating with the receiver to estimate SNR from the PHY layer. Although ACARS performs well in the presence of fading processes, it has slow response to path loss exponents and hence does not perform very well [11] [15].

In this paper, we will evaluate the performances of various rate selection schemes and discuss results obtained as it applies to road safety.

III. VEHICULAR COMMUNICATION

Vehicular communication can either be an Ad-Hoc network where all vehicles communicate with each other directly or infrastructure network where vehicles communicate via an Access Point (AP). We have only shown a Vehicle-to-Infrastructure (V21) in Figure 2, because that is the only network configuration we have used in this paper.

The growth of connected cars associated with Mobile Information and Communication Technologies (MICT) will change the way vehicular environments will be planed and maintained. In this scope, context-awareness rises as an important technology so as to achieve optimal vehicular-centric information , such as assisting vehicular applications with meaningful information.

A. IEEE 802.11p Multichannel Operation

The PHY layer is responsible for transmitting raw bits in wireless channels; this is achieved via channel assignment. IEEE 802.11p is an extension of 802.11 wireless LAN Medium Access (MAC) and PHY. Three different PHY Layer modes have been defined by 802.11-2007 standards. They are the 20 MHz, 10 MHz and 5 MHz These modes can be achieved by using a reduced clock/sampling rate [3] [4] [8] [9].

B. Medium-Access Control (MAC) Layer

The function of the MAC layer is to coordinate the use of the communication medium. MAC layer protocol decides which node will access the shared medium at any given time. The MAC layer uses the Collision Avoidance (CSMA/CA) mechanism to regular access to the channel. The physical CSMA/CA does not rely on the ability of stations to detect a collision by hearing their own transmission; an Acknowledgement (ACK) is transmitted by the destination station to signal the successful reception of the transmitted packets and then transmission of ACK is immediately done following the packet reception after a Short Interframe Space (SIFS).

IV. OVERVIEW OF ACARS

In vehicular communication, context-information include speed, acceleration of the vehicle, position, distance from the neighbouring vehicle, environmental factors such as location, time of day, weather, type of road traffic density. In ACARS, we only used two significant parameters: speed of vehicles and the distance of the vehicles from the AP. This algorithm is based on CARS scheme with some assumptions, and modifications to the original CARS algorithm. The full implementation of CARS algorithm is not known from [2] because, information such as context-information, Packet Error

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Rate (PER) were not discussed, making it difficult to implement line 4 of CARS algorithm [2].

In this design, we used some mathematical illustrations to derive parameters for context-information and use them in implementing the CARS algorithm. For this reason, we re-named the original CARS algorithm as seen in [2] as modified CARS, because it is not identical to the original CARS. The function $\mathbf{E_C}$ uses context-information, transmission rate and packet length as input parameters and estimated packet error rate as output. $\mathbf{E_H}$ uses Exponentially Weighted Moving Average (EWMA) of past transmission statistics for each bit rate which has same working principle as SampleRate [7]. To predict the link quality of the channel, we used **cars.α** which is based on speed of the vehicles. When speed is zero, there is no prediction of link quality using context-information; hence EWMA will be given preference at that condition. But when vehicles are moving with high speed, **cars.α** is given preference, and this relationship **α =max(0,min(speed/S))** helps to determine the values of **cars.α** with different speed normalizers. The values of **S=30m/s** is chosen based on research in [2].

The three basic layers among the seven layers of the Open System Interconnection (OSI) reference model that implement ACARS are the application, MAC and PHY layers. The vehicles also known as Mobile Nodes (MN) use information from the application layer available in each MN, while the MAC layer handles the rate selection algorithm, and the PHY layer handles RTS/CTS frame exchange, SNR estimation and power control.

Algorithm 1. The Adaptive Context-Aware Rate Selection Algorithm

Function: ACARS_GetRate
Output: Rate
Input : ctx, α, len

1: Update counter of packet transmissions
2: Update average RSSs of recent ACKS(RSS)
3: $Best_{Rate}$ = $Find_{Best}$_Rate try[ ]
4 : Determine α by using α= max(0,min(1, speed/S))
5: Compute backoff using
6: backoff = CW_{size} **x** slot time
7: Decrement all backoff counters
8: Update the simulation time accordingly
9: Requires: Mob_{Model}
10: (t,v,old_{pos} ,ap CommRange, n, x_{max} for Context-information)
11. Compute Bper from the PER table
p(n,:) = polyfit (Snr $_{(Ber)Mode1}$:,1), log(n($_{Ber)Mode1}$(:,2)),exp_n)
12 : Compute α using
cars. α = 1 - E_H>0) **x** max(0,min(1, v(iTx)/cars.S))
13: E_c= cars.Ec (iTx,:)
14: Determine E_H using
15: E_H= cars. E_H (iTx,:)
16: Compute E_C
17: cars.E_c (iTx,jj) = min(1, exp (polyval(Phy.p(jj,:), snr{$_{temp}$))}
18: Compute E_H using
19: cars.EH (TxVehic,RateLevel (TxVehic))= cars. E_H (TxVehic, RateLevel(TxVehic)) **x** (1-a)+ Bper **x** a
20: Compute PER using
PER=E_c cars. α +(1-cars. α) **x** E_H
$Avgr_{etries}$ = (N.PER^{(N+1)} -(N+1).PER^N+1)/(1-PER)+N.PER^N)
Thr =Rate/$avg_{retries}$.(1-PER^N)^/ρ
21: Select rate
22: IF Thr > Max_Thr
23: Update link condition
24: $Best_{Rate}$ ← bit-rate
25: Max_Thr ← Thr
26: ENDIF.

V. NETWORK CONCEPT

In this section, we will describe the network configuration used in implementing of our algorithm. We will also highlight on the parameters used in our simulation in MATLAB.

A. Simulation Scenario

In this network configuration, each time a vehicle enters into the communication range; it communicates with the Road Side Unit (RSU). It adds new vehicle information such as vehicle speed, position, distance, etc. This information helps the RSU to broadcast the emergency information to the vehicles. Every minute, vehicles leave and enter the communication range with high speed. RSU will communicate to vehicles as soon as they enter the communication range. For example, if there are no vehicles within range, and there is an accident or emergency message at that time , as soon as any vehicle enters the range, message will propagate through the first entered vehicle in that communication range. This RSU communication helps in communication when there is no vehicle in cluster range.

In this scenario, all vehicles act as clients. We use a fixed base station as server, which is similar to what is obtained in cities and highways having RSUs (e.g., kiosks and cafes) with wireless services. Our scenario consists of a road of length 1000 m with multiple lanes. The base station is located at the middle of the road. Vehicles select their speeds uniformly over the range [$Speed_{avg}$ *0.75, $Speed_{avg}$ *1.25] km/h. Tables I shows the simulation parameters used., while Figure 1 shows the V2I configuration used in our simulation.

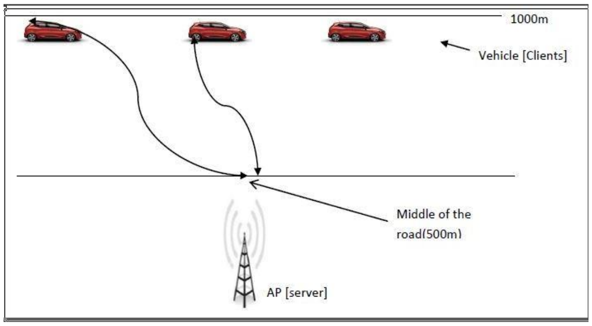

Figure 1. Network Setup.

$Speed_{avg}$ x 0.75, $Speed_{avg}$ x1.25km/h (1)

$$d= \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + \cdots + (x_n - y_n)^2} \quad (2)$$

where **d** is distance in meters, **x** and **y** are vehicle positions in the **x** and **y** coordinates and **$Speed_{avg}$** is average speed of vehicles. **$Speed_{avg}$** of 55 km/h was used for the different number of vehicles. The distance **d** between vehicles and Access Point (AP) or RSU with vehicle positions **x** and **y** were determined from equation (2). Parameters used in this simulation are listed in Table I.

TABLE 1. CONFIGURATION PARAMETERS

Parameters (Units)	Values
Length of Road (m)	1000
Number of Vehicles	150
Position of AP (m)	500
PHY and MAC Protocol	802.11p
Frequency (GHz)	5.89
Normalized Transmit Power (mW)	40
Noise Power (dBm)	-90
ϒ (Path Loss exponent, Urban area cellular radio)	2.0, 2.7-3.5
Sigma (dB)	6- 8
Communication Range (m)	300
DIFS (µs)	50
SIFS ((µs)	30
HPHY (bits)	192
HMAC (bits)	200
Data rate (Mbps)	3, 4.5, 6,9,12,24,27
Maximum Retransmission	3

B. Propagation Environment

Simulation was carried out by implementing a V2I network so that analysis of AP coordination for data transfer protocol and context-information can be evaluated. Mathematical calculations were integrated into our MATLAB code and were used in this implementation. To ensure accuracy of results, simulation was done to **4** iterations and for a highly dense network of **150** vehicles.

C. Free Space Path Loss

Free space path loss model is a power off that relates to distance. Due to high mobility of vehicles as speed changes, the distance between the transmitter and receiver changes. This makes empirical free space path loss necessary in order to model the effect of distance on packet delivery probability. This space loss accounts for the loss due to spreading of Radio Frequency (RF) energy as transmission of signals propagates through free space. From the equation (3) of path loss, it is seen that the power density is reduced by $\frac{1}{R^2}$ as distance is increased.

$$P_{rx} = p_{tx}\left(\frac{\lambda_o}{4\pi R}\right)^2 \quad (3)$$

where $\frac{P_{tx}}{4\pi R^2}$ is the power density, λ_o is wavelength in meters, P_{rx}, p_{tx} are received and transmit power respectively. In free space, the power of electromagnetic radiation varies inversely with the square of distance, making distance an ideal indicator of signal level as well as loss rate. Due to imperfect propagation environment, in practice, it is not exactly the inverse square. Distance between sender and receiver gives a high correlation between signal level and error rate as this affects the number of transmitted packets that will be received [19].

$$g_{(t)} = g_{p(t)} + g_{s(t)} + g_{m(t)} \quad (4)$$

$$P_{rx} = P_{tx} - g_t \quad (5)$$

$$RSS = P_{rx} - P_{noise} \quad (6)$$

where g_t is power gain, $g_{p(t)}$is path loss, $g_{s(t)}$ is shadowing and $g_{m(t)}$ is multipath fading P_{noise} is noise power while RSS is the Received Signal Strength.

D. Log-Normal Shadowing

Communication channel is a time varying power gain which consists of path loss, log-normal shadowing and multipath fading. The receivers experience a desired signal gain with respect to the transmit power $\mathbf{P_t}$ used by the transmitter. We used shadowing deviation and path loss exponent in our simulation as shown in Table I to evaluate the impact of environmental factor on RAAs.

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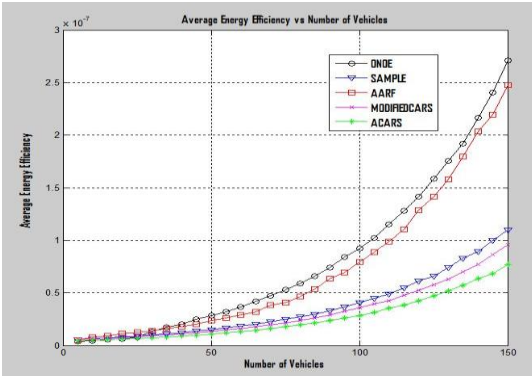

Figure 2. Average Energy Efficiency vs Number Of Vehicles.

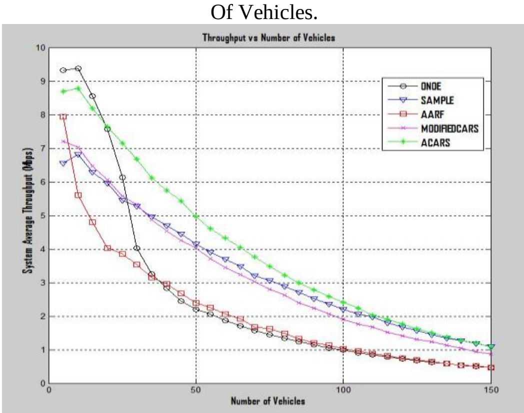

Figure 3. Average System Throughput vs Number of Vehicles.

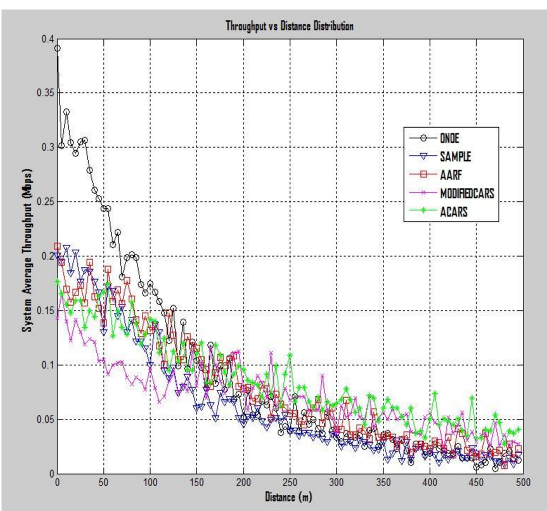

Figure 4. Average System throughput vs Distance.

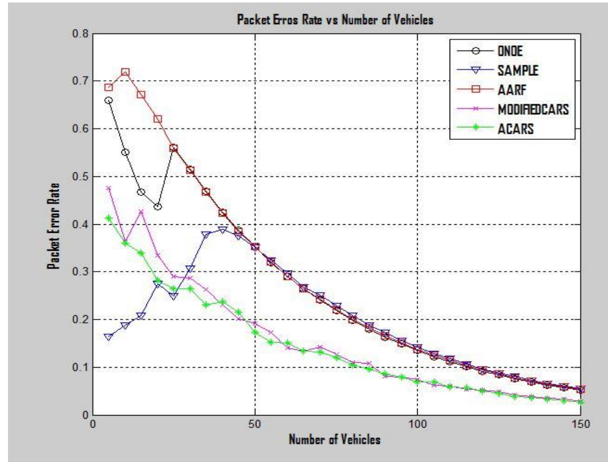

Figure 5. Packet Error Rate vs Number of Vehicles.

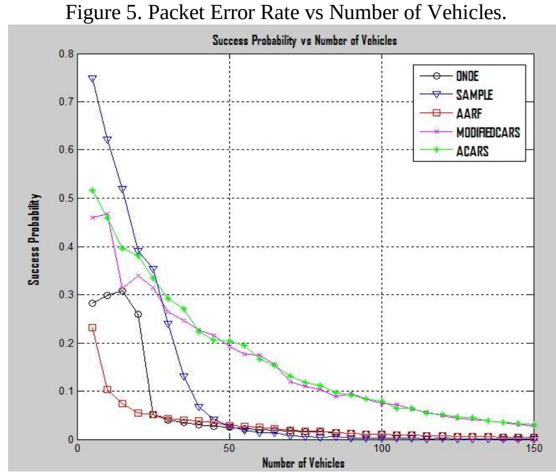

Figure 6. Success Probability vs Number of Vehicles.

VI. RESSULTS AND DISCUSSIONS

AARF has poor energy efficiency than all other rate selection schemes from Figure 2. From this figure, SampleRate performs better than the other rate schemes followed by ACARS. ONOE struggled to increase its efficiency at higher vehicle density. This trend is different from the behaviour of AARF that degrades its efficiency as the density of the vehicle increases.

ONOE is a credit-based rate adaptation algorithm; it spends about 10 seconds on each bit-rate before it increases rate and then scaling up to the highest bit-rate of 27 Mbps, therefore does not perform so well in this scenario. AARF and ONOE have same poor performances compared to the others, as seen in Figure 3. AARF waits for 10 consecutive successful transmission attempts before increasing rate. Since it is a transmitter-based rate adaptation algorithm, it cannot adapt fast in selecting the proper transmission rate that will match the channel condition, this may be one of the reasons for its low performance. ACARS performs better than all other rate adaptation schemes. Observation from this figure shows that SampleRate performs better than AARF, ONOE and MODIFIEDCARS.

As observed in Figure 4, mobility results in more rapid channel variations that are very challenging for rate selection algorithms. In such dynamic environments, we expect that it is critical to gain accurate channel information quickly in order to effectively utilize the channel. From this figure, ACARS and MODIFIEDCARS show some fluctuations in performance as the distance increases and perform better than the other rate selection schemes. ONOE performs worse than the others rate selection schemes. From this figure, it is observed that ONOE is affected greatly by vehicle mobility, because up to about **120** meters, it performs better than all others, but dropped greatly from **150** meters. This shows that ONOE cannot perform well in high mobility scenario especially as the inter-node distance increases

From Figure 4, ACARS and MODIFIEDCARS compete with each other and almost overlap as the network congestion increases due to increase of vehicles. Both of them did not perform badly as can be observed from this figure. SampleRate performs better than all other rate schemes, while AARF and ONOE did not perform well compared to the others. The reason for this may be because, both of them spend much time before changing rate in this circumstance thereby increasing the waiting time.

The performance measure between SampleRate and ACARS/MODIFIEDCARS is large. AARF also degrades fast as the number of vehicles increases. We can observe how the network congestion greatly affect AARF and ONOE.

The throughput performance of a network is affected by the rate at which packets are in error. From Figure 5, ACARS has a low PER rate, which helps in the overall throughput performance of this algorithm. On the other hand, AARF and ONOE perform very poorly compared to all other rate selection schemes. SampleRate struggles to compete with ACARS as can be seen from this figure. It also performs better that AARF, ONOE and MODIFIEDCARS in this scenario.

The success probability for both ACARS and MODIFIEDCARS are better than the others Figure 6. Success rate is proportional to network throughput. If the success rate is high then the final throughput of the system will be better. SampleRate performs poorly compared to the other rate selection schemes. The channel condition in this scenario may have greatly affected its ability to choose an appropriate transmission time in order to change rate.

From these results, we have seen that ACARS can be a good RAA, to be used for vehicle safety and data transfer in DSRC, because of its good throughout performance and high success rate.

VII. CONCLUSION AND FUTURE WORK

One of the key contributions in this paper is the implementation of a SNR-based rate adaptation algorithm that estimates SNR from the PHY layer, so as to be effective in packet delivery probability. With this feature, ACARS performs better than existing rate adaptation algorithms (RAAs) and this can be seen from most of our simulation results.

Another key contribution in this paper is the integration of power control into the design of ACARS algorithm and other existing rate adaptation algorithms. From literatures, it has either been rate adaptation analysis, or power control analysis respectively, without a combination of these two. We have combined these two in the design and implementation of ACARS. Results obtained show that ACARS can minimize energy consumption which is one of the major challenges of wireless mobile nodes. It can also reduce network congestion and enhance QoS with help of the power control scheme.

In the future, we will evaluate the performance of ACARS on other context- information and also consider a Vehicle-to-Vehicle (V2V) scenario.

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