UNIVERSITY OF LEEDS

This is a repository copy of *TDMA-Based MAC (CVTMAC) in Green Vehicular Networks*.

White Rose Research Online URL for this paper:
http://eprints.whiterose.ac.uk/106922/

Version: Accepted Version

Proceedings Paper:

Audu, GA, Bhattacharya, S and Elmirghani, JMH (2016) TDMA-Based MAC (CVTMAC) in Green Vehicular Networks. In: Al-Begain, K, (ed.) Proceedings. 2016 10th International Conference on Next Generation Mobile Applications, Security and Technologies (NGMAST 2016), 24-26 Aug 2016, Cardiff, UK. IEEE , Los Alamitos, CA, USA , pp. 24-29. ISBN 978-1-5090-0949-7

https://doi.org/10.1109/NGMAST.2016.11

© 2016 IEEE. This is an author produced version of a paper published in Proceedings: 2016 10th International Conference on Next Generation Mobile Applications, Security and Technologies (NGMAST 2016). Personal use of this material is permitted. Permission from IEEE must be obtained for all other uses, in any current or future media, including reprinting/republishing this material for advertising or promotional purposes, creating new collective works, for resale or redistribution to servers or lists, or reuse of any copyrighted component of this work in other works. Uploaded in accordance with the publisher's self-archiving policy.

Reuse
Unless indicated otherwise, fulltext items are protected by copyright with all rights reserved. The copyright exception in section 29 of the Copyright, Designs and Patents Act 1988 allows the making of a single copy solely for the purpose of non-commercial research or private study within the limits of fair dealing. The publisher or other rights-holder may allow further reproduction and re-use of this version - refer to the White Rose Research Online record for this item. Where records identify the publisher as the copyright holder, users can verify any specific terms of use on the publisher’s website.

Takedown
If you consider content in White Rose Research Online to be in breach of UK law, please notify us by emailing eprints@whiterose.ac.uk including the URL of the record and the reason for the withdrawal request.

White Rose
university consortium
Universities of Leeds, Sheffield & York

eprints@whiterose.ac.uk
https://eprints.whiterose.ac.uk/

TDMA-Based MAC (CVTMAC) in Green Vehicular Networks

George A. Audu, Samya Bhattacharya and Jaafar M. H. Elmirghani
School of Electronic and Electrical Engineering, University of Leeds, UK
elgaa@leeds.ac.uk, s.bhattacharya@leeds.ac.uk and j.m.h.elmirghani@leeds.ac.uk

Abstract— **The growing need to reduce the carbon footprint and the operation expenditure (OPEX) in communication networks necessitates the deployment of wind powered base stations (BSs) and roadside units (RSUs) for vehicular communication networks in windy countries with limited solar irradiation. This system finds ready application in sparse areas like countryside and motorways that lack the supply from the national grid for economic reasons. The stringent performance requirement of vehicular communication systems owed to their critical services poses challenges to their greening efforts. In this paper, we design a robust time-division multiple access (TDMA) based MAC for an infrastructure based green vehicular network in a motorway scenario and investigate the network performance against the stringent quality of service (QoS) thresholds. We call the proposed Centralised Vehicular TDMA based MAC as CVTMAC for short. To obtain a realistic performance evaluation, we model and simulate the proposed MAC protocol with the real channel characteristics of the motorway environment fully incorporated. The off grid RSU is powered solely by an economical and easy to deploy small standalone wind energy conversion systems (SSWECS). Wind energy-based rate adaptation is deployed in the RSU to enhance the efficient utilization of available energy (considering the intermittent nature of wind energy). In this study the real vehicular traffic profiles and wind data for a specified motorway region have been utilised. Both analytic and simulation results reveal that with the introduction of small battery capacity (27 Ah), the green vehicular network is able to support QoS for data, audio and video-related applications at each hour of the day in a motorway vehicular environment.**

Keywords—Roadside unit; vehicular network; renewable energy; adaptive rate; MAC; Rician fading.

I. INTRODUCTION

Vehicular network is a mobile network designed mainly for communications among vehicles and between vehicles and roadside infrastructures. It integrates wireless LAN (WLAN), cellular technology and ad hoc network to achieve intelligent vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communications. The participating vehicles are equipped with on-board units (OBU) which possess significant computing, communication and sensing capabilities to provide safety and entertainment services to travellers [1], and Global Positioning System (GPS) devices for position/location tracking. Vehicular communication systems are classified into (i) infrastructure-less communication systems, (ii) infrastructure-based communication systems, and (iii) hybrid communication systems which is the combination of (i) and (ii) [2].

The infrastructure-less networks which are called Vehicular Ad hoc Networks (VANETs) are concerned with V2V communications and they rely on the vehicles themselves to provide network functionality. The infrastructure-based vehicular networks have the presence of central infrastructures in form of access points (APs), RSUs or BSs to offer improved quality, resilience and reliability to the network. The communication here involves vehicle to RSU (V2R) or V2I, where the infrastructure provides the vehicles with access to online resources. Effective utilization of channel resources among the vehicles in this centralized communication system is enhanced by an efficient medium access control (MAC) protocol with signaling and coordination by the RSU or BS. The design and development of suitable and resilient MAC protocols therefore constitute a major research obligation in developing a viable vehicular communication network.

Deployment of RSUs with renewable energy sources can significantly reduce the carbon footprint while standalone off-grid wind powered RSUs can as well alleviate common issues associated with grid connected renewable energy farms, and provide ease of operation (deployment and maintenance) in remote areas such as countryside and motorways. Such deployments also eliminate several power systems related issues such as distribution, metering and grid maintenance. With the renewable power generation technologies becoming increasingly cost-competitive, the option of off-grid electrification in most areas and locations with good resources becomes most economic [3], and the renewable energy sources in conjunction with fast rechargeable batteries have become an attractive option to power the BSs/RSUs in sparse vehicular environments.

Since achievable renewable energy varies greatly based on the geographic locations and weather conditions, the design of reliable communication systems powered by renewable energy introduces additional complexity, especially in the case of standalone off-grid systems. Wind powered off-grid BSs/RSUs is a better option in windy countries like the UK, where the solar power is limited in several geographic locations for a substantial period of the year. The previous studies by authors in [4] investigated the feasibility of a standalone wind-powered RSU in the UK and have shown that the communication QoS requirements can be met with a very small battery if a sleep mechanism is employed. However, the option of maximizing the energy efficiency of the RSU through rate adaptation was not explored. The authors in [5] proposed a wind energy dependent rate adaptation for RSU in vehicular networks without implementing the effects of real channel characteristics and communication protocols of the studied environment.

Furthermore, the choice of a contention free TDMA based MAC protocol is premised on its superior performance to the popular carrier-sense multiple access (CSMA) based protocols which are prone to high collisions (with the associated collision avoidance overhead) at high load, a feature which becomes intolerable in high mobility scenario of V2R communications [6], [7]. A centralized TDMA based MAC that implements Rician fading and with regards to green RSU is lacking in the literature. The work in this paper attempts to fill these gaps by proposing a robust TDMA based MAC for an infrastructure based green vehicular network in a motorway scenario and investigating the network performance against the required stringent QoS criteria for vehicular communications. The physical channel characteristics of motorway environment that capture Rician fading are implemented in the proposed MAC. In order to minimise energy consumption in vehicular communication systems, the number of high power BSs is reduced by deploying pico-cells served by low power RSUs within a macro cell that is served by the BS intermittently. This heterogeneous network offers high data rates and reduced number of BSs while satisfying the QoS criteria [8].

Following the introduction, the remainder of the paper is organized as follows. Section II describes the proposed scenario with system parameters. Section III contains the wind energy model and RSU load model. The rate adaptation algorithm is described in Section IV. Section V discusses the performance results. Finally, the paper concludes in Section VI.

II. THE STUDIED SCENARIO

Our studied scenario is a 3 lane motorway with a set of RSUs, typically spaced 1 km apart in line with the Wireless Access in Vehicular Environments (WAVE) standard [9], installed along its stretch as shown in Fig. 1. The RSUs receive data from moving vehicles within their coverage areas and relay the information to a BS that is beyond the transmitting range of the vehicles. Each RSU is connected to a micro turbine for wind power generation through a compact chargeable battery. A small battery capable of supplementing the wind energy deficit to deliver acceptable quality of service with rate adaptation is utilized. The small battery size facilitates ease of deployment and maintenance of the off-grid RSUs in a motorway scenario. The communications between vehicles and a RSU is enabled through a wireless link using a scheduled based CVTMAC protocol. The standard data rate specifications of the RSUs and the BS would determine the number of RSUs that can be connected to the BS. A length of 10 km is considered in the studied scenario for the network analysis. Ten RSUs are therefore considered to be in this range and under the coverage of one BS. The system parameters are shown in Table I.

III. VCTMAC ARCHITECTURE

CVTMAC is a scheduled-based MAC protocol with the channel being made up of uplink and downlink frames which are divided into time slots. The BS is responsible for the signaling and coordination of the microcells which comprise the RSUs and vehicular nodes within their coverage region. The uplink frame consists of a reservation and information slots while the downlink frame consists of information and acknowledgement slots. The reservation slots are used by the vehicular nodes to send access request packets before data transmission. Fig. 2 shows the frame and slot structure of the protocol, where R, I and ACK represent reservation, information and acknowledgement slots respectively. To preclude the high collisions and congestion issues of slotted ALOHA slot reservation technique, orthogonal codes [10], [11] are used to

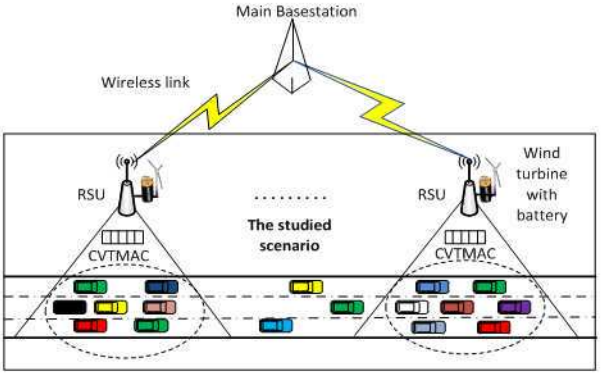

Fig. 1. Proposed rate adaptive RSUs in a motorway.

TABLE I: SYSTEM PARAMETERS

Parameters	**Values**
Micro turbine propeller length (diameter D)	1 m [12]
Swept area (A)	0.785 m^2 [12]
Coefficient of performance (C_p)	0.45 [12]
Air density (ρ) at 15°C	1.225 kg/m^3 [13]
Cut-in speed	3.5 m/s [14]
Cut-out speed	21 m/s [14]
Vehicle data generation rate (d_t)	320 kbps [15]
Maximum data rate (d_{r_Max}) of RSU	27 Mbps [16]
Average packet size	867.4 bytes [15]
RSU max. power consumption (P_{Max})	20 W [16]
RSU operational power (P_{op}^{RSU})	$P_{Max}/1.3548$ [17]
Maximum transmit power (P_{Tx-max})	$P_{Max} - P_{op}^{RSU}$ [17]

TABLE II: SYSTEM COMMUNICATION PARAMETERS

Parameter	**Notation**	**Value**
No of slots per uplink frame	c	15
Uplink channel data rate	d_r	15 Mbps
Speech peak bit rate	d_s	64 kbps
Video peak bit rate	d_v	320 kbps
Uplink/downlink frame duration	T_f	0.424 ms
Downlink timing signal	T_d	4 bits
Packet size with header	P_s	53 bytes
Packet's header	h	5 bytes
Speech maximum time delay	D_{max}	20 ms
Video maximum time delay	VD_{max}	150 ms

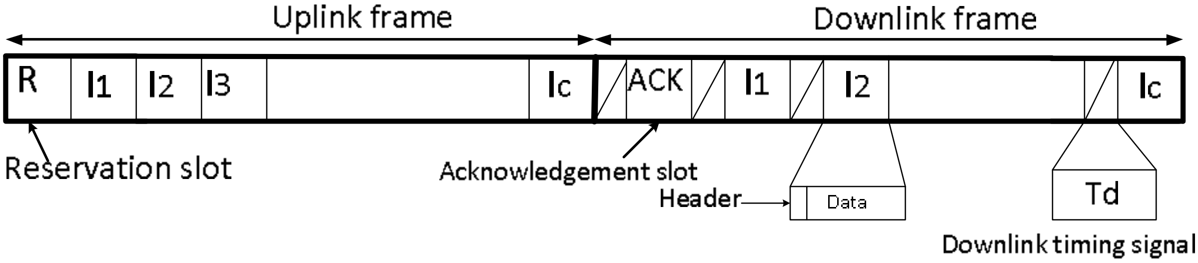

Fig. 2. Proposed CVTMAC time slots architecture

address collision issues that might arise when two more vehicles attempt slot reservation at the same time. The vehicular nodes would have to re-transmit their slot reservation request anytime access request collision occurs. Messages which indicate the current status of each downlink slot, such as scheduled reservations, after determining and arbitrating between the vehicular nodes that have applied for slot reservations are broadcasted by the BS using the *ACK* slot. The time duration of both the *R* and *ACK* slots depend on the value of maximum number of vehicular nodes that can be supported. The system communication parameters are shown in Table II.

IV. SYSTEM MODELLING AND SIMULATIONS

A. Simulations of CVTMAC Protocol and Rate Adaptive RSU

In order to realise the CVTMAC protocol with physical channel characteristics incorporated, and to implement the wind energy-dependent rate adaptation in the RSU, a JAVA based event-driven simulator based on vehicular measurements from the M4 motorway, UK, which was developed in [18] is adopted and modified appropriately. The distributions for the level crossing rate and the average fade durations of the Rician fading in the motorway environment are factored into the simulator to reflect channel outage (vacation) in the system performance. There are four classes in the simulator for the CVTMAC protocol. The first is a vehicle class which controls the vehicular mobility. The second which is slot class monitors the unavailability of slots due to channel outage, while the third, the distribution class generates the packet arrival, packet size, and slot outage duration. The fourth class which is the main class runs the simulation. The slots in the channel are constantly scanned to ascertain their availability status. When a slot is available, an arriving packet is allotted slot for immediate service, while the packet waits for one when no slot is available. The packet's service and waiting times are recorded and used to compute the average packet delay and service duration. A slot is unavailable for an exponentially distributed time when it commences vacation. The arriving packets and the packets being served at the instants of slot vacation are lost. The lost packets are accounted for by the computed packet loss ratio. The successfully transmitted packets constitute the arrival process at the RSU. The simulation runs for a period of 3600 s in microseconds, and the QoS parameters are calculated based on the packet timestamps and the values of the used variables for the hour. The hour is then incremented and the corresponding vehicular density updated by the simulator to obtain the QoS parameters for the whole hours of the day. The wind energy-based data rate distribution of the RSU obtained in [5] is also implemented in the RSU simulation process.

B. System Model and QoS Metrics

By considering the time slots within a channel frame of CVTMAC protocol as a bunch of parallel servers, a typical TDMA based protocol in a vehicular network with ideal channel can be modelled as an $M/M/c/\infty/M$ queue [18], where the first M represents the Poisson arrival of packets from the vehicles, the second M represents the negative exponentially distributed service time, c the number of parallel servers, ∞ an infinite buffer size and the last M the population size which is the number of vehicular nodes. The channel outages due to fading are represented in the queue model as asynchronous queue-length-independent vacations. Since the wireless channel is unpredictable in a dynamic vehicular environment, there is need to incorporate in the model the unavailability of the links due to fading. It is therefore necessary to determine the level-crossing rate which denotes the number of fades per second and the average fade duration (AFD) which depend upon parameters such as average received power, operating frequency, receiver sensitivity, fading statistics, and vehicle's speed [19]. The channel fading associated with motorway communications has been described by Rician distribution in the literatures [20]. Rician fading is similar to Rayleigh fading, except that a strong dominant component is present in Rician fading. This dominant component can for instance be the line-of-sight component typical in motorway communications. The level crossing rate (LCR) for Rician fading [19] is given by

$$L_z = \sqrt{2\pi(k+1)} f_d \rho e^{-k-(k+1)\rho^2} I_0\left(2\rho\sqrt{k(k+1)}\right) \quad (1)$$

where the Rician k-factor (fading parameter) is defined as the ratio of signal power in dominant component to the mean scattered power; f_d is the Doppler frequency, ρ is the normalized threshold and I_0 is the modified Bessel function of the first kind, zero order. The normalized threshold is given in terms of the threshold power level (P_o) and the average power level (P_r) as

$$\rho = \sqrt{P_o/P_r} \quad (2)$$

while the maximum Doppler shift $f_d = (vf)/s$ where v is the velocity of vehicle, f is the carrier frequency of the transmitter and s is the speed of light. Assuming isotropic scattering with one non-random component, the average Rician fade duration [21] is given as

$$\tau = \frac{1-Q\left(\sqrt{2\pi},\sqrt{2(k+1)\rho^2}\right)}{\sqrt{2\pi(k+1)}f_d\rho e^{-k-(k+1)\rho^2}I_0\left(2\rho\sqrt{k(k+1)}\right)} \quad (3)$$

where $Q(a,b)$ is the Marcum Q function.

At a transmitting frequency of 5.9 GHz and 30 m/s average speed of vehicle, the maximum Doppler shift equals 590 Hz. The average transmit power of a vehicle moving at an average speed of 30 m/s in a motorway environment is 30 dBm [20]. Furthermore, -90 dBm threshold power is required at the receiver to support communication with a channel capacity of 12 Mb/s [22]. Using these parameters an average power of -70.8 dBm is received with a normalized threshold of 0.11 at a distance of 500 m (i.e. the midpoint of adjacent RSUs). The AFD and LCR obtained from these parameters are used to compute the transition rates of the two-state Markov chain for modelling the channel outage.

The time slots in CVTMAC are considered as c independent servers, while the channel outages are queue length-independent (asynchronous) vacations. Considering the Poisson distributed arrival process of the packets from the vehicles with mean arrival rate λ', the combined arrival process from M vehicles follows a Poisson distribution with mean $\lambda = M\lambda'$. The packet service time follows a negative exponential distribution with mean $t = (1/\mu)$, where μ is the mean service rate of each server. Packets that arrive during the channel outage are dropped while only those that arrive when the server is available are served. The vacation rate and duration are based on AFD and LCR.

Using the steady state distribution of the number of packets in the system obtained in [23] for $M/M/c/\infty/M$ queue with asynchronous vacations, we have the mean queue length L as

$$L = \sum_{k=0}^{\infty} k\,p_k \quad (4)$$

By applying Little's law, the mean total time spent in the system by a packet becomes

$$W = \frac{L}{\lambda} \quad (5)$$

Furthermore, the probability that the channel slots (servers) are busy, i.e. the system utilisation U, is computed as

$$U = \frac{\sum_{j=1}^{c}\sum_{k=1}^{\infty}\min(j,k)p_{jk}}{c} \quad (6)$$

where p_{jk} is the probability of k packets when there are j available servers [23]. The packet loss ratio can be obtained as the difference of system utilisations with and without loss.

Similarly, the wind energy-based rate adaptive RSU whose input is the output of the output of CVTMAC can be modelled as an $M/G/1/K$queue. The departure rate of CVTMAC protocol become the arrival rate at the RSU which has Poisson distribution. The RSU has a general distributed service rate according to the wind energy-based data rate distribution as obtained in [5]. A singular (1) RSU (server) has a limited buffer size K. Since the queue is of finite capacity, packets that arrive when the buffer is full are blocked or lost. The blocking probability (P_b) which is the probability of packets being lost as a result of full buffer, as well as throughput and delay are therefore crucial performance metrics for a finite capacity system. Based on the equilibrium state probability p_k obtained for $M/G/1/K$queue in [24], the QoS metrics can be computed as follows:

$$N = \sum_{k=0}^{K} k\,p_k \quad (7)$$

The effective arrival rate (λ_c) can be expressed as

$$\lambda_c = \lambda(1 - P_b) \quad (8)$$

The mean total time spent in the system by a packet according to Little's law becomes

$$W = \frac{N}{\lambda_c} \quad (9)$$

V. RESULTS AND DISCUSSIONS

A. *CVTMAC Protocol Performance*

The analytic and simulation results of the key performance metrics of the proposed CVTMAC which include packet loss ratio, average packet delay and utilization are shown in Fig. 6-8.

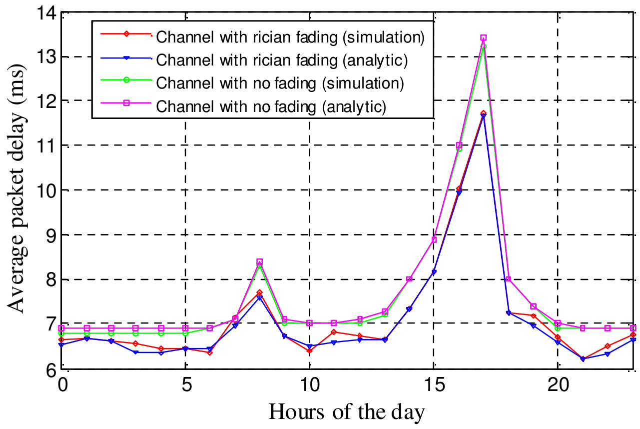

Fig. 6. Average packet delay with hourly varying load

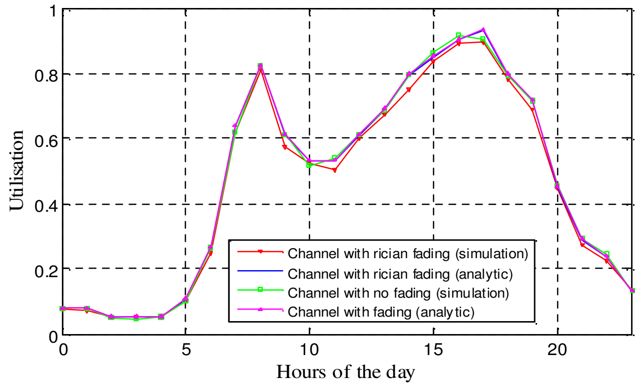

Fig. 7. Utilisation with hourly varying load

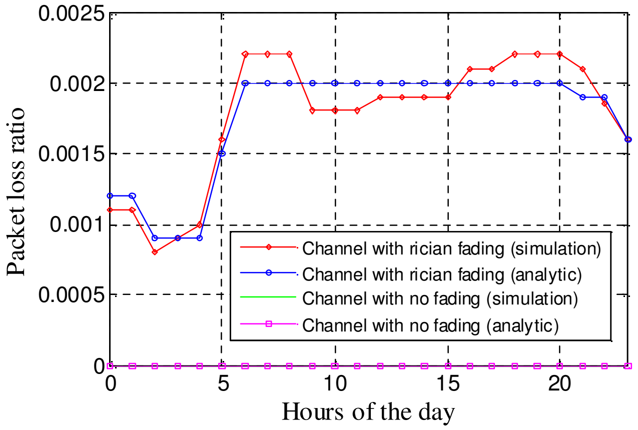

Fig. 8. Packet loss ratio with hourly varying load

The performance of CVTMAC protocol for a channel with 15 slots was investigated with Rician factor k=5, AFD=171.96 µs and LCR=3.489 fades/s. The results were obtained for real and ideal channel conditions. In Fig. 6 the average packet delay has two peaks at the periods of high vehicular traffic density of hours 8.00 and 17.00, which represent the rush hours of the day. The increased traffic density at these hours implies proportional increase of mean packet arrival rate, which leads to increased queue length and delay. At all hours of the day, the ideal channel (channel with no fading) has higher delay than the real channel because it has more packets on the queue awaiting service unlike the real channel that has some packets lost to fading. The delays are within the acceptable range of both audio and video related applications.

Fig. 7 shows the system utilizations in real and ideal channels. As expected, the utilization which depends on the traffic intensity (carried load) and the number of servers (slots) available, has two peak values of 0.81 and 0.92 at hours 8.00 and 17.00 respectively. The real channel utilization is marginally lower than that of ideal channel because the servers are less busy owed to some lost packets due to fading. Fig. 8 shows the packet loss ratio due to fading with hourly varying load. There is no packet loss in ideal channel as fading does not exist. The packet loss ratio during the off peak period is low, ranging from 0.0008 to about 0.0017. It becomes relatively high and constant (around 0.002) during mid and high peak periods. This is an indication that packet loss are largely due to channel outages due to fading and less dependent on the load.

B. Rate Adaptive RSU Performance

The performance of wind energy-based rate adaptive RSU whose communication with vehicles within its range is through the CVTMAC protocol is investigated in terms of packet blocking probability, average packet delay and utilization with varying hourly load and different buffer sizes as shown in Fig. 9-11. The mean hourly arrival rate at the RSU which is the mean departure rate of the CVTMAC constitutes the traffic load. As noticeable from Fig. 9-11, the performance metrics of the RSU vary with the arrival rates in the same pattern the performance metrics of CVTMAC vary with hourly vehicular density (load). Fig. 9 shows the variation of the average packet delay with the arrival rate. According to expectation, the average packet delay is highest when the RSU buffer size is highest (K=20) and lowest when K=3. With large buffer size, more packets are accommodated in the queue which implies longer waiting period for service and hence high average packet delay. This however reduces the packet blocking probability (PBP) as seen in Fig. 10. It is interesting to note that the system performs satisfactorily in terms of delay with a buffer size as small as 3. Fig. 10 shows how the PBP varies with the packet arrival rate. The buffer size of 20 proves to be optimal as it keeps the PBP at zero throughout the day. While the PBP with K=10 remains within the acceptable range (less than 1%), it becomes too high and unacceptable (PBP approaching 8%) with K=3 at some hours of the day. The blockage is mainly due to the limited capacity of the RSU which leads to buffer overflow after saturation. Fig. 11 shows the variation of system utilization with varying packet arrival rates (loads). Utilisation depends on the system capacity (buffer size K) and carried load. When K is large, the RSU would normally have a large of number of packets queued up in the buffer for service which implies high utilisation. As seen in Fig. 11, the utilization is highest when K=20 and lowest when K=3. Furthermore, the utilisation remains low at low loads and without remarkable difference with various buffer sizes because of underutilization. The utilisation increases with load and with remarkable difference according to the various buffer sizes.

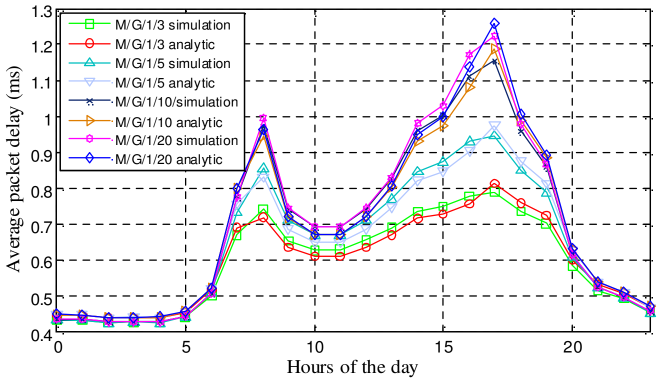

Fig. 9. Average packet delay with varying arrival rates

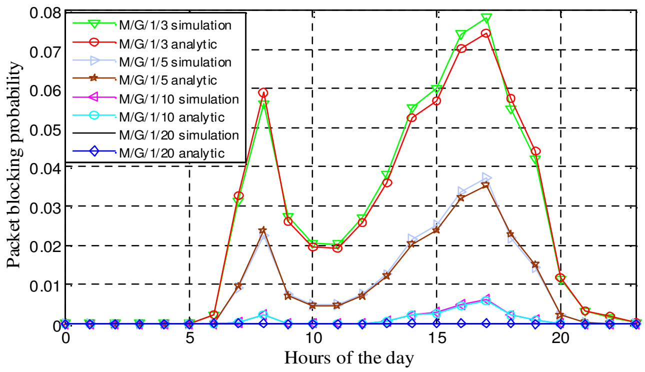

Fig. 10 Packet blocking probability with varying arrival rates

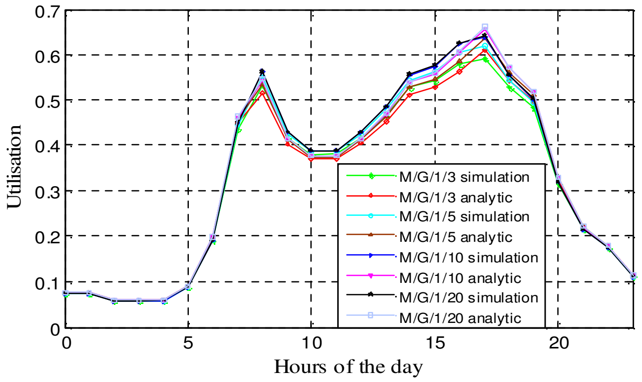

Fig. 11 Utilisation with varying arrival rates

VI. CONCLUSION

In this work we have developed a resilient and robust centralized vehicular TDMA-based MAC (CVTMAC) for green vehicular networks. The performance of the system (CVTMAC and the wind energy-based rate adaptive RSU) was investigated in terms of average packet delay, system utilisation and packet loss ratio/packet blocking probability. The simulation results obtained from the event-driven Java based simulator were validated by the analytic results. The queue model developed for the CVTMAC with the incorporation of physical channel impairments and the queue model for the rate adaptive RSU were solved in tandem; the departure process of CVTMAC became the arrival process of the RSU. With the channel data rate of 15 Mbps and 15 slots, and wind-powered RSU with battery size of 27 Ah and buffer sizes between 10 and 20, the system offers a high quality service with losses kept below 1% and delay below 1.3 ms at all times. The system can therefore support audio, video and data-related applications of vehicular communications.

ACKNOWLEDGMENT

The authors would like to acknowledge the support of the Engineering and Physical Sciences Research Council (EPSRC), UK for funding the INTelligent Energy awaRe NETworks (INTERNET) project under contract EP/H040536/1; and Petroleum Technology Trust Fund, Nigeria, for the Scholarship awarded to the first author to fund his PhD.

REFERENCES

[1] H. Wu, “Analysis and design of vehicular networks,” Ph.D. dissertation, Department of Computer Science, Georgia Institute of Technology, December 2005.

[2] M. Sichitiu and M. Kihl, “Inter-vehicle communication systems: a survey,”*IEEE Communications Surveys and Tutorials*, vol. 10, no. 2, pp. 88–105, 2008.

[3] Arent, D.J., A. Wise, and R. Gelman, *The status and prospects of renewable energy for combating global warming*. Energy Economics, 2011. **33**(4): p. 584-593.

[4] A. Muhtar, S. Bhattacharya, B. R. Qazi, and J. M. H. Elmirghani, "Greening vehicular networks with standalone wind powered RSUs: A performance case study," *in the IEEE International Conference on Communications (ICC)*, 2013.

[5] G. A. Audu, S. Bhattacharya, and J. M. H. Elmirghani, "Wind Energy dependent Rate Adaptation for Roadside Units in Vehicular Network," *Next Generation Mobile Applications, Services and Technologies, 2015 9th International Conference on*, pp. 156-160. IEEE, 2015.

[6] T. S. Rappaport, *Wireless Communications: Principles and Practice*. Upper Saddle River, NJ, USA: Prentice-Hall, 2002.

[7] W. Kumar, A. Muhtar, B. R. Qazi, and J. M. H. Elmirghani, “Energy and QoS evaluation for a V2R network,” in *Proc. IEEE GLOBECOM*, Dec. 2011, pp. 1–5.

[8] F. Richter, A. J. Fehske, and G. P. Fettweis, "Energy Efficiency Aspects of Base Station Deployment Strategies for Cellular Networks," in *Vehicular Technology Conference Fall (VTC 2009-Fall), 2009 IEEE 70th*, 2009, pp. 1-5.

[9] R. Uzcategui and G. Acosta-Marum, "Wave: A tutorial," *Communications Magazine, IEEE,* vol. 47, pp. 126-133, 2009.

[10] Y. Yu, S. Keroueden, and J. Yuan, “Closed-loop extended orthogonal space-time block codes for three and four transmit antennas,” *IEEE Signal Processing Letters,* vol.13, no. 5, 2006, pp.273-276.

[11] D. Gerakoulis and S. Ghassemzadeh, “Extended orthogonal code designs with applications in CDMA,” in *Proc. IEEE Sixth Int. Symp. Spread Spectrum Tech. Appl.*, 2000, pp. 657–661.

[12] *"Wren Micro-Turbine (datasheet)"*. supplemented with the manuscript: Samrey Generators & Turbines Ltd, 2007.

[13] G. M. Masters, *Renewable and Efficient Electric Power Systems*, 1st ed.: Wiley-Interscience Inc, 2004.

[14] *Wind Turbine Curves: Wind Power Program.* 2013 [cited 2013; Available from: http://www.wind-power-program.com/turbine_characteristics.htm.

[15] X. Wu, S. Wu, H. Sun, and L. Li, "Dynamic slot allocation multiple access protocol for wireless ATM networks," in *International Conference on Communications (ICC)*, Montreal, Canada, 1997, pp. 1560-1565.

[16] (October 2013). *Aruba Networks: Aruba AP-85FX and AP-85LX Access Points*. Available: http://www.mayflex.com/_assets/downloads/DS_AP85FXLX.pdf

[17] L. Haratcherev, M. Fiorito, and C. Balageas, "Low-Power Sleep Mode and Out-Of-Band Wake-Up for Indoor Access Points," in *IEEE GLOBECOM Workshops*, 2009, pp. 1-6.

[18] B. R. Qazi, H. Alshaer, and J. M. H. Elmirghani, “Analysis and design of a MAC protocol and vehicular traffic simulator for multimedia communication on motorways,” *IEEE Trans. Veh. Technol.*, vol. 59, no. 2, pp. 734–741, Feb. 2010.

[19] A. Goldsmith, *Wireless Communications*. Cambridge, U.K.: Cambridge Univ. Press, 2005.

[19] A. Goldsmith, *Wireless Communications*, 2005, Cambridge University Press, 2005.

[20] A. Muhtar, W. Kumar, B. R. Qazi, and J. M. H. Elmirghani, "Energy and QoS for vehicular communication in a motorway environment," *IEEE Wireless and Optical Communications Networks (WOCN), Eighth International Conference,* 2011.

[21] A. Abdi, K. Wills, H. A. Barger, M. –S. Alouini, M. Kaveh, "Comparison of the level crossing rate and average fade duration of Rayleigh, Rice and Nakagami fading models with mobile channel data," in *Vehicular Technology Conference, 52nd IEEE-VTS Fall VTC,* 2000.

[22] Smarter Vehicles, "Safer Roads MCNU R1551", [online]: http://ww1.prweb.com/prfiles/2008/10/22/915544/MCNUR1551.PDF (Accessed August 2014).

[23] W. Kumar, S. Bhattacharya, B. R. Qazi, and J. M. H. Elmirghani, "A vacation-based performance analysis of an energy-efficient motorway vehicular communication system," IEEE Trans. Veh. Technol., vol. 63, no. 4, pp. 1827-1842, 2014.

[24] Analysis of M/G/1/K Queue without Vacations, [online]; http://home.iitk.ac.in/~skb/qbook/MG1K_Queue.PDF (Accessed October 2015).