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Greening Vehicular Networks with Standalone Wind Powered RSUs: A Performance Case Study

Adnan Muhtar, Bilal R. Qazi, Samya Bhattacharya, Jaafar M. H. Elmirghani
School of Electronic and Electrical Engineering, University of Leeds, UK
{elamu, b.r.qazi, s.bhattacharya, j.m.h.elmirghani}@leeds.ac.uk

Abstract-The need for reducing the carbon footprint and reducing the operation expenditure (OPEX) in communication networks poses several challenges in the study, design and deployment of energy efficient networks in different environments. Recently there has been a considerable effort to green vehicular networks which is very challenging due to the very dynamic environment in which these networks operate. In this paper, we investigate the performance of the roadside units (RSUs) in a vehicular motorway network, and propose that these units are wind-powered and act as standalone entities. Real vehicular traffic profiles, reported data traffic measurements and reported wind measurements have been utilised to perform this study. We analyse the performance in several test cases and suggest an operational scenario. Both analytical and simulation results reveal that with the introduction of sleep cycles and a very small battery capacity (124 mAh), these RSUs are able to support quality of service (QoS) for video-related applications at each hour of the day in a motorway vehicular environment while increasing the energy efficiency by up to 32%.

I. INTRODUCTION

Vehicular communication has always had more difficulty in meeting the quality of service (QoS) requirements compared to traditional wireless networks due to the dynamic environment in which it operates. The global push to reduce the carbon footprint has only amplified the challenges that must be addressed by vehicular communication networks. The dispersed nature of outdoor wireless systems presents both high economic and environmental costs in systems that provide full coverage. This is especially due to the fact that as we achieve mobility in the wireless communication domain, ubiquitous deployments of wireless communication networks still retain the unyielding requirement of connecting to a power grid in rural areas. One such scenario is that of motorway communication, where continuous power supply to infrastructural devices is required to provide acceptable QoS. Traditionally basestation optimisation strategies focusing on efficient deployments [1,2] through the use of energy aware components and load adaptive hardware and software modules have been studied to address the environmental concern associated with the growing telecommunication industry. However a more economically attractive option that gives these devices complete independence is the use of renewable sources of energy such as wind or solar power [3]. An access point (AP) with a wireless backhaul, or in a mesh network, coupled with a renewable source of energy significantly increases the speed and flexibility of deploying infrastructural telecommunication devices in such a scenario.

The challenge of sustainable energy in wireless networks is divided into two main aspects. The first which has received a lot of attention in recent years is energy saving as a result of improved, more energy efficient communication schemes ranging from routing schemes [4] to RF optimisation [5] and proposals to enhance the existing 802.11 power saving mechanism (PSM) [6]. The second aspect is that of providing renewable energy to infrastructural devices. Studies investigating both aspects in conjunction are rare to find, while incorporating a motorway vehicular network in such a study is non-existent, to the best of our knowledge.

Various mesh networks have been deployed in America and developing nations which use solar power [7]. However, some of these networks' usage is limited to the day periods when solar power is available. On the other hand a motorway scenario relying on only renewable energy will require constant power even through the night as our real vehicular measurements show. Furthermore the solar irradiation values [8] that dictate the amount of solar energy that can be harnessed at those geographical locations are typically much higher than those of the UK, therefore a deployment of standalone solar powered AP will require larger photovoltaic arrays to provide enough energy for the expected load.

The viability of wind energy in such small scales has been tried and tested in several scenarios. Also known as small standalone wind energy conversion systems (SSWECS), these systems have been used to enhance the lives of rural residents in developing countries [9]. This work looking at the viability of wind power has developed methodologies to simulate the generating capacity and evaluate the adequacy of SSWECS. The evaluation however takes account of residential load and does not consider the stringent requirements seen in telecommunication networks to meet the QoS parameters.

The intermittent nature of wind power as wind speed rises and falls has pushed some, for example [10], to focus on energy storage systems coupled with wind power generation, however most of these papers concentrate on wind farms that generate huge amounts of energy in the hundreds of MW range to support large scale applications. These papers have also cited the necessity of appending storage systems to the generated wind energy, dealing with large amounts of energy without concern for flexibility. Hence, these studies fail to provide methods with which battery size can be scaled down to enhance the flexibility of deploying a dispersed system.

To the best of our knowledge the study of wind renewable energy has not been performed in conjunction with energy saving and QoS in any vehicular system. In [11] we introduced the use of sleep cycles in cluster heads to enhance energy saving while maintaining the QoS parameters. Here we implement random sleep cycles in APs to lower the energy requirements so that the available supply coming from the wind power is sufficient at lower and variable wind speeds. The introduction of random sleep cycles during the AP's inactive periods, where there is deficiency in wind energy, redefines the performance in terms of both QoS and energy consumption. Therefore thorough analytical and simulation studies of such an AP are required in order to understand the energy supply and demand profiles of the system.

Following the introduction, the paper is organised as follows: Section II describes the proposed scenario along with the vehicular traffic profile. Section III presents wind energy profiles. The analytical model for our system including sleep mechanisms is presented in Section IV. The performance evaluation for both analytical and simulation results is given in Section V followed by the conclusions in Section VI.

II. THE PROPOSED SCENARIO

Our proposed scenario considers a set of access points (APs), typically spaced 1 km apart, along a 3 lane motorway stretch, with approximately 300 such APs in a single motorway [11]. Each group of APs receive data from moving vehicles and relay that information to a basestation that is beyond the transmitting range of the vehicles. The investigation examines the energy profile of these access points if we consider them to be off grid entities dependent on renewable energy generation and the use of sleep cycles to conserve energy. Focusing on one of these access points we examine the load energy which is primarily dependent on the vehicular traffic profile, the energy generated which is dependent on a statistically derived average power in the wind, and the energy saved (through sleep cycles) during access point operation by pushing the blocking probability and delay to their limits while maintaining acceptable QoS.

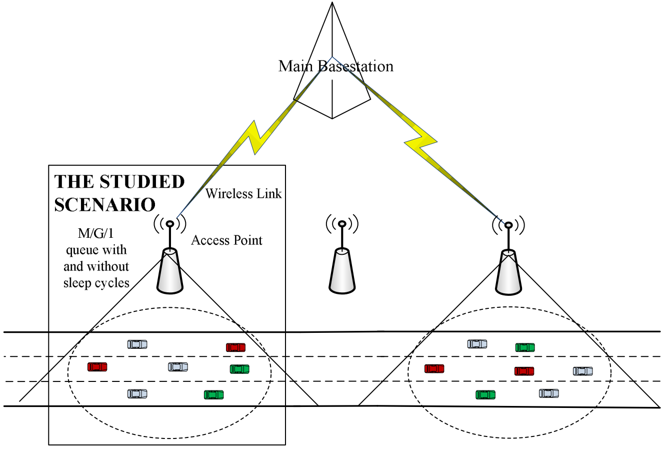

Fig. 1: Motorway Scenario.

A. *Vehicular Traffic Profile*

To fully grasp the mobility characteristics of motorway users, statistical analysis has been carried out on measured vehicular traffic flow profiles. These profiles recorded by inductive loop ID 2255 on the M4 motorway, UK, on Friday April 19, 2002 from 00:00h to 23:59h provide important mobility characteristics that can be used to derive an accurate vehicular traffic model. The parameters considered in this paper are vehicular traffic flow and average density, which help determine the intensity of packet arrivals.

Vehicle traffic is traditionally modelled using vehicle traffic flow theory [12, 13] in the transportation research literature. The three elementary parameters of vehicle traffic are flow q (vehicles/hour), speed s (km/h) and density d (vehicles/km). The average values of these quantities can be approximately related by the basic traffic stream model as $s = q/d_v$ [13]. With fewer vehicles on the motorway, the density d_v approaches zero but vehicles are assumed to reach their free flow speed s. As soon as more vehicles enter the motorway, both traffic flow q and density increase until the flow reaches its maximum value. As additional vehicles continue to enter the motorway, the traffic density increases but the flow begins to decrease. Fig. 2 shows the average density per km on hourly basis, demonstrating the increase in the density with an increased flow.

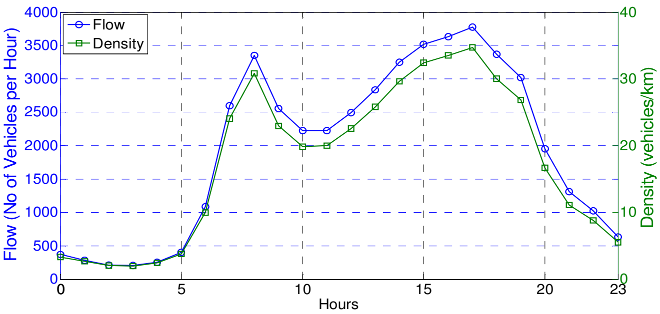

Fig. 2: Hourly Vehicular Flow and Density.

III. WIND ENERGY PROFILE

To analyse the adequacy of wind power in supporting the load demand in a communication system, the first step is to determine how much energy can be harnessed from the wind. The wind power harnessed is given by [14]

$$P_w = \frac{1}{2} C_p \varsigma A v^3 \tag{1}$$

where C_p is the coefficient of performance of the wind turbine which accounts for the decrease in the actual power harnessed from the wind due to several factors such as, rotor and blade design that lead to friction and equipment losses. The air density in kg/m^3 is ς, A is the cross-sectional area, in m^2, of the turbine through which the wind passes which in our case is assumed to be a conventional horizontal axis turbine with a circular turbine cross section of $(\pi/4)D^2$ with D being the diameter of the blade. The wind speed v, in m/s, causes a cubed increase in power when it rises. The wind speed values for our analysis have been obtained from the UK air information resource (AIR) database provided by the Department for Environment Food and Rural Affairs [15]. The data is comprised of hourly wind speeds for the whole of 2011 measured at one of their monitoring sites in Reading Newton, UK. We have selected their readings for this specific site as it is in the same geographical position as that of our M4 vehicular profiles and thus the location of our proposed network deployment. In view of the wind variation and as we are considering a day's vehicular traffic profile, it was necessary for us to derive the average generated wind power for each hour. The nonlinear relationship between generated power and wind speed means we cannot simply use the average wind speed to determine the average power generated. Therefore rewriting the generated power in terms of average values [15]

$$P_{avg} = \left(\frac{1}{2} C_p \varsigma A v^3\right)_{avg} = \frac{1}{2} C_p \varsigma A (v^3)_{avg} \tag{2}$$

In probabilistic terms the average value of v^3 is

$$(v^3)_{avg} = \sum_i [v_i{}^3 P(v = v_i)] \tag{3}$$

By considering the wind speeds in each hour for the whole year we obtain the average wind generated power in a 24 hour period as shown in Fig. 3 for our case study. The significant variation in the power generated calls for energy storage devices to better guarantee the required communications quality of service. The system parameters are presented in Table 1.

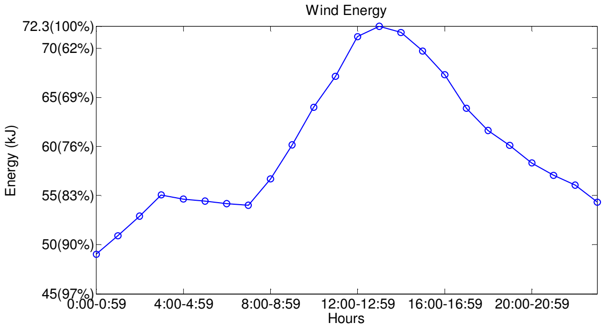

Fig. 3: Average Wind Energy.

Parameters	**Values**
AP data rate (d_r)	15 Mbps [16]
Vehicle data generation rate (d_t)	320 kbps [17]
Average packet size (P_s)	867.4 bytes [18]
Packet arrival rate (λ)	$d_t/(P_s \times 8)$
Packet departure rate (μ)	$d_r/(P_s \times 8)$
AP (fully operational) power	20 W [20]
Energy per bit	P_t/d_r (J/bit)
Propeller length in diameter (D)	0.5 m [21]
Swept area (A)	0.2 m^2
coefficient of performance (C_p)	0.45 [21]
Air density (ς) at 15^{0}C	1.225 kg/m^3 [15]

Table 1: System parameters

IV. SYSTEM MODEL AND QOS METRICS

The proposed model considers three different situations depending upon the energy available to power a standalone AP. In the first situation whenever the wind power is insufficient for operation, the AP has access to an alternative source of energy (non-renewable electric power). Under such a condition, the carbon foot print (and power consumption) of the AP will be highest and the AP transmits all the data generated by all the in-range vehicles, to the nearby basestation. The performance of the AP in this case can be modelled as a simple M/G/1/K queue where M corresponds to the memoryless Poisson process of the packet stream from the vehicles within the range of the AP, G represents the General distributed packet service discipline corresponding to real packet size measurement obtained from [18] (with average packet size of 867.4 bytes, dominated by acknowledgement packets and maximum Ethernet size packets), 1 represents the single server, i.e. the AP, and K represents the maximum number of packets that can be held by the AP in its buffer.

In the second situation the AP switches to a sleep state or low energy state (sleep cycle) with duration S when its buffer becomes empty. The sleep duration S is assumed to be negative exponentially distributed with mean $\bar{S}$ reflecting the arrival process. In the low state, the transmitter circuitry is switched off to save energy [19]. Thus, only the battery powered receiver and buffer circuitry of the AP remains active. In this scenario the AP transmitter does only have access to wind power (standalone entity with wind turbine as discussed in Section III). As soon as the transmitter of the AP becomes active, the AP starts processing the buffered packets (if any) along with the newly arriving packets.

In the third situation the AP follows a sleep cycle, irrespective of the available wind energy, in such a way that the required QoS is met at all times of the day. The AP, as in the second situation, is considered to be a standalone entity but now has a rechargeable battery (or capacitor) for its transmitter circuitry. The energy saved through sleep cycles as well as any excess wind energy is stored in the battery for future use to meet any energy deficit. Thus, our objectives here are (i) to determine whether the available wind energy can meet the energy demand of the AP maintaining the QoS and subsequently, (ii) the minimum battery size for successful operation, and (iii) maximum battery size needed for storing excess energy for future use.

The AP in the second and third situations is modelled as an M/G/1/K queue with sleep cycles [11]. The first scenario is a special case of M/G/1/K queue with sleep cycles, were $\bar{S} \rightarrow 0$. Let f_j (j = 0, 1,…,∞) be the probability of j packet arrivals in the system within a sleep cycle. The probability f_j can be obtained as a continuous summation of the products of the probability of j packet arrivals during a sleep cycle duration t and the probability that a sleep cycle is of time duration t, where t varies from 0 to ∞. The probability f_j [11] can be expressed as

$$f_j = \int_0^{\infty} \frac{(M\lambda t)^j}{j!} e^{-(M\lambda t)} \frac{1}{\bar{S}} e^{-\left(\frac{t}{s}\right)} dt \qquad (4)$$

where M is the number of vehicles in the APs range and λ is the packet arrival rate for vehicles. Let $\propto_j$ (j = 0, 1,…,∞) be similarly defined as the probability of j packet arrivals in a service time period which for realistic packet size distributions can be rewritten as

$$\propto_j = \sum_{t=t_1}^{t_n} \left[\frac{(M\lambda t)^j}{j!} e^{-(M\lambda t)} B(t) \right] \qquad (5)$$

where $B(t_1)$, $B(t_2)$,..., $B(t_n)$, are the probabilities of service durations corresponding to different packet sizes obtained from [18]. Thus, the mean service duration can be expressed as

$$\bar{X} = \sum_{t=t_1}^{t_n} tB(t) \qquad (6)$$

Thus, the offered load (ρ), can be expressed as

$$\rho = M\lambda\bar{X} \qquad (7)$$

if the expression for carried load ρ_c remains unchanged, presented in [11]. Thus, the packet blocking probability P_B can be computed as the utilisation of an AP and can be obtained as

$$U = M\lambda\bar{X}(1 - P_B) = \rho_c \qquad (8)$$

The energy savings, E_s per hour through sleep cycles can be obtained as

$$E_s = (1 - U)P_t.3600 \tag{9}$$

where P_t denotes the power saved when the AP switches to the low state [19]. This can be obtained using the fully operational power consumption of the AP [20] and the ratio between the fully operational power and the low state power consumptions [19]. Finally, the average packet delay can be expressed as

$$W = \frac{N}{M\lambda(1 - P_B)} \tag{10}$$

where N denotes the average number of packets in the AP (including waiting and transmitting packets) and is obtained from [11].

V. PERFORMANCE EVALUATION

A. Results

The performance of the system has been evaluated in terms of energy required, packet blocking probability and average packet delay. First we show analytic results for the transmission and operational energy requirements for the AP connected to a power grid under normal circumstances to compare that with our proposed strategies. The (original) energy required in this case is calculated by finding the total time required to transmit all the packets from all the vehicles in that hour. This time is then multiplied by the power required to transmit packets to determine the energy used in transmitting the total data traffic [22]. This is then added to the minimum operational energy of an AP. This is followed by a set of results assuming a large battery with no sleep cycle implementation. The next set of results shows the performance with sleep cycles implemented on an off grid AP assuming no battery is available and no bounds are placed on the QoS parameters. The final analytic results present a sleep cycle implementation using a small battery and putting bounds on the QoS parameters. These bounded analytic QoS results are verified through simulations and are found to be in good agreement with the simulations.

The original energy consumption, in Fig. 4, shows the system energy usage when assuming a grid connected AP. The energy curve follows the vehicular density curve as an increase in vehicles also increases the intensity of packet arrivals. Accordingly low energy usage is seen in the early hours with a minimum of 54 kJ at 4 am. The energy usage has two peaks during the rush hour periods with 66 kJ in the morning and 67.6 kJ in the evening rush hour period.

The curve representing a system with no sleep cycles using a large battery exhibits the same energy consumption as that of the original system connected to the grid. This is because a large battery provides sufficient energy throughout the day for the system and thus the system behaves like a grid connected system.

Next we introduce sleep cycles without keeping bounds on the QoS parameters to study the impact of this policy on packet blocking probability and average packet delay. Applying the sleep cycles without QoS bounds (and also without using batteries) achieves a lower energy curve with a minimum of 36.7 kJ consumed at 3am. Since this sleep is only applied at points where the average wind energy (Fig. 2) is deemed insufficient for the original energy consumption, sleep cycles are not used in the early morning hours of 3am and 4am, hence the system exhibits an increase in energy requirement at these hours matching that of original and no sleep systems. Though the wind energy does not peak at these times, the vehicular traffic is low enough and can be supported by the low wind energy. The same effect is seen at midday where wind energy peaks beyond the original required energy between 10am and 4pm. During that period sleep cycles are also not applied to save energy, and therefore the curve follows that of original energy requirements (without sleep cycles). Although the original load energy falls towards the end of the day, the power in the wind concurrently falls at that time (Fig. 2); therefore sleep cycles are applied to gain extra energy so that an energy sufficient system can be realised. Note that the rush hour periods of 8am to 9am in the morning and 5pm-6pm in the evening correspond to higher vehicular traffic but unfortunately there is a fall in the wind power during those times (Fig. 2). Hence, sleep cycles are applied to gain just enough energy at those times to serve all packets (waiting to be served in the buffer) eventually. However, this causes serious performance deterioration in terms of packet blocking probability and average packet delay as shown in Figs. 5 and 6, respectively.

To improve both packet blocking probability and average packet delay, and keep them under the bounds of 0.05 and 150ms respectively (for video-related applications) [11] while saving energy and meeting the demand, a small battery (see Section VB) is used and the mean duration of sleep cycles is set appropriately. This scenario primarily takes a more realistic battery size that allows flexibility in network deployment. Secondly, by enabling the sleep to rely on QoS parameter bounds, we are able to maximise energy savings by maximising the sleep durations. Furthermore the battery allows us to save surplus energy which can then be used at periods where the wind energy dips such as that seen at 9am. With the dip in energy at high traffic hours the battery also allows us to meet the QoS while meeting the energy requirement with stored energy. Overall, the enhanced system is able to save a maximum energy of up to 32% at the lowest traffic hour and a minimum of 7.5% at the highest traffic hour with an average of 20% energy savings in the 24hr period. Simulation results for this case (bounded QoS) are in good agreement with the analytical results, as shown in Fig. 4.

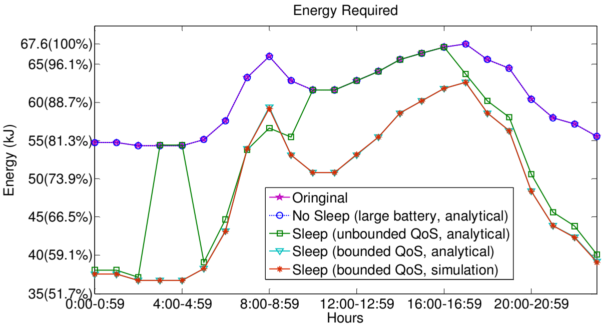

Fig. 4: Energy Required.

The packet blocking probability is shown in Fig. 5. The packet blocking probability without sleep using a large battery shows the system is very efficient and exhibits excellent QoS performance with negligible packet blocking throughout the day. The sleep with an unbounded QoS has a P_B peak. It starts rising at 7am and reaches an unacceptable level of 0.27 at 8am and then declines to a very small value at 9am to maximise energy savings without fulfilling the QoS. Therefore, the energy demands are met through sleep at the cost of poor QoS. The rest of the day then exhibits very low packet blocking probability since sleep is only used to meet energy requirements, and the required energy can be met with wind and sleep without causing a rise in the packet blocking probability.

Sleep cycles with bounded QoS also exhibit a trend where the system keeps the packet blocking very low, near zero in the early hours of the day. This trend also suddenly changes starting at 7am but continues with a packet blocking probability bound below 0.05 between 8am and 8pm after which it drops to a P_B of 0.007 at 9pm and then back to very low, near zero P_B for the rest of the night. These trends show that the introduction of sleep cycles is bound to increase the packet blocking probability at moderate and high traffic levels. The packet blocking probability however can be maintained within the 0.05 bound for acceptable QoS. A simulation of this bounded system has also been performed and is in good agreement with the analytical results.

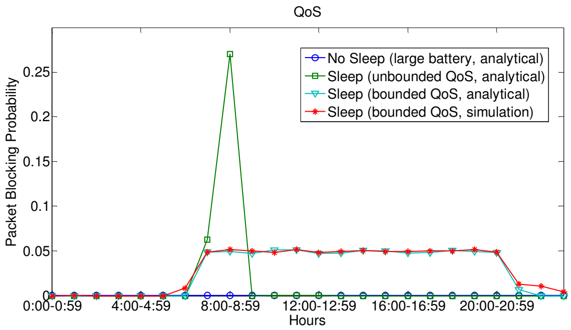

Fig. 5: Packet Blocking Probability.

The average packet delay is shown in Fig. 6. As expected the system without sleep only incurred minimal delays of less than 67 microseconds (approximately equivalent to the service duration) throughout the day. The system with sleep cycles and with unbounded QoS exhibits increased average packet delay at all points where extra energy was required to meet the original load demand. The average packet delay is however within an acceptable level of 150ms throughout the day except for the morning rush hours of 8am and 9am where the energy demands had to be met at the cost of QoS. At this time, the average packet delay peaked to 259ms at 8am and 321ms at 9am.

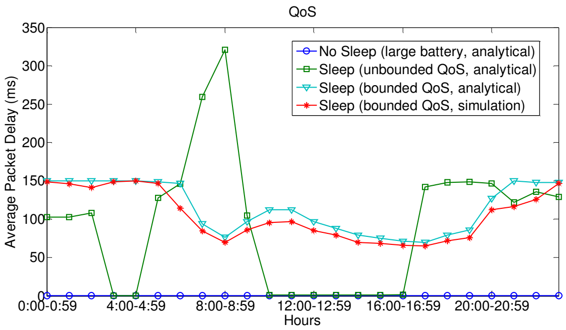

Fig. 6: Average Packet Delay.

The system with sleep cycles and bounded QoS maintained delay at 150 ms until 7am where the stricter bound on packet blocking caused the average packet delay to fall even lower during moderate and high vehicular traffic. Subsequently we can see the fall in average packet delay follows the vehicular traffic between 7am and 10pm. The delay obtained through simulation with bounded QoS falls slightly lower than the analytical result because of the sensitivity of the delay when the packet blocking probability is bound. Bounding the packet blocking probability results in the arrival process becoming critical and as the simulator introduces more accuracy through realistic vehicular arrivals, a lower average packet delay is observed.

With the original energy consumption of the AP, it is evident that there are certain durations of the day, when the traffic is high and the wind power is low. Thus, the wind energy is unable to support the operation of the AP during those time periods. We examined sleep cycle techniques in these durations where the AP by going into a low operational state lowers energy consumption. We noticed that this greedy sleep cycle technique meets the power deficit during the required periods, however it deteriorates the QoS in such a way that it violates the acceptable QoS levels in some instances. Thus to maintain the QoS as well as meet the energy requirements, we proposed a constrained sleep cycle which bounds the QoS within an acceptable level. This leads to an overall surplus of wind energy at certain parts of the day because the total energy consumption reduces substantially through the sleep cycles. It is observed however that there can be a time period where the instantaneous energy demand is not met by the wind energy, though the number of such instances and their durations decreased considerably. Thus energy storage is needed in the form of capacitor or battery. The capacity of battery depends upon the intention behind its use. If we strictly use the battery to meet only the instantaneous deficit, the battery size can become negligibly small and thus a capacitor might serve the purpose. But, if we aim to store as much energy as possible for future support of a calm day (little wind energy available), then a small battery is needed. A brief analysis is given in this paper to determine the battery size.

B. Battery Capacity

Fig. 7 shows the "supply minus demand" excess energy accumulated in our system. From Fig. 7, it is evident that if the battery only needs to meet the in-hour emergency demand then there is only one decline in the cumulative energy storage in the scenario considered. This decline corresponds to the 8 a.m. morning hour when the traffic demand is high and the wind energy supply is low. The deficit is about 2.68 kJ. Thus, for a small battery we need to store only this energy. Expressing energy in terms of capacity of the battery in Ah and considering 50% depth of discharge (DOD) [23] and a 12V battery, the battery capacity should be 124.07 mAh. In the case of a large battery, we aim to store the surplus wind energy in each hour where the AP uses sleep cycles. The maximum cumulative surplus for this case is 262 kJ. Thus, in a similar fashion, we obtain the battery size as 12.13 Ah. Note that a typical small family vehicle battery is typically 40 Ah [24].

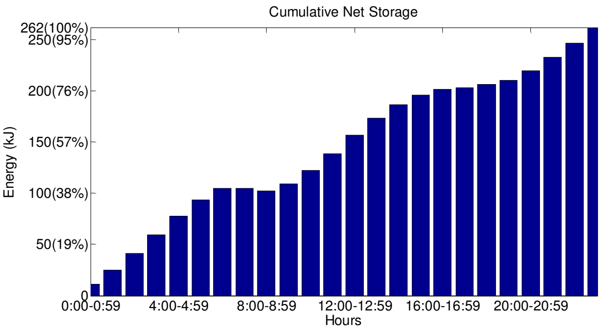

Fig. 7: Cumulate Energy Storage.

VI. CONCLUSIONS

With the main aim of reducing the carbon footprint of a motorway road side vehicular communication system, we have proposed various strategies that can be used to tackle the deployment of ubiquitous coverage along a motorway stretch. A combined investigation of energy supply and load along with the effects on QoS has been carried out and reported. Increased realism is provided through the input parameters to the investigation which include statistical vehicular profiles and wind energy profiles for the same location at a stretch of the M4 UK motorway. The resulting performance of the network has been examined with bounds on QoS parameters along with proposed battery analysis which suggested that a very small battery size (capacitor) is needed to meet these bounds. The wind powered access points reduce the carbon foot print of the proposed vehicular communication system, while the proposed sleep cycles with bounded QoS can save up to 32% of the current system's expected energy expenditure while meeting QoS.

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REFERENCES

[1] O. Arnold, F. Richter, G. Fettweis, and O. Blume, "Power consumption modeling of different base station types in heterogeneous cellular networks," in the 19th Future Network & MobileSummit, pp. 1-8, June 2010.

[2] F. Richter, A.J. Fehske, G.P. Fettweis, "Energy Efficiency Aspects of Base Station Deployment Strategies for Cellular Networks," in the 70th IEEE Vehicular Technology Conference Fall, pp.1-5, 20-23 Sept. 2009.

[3] T.D. Todd, A.A. Sayegh, M.N. Smadi, D. Zhao, "The need for access point power saving in solar powered WLAN mesh networks," IEEE Network, vol.22, no.3, pp.4-10, May-June 2008.

[4] J. Yu and P. Chong, "A survey of clustering schemes for mobile ad hoc networks," IEEE Communications Surveys & Tutorials, vol. 7, no. 1, pp.32–48, 2005.

[5] W.R. Heinzelman, A. Chandrakasan, H. Balakrishnan, "Energy-efficient communication protocol for wireless microsensor networks," in the 33rd Annual Hawaii International Conference on System Sciences, pp. 10 pp. vol.2, Jan. 2000.

[6] S.-H. Wu, C.-M. Chen, and M.-S. Chen, "An asymmetric and asynchronous energy conservation protocol for vehicular networks," IEEE Transactions on Mobile Computing, vol. 9, no. 1, pp. 98–111, Jan. 2010.

[7] P. Hu, R. Karki, R. Billinton, "Reliability evaluation of generating systems containing wind power and energy storage," IET Generation, Transmission & Distribution, vol.3, no.8, pp.783-791, August 2009.

[8] Institute for Energy and Transport, Photovoltaic Geographical Information System (PVGIS), Available [Online]: http://re.jrc.ec.europa.eu/pvgis/cmaps/eur.htm (visited August 2012).

[9] R. Billinton, Bagen, "A sequential simulation method for the generating capacity adequacy evaluation of small stand-alone wind energy conversion systems," in the IEEE Canadian Conference on Electrical and Computer Engineering, vol.1, pp. 72- 77 vol.1, 2002.

[10] Ming-Shun Lu; Chung-Liang Chang; Wei-Jen Lee; Li Wang; , "Combining the Wind Power Generation System With Energy Storage Equipment," IEEE Transactions on Industry Applications, vol.45, no.6, pp.2109-2115, Nov.-Dec. 2009.

[11] W. Kumar, S. Bhattacharya, B. R. Qazi, and J. M. H. Elmirghani, "An energy efficient double cluster head routing scheme for motorway vehicular networks," in the IEEE International Conference on Communications (ICC), June 2012.

[12] M. Rudack, M. Meincke and M. Lott, "On the dynamics of ad-hoc networks for intervehicle communications," In the International Conference on Wireless Networks, 2002.

[13] A.D. May, "Traffic Flow Fundamentals". Prentice-Hall Inc., 1990.

[14] G.M. Masters, "Renewable and Efficient Electric Power Systems". Wiley-Interscience Inc., 2004.

[15] Department for Environment Food and Rural Affairs, "UK Air Information Resource" Database for Reading New Town [Online]: http://uk-air.defra.gov.uk/ (Accessed July 2012).

[16] S. G. Soriga, "ITS-G5 and Mobile Wimax Perfomance in Vehicle-To-Infracstructure Communications", U.P.B. Sci. Bull., Series C, Vol. 74, Iss. 2, pp.143-156, 2012.

[17] X. Wu, S. Wu, H. Sun, and L. Li, "Dynamic slot allocation multiple access protocol for wireless ATM networks," in the IEEE International Conference on Communications, vol. 3, pp. 1560–1565, Jun. 1997.

[18] C. Fraleigh, S. Moon, B. Lyles, C. Cotton, M. Khan, D. Moll, R. Rockell, T. Seely, and S. C. Diot, "Packet-level traffic measurements from the Sprint IP backbone," IEEE Network, vol. 17, no. 6, pp. 6–16, Nov.-Dec. 2003.

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

[20] ARUBA Networks "Aruba AP-85FX and AP-85LX Access Points", Data Sheet,[Online]: http://www.wickhill.de/produkte (Accessed August 2012).

[21] Practical Action, "Wind Electricity Generation",[Online]: http://practicalaction.org/docs/technical_information_service/wind_electricity_generation.pdf (Accessed August 2012).

[22] W. Kumar, A. Muhtar, B.R. Qazi, J.M.H. Elmirghani, "Energy and QoS Evaluation for a V2R Network," in IEEE Global Telecommunications Conference, pp.1-5, December 2011.

[23] C. Honsberg, S. Bowden, PVCDROM. Available [Online]: http://pvcdrom.pveducation.org/BATTERY/capacity.htm (Accessed September 2012).

[24] N.H Fuengwarodsakul, "Retrofitting a used car with hybrid electric propulsion system," in the 6th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON), pp.114-117, May 2009.