Proceedings Paper:

Kumar, W, Bhattacharya, S, Qazi, BR et al. (1 more author) (2012) An energy efficient double cluster head routing scheme for motorway vehicular networks. In: IEEE International Conference on Communications. IEEE International Conference on Communications, 10-15 June 2012, Ottawa, Canada. IEEE , 141 - 146. ISBN 978-1-4577-2052-9

https://doi.org/10.1109/ICC.2012.6364355

An Energy Efficient Double Cluster Head Routing Scheme for Motorway Vehicular Networks

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

Abstract—**In this paper, we propose a novel double cluster-head routing scheme for motorway vehicular networks, which is generically modelled and can be applied to single or multiple cluster-head routing schemes, to save a significant amount of energy through adaptive sleep cycles while maintaining the required quality of service. Real vehicular and data traffic measurements are utilised to evaluate the performance of the double cluster-head scheme and compare with the existing (a single cluster-head) scheme. The results, also verified with the simulations, reveal that the DCH scheme is able to achieve 2x lower packet blocking probability compared to the SCH scheme. Furthermore, on an average energy saving of 94% with service-tolerant delay during the whole day is achieved. In addition, we found that with a lower market penetration ratio, which represents the near future vehicular communication trend, more than 4x energy is saved during peak hours in a motorway vehicular environment.**

I. INTRODUCTION

The field of vehicular communications, having a very low *market penetration ratio* (MPR) compared to mobile communications (over 100% MPR), offers immense future deployment potential. In *vehicle-to-vehicle* (V2V) communications, the use of flat routing schemes does not address the issue of scalability and yield the desired results as routing table updates are frequently required at each node. For example, in some cases the communication overhead of some proactive routing approaches increases with the square of the number of nodes in the network [1]. Therefore, a hierarchical routing mechanism can be adopted which groups the nodes according to certain requirements in order to facilitate efficient routing [1]. Since, in vehicular networks, the vehicles move constantly, a mobility based clustering scheme is appropriate to form clusters. In a *single cluster-head* (SCH) scheme, for example MOBIC [2], the nodes with lower speed variances are selected as *cluster-heads* (CHs).

Traditionally, queueing theory based models are extensively used in predicting the *quality of service* (QoS) of access networks. In [3], mechanical failures or unexpected road hazards lead to safety messages which were modelled using an M/M/1 queue with delay and throughput as performance metrics. In another work [4], the authors described a multi-server multi-priority queueing model for vehicular access networks using M/M/c and M/G/c queues. Since the number of communicating nodes were finite in [3] and [4], queues with finite population could have been a more appropriate model.

Previous research has suggested the optimisation of RF output power to save energy [5], [6]. However, a different view is presented in [7] where circuitry was shown to consume very high power compared to the transmitter output power. Further, other studies show that by considering a sleep strategy at a node during its inactivity, a certain amount of energy can be saved [8], [9]. In [8], two cluster-based semi-asynchronous power saving approaches based on sleep strategy for multi-hop mobile networks are proposed. Another power saving scheme called packet driven dynamic NIC switching-off protocol 802.11NPS for ad hoc networks is proposed in [9]. Very limited research has been carried out in greening vehicular networks with [10] being the main exception where the authors have enhanced the IEEE 802.11 *Power Save Mechanism* (PSM) to achieve energy savings. However, [10] did not introduce any sleeping mechanism and the only QoS parameter considered in their work, with respect to energy savings, was end-to-end delay. Thus, the other key QoS parameter for real-time communications, the packet blocking probability, was not studied.

To the best of our knowledge, a detailed queueing analysis with finite population and finite buffer size for energy efficiency (using sleep strategies) has not been performed in conjunction with QoS parameters such as *packet blocking probability* (P_B), *utilisation* (U) and *average packet delay* (W) for real-time data services. Solving this practical problem becomes more challenging in a motorway environment due to the variable vehicular density, which depends on the hour of the day. Therefore, in this paper, we propose a novel clustering scheme, *double cluster-head* (DCH), which considers mobility in selecting cluster-heads and saves energy through random sleep cycles (that take traffic into account) while maintaining the required QoS. In addition, a generic analytical model of our proposed system, which can be applied to single or multiple cluster-head routing schemes, has been developed. It can also be used with any distribution or unknown distribution with probability known only at certain points. To verify the analytical results, we developed a be-spoke DCH motorway vehicular simulator, which takes real vehicular traces [11] from the M4 motorway, UK, as an input and emulate realistic movement of vehicular nodes. A preliminary version of the DCH scheme was presented in [12], however without any analytical model and energy considerations.

Following the introduction, the paper is organised as follows: An analysis of motorway vehicular traffic is summarised in Section II. The DCH scheme with its queueing analysis and simulation implementation is discussed in Section III. The performance of the system has been evaluated and compared with the SCH (MOBIC) scheme in Section IV. Finally, the paper concludes in Section V.

II. MOTORWAY VEHICULAR TRAFFIC ANALYSIS

Statistical analysis has been carried out on vehicular traffic flow profiles recorded by an inductive loop ID 2255 on the M4 motorway, UK from 00:00 to 23:59 hours [11]. The impact of different vehicular traffic scenarios (low, varying, and congested) for real-time communications is studied. Further analysis was carried out on the data based on other inductive loops at other times and dates, and similar trends were observed [11]. The instrumented vehicular density, defined as the number of instrumented vehicular nodes per km, is shown in Fig. 1. Two peaks, as can be seen in Fig. 1, reflect office traffic during the morning and evening hours of the day. Additionally, the figure shows the density with different MPRs where the MPR refers to the percentage of vehicles enabled with the respective technology.

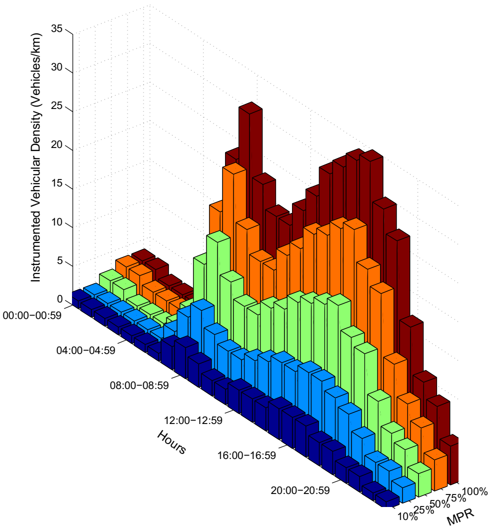

Fig. 1. Instrumented vehicular density (vehicles/km).

This analysis helped us determine the mobility patterns and accordingly develop the DCH analytical model and the motorway vehicular simulator.

III. DOUBLE CLUSTER-HEAD (DCH) SCHEME

Generally, in cluster-based schemes, a cluster is composed of a cluster-head and cluster members. Cluster members forward their data to the cluster-head who is responsible for inter and intra-cluster communications [13]. However, the performance of these schemes degrades considerably with an increase in the number of nodes causing significant overheads on the cluster-head. Thus, we propose a novel double cluster-head (DCH) based routing scheme, shown in Fig. 2, which not only improves the QoS substantially but also achieves significant energy savings. In this work, the DCH scheme is implemented on a 3-lane motorway stretch (considering one direction of travel of 1 km), as shown in Fig. 2. An implementation of the DCH scheme is detailed in Section III-A.

A. DCH Implementation

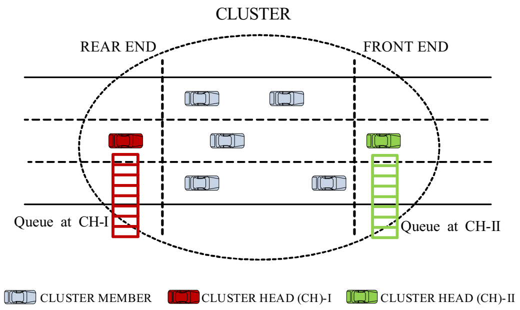

Fig. 2. Double cluster-head (DCH) routing scheme.

In the DCH scheme, a vehicle (node) can perform four possible roles: 1) cluster-member (CLM); 2) cluster-head 1 (CH1) (situated near the front end of the transmission range span); 3) cluster-head 2 (CH2) (located near the rear end of the transmission range span); and 4) undecided state (act as an independent entity – not a part of any cluster).

1) Cluster Formation: Two or more nodes can form a cluster as long as they are all in each others' vicinity which is determined by a communication range. Two nodes, within the communication range, with the largest distance between them are elected as CH1 and CH2. All the other nodes within that range become cluster-members. Each time a new cluster is created, the cluster-heads allocate a cluster ID to the member vehicles in order to facilitate communication.

2) Cluster Maintenance: A scan process is continuously carried out to check the vehicles' positions. If a vehicle has not moved out of the cluster, then its cluster ID remains the same. However, its position is checked in terms of its communication range. If it is found close to the front or the rear ends (see Fig. 2), then the vehicle assumes the role of the cluster-head (CH1 or CH2) and the old cluster-head changes its status to a member vehicle (CLM). Furthermore, if the vehicle has moved out of the cluster or has left the motorway stretch, it is removed from the cluster and the update process is carried out. If the vehicle is allowed to join a nearby cluster in the first instance, then the cluster-heads are updated and the vehicle is assigned with the cluster ID. If cluster-heads go out of each other's range due to mobility pattern variations, the update process is initiated and the nearest cluster-member assumes the role of the cluster-head leading to a position update of all other members. In the worst case, if the cluster-heads go out of each other's range and if there is no other vehicle in the cluster then that cluster is deformed.

B. Analytical modelling of DCH with multiple sleep cycles

We represent the arriving traffic in each cluster-head as a queue of type M/G/1/K/M [14] where the cluster-head follows a sleep cycle. It goes into sleep mode when it is idle to save energy. A multiple sleep model is considered where a cluster-head, on returning from sleep mode, goes for another sleep if it still finds the system empty. It is evident that this leads to higher energy savings as compared with a single sleep mode where the cluster remains awake even if there is no traffic. We assume that the arrivals come from M vehicles where the packet arrivals from each vehicle are Poisson distributed with mean arrival rate, λ (see Table I). The service times in a CH are General distributed with mean service time, $\bar{X} = \mu^{-1}$ and *probability density function* (pdf), $b(t)$. Similarly, the sleep cycles are General distributed with mean sleep cycle time $\bar{S}$ and pdf $f_S(t)$. A CH can hold a maximum of K packets at any point in time. The service times and sleep cycle times are independent and identically distributed (iid) random variables which are also independent of each other.

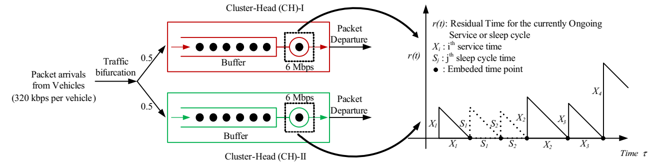

Fig. 3. M/G/1/K/M queues with sleep cycles.

The system states at the embedded points, shown in Fig. 3, are represented by both the number in the system (waiting and in-service) immediately after the selected time instant and the nature of the embedded point i.e. whether it is a service completion or a sleep cycle completion. The system state at the i^{th} embedded point is represented by (n_i, ϕ_i) where

$n_i =$ number of packets in the CH just after the i^{th} embedded point and
$\phi_i =$ 0 if the i^{th} embedded point was a sleep cycle completion,
$\phi_i =$ 1 if the i^{th} embedded point was a service completion.

Considering the system in equilibrium, let q_k, $k = 0, 1, \ldots, K$ be the probability of the state $(k, 0)$ and r_k, $k = 0, 1, \ldots, (K-1)$ be the probability of the state $(k, 1)$. Note that r_k is only defined till $k = K-1$ since the system, just after a service completion, cannot be in state K. The arrival processes from M vehicles can be represented as multiple Poisson processes, where each vehicle, after transmitting a packet, becomes free until the next packet is generated. Let f_j $(j = 0, 1, \ldots, \infty)$ be the probability of j packet arrivals in the system within a sleep cycle. The probability f_j can be expressed as

$$f_j = \int_0^\infty \frac{(M\frac{\lambda}{N_{CH}}t)^j}{j!} e^{-(M\frac{\lambda}{N_{CH}}t)} f_S(t)dt \quad j = 0, \ldots, \infty \tag{1}$$

Let α_j $(j = 0, 1, \ldots, \infty)$ be similarly defined as the probability of j packet arrivals in a service time which can be expressed as

$$\alpha_j = \int_0^\infty \frac{(M\frac{\lambda}{N_{CH}}t)^j}{j!} e^{-(M\frac{\lambda}{N_{CH}}t)} b(t)dt \quad j = 0, \ldots, \infty \tag{2}$$

Considering the system states just after the embedded points, the following transition equations are obtained.

$$q_k = (q_0 + r_0)\, f_k \qquad k = 0, 1, \ldots, (K-1) \tag{3}$$

$$q_K = (q_0 + r_0) \sum_{j=K}^{\infty} f_j \qquad k = K \tag{4}$$

$$r_k = \sum_{j=1}^{k+1} (q_j + r_j)\, \alpha_{k-j+1} \qquad k = 0, 1, \ldots, (K-2) \tag{5}$$

$$r_{K-1} = q_K + \sum_{j=1}^{K-1} (q_j + r_j) \sum_{k=K-j}^{\infty} \alpha_k \qquad k = K-1 \tag{6}$$

where q_0 and r_0 signify the probabilities of the system being empty after a sleep cycle completion and a service completion respectively. Summing up the probabilities of all possible states, we get

$$\sum_{j=0}^{K} q_j + \sum_{j=0}^{K-1} r_j = 1 \tag{7}$$

To solve Eqn. (3)-(7) recursively for q_k, r_k, we define an intermediate variable β_k $(k = 0, 1, \ldots, K-1)$ as

$$\beta_k = \frac{q_k + r_k}{q_0 + r_0} \tag{8}$$

It is a ratio of the probability of the system having k packets to the probability of the system being empty. Using Eqn. (3) and (5), Eqn. (8) is recursively defined as

$$\begin{aligned}
\beta_0 &= 1 && \text{and} \\
\beta_1 &= \frac{\beta_0 - f_0}{\alpha_0} && \text{and} \\
\beta_k &= \frac{(q_0 + r_0)\, f_k + \sum_{j=1}^{k+1} (q_j + r_j)\, \alpha_{k-j+1}}{(q_0 + r_0)} && \\
\beta_{k+1} &= \frac{\beta_k - f_k - \sum_{j=1}^{k} \beta_j \alpha_{k-j+1}}{\alpha_0} && k = 2, \ldots, K-1
\end{aligned} \tag{9}$$

Substituting Eqn. (3), (4), (8) in Eqn. (7), we obtain

$$(q_0 + r_0) \sum_{k=K}^{\infty} f_k + \sum_{k=0}^{K-1} q_k + \sum_{j=0}^{K-1} r_j = 1$$

$$(q_0 + r_0) \left[\sum_{k=K}^{\infty} f_k + 1 + \sum_{k=1}^{K-1} \beta_k \right] = 1$$

Using $\beta_0 = 1$, the probability of the system being empty $(q_0 + r_0)$ can be expressed as

$$q_0 + r_0 = \frac{1}{\left[\sum_{k=K}^{\infty} f_k + \sum_{k=0}^{K-1} \beta_k \right]} \tag{10}$$

Substituting the value of $q_0 + r_0$ from Eqn. (10) in Eqn. (3) and (4), we find q_k, $k = 0, 1, \ldots, K$. Further, using these values of q_k and values of β_k (derived earlier), we obtain r_k, $k = 0, 1, \ldots, (K-1)$ as

$$r_k = (q_0 + r_0)\, \beta_k - q_k \qquad k = 0, 1, \ldots, (K-1) \tag{11}$$

The probabilities, q_k and r_k, are now used to compute the QoS and energy parameters of the system. Let ρ_c be defined as the carried load, i.e. the probability that the CH is busy at an arbitrary time. Analysing all the intervals between successive embedded points over a long time duration (say T), we conclude that

$$\begin{aligned}
\rho_c &= \lim_{T\to\infty} \frac{\sum \text{service times in } T}{\sum \text{sleep cycle times in } T + \sum \text{service times in } T} \\
&= \frac{(1 - q_0 - r_0)\, \bar{X}}{(q_0 + r_0)\, \bar{S} + (1 - q_0 - r_0)\, \bar{X}}
\end{aligned} \tag{12}$$

Variable	Notation	SCH	DCH
Number of Cluster-Heads	N_{CH}	1	2
Channel Data Rate per CH	d_r	12 Mbps	6 Mbps
Traffic Generation Rate/Node	d_t	320 kbps [16]	320 kbps [16]
Average Packet Size	P_S	867.4 Bytes [17]	867.4 Bytes [17]
Buffer Size per CH	K	15 packets	15 packets
Arrival Rate per CH	λ	$d_t/(P_S \times 8 \times N_{CH})$	$d_t/(P_S \times 8 \times N_{CH})$
Service Rate per CH	μ	$d_r/(P_S \times 8)$	$d_r/(P_S \times 8)$
Transmit Power of a CH	P_t	10 W [15]	10 W [15]

TABLE I
SYSTEM PARAMETERS

The offered load, ρ in this case, is defined as

$$\rho = \frac{M\lambda\bar{X}}{N_{CH}} \tag{13}$$

where N_{CH} denotes the number of CHs utilised (see Table I). Using Eqn. (12) and (13), the packet blocking probability, P_B, can be obtained as

$$P_B = \frac{\rho - \rho_c}{\rho} \tag{14}$$

Since a fraction, P_B, of the arrivals will be blocked and will not be allowed to enter the CH, the *utilisation*, U, of the system can be obtained as

$$U = \frac{M\lambda\bar{X}}{N_{CH}}(1 - P_B) = \rho_c \tag{15}$$

The *energy savings*, E_S, per hour through sleep cycles for both CHs can be expressed as

$$E_S = (1 - U) \times P_t \times 3600 \times N_{CH} \tag{16}$$

where P_t denotes the transmit power of a CH [15]. In order to obtain the other performance parameters like average packet delay, W and number of packets in each CH, N, we define a quantity, D, which is the mean time between successive embedded points of the above analysis, when the system is in equilibrium. By definition, we write

$$D = (q_0 + r_0)\,\bar{S} + (1 - q_0 - r_0)\,\bar{X} \tag{17}$$

Using Eqn. 17, N and W are, respectively, given as

$$N = \frac{N_{CH}}{M\lambda D}\sum_{j=1}^{K-1} j r_j + K\left(\frac{\rho - \rho_c}{\rho}\right) \tag{18}$$

$$W = \frac{N \times N_{CH}}{M\lambda(1 - P_B)} \tag{19}$$

IV. PERFORMANCE EVALUATION

We begin with the performance evaluation of the proposed DCH scheme in terms of U, P_B and W with respect to different hours of the day in Section IV-A. Furthermore, the results of the DCH scheme are compared with the SCH scheme for different sleep cycles (0 ms, 5 ms and 10 ms). Both analytical and simulation results are found to be in good agreement. Finally in Section IV-B, to achieve maximum E_S at each hour of the day, the DCH scheme is evaluated by maintaining $P_B \leq 0.05$ for different MPRs (100%, 75%, 50%, 25% and 10%) and its impact on W is shown. The system parameters are given in Table I.

A. Comparison of DCH and SCH schemes

Fig. 4 shows U for both schemes with different sleep cycles. As can be realised from Eqn. (14) and Eqn. (15) that U is directly proportional to the carried load and thus dependent on the number of vehicles. Hence, it follows the trend of vehicular density (Fig. 1). At 17:00 hour, U for both schemes without any sleep is 0.9. This shows the fairness of the proposed DCH scheme in comparison with the SCH scheme. For both schemes, U gets lower with the introduction of sleep cycles because the CH(s) spend(s) a certain amount of time in sleep mode to save energy, however, at the expense of higher P_B (Fig. 5). In the DCH scheme, U reaches 0.88 and 0.85 with 5 ms and 10 ms sleep cycles, respectively. On the other hand, U is much lower under the SCH scheme i.e. 0.85 and 0.79 with 5 ms and 10 ms sleep cycles, respectively.

Fig. 5 illustrates the variation of P_B for both schemes with different sleep cycles. Recalling Eqn. (14), P_B increases with the increase in vehicular density but is not in direct proportion because of ρ_c (Eqn. (12)). Without any sleep cycle, P_B in each scheme is comparable and lower than 0.04, well below the threshold, even during peak hours of the day. This reassures the fairness of the DCH scheme with respect to the SCH scheme. With the introduction of sleep cycles, P_B for each scheme increases during the peak hours of the day. However, the rate of increment is higher in the case of the SCH compared to that of the DCH. For instance at 17:00 hour, P_B for the SCH is 0.16 for 10 ms sleep compared to 0.085 under the DCH scheme. In addition, the figure also reveals that the CHs can have even larger sleep cycles than 10 ms during the off-peak hours of the day to save more energy.

Finally, Fig. 6 shows the variation of W for both schemes with different sleep cycles. Without any sleep cycle, W under the DCH scheme is approximately 2x higher compared to that of the SCH. This is because the collective buffer size in the DCH scheme is twice compared to that of the SCH scheme. Note that the buffer size in each vehicle is hardware dependent and thus remains unchanged. As can be seen in Fig. 6, W in both schemes is higher during peak hours without any sleep cycle because a packet, on an average, has to wait for a longer duration before being served. However, this trend changes with

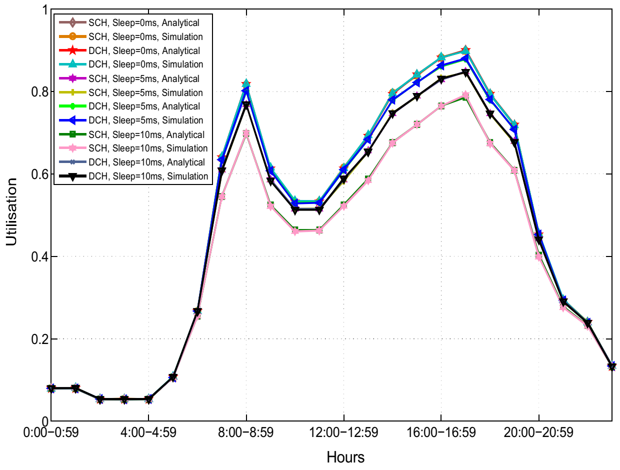

Fig. 4. Utilisation (U).

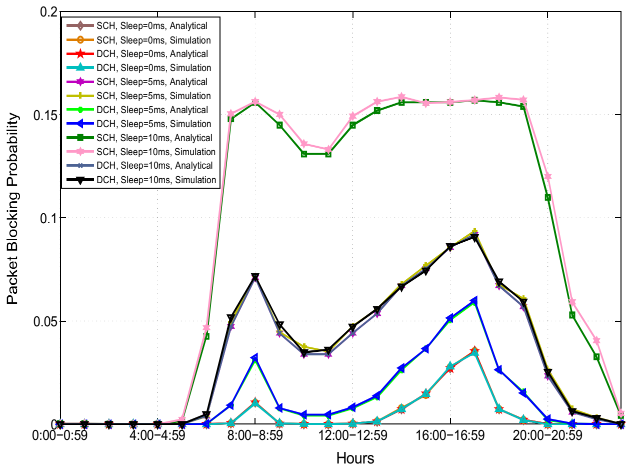

Fig. 5. Packet blocking probability (P_B).

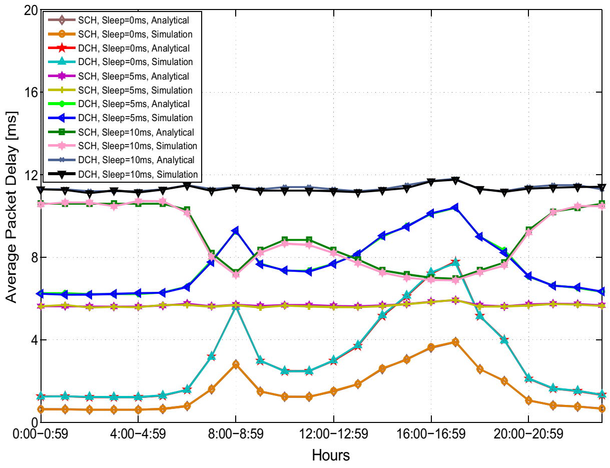

Fig. 6. Average packet delay (W).

the introduction of sleep cycles as the arrived packets may not find the server awake or available even during off-peak hours of the day. In case of the SCH scheme with 5 ms sleep cycles, the off-peak W becomes approximately equal to that of the peak hours as the CH cannot sleep as frequent as compared to the case of the off-peak hours. The same behaviour is observed in the case of the DCH with 10 ms sleep cycles. Note that the trends (SCH with 5 ms sleep and DCH with 10 ms sleep) observed are not flat but follow the same behaviour as of the vehicular density however at a much lower scale. During off-peak hours, in case of the SCH with 10 ms sleep cycles, the CH can sleep more often which, in turn, increases W. On the other hand, the CH cannot sleep that frequently during peak hours consequently, the packets wait for shorter duration compared to the previous case, which effectively decreases W. Note that the proposed DCH scheme is able to support video and data applications (email, file and video downloads etc) where blocking/error is more critical than delay. A lower W can also be achieved by increasing the channel data rate per CH (12 Mbps instead of 6 Mbps). However the fairness of the system will become questionable.

So far, we have not demonstrated the DCH scheme's ability to save energy while maintaining the required P_B at each hour of the day. For this purpose, we maintain $P_B \leq 0.05$ (an acceptable level needed for video transmission) for each hour of the day while achieving the maximum E_S and show its impact on W in Section IV-B.

B. Varying MPR with blocking constraint

Fig. 7 illustrates that during peak hours of the day and with 100% MPR, the CHs barely sleep which results in insignificant energy savings. Further, P_B as shown in Fig. 5, approaches 0.04 without any sleep cycle, hence leaving very little leeway to introduce any sleep cycle. On the other hand, it is negligible even with 10 ms sleep cycle during off-peak hours, hence allows us to introduce long sleep cycles to save maximum energy. However, this can only be achieved at the expense of higher W, shown in Fig. 8, as the packets would have to wait for longer durations. On an average energy saving of 94% with service-tolerant delay during the whole day is achieved.

For all MPRs, E_S of around 68 kJ are achieved during off-peak hours. During peak (13:00-19:00) hours, the system is able to save a total of 463 kJ with 10% MPR as compared to only 113 kJ in the case of 100% MPR. These results reveal that significant E_S can be achieved with lower MPR during peak hours of the day.

Fig. 8 shows W while maintaining $P_B \leq 0.05$ for all MPRs. Note that W for higher MPRs such as 100%, 75% and 50% is low compared to that of the 25% and 10%. This is because a higher MPR increases the traffic load which, in turn, keeps the CHs awake thereby increases overall service rate. Thus, the effective W decreases. In case of low MPRs, very low vehicular nodes with enabled respective technologies are considered, which allows both CHs to sleep for longer periods resulting in higher W.

Note that the reason for achieving a bound on maximum E_S, i.e. 72 kJ, at each hour in all MPRs is justified in Eqn. (16). On the other hand, W is unbounded and can reach any limit to achieve the bounded P_B (i.e. ≤ 0.05). However, the maximum observed W of around 100 ms, in each MPR, is

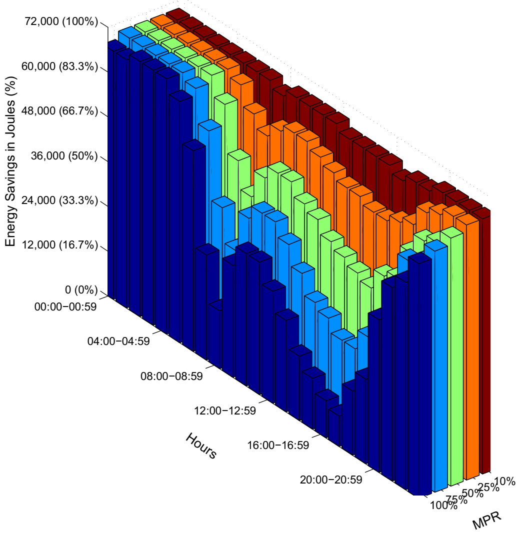

Fig. 7. Energy savings (E_S) with 0.05 blocking constraint.

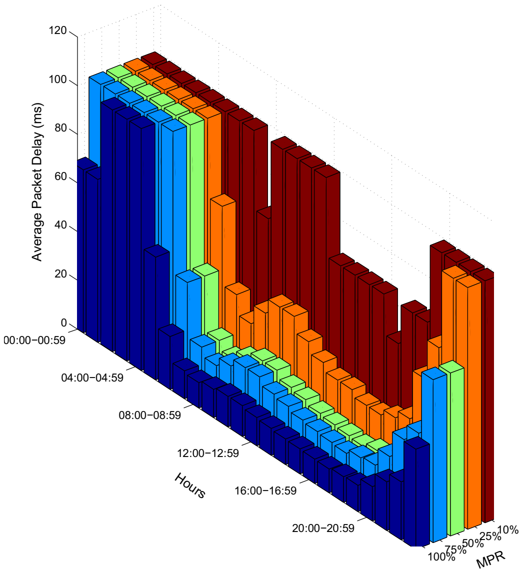

Fig. 8. Average packet delay (W) with 0.05 blocking constraint.

well below the threshold of 150 ms for a video-conferencing model [16]. This reveals that the proposed DCH scheme is able to save significant amount of energy while maintaining service-tolerant W.

V. CONCLUSIONS

To achieve significant energy savings while maintaining the required QoS in motorway vehicular networks, we, in this paper, have proposed a novel DCH routing scheme. A generic analytical model of the scheme and its simulations were developed and followed by the comparison of the performance parameters using real measurements (vehicular and data traffic). Without any sleep cycle, both schemes achieved utilisation of 0.9 ensuring the fairness of the proposed scheme. However with the introduction of sleep cycle, it can be concluded that the DCH scheme utilised the resources in a better way during the peak hours compared to the SCH scheme. Moreover, it was able to achieve approximately 2x lower packet blocking probability compared to the SCH scheme however at the expense of higher delay which was still within the acceptable limit. Such a scheme is more practical for video and data applications (email, file and video downloads etc) where blocking/error is more critical than delay.

The results also revealed that the proposed DCH scheme was able to save significant energy while maintaining the required packet blocking probability threshold throughout the day with different MPRs. During the whole day, the system is able to save around 956 kJ with 100% MPR, 1.1 MJ with 75% MPR, 1.3 kJ with 50% MPR, 1.5 MJ with 25% MPR and 1.6 MJ with 10% MPR. On an average energy saving of 94% with service-tolerant delay during the whole day was achieved. A lower MPR, which reflects current vehicular communication trend, was able to save 4x more energy than a higher MPR of 100% while maintaining the required QoS. This highlights the importance of developing such a system for a motorway vehicular environment.

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.

REFERENCES

[1] 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.
[2] P. Basu, N. Khan, and T. Little, "A mobility based metric for clustering in mobile ad hoc networks," in *International Conference on Distributed Computing Systems Workshop*, Apr 2001, pp. 413–418.
[3] X. Yang, L. Liu, N. Vaidya, and F. Zhao, "A vehicle-to-vehicle communication protocol for cooperative collision warning," in *The First Annual International Conference on Mobile and Ubiquitous Systems: Networking and Services (MOBIQUITOUS)*, Aug. 2004, pp. 114–123.
[4] S. Chen, A. Wyglinski, R. Vuyyuru, and O. Altintas, "Feasibility analysis of vehicular dynamic spectrum access via queueing theory model," in *IEEE Vehicular Networking Conference (VNC)*, Dec. 2010, pp. 223–230.
[5] W. Heinzelman, A. Chandrakasan, and H. Balakrishnan, "Energy-efficient communication protocol for wireless microsensor networks," in *Proceedings of the 33rd Annual Hawaii International Conference on System Sciences*, Jan. 2000.
[6] P. Kolios, V. Friderikos, and K. Papadaki, "Ultra low energy store-carry and forward relaying within the cell," in *IEEE 70th Vehicular Technology Conference Fall (VTC Fall)*, Sept. 2009, pp. 1–5.
[7] E. Callaway, "Low power consumption features of the IEEE 802.15.4/Zigbee LRWPAN standard," in *Mini-tutorial, ACM SensysŠ03, Los Angeles, CA, USA*, November 5-7 2003.
[8] C.-S. Hsu and Y.-C. Tseng, "Cluster-based semi-asynchronous power-saving protocols for multi-hop ad hoc networks," in *IEEE International Conference on Communications (ICC)*, May 2005, pp. 3166–3170.
[9] L. Ning, X. Yuan, and X. Sheng-li, "A power-saving protocol for ad hoc networks," in *International Conference on Wireless Communications, Networking and Mobile Computing*, vol. 2, Sept. 2005, pp. 808–811.
[10] 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.
[11] 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 Transactions on Vehicular Technology (TVT)*, vol. 59, no. 2, pp. 734–741, Feb. 2010.
[12] B. R. Qazi, A. Muhtar, W. Kumar, and J. M. H. Elmirghani, "Performance of a double cluster head routing scheme in a motorway environment," in *IEEE GLOBECOM Workshops (GC Wkshps)*, Dec. 2010, pp. 783–787.
[13] F. Li and Y. Wang, "Routing in vehicular ad hoc networks: A survey," *IEEE Vehicular Technology Magazine*, vol. 2, no. 2, pp. 12–22, Jun. 2007.
[14] S. K. Bose, *An Introduction to Queuing Systems*. Kluwer Academic / Plenum Publishers, 2002.
[15] W. Kumar, A. Muhtar, B. R. Qazi, and J. M. H. Elmirghani, "Energy and QoS evaluation for a V2R network," in *IEEE Global Communications Conference (GLOBECOM)*, 2011.
[16] X. Wu, S. Wu, H. Sun, and L. Li, "Dynamic slot allocation multiple access protocol for wireless ATM networks," in *IEEE International Conference on Communications (ICC)*, vol. 3, Jun. 1997, pp. 1560–1565.
[17] 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.