Vehicular Communications 7 (2017) 21–39

Contents lists available at ScienceDirect

Vehicular Communications

www.elsevier.com/locate/vehcom

Sleep-enabled roadside units for motorway vehicular networks

Samya Bhattacharya [a,*], Bilal R. Qazi [a], Adnan Muhtar [a], Wanod Kumar [b], Jaafar M.H. Elmirghani [a]

[a] School of Electronic and Electrical Engineering, University of Leeds, Leeds LS2 9JT, UK
[b] Department of Electronic Engineering, Mehran University, Pakistan

ARTICLE INFO

Article history:
Received 6 October 2016
Received in revised form 28 November 2016
Accepted 18 January 2017
Available online 27 January 2017

Keywords:
Embedded states
Energy
Quality of service (QoS)
Queuing
Roadside unit (RSU)
Sleep cycles

ABSTRACT

In this paper, we introduce a number of generic sleep mechanisms for energy saving at the vehicular roadside units (RSUs). Since random sleep cycles (sleep cycles type-I) were already introduced before, we term the introduced mechanisms sleep cycles (type-II, III, IV, V, VI). Each sleep cycles type arranges the service and sleep sequences distinctively to yield various levels of energy savings and average packet delay. A generic analytic model for the roadside unit (RSU) with such sleep cycles is proposed using G/G/1/K G-vacation queuing, where real vehicular traffic profiles and packet size measurements are utilised. The performance evaluation reveals that with one of the proposed sleep cycles (type-IV), the RSU achieves 68% energy savings and 7.3 ms average packet delay over the day, resulting in respective improvements of 10% and 28% compared to the existing random sleep cycles. These improvements have been achieved under a very conservative operating delay bound for audio conferencing applications. However, modern compression and codecs, due to their leniency on Quality of Service (QoS), would potentially enable higher energy savings through the proposed sleep cycles.

1. Introduction

With the emerging trends of 'connected vehicles', the growth of vehicular communication networks comes at a critical time when existing communication technologies are already consuming significant amounts of energy, and environmental concerns are increasingly gaining importance [1]. On one hand, a looming spectrum shortage reduces the likelihood of the use of incumbent cellular networks to support multimedia communications in vehicular networks. On the other hand, extensive cellular base station (BS) deployment to support ubiquitous vehicular network coverage is rendered impractical due to the difficulty of providing high data rates at lower overall costs while maintaining the required quality of service (QoS) [2]. The QoS in a network is measured using certain parameters such as end-to-end latency, average packet delay, delay variation (jitter), and packet loss. Ubiquitous vehicular communication can nevertheless be achieved [3] through heterogeneous use of micro cells served by roadside units (RSUs) within a macro cell [4] where the RSUs enable higher data rates [2]. The roadside units (RSUs) are dedicated wireless communication devices which communicate with vehicles within short range and therefore provide each other with information, such as safety warnings, locations and traffic. Such architecture can become part of the 5G offerings. It can reduce the overall energy consumption of the network [2] where the locations and numbers of RSUs/BSs are pre-optimised from performance and energy perspectives.

However, further operational energy savings in an RSU/BS may be possible by utilising sleep mechanisms, where the transmitting circuitry is switched off to set the transceiver into low energy state [4–7]. Such sleep strategies could be impractical for 'base station only' scenarios due to the large coverage, long resource activation time and high overheads that may arise from the ping-pong effect of consistently turning a BS ON and OFF [8].

Even though an RSU performs somewhat similar operations to that of a BS, it does so at a much smaller scale making it feasible to switch into low power state and then back to the fully operational state in a relatively small time. Thus, the switching overhead is remarkably low compared to that of a BS.

Please note that in this paper, we considered the primary types of sleep cycles developed taking into consideration the very basic types of traffic variations. There might be sleep cycles either with fixed time duration or sporadic nature or sleep cycles that follow

* Corresponding author.
E-mail addresses: s.bhattacharya@leeds.ac.uk (S. Bhattacharya), bilalqazipk@gmail.com (B.R. Qazi), adnanmuhtar@hotmail.com (A. Muhtar), wanod.kumar@faculty.muet.edu.pk (W. Kumar), j.m.h.elmirghani@leeds.ac.uk (J.M.H. Elmirghani).

http://dx.doi.org/10.1016/j.vehcom.2017.01.001
2214-2096/

some probabilistic distribution. However, these are all incremental and minor variations of the basic types proposed here.

The key contributions in this paper are:

1) Introduction of five new sleep mechanisms and their comparisons
2) Introduction of the new G-vacation concept to queuing theory
3) A workable (closed form) generic model for these sleep mechanisms
4) Analyses of these six sleep mechanisms (including the existing one) in a vehicular roadside unit

The remainder of this paper is organised as follows: Related work is presented in Section 2. In Section 3, the sleep cycles operating scenario is discussed in the context of a typical motorway vehicular network. Section 4 describes the delay minimisation technique at the CHs. In Section 5, different types of sleep cycles are introduced and subsequently an analytic model for the RSU is developed with the proposed sleep cycles. Section 6 discusses the performance results in terms of QoS and energy savings at the RSU. Finally, the paper concludes in Section 7.

2. Related work

A number of studies showed that by considering a sleep strategy at a node during its inactivity, a certain amount of energy can be saved [2,5,9,12–15]. Sleep strategies in the recent past have been introduced as a solution to reduce the network power consumption as they do not need a complete overhaul of network devices and protocols. In [12,13], the authors proposed sleep strategies for the line-cards in the routers depending upon the backbone traffic. The heuristic in [12] achieved 79% reduction in backbone energy consumption, which was achieved at the typical low link utilisation (30%) in the Internet Service Providers (ISPs) backbone. Such major reduction may not be feasible in wireless and mobile networks (e.g. cellular or vehicular) as they are not intrinsically over-provisioned and the link quality which depends upon the varying wireless channel, makes such networks susceptible to degraded QoS. Nevertheless, several research groups around the world are considering various sleep strategies to make cellular networks more energy efficient [2,14,15].

In [14], the authors proposed dynamic switching for a BS in low traffic conditions. However, fast switching may not be feasible to accommodate transient traffic behaviour because of the number of operations a large BS has to perform [8]. The problems are compounded in such an approach when considered for vehicular networks characterised by their very high mobility. In another study [15], the authors studied a periodic sleep strategy for cellular networks, which led to 46% reduction in operating energy expenditure. However, the architecture proposed was of the multi-layered type and deployed a cell breathing technique. Again, the cell breathing solution with its incurred overhead cannot accommodate fast user movement and variation in traffic demand, making it inapplicable for vehicular networks, especially in a motorway environment. Hence, a macro–micro cellular structure is considered in this paper, where a number of micro-cells are served by the Access Points (APs)/Roadside Units (RSUs) within a macro-cell served by a BS [4], making it feasible to operate various sleep strategies for energy savings at the APs/RSUs. One such strategy is sleep cycles where an RSU switches OFF only its transmitter part for a randomly distributed time duration when there is no request to serve [9]. The RSU remains in such mode for the entire time duration (randomly generated with a certain mean value) even if packets are waiting to be served, thus degrading the system performance. Similarly a random sleep strategy was utilised in [10], which resulted in an unacceptable average packet delay [10] for audio-conferencing applications [11]. Moreover, saving energy through sleep cycles at the RSU incurs wake-up overheads, associated with each sleep cycle [9]. Therefore, there is a need to introduce various types of sleep cycles which not only improve the QoS but also reduce the wake-up overhead while maximising energy savings at the RSU in a motorway vehicular environment. These redefine the performance analysis of such systems from both QoS and energy perspectives and call for the development of analytic vacation queuing models.

Security and privacy are important in vehicular networks as for the first time external remote users can gain access to vehicles and their systems. With RSUs responding to users' behaviour and demands through entering into/exiting sleep mechanisms, new attack scenarios can be envisaged and security and privacy in the presence of sleep mechanisms warrants further study. It is worth noting here for example the temporal and rate privacy concepts in [16].

Traditionally, queuing theory based models were extensively used in predicting the QoS of access networks with little emphasis on vacation queues. In [17], an M/M/c queue was analysed with queue length independent random vacations of the servers and their impact on average system delay and utilisation were studied. In [9], the authors studied two types of random vacations where the vacation duration was Negative exponential distributed using (1) queue length independent vacations to model the wireless channel impairments, and (2) queue length dependent vacations to model random sleep cycles (type-I). Both the arrival and the service discipline of packets were assumed to be memory-less Poisson type as a simplistic case. Hence, the respective scenarios were modelled as M/M/c and M/M/1/K queues with random vacations. Since both of these scenarios can be represented using simplistic Markov Chains, a Matrix Geometric Method (MGM) was adopted to solve these Markov Chains. In [10], the authors utilised the same random sleep cycles (type-I) at the CHs to save energy in a vehicle-to-vehicle (V2V) communication scenario. The arrival of the packets at the CHs was considered Poisson distributed. Since packet size distribution was considered random as a simplistic case, the service duration and vacation duration followed Negative exponential distributions. Hence, each CH was modelled as an M/M/1/K queue with random queue length dependent sleep cycles. However, to the best of our knowledge, General distributed packet arrival along with General distributed service discipline and various types of General distributed sleep cycles have not been considered or studied in conjunction.

2.1. Classification of vacations

The authors in [9] proposed a sleep strategy which reduced the power consumption of the RSU by switching OFF only its transmitter part for a randomly distributed time duration when there is no request to serve. The RSU remained in sleep mode for a fixed time duration (randomly generated with a certain mean value) even if packets were waiting to be served. Upon waking up, the RSU served the arrived packets (if any) and switched back to sleep mode when the buffer became empty. This mechanism was called random sleep cycles. The same random sleep cycles were utilised in [10], which resulted in an unacceptable average packet delay for audio-conferencing applications [11]. For ease of reference, the random sleep cycles introduced in [9,10] are termed sleep cycles type-I in this paper. These types of sleep cycles degrade the system performance when a large number of packets wait to be served. Since energy saving through sleep cycles of type-I was achieved at the expense of degraded QoS [10] and incurred wake-up overheads, associated with each sleep cycle [9], there is a need to improve QoS and reduce wake-up overhead while maximising energy