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An improved multicast based energy efficient opportunistic data scheduling algorithm for VANET

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ABSTRACT

A road side unit in VANET is capable of providing various infotainment services. With the increase in demand for data download amongst the vehicular users, power consumption, both at vehicle end and the road side unit is also increasing proportionally. Hence, there is a need for improving energy efficiency as well as the throughput of the system. In this work, we focus on improving energy efficiency and throughput of the road side unit. We propose an improved multicast based energy efficient opportunistic data scheduling algorithm. We estimate optimum data rate and optimum number of users having good channel conditions, thus obviating the need to know the channel state information at the transmitter. The group of users so selected is served by multicasting the service at optimal data rate. Results show that the proposed algorithm is not only energy efficient but also throughput optimal. It is also possible to estimate the maximum throughput accurately and with low search complexity ($O(N)$) using the proposed method. Simulations are done for two different cases in order to test the flexibility of the algorithm—one, when no new user is entertained until all the initial users get served; two, new users can enter the system in every time slot.

1. Introduction

Vehicular Adhoc Network (VANET) is a wireless technology capable of providing infotainment services to the vehicles. There are two modes in VANET—Vehicle to Vehicle (V2V), and Vehicle to Infrastructure (V2I) also called road side unit (RSU). Energy consumption is not a major issue in V2V mode because vehicles continuously get recharged while in motion. In V2I mode, sources such as battery, sunlight and wind are used to power the RSU on the highways and rural areas where regular sources are not available. This introduces a challenge to reduce power consumption in transmission of data at RSU [1,2]. One of the ways to achieve this reduction in power consumption is to do intelligent and energy efficient data scheduling. Data scheduling is a method to allocate resources amongst the users. A scheduling algorithm mainly decides which user will transmit or receive and the corresponding time of transmission or reception. Various data scheduling schemes are suggested in the literature [3], for achieving different Quality of Service (QoS) objectives such as minimizing delay, maximizing throughput or minimizing energy. Some authors [14,15] consider speed, deadline, data size and number of users demanding a service for data scheduling in VANET. A $D \times S$ algorithm and its extension $D \times S/N$ algorithm are proposed by Zhang et al. [14], where D is deadline and S is data size and pending requests (N) of a service. Here, N improves fairness of the system. Shrivastava et al. [15] propose a new priority based NDS algorithm with broadcast scheduling in VANET. The idea behind using broadcast is to improve throughput but they do not consider energy efficiency.

In wireless communication, channel statistics are dynamic in nature due to fading and multipath. Zhao et al. [4] propose an energy efficient scheduling algorithm with transmission modulation and deadline constraint. The emphasis of this algorithm is on scheduling number of bits to be transmitted in a given time slot. Koutsakis et al. [5] propose a bandwidth scheduling algorithm along with call admission control aiming high speed wireless users for different multimedia traffic. They claim that by using channel prediction a better resource allocation can be done.

The channel state remains constant for a fixed time slot, which is proportional to coherence time. Channels are assumed to be in two states, either good or bad. A data scheduling scheme which can exploit channel conditions of different users, such that the users with good channels are scheduled first, is called opportunistic data scheduling. This is so because when channel condition is good, less power is

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required for the transmission of data. Knopp and Humblet [6], proposed for the first time the opportunistic scheduling for improving capacity of the system using multi user diversity. Opportunistic schedulers for minimizing the transmission power are also proposed in the literature. Amongst the users who demand similar type of service, the users with good channel conditions form a multicast group. Instead of serving each user in a unicast manner, multicasting can be used to serve them simultaneously. An interesting analysis of multicast throughput and energy efficiency for wireless sensor networks using Extreme Value Theory (EVT) is done by Bahl et al. [7], however, in our work, we have done these analyses for adhoc networks without using EVT. A comparison between direct and multi-hop communication for energy efficient multicast scheduling is discussed by Qiang et al. [12]. In conventional method of multicast based opportunistic scheduling [10], the base station arranges all the received Signal-to-Noise Ratios (SNRs) in the descending order and multicast the service at a rate decided by the worst channel condition (lowest SNR). Another such algorithm is median opportunistic multicast scheduling (median OMS) [8,9], in which top half of the users are served. Median OMS exhibits better throughput than the traditional opportunistic multicast scheduling. The problem with conventional and median OMS schemes is that they do not guarantee the optimal throughput or the optimal energy per bit. Veshi et al. [11] propose Opportunistic Multicast Optimal group Size (OppMC–OS) algorithm, which assumes that the Channel State Information (CSI) is available at the base station. In OppMC–OS strategy, the user with k^{th} highest SNR value is targeted. In a time slot, k out of N users get served using multicast. Each of these k users are served with a data rate, $R = B\log_2(1 + \mathrm{SNR}_k)$. The total throughput of the system is $kB\log_2(1 + \mathrm{SNR}_k)$. Therefore, k should be chosen such that it maximizes the system throughput. In the multicast based opportunistic scheduling algorithms including OppMC–OS, the same data is transmitted in every time slot until it is received by all the requesting users. The major problem with such a strategy is that some users may get repeatedly selected and thus get redundant data, which decreases the throughput of the system. It is also assumed that CSI at the transmitter is known through the feedback channel in conventional and OppMC–OS schemes, which is not always practical. In view of these problems, Qian et al. [13] propose a multicast based scheduling algorithm based on adaptive user selection (A–OMS) with a view to improve the throughput and decrease the search complexity. Users once get selected and received desired data, are not considered in subsequent time slots, hence user selection becomes adaptive. In A–OMS algorithm, the adaptive selection of users is done by approximating the system throughput statistically using Estimated System Throughput Matrix (ESTM). The A–OMS algorithm is not effective for small number of users because the estimates are not very accurate. Also, for finding the maximum throughput in each time slot, a row of ESTM is scanned, which increases the search complexity with increased number of users. Looking at this, there is a need of an improved OMS algorithm which can estimate the maximum throughput more accurately and with low search complexity. Such an algorithm should work efficiently for any number of users. Considering these issues, we propose an improved multicast based opportunistic data scheduling algorithm for VANET in this paper.

The rest of the paper is organized as follows: The system model is discussed in Section 2, whereas Section 3 has details of the proposed algorithm. In Section 4, results are shown where the proposed algorithm is compared with some existing algorithms. Finally, conclusion with possible extension of the work is presented in Section 5.

2. System model

An RSU is considered which provides infotainment services to the vehicles within its coverage area. The RSU collects requests from the vehicular users. Vehicles are assumed to be equipped with an On Board Unit (OBU) through which requests for services can be sent and data can be received. The GPS module in the OBU helps in collecting coordinates, speed and direction of a vehicle.

Time is divided into slots. Each time slot is equivalent to the coherence time during which the channel remains constant. We assume slow Rayleigh fading channels. Further, we neglect the effect of shadowing as we consider a VANET scenario with the assumption that obstacles are fewer in number.

The optimum value of SNR of a channel at which the throughput of the system is maximum or equivalently the energy per bit is minimum is calculated. This optimum SNR is used to decide the rate at which the data is to be transmitted; therefore, the knowledge of CSI is not required at RSU. The users with SNR greater than the optimum SNR can decode this data.

The energy metric, which we define as energy per bit (U) is given by (1).

$$U = \frac{P}{T} \quad \text{joule per } bit \tag{1}$$

where P denotes the transmit power, which is a constant; and T denotes the throughput, which is calculated for a time slot and is given by (2).

$$T = kR \tag{2}$$

In (2), k and R respectively denote the number of users with good channel conditions and the rate at which the data is multicast. The objective is to minimize U which can be stated as (3).

$$U_{\min} = {}^{\min}U = {}^{\min}\frac{P}{T} \quad \text{joule per bit} \tag{3}$$

From (1), U is inversely proportional to T. Since P is constant, the minimization of energy per bit is equivalent to maximizing the throughput. Accordingly, (3) can be restated as (4).

$$T_{\max} = \max T = \max kR \tag{4}$$

$$\text{s.t. } k > 0, R > 0$$

The bit rate R can be given by Shannon's formula as $R = B\log_2(1 + \Gamma)$. Here, Γ denotes SNR of the channel. Substituting this expression of R in (4), we get

$$T_{\max} = \max kB\log_2(1 + \Gamma) \tag{5}$$

$$\text{s.t. } k > 0, \Gamma > 0$$

Further, to estimate k, we assume that there are n number of users with good channel conditions out of N users who have demanded certain service. The number of users, n, can be modeled as Binomial distribution with the probability mass function given in (6)

$$\Pr(n \text{ good users out of} N) = {}^{N}C_n p^n (1-p)^{N-n} \tag{6}$$

where p is the probability that a channel is good and this probability can be further calculated as per (7).

$$p = \Pr(\Gamma > \gamma) = 1 - \Pr(\Gamma \leqslant \gamma) \tag{7}$$

A channel is considered as good if its SNR, Γ, is more than a threshold, γ. The cumulative distribution function of SNR is defined as

$$F_\gamma(\Gamma) = \Pr(\Gamma \leqslant \gamma) \tag{8}$$

For the assumed Rayleigh channel, the SNR is exponentially distributed [7]. Since, $\Gamma = \frac{P|h|^2}{N_0 B}$, where N_0 is power spectral density of Gaussian noise, B is bandwidth of the channel and $|h|^2$ is the channel gain. Therefore, $F_\Gamma(\gamma) = 1 - e^{-\frac{\gamma}{\bar{\gamma}}}$, which on substitution in (7) gives

$$p = e^{-\frac{\gamma}{\bar{\gamma}}} \tag{9}$$

As the number of users with good channel condition in a time slot is Binomial distributed, we estimate k as its mean value (10).

$$k = Np = Ne^{-\frac{\gamma}{\bar{\gamma}}} \tag{10}$$

Eq. (5) can be rewritten, after substituting this value of k, as