

Towards Scalable Beaconing in VANETs

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Abstract. Beaconing is envisioned to build a cooperative awareness in future intelligent vehicles, from which many ITS applications can draw their inputs. The problem of scalability has received ample attention over the past years and is primarily approached using power control methods. We reason power control alone will not be sufficient if we are to meet application requirements; the rate at which beacons are generated must also be controlled. Ultimately, adaptive approaches based on actual channel and traffic state can tune MAC and beaconing properties to optimal values in the dynamic VANET environment.

Key words: VANETs, beaconing, 802.11p, V2V

1 Introduction

Many Intelligent Transportation System (ITS) applications can be based on the concept of cooperative awareness. In Vehicle-to-Vehicle (V2V) communications, an important method of communication is the periodic transmission of short status messages or beacons. They contain such information as speed, position and vehicle state, from which a cooperative awareness can be constructed. The message format is standardised in the European ITS VANET Protocol (EIVP) [1] Cooperative Awareness Message (CAM). So far, these messages are defined to be “broadcast on a periodic basis”, generally 10Hz. Several proof-of-concept implementations have seen the streets (e.g. CVIS [2] and Safespot [3]) but all on a small scale. Before such systems can be deployed on a large scale, there are some serious scalability issues which need to be resolved.

This short paper focuses on the following question: How can we build a cooperative awareness with beaconing in a scalable manner? We propose to achieve this with an adaptive architecture and adapting timing aspects of beacon generation. Background is presented in Section 2. We briefly present the requirements in Section 3. In Section 4 we elaborate on beacon generation and present several methods, including the adaptive architecture. Section 5 gives an outlook on future work.

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2 Background

The IEEE 1609 and CALM M5 standards denote IEEE 802.11p to be the MAC and Physical layer for VANETs. The random access nature of 802.11's CSMA/CA is reasoned by [4] not to be the best MAC for applications with strict delay requirements, because no upper bound to delay can be given.

As shown in [5] and also observed in [6], the wireless channel rapidly becomes overloaded with beacon messages under high vehicle densities typical for congested traffic. As a result, the performance of the beaconing system deteriorates. This has several causes, the most trivial of which are an increasing number of nodes n and a high generation rate λ_g in (1), which we use to illustrate the normalised channel load:

$$\mu = n \cdot \lambda_g \cdot t_b. \quad (1)$$

Here t_b is the duration of one beacon transmission, which depends on the number of bytes and the bit rate. Generally, as μ approaches 1 (the theoretical maximum capacity) the useful throughput declines as loss increases. This loss is reflected in the probability of successful beacon reception P_s , decline of which is caused by the inability of 802.11 broadcasting to operate under high-load conditions. This has several causes:

- **no acknowledgements** for broadcast messages: a source cannot infer correct reception by the destination and no retransmissions are performed.
- **no reaction to load** on the network: there is no exponential Contention Window (CW) increase like in unicast.
- **no reservation** by means of RTS/CTS: increased susceptibility to the hidden terminal problem.

The beacon reception rate λ_r can be expressed as $\lambda_g \cdot P_s$. Alleviating the shortcomings with proper MAC configuration and network-layer measures can raise P_s , and hence raise λ_r and the quality of the cooperative awareness.

3 Requirements

ITS applications require awareness with certain qualities. Aside from the contents of the beacon messages (extensively covered in [1]), these qualities are in the spatial and temporal domain, as illustrated in Fig. 1(a). They are:

Range of Awareness - distance up to which a vehicle has information about other vehicles.

Accuracy of Awareness - freshness (delay) and update rate.

In this light we use a functional design as illustrated in Fig. 1(b). As an application we use Cooperative Adaptive Cruise Control (CACC), which is under development in the Connect&Drive project [7]. From this we derive requirements for the cooperative awareness: range is expressed as 200m or 15 vehicles, accuracy as up to 25Hz, although these values are themselves subject of research from the CACC controller point of view.

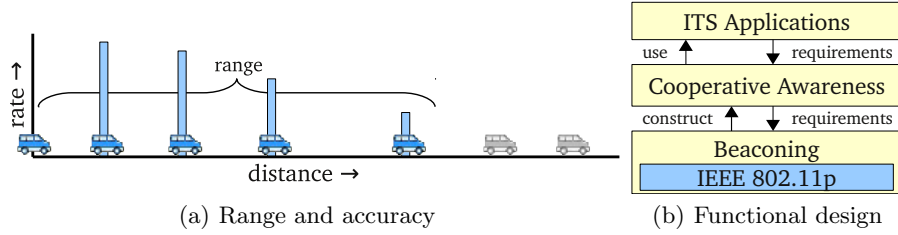


Fig. 1. Cooperative Awareness

4 Beaconing Solutions

Many research activities propose to solve the scalability problem using Transmission Power Control, effectively reducing the space covered by a transmission; increasing frequency reuse. This approach reduces n in (1). Examples include D-FPAV [6], DTRA [8] and the method in [9]. The aim is to reduce transmission power when the vehicle density increases while guaranteeing fairness, i.e. each vehicle has equal opportunity to communicate its beacons to its neighbours. Though effective, reducing the transmission range cannot be done indefinitely. A minimum range of awareness is required for the ITS applications to run.

When searching for a scalable solution for beaconing, we may sacrifice some accuracy for range. The reasoning behind this is that information at lower update rates is better than no information at all. Furthermore, we reason adaptive configuration of MAC properties based on channel estimations may be able to increase performance of 802.11's CSMA/CA under a large variety of circumstances. An ultimate solution lies in the application of adaptive control in both space and time, and dynamic configuration based on channel and traffic state.

We present several beacon generation approaches in 4.1, and an adaptive architecture in 4.2.

4.1 Beacon Generation Schemes

We propose to control the beacon generation rate, λ_g in (1). The aim is to limit the supplied load to the channel. This has several motivations:

1. Inherent unreliability of wireless communication implies that $\lambda_r \leq \lambda_g$. Applications should cope with this (e.g. Kalman filtering, predictions, etc.).
2. More load leads to more loss - in some cases λ_r may even be raised by deliberately lowering λ_g because of its effect on P_s .
3. Traffic dynamics decrease as vehicle density increases, high update rates may not always be necessary. Note this also depends on the traffic context.

Controlling timing of beacon generation can increase coordination, e.g. temporal alignment improves. This is mostly reflected in the timing relative to others. Medium access can be deliberately delayed or jittered in order to break or avoid synchronisation and spread beacon transmission attempts evenly over time. We now present five generation schemes.

Simple Timer This is the base case of beaconing, as interpreted by most literature [6, 9, 10]. A node transmits a beacon when a timer τ expires, and then resets τ . The timer is set to $\frac{1}{\lambda_g}$, e.g. 100ms for 10Hz. A problem is that nodes can become synchronised. The medium may be very busy for a few milliseconds in which a cluster of collisions occur, followed by a period of silence.

Jitter Timer This scheme is similar to the above, except on reset τ is randomly chosen from a uniform distribution $[\frac{1}{\lambda_g} - \sigma, \frac{1}{\lambda_g} + \sigma]$. The random element aims to break the synchronisation and spread medium access attempts evenly over time while still satisfying the average λ_g . This breaks what has been identified in [11] as the Timeslot Boundary Synchronisation Problem. The same happens—though on a finer granularity—in the CSMA/CA backoff procedure.

TDMA-like schemes These schemes observe the medium for a while and then synchronises τ to expire in the periods when the channel is least busy. A proposal by [4] is to use a Spatial Time Division Multiple Access method instead of the Random Access provided by 802.11. The “spatial” element here is that, when all slots are taken, a node chooses a slot occupied by the most remote node (or the weakest signal). Subsequent transmission in that slot will locally “overwrite” transmissions by the other node. TDMA *on top* of 802.11 has been proposed in [12] for low power video surveillance in a sensor network, or for strict QoS requirements [13] but also for application in a VANET [10], albeit at relatively low rate (2Hz). Generally, these methods require some form of master node for coordination and rely on tight synchronisation. Especially the latter is problematic in a VANET. Nonetheless, for application in a VANET a distributed Soft TDMA overlay on top of CSMA/CA may be beneficial. Based on channel estimations, the periodic broadcast is performed when the probability of success is highest. Soft in this case means that it is not strict TDMA, but timers are loosely synchronised. This method spreads access attempts over time, relieving the burden on CSMA/CA.

GeoMapped Beaconing A solution developed in the GeoNet project [14] provides a coordinated time reference by means of Global Navigation Satellite signals [15]. Based on a geographic overlay grid a vehicle determines when to transmit its beacon. This scheme is designed primarily to alleviate the hidden terminal problem, but has not yet been analysed from a scalability point of view.

Reactive Beaconing Whereas the Jitter Timer and TDMA schemes aim to keep a node’s transmission away from transmissions by others, we propose a new scheme where a node transmits its beacon in reaction to reception of a beacon from a vehicle in front. This method relies on a modification to a slotted position-aware flooding scheme and functions on top of 802.11. The aim is a cascade of beacon transmissions which moves against the flow of traffic, followed at a certain distance by the next. This distance is chosen appropriate for frequency reuse. A timer τ is set in reaction to reception of a beacon. This timer is proportional to the distance. A second timer κ ensures a minimum generation rate if there are

no vehicles in front. κ is set to a little more than $\frac{1}{\lambda_g}$. The following code snippet describes the Reactive Beaconing:

```

scheduleEvent(kappa)
loop
  if event tau || event kappa then
    sendDown(new beacon) && scheduleEvent(kappa)
  if event beaconReception && notScheduled(tau) then
    scheduleEvent(new tau) //proportional to distance to transmitter
  end loop

```

At this moment this scheme exists only on a conceptual level, actual feasibility and comparison to other methods is future work.

4.2 Adaptive Architecture

In the dynamic context of VANETs, a static MAC configuration is not always optimal, as shown in Section 2. We propose an architecture which adapts the beacon generator and MAC layer. An estimator observes both network and traffic context, as also described in [16]. To estimate channel load, the estimator obtains information from the driver [17] by means of Clear Channel Assessment and RSSI measurements, or by analysis of information from received beacons (e.g. sequence numbers [9]). MAC properties such as CW or transmission power can be adapted. In this way we can mimic the increase of the CW in response to high load on the channel. In the generator, properties such as λ_g and the scheduling of τ as presented in 4.1 can be adapted.

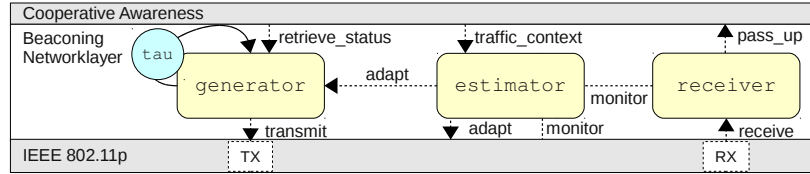


Fig. 2. Adaptive beacon generator and MAC based on channel estimates

Fig. 2 shows our proposed adaptive architecture. Responsibility for the beaconing is located in the network layer and allows ITS applications to obtain information from a cooperative awareness as shown in Fig. 1(b).

5 Conclusion & Future Work

At this moment, beaconing cannot yet be used in a scalable manner to generate a cooperative awareness in vehicles in a large-scale deployment scenario. We propose an adaptive architecture to tune network and MAC-layer parameters

to match configuration to the context. New is the concept of adapting timing aspects of beacon generation in conjunction with transmission power and MAC layer configuration. Due to space limitations the description in this work-in-progress paper is necessarily brief.

Evaluation of the adaptive architecture by means of simulation using the OMNeT++[18]/MiXiM[19] framework is planned. The existing beacon generation schemes and the proposed Reactive Beaconing will be evaluated. Comparison to analytical modelling and measurements from field tests carried out in the Connect&Drive project will help tweak models and gain more insight. Another point of interest is the channel estimator, which will be the subject of future research.

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