

# Information Dissemination in VANETS by Piggybacking on Beacons – An Analysis of the Impact of Network Parameters

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**Abstract**—Piggybacking on beacons is a forwarding technique that is regularly used in vehicular ad-hoc network (VANET) research as a means to disseminate data. With this technique data is attached to and transmitted along with scheduled beacons, without changing the timing of the beacons. In this paper we evaluate the effect that several network parameters – such as the network density, the beacon frequency, and the transmission power level – have on the piggybacking performance. As performance metrics we measure the delay, the reception probability, and the reception probability as a function of time elapsed since transmission. Our eventual goal is to model the latter metric as a function of the network parameters. Here we analyse which network parameters should be taken into account in such a model. We show that the transmission power, the transmission bit rate, the inter-node distance, the dissemination distance, and the beacon frequency should be taken into account.

**Index Terms**—beaconing, dissemination, piggybacking, VANET

## I. INTRODUCTION

Vehicular networking can be considered as one of the most important enabling technologies for Intelligent Transportation Systems (ITS). Vehicular networking is concerned with communication between vehicles and infrastructural devices, supporting a multitude of traffic applications.

Traffic applications can typically be categorized as either a safety applications or efficiency applications. A typical example of the former is the ‘Emergency electronic brake lights’ use case [1] in which a vehicle<sup>1</sup> sends out a high-priority warning to all nearby vehicles. It is critical that such a warning is disseminated fast ( $\leq 100$  ms) to all relevant (i.e., nearby) vehicles – messages will therefore be disseminated with an increased priority. Non-delivery of a message can cause unsafe situations. The distances involved are limited and can be covered by at most a few transmission hops. In contrast to this, traffic efficiency messages are typically targeted at a larger geographical region and may have a lifetime of tens of seconds. Non-delivery of a message can cause less efficient behaviour (e.g., increased travel time) but will not cause dangerous situations. A typical example is the ‘Decentralized floating car data’ use case, see [1].

The issue of disseminating safety messages has so far received a lot of attention, leading to a large number of

(mainly) flooding-based solutions. When applied to disseminating efficiency messages however these solutions are far from optimal. For this reason attention has been shifting to more delay-tolerant dissemination strategies for the delivery of efficiency messages.

One such strategy is disseminating messages by attaching them to network-level *beacons*. *Beaconing* is a communication mechanism in which every node broadcasts short status messages at a certain frequency. We refer to this technique of attaching messages to scheduled beacons as *dissemination by beaconing* or *piggybacking*. Since the scheduling of beacons is a far from trivial problem, it seems preferable that the piggybacking process should not influence the beacon scheduling, thus keeping the timing of the beacons unchanged. Forwarding by piggybacking is therefore relatively slow when for instance compared to a flooding strategy. As was already noted in [2] the speed with which information is disseminated depends amongst others on the beaconing frequency, the network density, and the transmission distance. However, a main *expected* advantage of piggybacking is that the impact piggybacking has on the network load should be considerably less when compared to other forwarding strategies:

- Since the packets are attached to already scheduled beacons network- and security overhead for every transmitted packet can be saved. Together this overhead may be more than 200 bytes [3] [4].
- Additionally one access to the wireless medium per packet is avoided, thus reducing contention and the risk of network collisions.

Based on our own experiences in [2] and reported results by others (see the discussion in Section II) our ongoing research focuses on piggybacking.

Consider a source node  $S$  that geo-broadcasts an application packet at  $\tau = 0$  by means of piggybacking it on one of its beacons, and that this packet is further piggybacked by surrounding nodes in the destination direction. Consider as well a destination node  $D$  that is located  $d$  meters from  $S$  in the direction of the destination. Our long-term goal is to analytically model the probability that any node  $D$  will have received the packet within  $\tau$  seconds as a function of the distance  $d$  and network parameters such as the network density, the transmission power, the beaconing frequency, etc.

<sup>1</sup>Or node. In the context of vehicular networking we use the terms interchangeably.

This model applies both to one-to-one geo-broadcast scenarios (in which only a single destination node  $D$  is considered) and one-to-many geo-broadcast scenarios (in which multiple destination nodes are considered, each with its own distance  $d$ ). An example of the latter scenario is a situation in which a source node  $S$  piggybacks information to any node that is located up to 1 km north of the source.

To be able to create such a model one needs to know which network parameters should be taken into account, and what their effect is on the piggybacking. In this paper we focus on answering the following research questions:

- 1) Which network parameters should be taken into account to express the probability that a packet has been piggybacked a certain distance within a certain time interval?
- 2) How significant is their impact on performance, and in what way do they affect performance?
- 3) Can the effect of some network parameters be combined into a single parameter?

To answer these questions we have performed a simulation study in which we have simulated a simple piggyback protocol. We have varied a number of network parameters and analyse their effect. We have measured the delay, the reception probability, and the reception probability as a function of time.

The outline of this paper is as follows. In Section II some background is given on piggybacking and related means of dissemination. In Section III the modelling approach used in this paper is introduced. In Section IV the set-up of our simulation experiment is given, and the network parameters that have been varied are listed. Experimental results are discussed in Section V. We conclude our work in Section VI and mention our next steps.

## II. BACKGROUND AND RELATED WORK

The European Telecommunications Standards Institute (ETSI) is concerned with the standardisation of (the development of) ITS applications. In [1] they have provided a list of applications that serve as an envisioned first generation of ITS applications. Applications are classified as ‘Co-operative road safety’ applications, ‘Traffic Efficiency’ applications or ‘Others’. Co-operative road safety applications often concern just-in-time warnings of dangerous local traffic situations, whereas traffic efficiency applications are concerned with less time-critical data that is disseminated over a larger area.

Beaconing refers to the periodical 1-hop broadcast of network-level status messages. These messages contain information that is both relevant for network-level routing and application-level safety applications. Almost all co-operative road safety applications in [1] are based on beaconing. Received beacons are used to create a location table that is used by the geo-networking routing protocols [5].

It was quickly realized that as node density in a network increases, creating a scalable beaconing approach becomes a challenging task [6]. In general the more advanced beaconing solutions propose to adapt – in a distributed fashion – the frequency and the used transmission power with which beacons are sent, in such a way that the wireless medium does not

become congested [7] [8] [9] and bandwidth is shared fairly. Due to the distributed nature of these schemes – all nodes are expected to exhibit identical behaviour w.r.t. beaconing – these schemes perform better when external (non-beaconing) traffic is kept to a minimum.

In [2] we have evaluated a dissemination protocol that uses beaconing as a means of dissemination. During our analysis it quickly became apparent that some performance metrics are in such a way dependent on the state of the network, that the measured performance can be expressed as a function of these network parameters. These performance metrics are (i) the time it takes to disseminate information over a certain distance, (ii) the impact this has on the network, and (iii) the probability of successful delivery. It was furthermore shown that dissemination by beaconing has some inherent benefits (compared to e.g. flooding solutions) w.r.t. the reliability of forwarding. Synchronisation problems – which occur as nodes react on information transmitted by other nodes, e.g., the *broadcasting storm problem* – are for instance implicitly dealt with by the beaconing process, since nodes are forced to wait for a next scheduled beaconing moment before being able to further disseminate information.

Using beacons to piggyback data inside a VANET is a common method that has been applied in a number of dissemination schemes [2] [9] [10]. The schemes in [2] and [9] can be considered pure piggybacking approaches. The approach in [10] suffers from the scalability problems mentioned in [6], causing the network to become congested. Although all of the works mentioned here have evaluated the effectiveness of their respective beaconing-based solutions, none has made an attempt at expressing the speed with which information is disseminated as a function of network parameters.

## III. MODELLING APPROACH

Piggybacking may be implemented in a number of ways, and it is impossible to create a single model that is able to capture the behavioural details of every possible implementation. In Section III-A we describe how we model the behaviour of a piggyback protocol in a generic manner. In III-B we list the assumptions that our model contains. In Section III-C we present the simple piggyback protocol that we have used during our experiments to test the impact of the network parameters.

### A. Forwarding model

Any dissemination protocol in an intermittently connected VANET must employ two different forwarding strategies, depending on the state of the network [2] [9] [10] [11]:

- 1) As long as a node is able to forward the data to a node that is closer to the destination the data will actively be forwarded in that direction.
- 2) When an intermediate forwarder is not able to forward the data to a node that is closer to the destination, then the *store-carry-forward* mechanism is used: the data is locally stored by a node that moves in the direction of the destination. This node will carry the data until it finds

a node that is closer to the destination, and will then forward the data to this node, at which point the first strategy is again applied.

The above two-step approach also holds for piggybacking. Thus, the time it takes to piggyback data from the source to the destination depends on:

- 1)  $d_{forwarding}$  – The forwarding delay: the time it takes to actively forward data a certain distance.
- 2)  $d_{carrying}$  – The carrying delay: the time it takes for a node to carry the data to a node that is closer to the destination.

In our model we treat these two delays independently. Work on calculating  $d_{carrying}$  can be found in [12]. Our work initially focuses on  $d_{forwarding}$ ; later on we will combine the two delays into a single model.

### B. Assumptions

Our long-term goal is to create an analytical model for  $d_{forwarding}$  that has a high level of realism, taking into account as many significant factors as possible. In this initial stage of our research however we still lack the fundamental insights required to create such a model. Our first steps focus therefore on gaining fundamental insights that will let us create a first, simplified piggybacking model. In this section we mention and discuss the assumptions we have made in our simulation study. We aim at letting go of some of these assumptions later on, specifically those regarding the beacon frequency and the network topology.

Nodes are assumed to beacon at a fixed frequency and with a fixed transmission power. Section II shows that this assumption does not always apply, since recent beconing mechanisms adapt the beconing frequency, and in some cases the transmission power as well, to prevent the network from becoming congested. Our assumption of a fixed beconing frequency therefore only holds for a network in an uncongested state. Most of our experiments have been performed while the network was in an uncongested state – the issue is addressed in Section V-B.

Until we have investigated the effect piggybacking has on the beconing mechanism we assume that the beconing mechanism is left unaffected by the piggybacking.

In our simulations we only consider static networks, to be better able to judge the impact of the tested network parameters. We expect the effect of mobility on the forwarding delay to be limited however, since the speeds with which vehicles move are typically not significant w.r.t. the transmission ranges and beacon frequencies involved.

Regarding the network topology we make two assumptions that in our view will not diminish the applicability of our model. The first assumption is that both source and destination are situated on the same stretch of road. The second assumption is that this stretch of road is straight.

The first assumption is rather unrealistic of course, but since the node topology in a VANET is by definition limited to the road network every possible route between a source and a

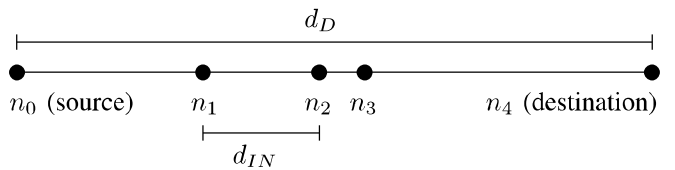


Fig. 1. The experimental set-up.

destination can be broken down into a limited set of stretches of road. For each of these stretches our assumption holds.

W.r.t. the second assumption, we do not expect it to have a significant impact on the model. In non-urban situations curves in a road are rather gradual, while inside an urban area sharp curves often imply a new stretch of road, or can be modelled as such.

### C. The Protocol

The piggyback protocol that we have used in our experiments is relatively simple, such that we are better able to judge the impact of the network parameters. It is similar to the protocol we have used earlier [2], and although it is quite simple, it also proved to be quite effective. Once we have fully modelled the performance of this protocol as a function of network parameters, we expect that it should take considerably less effort to model more involved protocols.

As stated before we only consider a connected network. The forwarding rules for every node are as follows. At  $\tau = 0$  the source node piggybacks a service data unit (SDU). When a node receives a beacon that contains the SDU then it will encapsulate this SDU in its next scheduled beacon if by that time all of the following (still) hold:

- The node is not the source of the SDU.
- The node has not received the SDU from another node that is located closer to the sink node.
- The node has not included the SDU in a previous beacon.

## IV. EXPERIMENT

In this section we describe our experiment. The set-up of the experiment, as well as the measurement details, are presented in Section IV-A. The network parameters that have been varied are listed in Section IV-B. Details on the simulation environment are given in Section IV-D.

### A. Experimental Set-up

We consider a static set-up in which nodes are distributed over a straight line, see Fig. 1. The source node and the sink node are located at the two extreme ends of the line on which the nodes are placed. The distance between two adjacent nodes  $i$  and  $i + 1$  is called the *inter-node distance*  $d_{IN}$ . There are as many nodes as are needed to cover the dissemination distance ( $d_D$ ). Every node beacons with *beacon frequency*  $f_B$ . The time between two beacons is partly randomized by uniformly choosing a value from a *beacon window*  $\tau_{BW}$  around the expected moment of the next beacon:

$$\tau_{inter-beacon} = \frac{1}{f_B} + U\left(\frac{-\tau_{BW}}{2}, \frac{\tau_{BW}}{2}\right). \quad (1)$$

Beacons are  $b_{BCN}$  bits large, SDUs are  $b_{SDU}$  bits large – if a beacon carries an SDU then it will be  $b_{BCN} + b_{SDU}$  bits large. During a single experiment 1 SDU is transmitted by the source. The SDU is first sent to the network layer. There the SDU must wait until the next beacon is scheduled to be transmitted. The moment that the source piggybacks the SDU is defined as  $\tau = 0$ .

We measure for each transmitted SDU the forwarding delay  $d_{forwarding}$ , the time it takes for the SDU to reach the destination node from  $\tau = 0$ . SDUs may get lost as a transmission between two nodes is unsuccessful. We express the fraction of SDUs that do reach the destination as  $P_{pr}$ . The fraction of SDUs that have reached the destination within  $\tau$  seconds is expressed as  $P_{pr}(\tau)$ .

In order to obtain statistically valid results we repeat each experiment 500 times with different random number generator seeds. Although 95% confidence intervals have been calculated for all experiments, these have been left out in those cases where the intervals were negligibly small.

### B. Network Parameters

During our experiments we vary the following network parameters. For a single experiment the network parameters do not change.

*Dissemination distance ( $d_D$ )*. The dissemination distance (in m) is varied over the set  $\{1000, 2000, 3000, 4000, 5000, 6000, 8000, 10000, 12000\}$ .

*Inter-node distance ( $d_{IN}$ )*. The inter-vehicle distance (in m) between two neighbouring nodes is distributed exponentially, with a mean value that varies over the set  $\{10, 20, 25, 50, 100\}$ . The CDF of three of these distributions can be seen in Fig. 2.

*Transmission power ( $P_{Tx}$ )*. All nodes transmit with the same transmission power. The transmission power is varied (in dBm) over the set  $\{18, 28, 33\}$ .

*Bit rate ( $R$ )*. The bit rate (in Mb/s) with which a beacon is transmitted is varied over the set  $\{3, 6, 9\}$ . The resulting packet reception probability as a function of distance for varying power levels and bit rates can be seen in Fig. 2.

*Beacon frequency ( $f_B$ )*. The frequency with which a node beacons (in Hz) is varied over the set  $\{1, 2, 4, 5, 10, 20, 30\}$ .

*Size of the beacon window ( $\tau_{BW}$ )*. The size of the beacon window (in ms) is varied over the set  $\{10, 50, 100, 500\}$ .

*Beacon size ( $b_{BCN}$ )*. The size of a beacon (in b) at link level (i.e., including the 802.11p header), but without the additional bits of an encapsulated SDU, is varied over the set  $\{500, 1000, 2000, 3000, 5000, 10000\}$ .

*SDU size ( $b_{SDU}$ )*. The size of an SDU (in b) is varied over the set  $\{1, 10, 100, 1000, 2000, 3000, 5000, 10000\}$ .

### C. Single-Hop Experiment

To give an indication of the per-hop  $P_{pr}$  we perform the following experiment. 101 Nodes are placed on a straight line of 1000 m length, with 10 m in-between each node. The node at position 0 transmits 2000 beacons for varying  $P_{Tx}$  and  $R$ ; no other nodes transmit. Each receiving node logs the fraction of successfully received beacons.

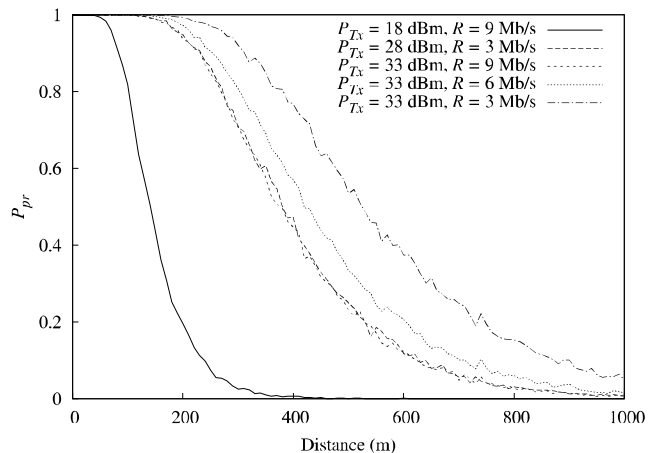


Fig. 2. The single-hop experiment. Measured  $P_{pr}$  between two nodes as a function of the distance between them for varying  $P_{Tx}$  and  $R$ . The lines have been listed in a top to bottom, left to right order. Parameter  $b_{BCN} = 1000$  b,  $b_{SDU} = 100$  b.

### D. Simulation Environment

For our simulations we use the OMNET++ network simulator v4.1 [13] combined with the MiXiM framework v2.1 [14]. To model the behaviour of the 802.11p protocol as accurately as possible we have altered the IEEE 802.11 medium access module in such a way that all parameters follow the 802.11p specification [15]. The available 802.11 MiXiM physical layer was adapted to include bit error rates (BER) and packet error rates (PER) for all transmission bit rates used in our experiments. The centre frequency was set to 5.9 MHz and access category (AC) 0 was used.

Due to its ability to model both long-term and short-term fading we use the log-normal shadowing model [16] for signal propagation. The path loss exponent has been set to 3.5 and the standard deviation to 6.

## V. RESULTS ANALYSIS

Our analysis focuses on the effect that the various network parameters have on  $d_{forwarding}$ ,  $P_{pr}$ , and  $P_{pr}(\tau)$ . We did not simulate each and every combination of parameter values as listed in Section IV-B due to the time it would require. Instead we performed initial lightweight simulations in which we combined all network parameters, and performed more rigorous simulations for those combinations of parameters that proved most interesting. In our analysis we present a selection of the most interesting results from this latter set of simulations.

We first discuss the single-hop experiment, followed by a discussion on the effect some of the network parameters have on the network load, and how in turn the network load influences the packet reception probability and the forwarding delay. We then discuss for each parameter in turn its effect on  $d_{forwarding}$ ,  $P_{pr}$ , and  $P_{pr}(\tau)$ .

Note that graphs of  $P_{pr}(\tau)$  show three facts:

- 1) The measured  $P_{pr}$  as a function of elapsed time, shown as a cumulative distribution function.

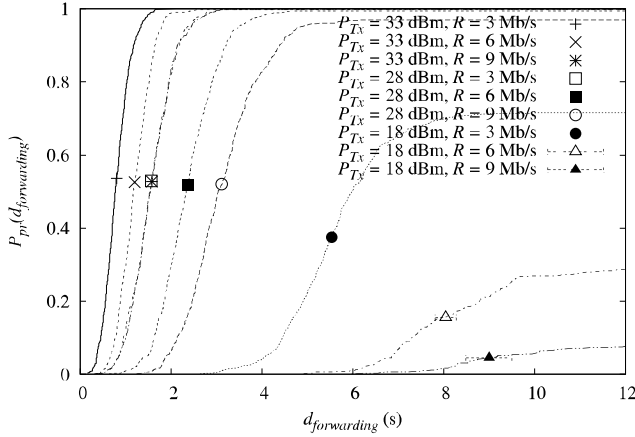


Fig. 3. Measured  $P_{pr}(\tau)$  for varying  $P_{Tx}$  and  $R$ , with  $d_D = 4000$  m,  $d_{IN} = 50$  m,  $f_B = 1$  Hz,  $b_{BCN} = 1000$  b,  $b_{SDU} = 100$  b,  $\tau_{BW} = 10$  ms.

- 2) The average  $d_{forwarding}$ , shown as a point on the line. Note that only the x-coordinate matters for this point – the y-coordinate can be ignored.
- 3) The overall  $P_{pr}$ , shown as  $P_{pr}(\tau_{max})$  (i.e., the position of a line on the y-axis for the highest value of  $\tau$ ).

The effect of the size of the beacon window on  $d_{forwarding}$  and  $P_{pr}$  proved to be trivial and is not discussed here.

For all multi-hop experiments holds that if the forwarding delay increases the variance also increases.

#### A. Single-Hop Experiment

To give an indication of the per-hop  $P_{pr}$  (as a function of the inter-node distance) the outcome of the single-hop experiment has been plotted in Fig. 2. Note that these curves represent the probability of a successful reception of an isolated transmission, i.e., without interfering transmissions. The goal of these curves is to give an indication of the effect of the propagation model that has been used during our experiments, as well as the effect of  $R$  and  $P_{Tx}$  on  $P_{pr}$ .

It can be seen that  $P_{pr}$  increases as  $P_{Tx}$  increases (due to an increase in the signal-to-noise plus interference ratio, or SNIR), and decreases as  $R$  increases (since a higher SNIR is required for correct demodulation of the received signal). These effects are well known facts that have been extensively researched in the past, see for instance [17] and [18].

#### B. Effect of the Network Load

Being a CSMA/CA system, the throughput of a network consisting of IEEE 802.11 nodes depends on the offered network load. The throughput is optimised for a certain network load: If the load is less than this optimum an increase of load will also increase the throughput – if the load is beyond this optimum a further increase of the load will result in a decrease of the throughput. This decrease is due to an increase in the medium contention and the number of network collisions. If the load of a network is beyond the optimum value then we refer to the network as being *congested*.

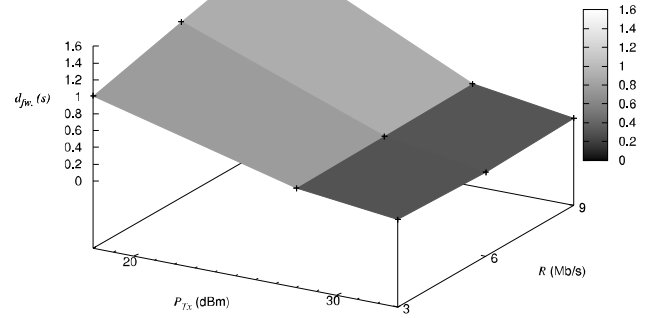


Fig. 4. Measured  $d_{forwarding}$  for varying  $P_{Tx}$  and  $R$ , with  $d_D = 2000$  m,  $d_{IN} = 10$  m,  $f_B = 1$  Hz,  $b_{BCN} = 18335$  b,  $b_{SDU} = 1$  b,  $\tau_{BW} = 10$  ms.

The network parameters that influence the network load are the transmission bit rate, the transmission power level, the inter-node distance, the beacon frequency, and the beacon size. For each parameter its effect on the network load is described in its respective subsection. As a network goes from an uncongested state into a congested state the effect that these parameters have on the performance is often reversed. E.g., whereas an increase of the transmission power level in an uncongested network will increase the packet reception probability, in congested state it will only increase congestion, and thereby reduce the packet reception probability.

All beaconing schemes mentioned in Section II have as a goal to keep the network in an uncongested state (see also the discussion in Section III-B). Our analysis mainly focuses on the effect of the network parameters on an uncongested network, although we also show some results for congested scenarios.

#### C. Transmission Bit Rate ( $R$ )

The two main effects of increasing the transmission bit rate are an increase of  $d_{forwarding}$  and a decrease of  $P_{pr}$ . Both effects are due to the fact that increasing the transmission bit rate decreases the effective communication range of a node. Fig. 2 demonstrates this. As the transmission bit rate increases the transmitted signal becomes more susceptible to interference, and the single-hop packet reception probability drops. For a multi-hop scenario this has the effect that  $d_{forwarding}$  increases and  $P_{pr}$  decreases. Both effects can be seen in Fig. 3.

The increase of  $d_{forwarding}$  was shown to be linear, see Fig. 4. The effect of the transmission bit rate on  $d_{forwarding}$  increases as the transmission bit rate decreases.

One might expect that a higher transmission bit rate will also have a positive effect on  $d_{forwarding}$ , since it takes less time to transmit a packet. This does not hold for the multi-hop case however: once a packet has been received by a node it will not be forwarded immediately, but it will have to wait for that

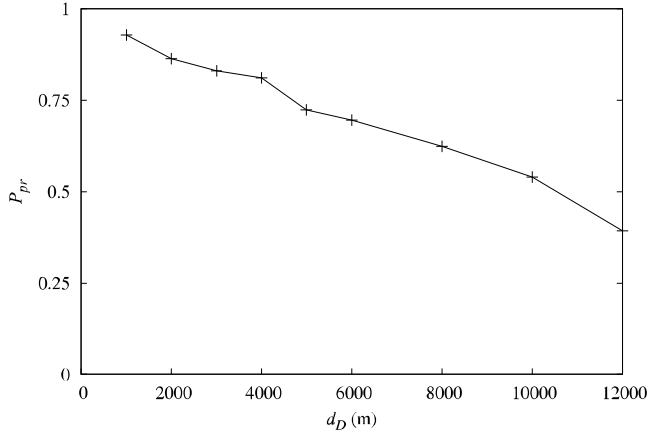


Fig. 5. Measured  $P_{pr}$  for varying  $d_D$ , with  $d_{IN} = 100$  m,  $R = 3$  Mb/s,  $P_{Tx} = 28$  dBm,  $f_B = 1$  Hz,  $b_{BCN} = 1000$  b,  $b_{SDU} = 100$  b,  $\tau_{BW} = 10$  ms.

node's next scheduled beaconing moment. Metric  $d_{forwarding}$  is therefore fully dependent on this inter-beacon waiting time.

#### D. Transmission Power Level ( $P_{Tx}$ )

The two main effects of increasing the transmission power level are a decrease of  $d_{forwarding}$  and an increase of  $P_{pr}$ . Both effects are due to the fact that increasing the transmission power level increases the effective communication range of a node. Fig. 2 demonstrates this, and Fig. 3 shows the effect for the multi-hop case. The measured  $P_{pr}$  increases as the transmission power level increases, since (i) the probability that a transmission between two nodes is successful increases, and (ii) fewer hops are needed to cover the same distance. Due to the latter reason  $d_{forwarding}$  decreases as well; this decrease can be seen in Fig. 4. The figure shows that the effect is not linear and that an increase in the transmission power level has more effect for higher transmission bit rates.

As the transmission power level increases the network load increases as well, since signals propagate further.

In Fig. 2 it can be seen that the single-hop reception probabilities for the cases  $P_{Tx} = 28$  dBm,  $R = 3$  Mb/s and  $P_{Tx} = 33$  dBm,  $R = 9$  Mb/s are almost identical. For our multi-hop experiments we observe that these two cases again overlap in Fig. 3. We have not yet investigated whether this observation can be generalized (e.g., if any two curves that overlap in Fig. 2 will also do so in Fig. 3).

#### E. Dissemination Distance ( $d_D$ )

The two main effects of increasing the dissemination distance are an increase of  $d_{forwarding}$  and, for those scenarios in which there is a significant probability that a transmission between two adjacent nodes is not successful, a decrease of  $P_{pr}$ . Fig. 7 shows how  $d_{forwarding}$  increases linearly as a function of the dissemination distance. This fact is further exemplified by the *normalized*  $d_{forwarding}$ . The normalization has been performed w.r.t. the value of  $d_{forwarding}$  for  $d_D = 1000$ .

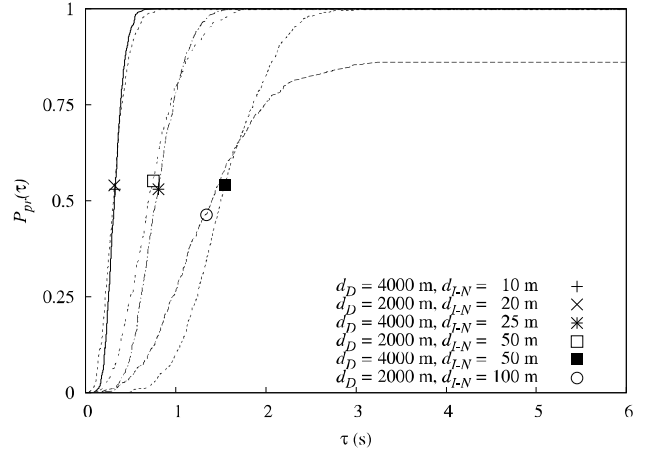


Fig. 6. Measured  $P_{pr}(\tau)$  for varying  $d_D$  and  $d_{IN}$ , with  $P_{Tx} = 28$  dBm,  $R = 3$  Mb/s,  $f_B = 1$  Hz,  $b_{BCN} = 1000$  b,  $b_{SDU} = 100$  b,  $\tau_{BW} = 10$  ms.

It can be seen that the normalized  $d_{forwarding}$  stays close to 1, meaning that as the dissemination distance doubles,  $d_{forwarding}$  doubles as well. This relation is because the delay per hop is determined by the beacon frequency, which is on average the same per hop. As the number of hops increase, the delays per hop can simply be added.

The decrease of the packet reception probability is linear within the range of distances that we have varied over, as can be seen in Fig. 5.

The dissemination distance has no effect on the network load.

#### F. Inter-Node Distance ( $d_{IN}$ )

The main effect of increasing the mean inter-node distance is an increase of  $d_{forwarding}$  and a decrease of  $P_{pr}$ . The top line of Fig. 8 shows how  $d_{forwarding}$  increases linearly as a function of  $d_{IN}$ . The lower line shows the normalized increase of  $d_{forwarding}$  w.r.t. the value of  $d_{forwarding}$  for  $d_{IN} = 10$ .

It can be seen that the normalized  $d_{forwarding}$  stays close to 1, meaning that as  $d_{IN}$  doubles,  $d_{forwarding}$  doubles as well. This is similar to how  $d_{forwarding}$  is influenced by  $d_D$ . Fig. 6 shows how the two effects cancel each other out: if for a given scenario (e.g.,  $d_D = 4000$ ,  $d_{IN} = 10$ )  $d_{IN}$  doubles while  $d_D$  is halved, then the new measured  $P_{pr}(\tau)$  will remain within a few % of its original value. This effect does not hold when packet losses become significant, see the scenario  $d_D = 4000$ ,  $d_{IN} = 10$  in Fig. 6.

As the inter-node distance decreases the network load increases, since a node must share the medium with more nodes while the per-node network load remains the same.

#### G. Beacon Frequency ( $f_B$ )

The main effect of increasing the beacon frequency is a decrease in  $d_{forwarding}$ , since the beacon frequency determines the per-hop delay. The decrease of  $d_{forwarding}$  has a negative exponential curve w.r.t the beacon frequency, see Fig. 9.

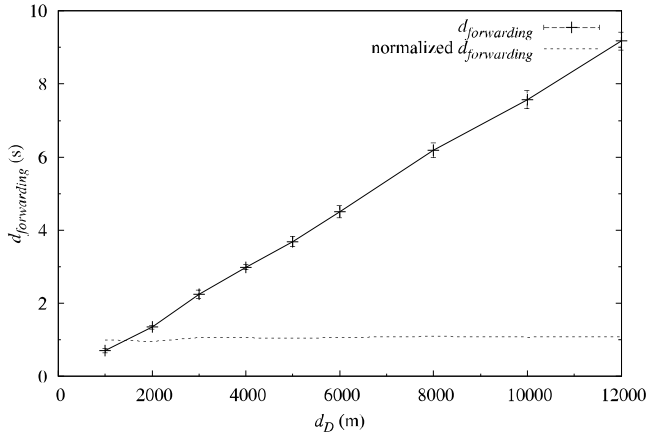


Fig. 7. Average and normalized  $d_{forwarding}$  for varying  $d_D$ , with  $d_{IN} = 50$  m,  $P_{Tx} = 28$  dBm,  $R = 3$  Mb/s,  $f_B = 1$  Hz,  $b_{BCN} = 1000$  b,  $b_{SDU} = 100$  b,  $\tau_{BW} = 10$  ms.

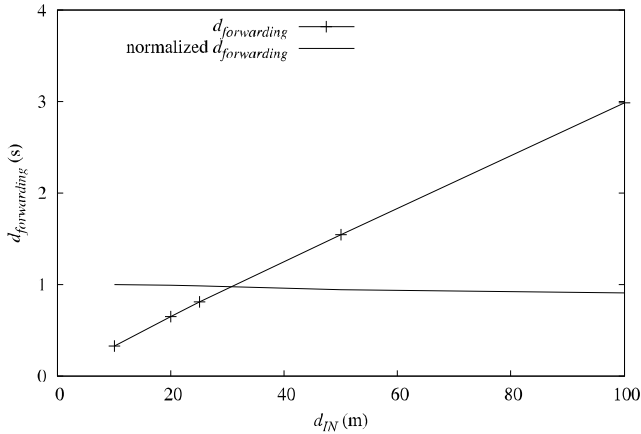


Fig. 8. Average and normalized  $d_{forwarding}$  for varying  $d_{IN}$ , with  $d_D = 4000$  m,  $P_{Tx} = 28$  dBm,  $R = 3$  Mb/s,  $f_B = 1$  Hz,  $b_{BCN} = 1000$  b,  $b_{SDU} = 100$  b,  $\tau_{BW} = 10$  ms.

As the beacon frequency increases the network load increases as well. In uncongested state increasing the beacon frequency has no effect on the packet reception probability. This changes as the network becomes congested. Fig. 9 shows how the packet reception probability decreases w.r.t. the beacon frequency and w.r.t. the inter-beacon period. The effect on the forwarding delay remains unchanged.

#### H. Beacon Size ( $b_{BCN}$ )

The main effect of increasing the beacon size is an increase in the forwarding delay, see Fig. 10. Although not shown here, this effect proved to be linear. The added delay is due to the fact that the medium occupation increases as well, causing more contention on the medium. Nodes spend therefore more time waiting for other nodes to finish transmitting before they can transmit their own beacon.

As the beacon size increases the network load increases as well.

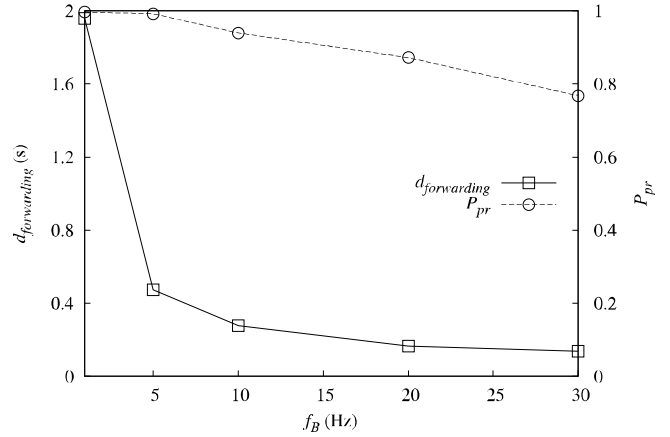


Fig. 9. Measured  $d_{forwarding}$  and  $P_{pr}$  for varying  $f_B$ , with  $d_D = 4000$  m,  $d_{IN} = 50$  m,  $P_{Tx} = 28$  dBm,  $R = 3$  Mb/s,  $b_{BCN} = 1000$  b,  $b_{SDU} = 100$  b,  $\tau_{BW} = 10$  ms. The squares are set against the left vertical axis; the circles are set against the right vertical axis.

#### I. SDU Size ( $b_{SDU}$ )

The main effect of increasing the SDU size is a logarithmic increase in the forwarding delay. As the beacon size decreases the relative size of the SDU increases, and its effect on  $d_{forwarding}$  increases as well, see Fig. 10. Overall however the impact of  $b_{SDU}$  on performance is limited compared to the other network parameters studied.

Increasing the SDU size will not lead to the network becoming congested since the SDU will only be transmitted a limited number of times, and the payload limit of an IEEE 802.11 packet is 18336 b.

## VI. CONCLUSIONS & FUTURE WORK

We have evaluated the effect of a number of network parameters on the performance of a simple piggybacking mechanism. The evaluation has been performed by means of simulation of the piggyback protocol in a number of static multi-hop networks. We have measured the forwarding delay  $d_{forwarding}$ , the packet reception probability  $P_{pr}$ , and the packet reception probability as a function of the elapsed time  $P_{pr}(\tau)$ . The latter gives the probability that a packet has reached its destination within  $\tau$  seconds.

Our eventual goal is to model these performance metrics as a function of the network parameters. To achieve this we have analysed the effect that the different network parameters have on performance, e.g., whether beacon sizes will influence the forwarding delay, and in what manner: positive or negative, linearly or exponentially.

The effect of each individual network parameter has been discussed in Section V. The following network parameters should at least be taken into account when modelling piggybacking: the dissemination distance, the average distance between nodes, the transmission power, the transmission bit rate, and the beacon frequency. Although the beacon size and the size of the SDU also impact performance significantly,

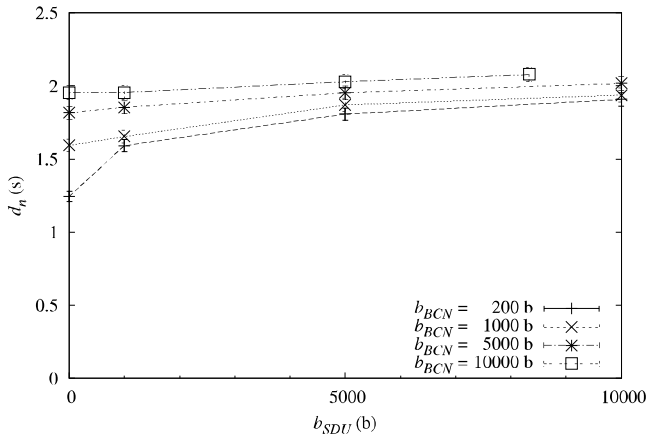


Fig. 10. Measured  $d_{forwarding}$  for varying  $b_{BCN}$  and  $b_{SDU}$ , with  $d_D = 4000$  m,  $d_{IN} = 50$  m,  $P_{Tx} = 28$  dBm,  $R = 3$  Mb/s,  $f_B = 1$  Hz,  $\tau_{BW} = 10$  ms. Note that for  $b_{BCN} = 10000$  the maximum possible value for  $b_{SDU}$  is 8336 b, due to the maximum packet size of an IEEE 802.11 packet.

their effect is an order of magnitude less. The size of the beacon window was found to have no significant effect.

We have shown that the dissemination distance and the inter-node distance cancel each other out: when one parameter is doubled while the other is halved, the measured performance metrics remain largely the same.

Our next step will be to model the performance of the piggyback protocol using the evaluated network parameters (excluding the beacon window). Once this step has been completed we will analyse the impact of mobility on performance, and add its effect to our model.

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