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Abstract: Lack of updated information due to a high beacon loss rate is a key challenge in car-to-car beaconing strategies. One potential solution for this issue is to re-broadcast lost beacons. However, the repeated dissemination of each lost beacon is infeasible due to the limited bandwidth of wireless channels. To overcome this limitation, network coding is a promising technique, through which a node combines (i.e. codes) multiple packets from different sources and re-broadcasts them through one transmission for the efficient bandwidth usage. In the past, network coding has been employed only for data packets. In this paper, this idea is used for periodic beacons in car-to-car communication to analyze, how much it is effective for the recovery of lost beacons. To this end, we propose two approaches: random selection and radius-based, and compare them to determine, which scheme recovers more beacons. We evaluate these approaches in both sparse and dense highway traffic scenarios with probabilistic radio propagation characteristics.

Keywords: Car-to-Car communication, Beaconing strategies, Network coding

1 Introduction

Keeping vehicles updated about their neighboring vehicles is a key research area in car-to-car communication. In this regard, multiple beaconing strategies [KSWL08, TSH06] have been developed, through which each vehicle broadcasts its beacon periodically. This beacon consists of information like a vehicle's lane, speed and position.

The main concern is that these approaches suffer heavily from the low reception due to problems like the hidden terminal and the near-far effect as explained in [TCSH06, TJH04]. This leads to several problems, for instance, vehicles *A* and *B* in Figure 1a lost beacons from each other, which causes outdated position information. An accident can happen, if one of them relies on this information and changes its lane. Furthermore, intermediate nodes in the position-based routing [MWH01] are selected with respect to their current positions. Outdated position information degrades the performance of this protocol.

One potential solution to minimize this lack of up-to-date information is to recover the lost beacons through re-broadcasting. However, the re-broadcast of each lost beacon requires a significant bandwidth that is already limited in wireless environments. For the efficient bandwidth

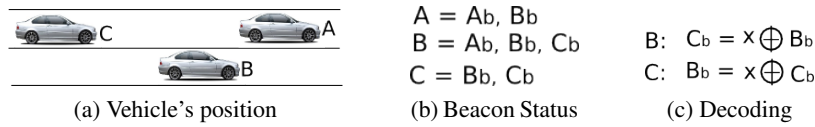


Figure 1: An example scenario

usage, researchers [KHH⁺08] proposed *network coding* where a node combines multiple packets into one packet and broadcasts it. A node performs encoding of packets as $p = p_1 \oplus \dots \oplus p_l$ and broadcasts p , where \oplus represents the XOR operation. If a receiver of p has already p_1, \dots, p_{l-1} , it decodes as $p_l = p \oplus p_1 \oplus \dots \oplus p_{l-1}$ to recover the original packet p_l .

In the past, network coding has been considered to encode data packets, while in this paper, it is used to encode periodic beacons in order to analyze, how much it is useful to recover lost beacons. To understand how this technique is beneficial for beaconing strategies, an example is shown in Figure 1. Suppose that three vehicles A to C drive in the same direction and are all within the radio ranges of each other. Each vehicle i sends beacon i_b periodically. After time t , the status of stored beacons at different nodes is given in Figure 1b. At $t + 1$, B wants to send its periodic beacon. It encodes all received beacons from neighbors ($x = A_b \oplus C_b$) and sends it with B_b . Upon receiving, each vehicle can recover a lost beacon through decoding as illustrated in Figure 1c. Thus, one broadcast is enough to recover multiple lost beacons.

However, if a vehicle has received a large number of beacons due to a large number of neighbors, encoding of all (l) beacons reduces the probability of decoding. Because with a high beacon loss rate, it is possible that intended receivers have not ($l - 1$) beacons for decoding. To solve this problem, the traditional approaches [ALLY00, DFZ05, HKM⁺03, LYC03, CDA⁺07, YY06, KHH⁺08] used periodic reports sent by each neighbor which give information about received beacons. Based on this knowledge, beacons are encoded.

Since these reports increase traffic load over a wireless channel heavily, the collision rate could increase. To encode beacons without requiring these reports, we propose two approaches, *random selection* and *radius-based*. Through the first scheme, a node encodes beacons randomly regardless of successful decoding. In contrast, the other scheme takes an advantage of dead-reckoning [KFTE05] and radio ranges, and encodes only those (appropriate) beacons, which have a high decoding probability. Our intention behind the random selection is to determine whether a particular strategy is necessary to encode appropriate beacons. The idea is that all nodes within the same radio range can receive beacons from each other, they are supposed to have enough beacons for decoding.

The remainder of the paper is structured as follows: Section 2 gives a brief overview of the related work. The proposed approaches are explained in Section 3. Simulation results are presented in Section 4. Finally, Section 5 gives the conclusions.

2 Related Work

One main reason of a high beacon loss rate is congestion over a wireless channel due to a large transmission range when many nodes share the channel. To overcome this problem, Moreno

et. al. [TSH06] proposed a beaconing scheme that reduces the transmission range based on the geographical distance of nearby nodes. However, this behavior is infeasible for position-based routing [MWH01] where the far most one-hop neighbor (nearest to the destination) is selected as an intermediate node. By reducing transmission range, the direct communication with this node may not be possible. Therefore, this protocol must find a new intermediate node which has negative impact on its efficiency. Yousefi et. al. [YBF07] investigated that the reception rate is very low after a certain distance (200 m). This means that 100% reception rate is very difficult (might be impossible) particularly after 200 m while the transmission range is up to 500 m [TTLB08]. Thus, beacon losses cannot be completely avoided. Therefore, this paper focuses on the recovery of lost beacons through network coding instead of preventing beacon losses.

The idea of network coding was mostly evaluated in wired networks [ALLY00, DFZ05, HKM⁺03, LYC03], however, soon some researchers described advantages and challenges for the wireless network [CDA⁺07]. In particular, Yufang et. al. [YY06] investigated network coding to address the minimum-cost multicast problem in the presence of interference-limited wireless networks where link capacities are functions of the signal-to-noise-plus-interference ratio (SINR). With COPE [KHH⁺08], a new architecture for wireless mesh networks has been developed. In contrast to prior work, where the main focus was on multicast traffic, the authors investigated unicast traffic. Our work is different in that sense that the existing approaches employ network coding for data packets within multi-hop environments, while we use this idea for periodic beacons in one-hop environments.

3 System Design

In this section, we present the design of our system. It is classified into three phases: i) encoding, ii) broadcasting of encoded beacons and iii) decoding.

3.1 Encoding

The first step is to encode beacons received by a vehicle (node). For encoding, the traditional approaches demand information about the packets stored at neighbors. Due to this reason, each node broadcasts reports periodically. However, the dissemination of these reports is infeasible for periodic beaconing because each node usually receives one or more beacons per interval, which updates the list of stored packets. If there are n one-hop neighbors of a node, then n reports are required in a single interval to encode up-to-date beacons. This may overload a wireless channel heavily, which results in collisions. To encode beacons without requiring periodic reports, we propose two approaches: *random selection* and *radius-based*.

3.1.1 Random selection

Through this scheme, a set of random but unique beacons are encoded. Although this approach is very simple but it may suffer from many decoding failures. The randomness can cause encoding of such beacons, which cannot be decoded at intended receivers. There are two main reasons for this failure: *i*) If beacons of those nodes have been encoded, which are one hop away from an *encoder* (a node performing encoding) while two hops away from a decoder (a node performing

decoding), then decoding fails. This is because the decoder is unable to receive periodic beacons from its two hop neighbors. This error is described as *fail-2hop*. ii) In some cases, all nodes whose beacons are encoded, are at one-hop distance from a decoder but that decoder may not have $(l-1)$ encoded beacons. This flaw is named *fail 1-hop*. It occurs mostly when the reception rate between one-hop neighbors is low. Beacons causing these errors are called *failed* beacons, while those resulting in successful decoding are referred as *successful* beacons.

If the number of failed beacons is higher than the successful ones, then the probability for latter beacons to be encoded is lower than the former one. To clarify this observation, let u denote the number of failed beacons, b be the total number of beacons and l be the number of beacons per encoding, then the probability to encode only failed beacons per encoding is

$$\frac{u}{b} \frac{u-1}{b-1} \cdots \frac{u-(l-1)}{b-(l-1)} = \prod_{j=0}^{l-1} \frac{u-j}{b-j}$$

For simplicity, we suppose $l < u$ and b remains constant (no new beacon arrives). From Equation above, the probability p of choosing at least one or more successful beacons per encoding can be derived as $p = 1 - \prod_{j=0}^{l-1} \frac{u-j}{b-j}$. Due to the constant b , p remains the same regardless of how many times a node performs encoding. This shows that failed beacons always have a higher probability to be encoded than successful ones, if their number is greater than that of the successful beacons. In the worst case, only failed beacons are encoded and their broadcast wastes bandwidth. To reduce the probability of encoding failed beacons, the radius-based strategy is being proposed.

3.1.2 Radius-based approach

The main purpose of this scheme is to reduce the encoding probability of failed beacons so that nodes particularly close together, have a high decoding probability. This can be achieved when beacons of those nodes are encoded where each is one hop away from each other (or close together). Since they are able to receive periodic beacons from each other, the probability of having sufficient beacons for decoding is increased. To do this, an encoder defines a certain radius w called *Encoding Range (ER)*, within which all neighbors are at one hop distance from each other. It is supposed that all nodes have equal radio ranges. In order to observe whether a neighbor j lies within w , encoder i first determines the current position of j using dead-reckoning [KFTE05] as following:

$$x_j(t) = x_j + (t - t_j)v_j, \quad 1 \leq j \leq n_i \quad (1)$$

where n_i is the number of neighbors of i , t is the current time, t_j the receiving time of a beacon of j , x_j and v_j are the received position and speed respectively. Base on this Equation, i measures the distance to its neighbor j as $d_j = |x_i - x_j(t)|$. If B_i be the set of all received beacons from neighbors, a subset $y_i \subseteq B_i$ separates beacons of all nodes lying within w as

$$y_i = \{b_j \in B_i : d_j \leq w \mid 1 \leq j \leq n_i\} \quad (2)$$

If $y_i = \{\emptyset\}$, i does not need to perform encoding. Otherwise it encodes all beacons within y_i .

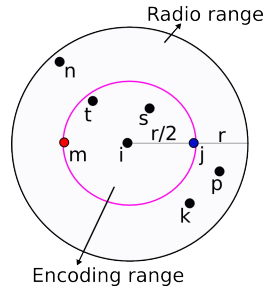


Figure 2: Radius-based approach

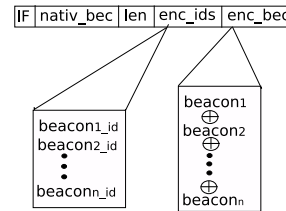


Figure 3: Encoded packet

To understand in a simple way, it can be considered that each node has two ranges: normal communication range (outer circle) and ER (inner circle) as shown in Figure 2. Note that ER does not reduce the transmission range of a node. Instead it is logical and used to encode beacons. In this example, r is the radius of the normal radio range of i and $w = \frac{r}{2}$ for ER. Node i uses Equation 2 to identify its neighbors lying within w , which are $\{j, m, s, v, t\}$ in this example, and encodes their beacons. This reduces the encoding probability of failed beacons causing fail-2hop, which, in turn, increases the decoding probability. The question is whether ER can be increased (or decreased) to further increase the decoding probability. This is discussed below.

Adaptiveness of encoding range ER can be increased as long as fail-1hop and -2hop do not occur. Suppose that there is no fail-1hop and only fail-2hop error occurs. In this case, the maximum ER can be $w = \frac{r}{2}$. Because if a node increases $w = \frac{r}{2} + \delta$, $\delta > 0$, then nodes within $(r, r + \delta]$ in opposite directions (n and k in Figure 2) will be two hops away from each other. Similarly two-hop distance might be true for nodes within $(0, \delta]$ and $(r, r + \delta]$. If beacons of all nodes within $(0, r + \delta]$ are encoded, fail-2hop can occur. For example, if node i in the above example increases its ER and encodes also beacons of p and k , then nodes $(m, t, p, k$ of Figure 2) cannot decode beacons because m and t are two hops away from p and k , and vice-versa. Therefore, they can have at maximum $l - 2$ encoded beacons that are insufficient for decoding. Due to this reason, the maximum ER is $w = \frac{r}{2}$.

Now suppose that fail-1hop also happens in addition to fail-2hop. In this case, ER ($w = \frac{r}{2}$) can already be too large because the distance between edging nodes (m and j in Figure 2) is r . For $r > 200$ m, the reception rate between these nodes is very low [YBF07]. They would not have sufficient beacons for decoding which leads to fail-1hop. To prevent this problem, ER can be reduced to $\frac{r}{2} - \delta$, $\delta > 0$. The smaller ER, the smaller the distance between nodes whose beacons are encoded. Since the reception rate between nearby nodes is usually high, they would have enough beacons for decoding with higher probability. This reasoning is also true for the mobility aspect where nodes may frequently enter and leave ER. Due to the smaller distance, nodes leaving ER do not become two-hop neighbors immediately and can receive beacons from each other even during mobility. Therefore, the probability of having enough beacons for decoding is high. This implies that the ER with a high decoding probability can be either $w = \frac{r}{2}$ or $w = \frac{r}{2} - \delta$.

3.2 Broadcasting of encoded beacons

By applying network coding on multiple beacons of different nodes, a new beacon is formed called an encoded beacon. The next step is the broadcast of this beacon. There are two variants: either this beacon can be sent separately from a periodic beacon or combined as a larger message called an *encoded packet* and then be broadcasted. The first case increases the sending rate, which may increase the collision rate. Moreover, combining many shorter messages into a larger one is generally better than sending them individually. This reduces the competition of accessing the channel between nodes, which helps to reduce collisions. Due to this reason, we adapt the latter variant. Since a large message requires long time to reach its destinations, an other node may interfere as the hidden terminal. However, this occurs rarely because an encoded packet is still a short message, whose size is equal to the size of two periodic beacons plus meta information as explained in Section 3. The problem is to decide whether the broadcast of this packet should take place once per beacon interval between each two periodic beacons or after n beacon intervals. To solve this problem, we named this n (the time period between two encoded packets) the *Encoding Interval (EI)* and use a metric to determine its suitable value. Another problem is that an encoded packet can also be lost. Since this issue is related to channel load effects generated by other traffic like periodic beaconing, we consider it out of scope of this paper and ignore it therefore.

3.3 Decoding

Upon receiving a message, a node decodes it in two steps:

Encoded beacon identification Before decoding, a node identifies whether the received message has an encoded beacon. If yes, the IF-flag shown in Figure 3 is verified. If it is true, the message is an encoded packet, otherwise it contains only a periodic beacon. In case of an encoded packet, it is first separated based on its fixed size and then decoding of the encoded packet is performed.

Packet decoding After separation of an encoded part from a packet, it is determined whether all l encoded beacons already exist. This is done based on the identifiers lying within *bec_ids* given in Figure 3. If all beacons exist, then there is no need of decoding and the encoded beacon is discarded. In case of only one missing beacon, $(l - 1)$ XOR-operations are performed to decode the l^{th} beacon. For all other cases, decoding is failed. After a successful decoding, the time stamp of the decoded beacon is compared with older beacons having the same sender id as the decoded beacon. If it is greater than that of the older beacons or the decoded beacon is first with this id, it will be added, otherwise discarded. This confirms the recovery of only updated beacons.

4 Evaluation

This Section presents detailed results of the simulation experiments that were carried out to evaluate the designed system. First, we explain the packet format and then describe the simulation

environment. Afterwards, results validate the performance of the proposed techniques.

4.1 Encoded Packet Format

An encoded packet consists of five fields; two mandatory: *IF* and *native_bec*, and three optional: *len*, *enc_ids* and *enc_bec*.

Identification flag (IF): If $IF = 0$, then a message has only a periodic beacon and consists of mandatory fields. Otherwise it is an encoded packet as shown in Figure 3.

Periodic beacon (nativ_bec): A simple periodic beacon whose size is fixed.

Length (len): It represents the total number of identifiers of encoded beacons recorded in (*enc_ids*) where each identifier has the same size.

Encoded beacon IDs (enc_ids): This field records meta data to enable the decoding of a beacon. It is a list in which id of each beacon that has been encoded, is added, so that at the time of decoding, a receiver can determine which beacons have been encoded.

Encoded beacon (enc_bec): This is an encoded beacon, which is appended in the last field when $IF = 1$. Its size is equal to the size of one periodic beacon.

4.2 Simulation Setup

We used the microscopic traffic simulator SUMO [sum] to generate vehicular movements. Our traffic scenario consists of two parallel one-way roads in opposite directions. Each road has two lanes and is divided into three road segments, each one is 1 km long and 15 m wide. The whole geographical area is about 3 km long. The average number of vehicles per kilometer in each lane is 14. For network simulation, the network simulator ns-2 [ns2] has been used. It, in turn, uses the two-ray radio wave propagation model with different communication ranges from 100 to 300 meters. IEEE 802.11p is employed as the MAC protocol.

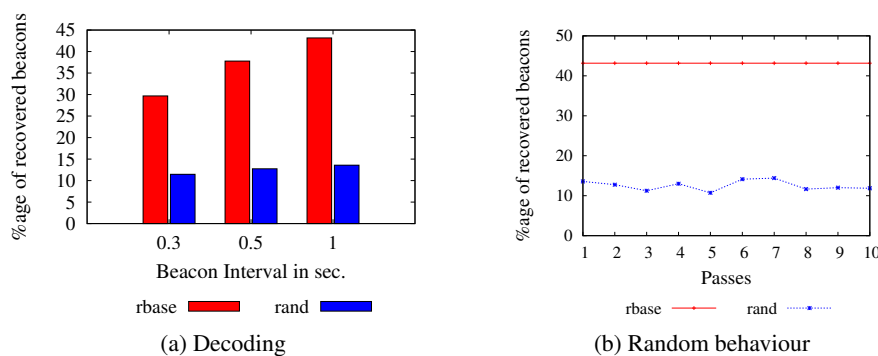


Figure 4: Percentage of recovered beacons that have been lost.

4.3 Decoding

This Section illustrates a detailed comparison of the designed approaches in terms of recovering the lost beacons. Note that percentage and ratio terms will be used interchangeably.

4.3.1 Recovery of lost beacons

To determine the number of recovered beacons, Figure 4a describes the recovery ratio in relation to the beacon interval. Here the number of beacons (l) per encoding are set to three for the random selection because it has the highest recovery ratio with $l = 3$ while the radius-based scheme is independent of l . The radio range is 200 m and EI is set to three. Note that for all simulations $ER = \frac{r}{2}$ and EI are the same until they are mentioned explicitly. Due to a high decoding probability, the radius-based scheme always recovers more than twice (in some cases thrice) beacons as compared to the random selection. Another observation is that the recovery ratio increases with increasing the beacon interval in both approaches. The reason is that the beacon reception rate increases with increasing the beacon interval. As a result, more nodes have enough beacons for decoding.

One factor for the poor performance of the random selection is the lower encoding ratio (encoding of the smaller number of loss beacons), which is about half of the radius-based (due to the space limit, these results are not shown here). As higher this ratio, the more beacons are received for decoding which increases the probability to recover more beacons. To see this impact, we change encoding ratio of the random selection with variable l is shown in Figure 5. The results describe that the best performance is for $l = 3$. The recovery ratio decreases for $l > 3$ although the encoding ratio reaches up to 92%. The main reason is the random behavior that encodes (inappropriate) beacons, which cannot be decoded. Furthermore, with increasing l , more beacons are encoded randomly which, in turn, increases a probability of encoding inappropriate beacons. This leads to fail-1hop and -2hop.

4.3.2 Frequency of fail-2hop error

For detailed analysis, Figure 6 describes the ratios of fail-1hop and -2hop. Here we split $rbase$ into $irbase$ and $orbase$ representing nodes lying in and out of the radius $[0, r/2]$ respectively to show the effectiveness of $ER = \frac{r}{2}$. As expected, fail-2hop in $irbase$ has a negligible impact due to the high decoding probability. However, this error occurs frequently in the $orbase$ and the random selection (75%,90% respectively) because in both cases, the schemes do not care whether nodes are able to decode. This shows that the radius-based within ER is very useful against both errors.

4.3.3 Performance

Since the recovery ratios of a single scenario alone are not sufficient for performance analysis, the 95% confidence interval is used as given in Figure 7. As shown, the radius-based approach recovers 30-43% beacons depending upon the beacon interval, which are always 3-4 times more than the random selection. However, this ratio can be changed by changing the encoding interval (EI). The smaller EI, the smaller the time span between two encoded packets. A smaller EI encodes more lost beacons, and broadcasts more encoded beacons. As a result, more nodes receive packets for decoding, which increases the probability of a high recovery ratio as shown in Figure 7b. As expected, the recovery ratio increases with decreasing EI and vice-versa. Here $n = 1$ shows the maximum recovery percentage where the radius-based scheme reaches up to 70%, while the random selection recovers 30%.

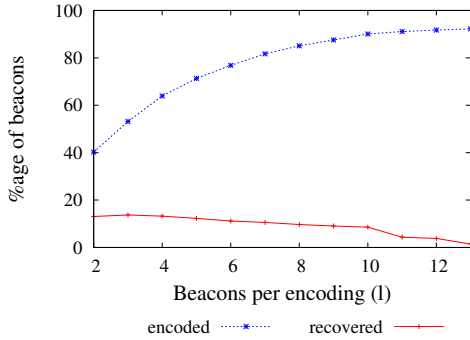


Figure 5: Encoding and decoding

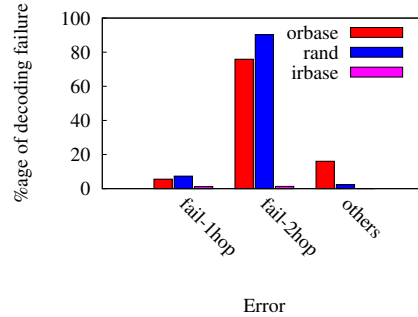
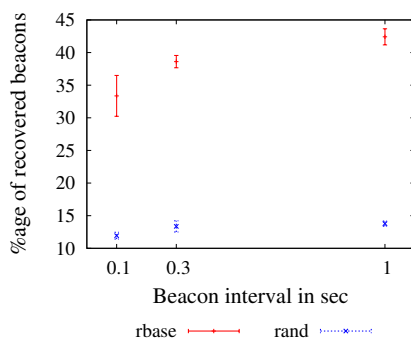


Figure 6: Percentage of decoding failure in relation to the specific error



(a) Variable beacon interval, EI is 3.

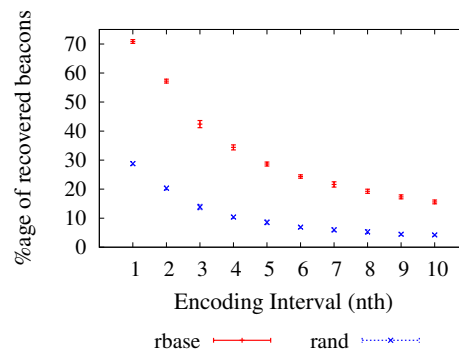

 (b) Variable EI, $l = 3$, beacon period = 1 s

Figure 7: Percentage of recovered beacons using 95% confidence interval.

4.3.4 Impact of beacon loss

Another factor influencing the recovery ratio is the beacon loss rate. The higher this rate, the lower the probability for a node to have sufficient beacons for decoding, which decreases the recovery ratio and vice-versa. A recovery ratio of zero can be considered as the worst case and the highest ratio of 100% as the best case. To show both cases, the beacon loss rate is changed randomly as given in Figure 8a. Here the beacon interval is 1 s. As can be seen, the recovery ratio decreases with increasing beacon loss rate. This ratio decreases sharply in the radius-based approach because it encodes a large number of beacons and with increasing the beacon loss rate, nodes suffer heavily from fail-1hop. To reduce this error, a smaller ER is useful as discussed in Section 3.1.2. In this regards, the best ER (having the highest recovery ratio) for the corresponding beacon loss rate is shown in Figure 8.

The results confirm our observation that a smaller ER is usually necessary to obtain better performance with a high beacon loss ratio. It can be examined that at the same beacon loss ratio, the recovery ratio of the radius-based approach with $ER=100$ m in Figure 8a is smaller than $ER < 100$ m in Figure 8b. Moreover, $ER = 20$ m recovers beacons even when $ER = 100$ m

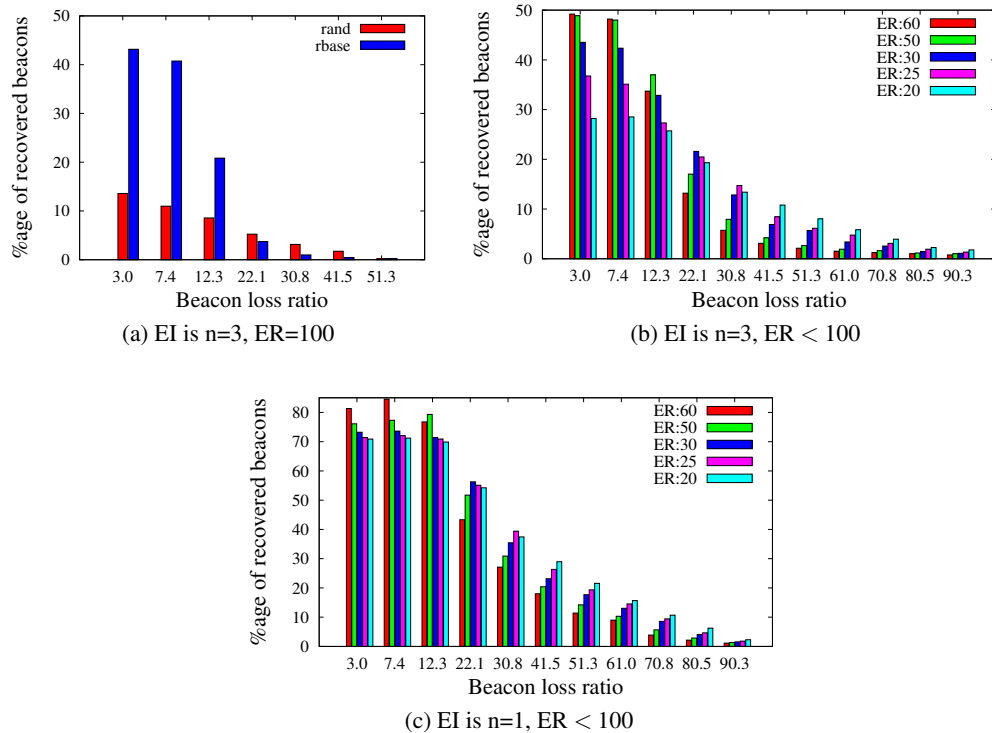


Figure 8: Percentage of recovered beacons in relation to a variable beacon loss ratio.

completely fails to decode. A key factor is that a smaller ER has usually a smaller number of beacons per encoding than a larger ER. This requires a smaller number of beacons for decoding, which increases the decoding probability. The recovery ratio can be increased even more with decreasing EI as shown in Figure 8c. For instance, at ER=50m the recovery ratio is improved from 37% to 80% when EI decreases from $n = 3$ to $n = 1$. The radius-based scheme recovers beacons even when the beacon loss is $> 90\%$, while the random selection fails completely when it is $\geq 50\%$. These results also include indirectly the impact of fading [PWK08] because this influence increases collision rate as evaluated here.

4.3.5 Impact of Radio ranges

Until now all experiments have been investigated with a radio range of 200 m. Since the collision rate and number of one-hop neighbors change with different radio ranges, the proposed schemes may behave differently. This impact is given in Figure 9. The other parameters are: beacon period is 1s and $l = 3$. As shown, both schemes (particularly radius-based) increase their performance with the radio ranges. The reason is that the number of nodes lying within ER increases with increasing radio ranges. As a result, more nodes have a high decoding probability, which increases the recovery ratio.

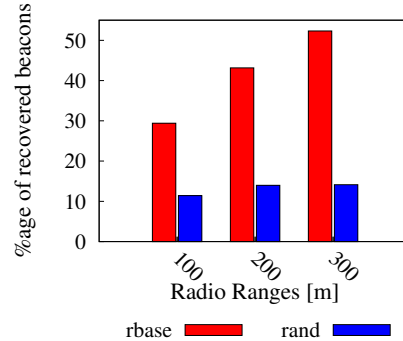


Figure 9: Percentage of recovered beacons for the different radio ranges.

4.3.6 Distance-based recovery

For the safety aspect, it might be important to observe the recovery ratio of vehicles that are close together. In this respect, Table 1 describes the percentage of recovered beacons based on the distance between sender and receiver. Here, the beacon interval is 1s, $ER = 60$ m and $l = 3$. As can be seen, the recovery ratio in the radius-based scheme remains nearly stable with increasing distance. Up to 60 m it is $\geq 99.94\%$ and from 60 m to 100 m, it varies from 99.61 to 99.87%. In the random selection approach, this ratio changes significantly with increasing distance due to the randomness. This means that the radius-based approach is very useful to keep nearby vehicles updated about each other.

Table 1: Percentage of recovered beacons w.r.t. distance between sender and receiver.

Distance [m]	Radius-based	Random selection
30	99.98	79.14
40	99.94	72.32
50	99.95	55.35
60	99.94	47.08
70	99.87	58.24
80	99.85	45.99
90	99.84	34.64
100	99.61	47.26

5 Summary

In this paper we have addressed the issue of lack of information for beaconing strategies in car-to-car communication using network coding. We determined that network coding is very useful to recover lost beacons. However, the problem of encoding beacons which have a high decoding probability needs to be addressed. For this purpose, the existing approaches use periodic reports, which are infeasible for one-hop beaconing because it increases the load on the wireless channel. To solve this problem, two approaches, *random selection* and *radius-based* have been proposed. The former scheme encodes beacons randomly and the experiments showed that it suffers heavily from decoding failures. To reduce this failure rate, we designed the radius-based approach. The

results described that this approach is a promising technique for the recovery of a significant number of lost beacons. Due to the adaptive nature, this scheme can recover beacons even when the beacons loss rate is very high ($> 90\%$).

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