To Beacon or Not?: Speed Based Probabilistic Adaptive Beaconing Approach for Vehicular Ad-Hoc Networks

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Abstract. Emergence of Wireless Sensor Networks provided the ability to connect, collect and disseminate information across various sensor nodes. Deploying this concept in the transportation domain evolved into the concept of Vehicular Ad-hoc Sensor Networks (VASNETs) or Vehicular Ad-hoc Networks (VANETs). VANETs turned out to act as a boon to enhance the safety and non-safety aspects of the transportation domain, giving way to the future of Intelligent Transport Systems. To generate cooperative awareness in the network, VANETs use beacons, which are small packets of information transmitted as BSMs (Basic Safety Messages). Beaconing was developed in the initial phases of development of VANETs and mainly suffers a trade-off between channel congestion and the level of accuracy of exchanged information. In this work, an adaptive speed based beaconing approach is proposed, the approach uses probability as a means to answer two key questions. First is whether to beacon or not and second is at what rate beaconing should be done to reduce channel congestion and increase the accuracy of information. The results are compared with an adaptive density-based approach and with normal static beaconing cases. Performance evaluation on Veins framework demonstrates that it gives better results as compared to both the other approaches. Further, the results concerning generated BSMs, received BSMs and total packet loss are compared. The simulation is modeled to make it as realistic as possible by introducing a vast heterogeneous network with random vehicle mobility trips.

Keywords: Wireless Sensor Networks (WSN) · Vehicular Ad-hoc Sensor Networks (VASNETs) · Vehicular Ad-hoc Networks (VANETs) · Intelligent Transport Systems (ITS) · Vehicular Ad-hoc Networks · Beacons · Adaptive beaconing · Basic safety messages · Veins

1 Introduction

Advancement in the field of Information and Communication Technology in the past couple of decades has tremendously increased. The incorporation of these technologies

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in the domain of transportation has opened a whole new arena of beneficial applications, ranging from safety to non-safety ones [1, 2]. VANETs are rapidly emerging with the constant effort being put by researchers leading to its enormous growth in the past decade itself. The advancement in VANETs is paving the way for the future of Intelligent Transport Systems [3].

Most of the vehicles come equipped with numerous technical modules out of which wireless communication system or module is of tremendous help in Vehicular ad-hoc networks. VANETs make use of this module to exchange information which is later on used in various ways to enhance user safety, user experience and lead to optimized utilization of resources.

VANETs are primarily composed of three major components which are Road Side Unit, On Board Unit and Application Unit [4]. Road Side Unit is a fixed device alongside roads, primarily used for infrastructure to vehicle communication. It is capable of providing strong compute services and communication services to the vehicles which are in range. On-Board Unit is a WAVE device mounted on the vehicle which provides resources for use via Resource Command Processor and communicates with the RSUs. Application Unit is a device used for running applications by using information provided by the OBU. It can be fixed or a mobile device such as Personal Digital Assistants.

The center of VANET based applications lies in maintaining updated information about the network in which any vehicle is present. This up to date information leads to the emergence of cooperative awareness in the network. Based on this cooperative awareness, realistic decisions can be made in real-time by the vehicles itself or by the users. VANETs make use of beacons to achieve cooperative awareness. Beacons are small packets of information which contain data such as the location of any vehicle, its ID, its moving direction and speed of motion [5]. The process of transmission and exchange of beacons in the network is termed as beaconing [6, 7].

Safety related messages in VANETs belong to either of the two categories: periodic messages or non-periodic messages [8]. Periodic messages are also known as heart beat messages or beacons which are responsible for maintaining updated information in the network. Non periodic messages comprise of information which need immediate attention or the one which is requested by user such as emergency information or audio/video requests by user.

There are two key aspects to spread information in the VANETs. One is beaconing and the other is information dissemination [9]. Beaconing is responsible for constructing the underlying knowledge base using which important information can be disseminated in a timely and efficient manner.

Wireless Access for Vehicular Environment or WAVE is a protocol stack used to provide wireless communication capability to VANETs. Its extension came out in the form IEEE 802.11p, which is a communication standard for VANETs [10]. Under IEEE 802.11p, beaconing is achieved by sending periodic BSMs or Basic Safety Messages on the CCH (control channel) which has a bandwidth of 10 MHz [11]. Beaconing has been mostly done by flooding the beacons in the network. Whenever a vehicle joins or leaves or moves across the network, it will constantly transmit the beacons generated by it. However, it does not turn out to be efficient in certain cases. When the vehicular density is high, the channel becomes congested by the constant traffic generated due to beacons. This also leads to wastage of channel bandwidth as the mostly the same information is going around in the network and somehow obstructs the path to more important information [12].

In the last decade, researchers have come up with the concept of adaptive beaconing, which has the potential to reduce unnecessary channel congestion in the network. The two types of adaptive approaches have come in the light as a result. First one is beacon generation rate adaptation where the rate of generation of beacons is adapted based on some custom defined parameters [13–17]. The other one is beacon transmission power adaptation where the transmission power of beacons is adjusted which materializes in the form of distance up to which the beacon will travel [18–20]. This work focus on the first approach, based on it the adaptive beaconing approach is proposed.

When vehicles move in the real world environment, the resulting network can be dense, relatively constant or sparse in terms of the number of vehicles on the road segment. A solution for beaconing is needed which can suit itself to all these three cases. Hence, an adaptive beaconing approach is proposed in this work, the proposed approach is based on the speed of vehicles in the network. The probability is calculated from the various parameters and it decides the frequency or transmission rate of the beacons in the network.

The work proposes two adaptive beaconing approaches, first is based on the density of one-hop neighbors of any vehicle at any instant, and the second is based upon both, the speed as well as the density around a vehicle. Both the proposed approaches are compared among them and with the static beaconing, which is configured to the frequency of 10ms. Further, it was observed that incorporating multiple parameters into the decision of beacon rate control yields more beneficial results as compared to using just one of the parameters or not at all.

The rest of the paper is organized as Sect. 2 highlights some of the key works done in this area of adaptive beaconing. Section 3 highlights the proposed work focusing on the algorithm, which contains a rule-based system for beaconing within it. Section 4 sheds light on the combination of simulators and why they have been chosen. Section 5 showcases the obtained results of the proposed approach based on three key parameters. Section 6 discusses the results and lastly, we conclude the work leaving the open future work.

2 Literature Review

This section is focused upon discussion of the works already been done in the domain of adaptive beaconing in VANETs:

A mobility prediction based adaptive beacon rate control (MPBR) is proposed in [21] where beacon rate is adjusted as per the predicted positions of the vehicles, rather than following the periodic beaconing scheme. As the location prediction may suffer from errors from time to time, they propose a threshold value crossing which beacon broadcasting will be initiated. The approach also classifies the traffic status on the road into categories, which makes it easier to determine the threshold value. However, when to comes to sparse network conditions, the approach does not work effectively resulting in a loss of coverage and a failure to disseminate data effectively.

ENeP-AB or Estimation of Neighbors Position privacy scheme with an Adaptive Beaconing approach proposes a modification in the pseudonym based on density and the predicted positions of the vehicles at any given point of time [22]. This scheme is extended to propose a protocol called E-ABRP standing for Adaptive Beaconing Rate Protocols, which aims at improving the quality of service while maintaining a steady beacon rate. This approach makes a modification by using the density as a parameter for beacon rate adjustment thereby covering the requirements of a sparse as well as a dense network. The algorithm proposed relies on spatial linking of vehicles and does not focus on the temporal aspect which might lead to congestion, thereby undermining the Quality of Service in the network.

A large solution space for adaptive beaconing is explored in [23, 24], where the focus is on several alternatives to determine the beacon rate. The work have proposed a situation based adaptive beaconing scheme where beacon rate can depend on either the vehicles own parameters or be altered by macroscopic or maybe microscopic elements of the network.

Beacon inter-reception time Ensured Adaptive Transmission is proposed in [18] for vehicle to vehicle safety communication. It is a congestion control algorithm for reducing contention occurring due to the beaconing. It leads to a supervised regulation of beacon rate intervals, thereby making it adaptive yet designed in a way to avoid channel congestion specifically. Extending this in [25], the usefulness of density as a parameter is judged by combining it with various other attributes. This leads to the conclusion that density based approaches give highly satisfactory results while calculating beacon rate control. The choice of parameters which must be ideal is not provided.

Use of ABC or Adaptive Beacon Control is proposed in [26], the authors used a new factor ρ called as danger coefficient with the help of which read end collisions are avoided in the VANETs. Leveraging this, the approach also propose a fully distributed beacon rate control scheme which uses a TDMA based MAC protocol to solve an NP-hard optimal problem by using a greedy heuristic algorithm. In [27], a collision based approach is provided to find the beacon rate but a collision in the network is needed for it to work. Both of the approaches fail to address the conditions where network is fast changing and collisions are not present. The calculated beacon rate has the potential to overuse the channel bandwidth, which will be counter effective during information dissemination.

Based on opportunistic routing and the nature of wireless channel used, authors in [28] have proposed a beacon rate adjusting scheme which focuses on estimated link-time between vehicles and the set of forwarding rules which will be active until some change in topology occurs.

Adaptive Beacon Rate Adjusting mechanism based on neural networks and back propagation is proposed in [8] where beacon rate adapts as per the QoS metric defined which includes delay and rate of packet loss. The proposed mechanism relies totally on the RSUs for the compute intensive work and assumes that vehicles are always connected to RSUs. It is unable to cope up with scenarios where connectivity is intermittent.

LIMERIC or Linear Message Rate Integrated Control algorithm is proposed in [29] where full precision controlled inputs are received from the wireless channel. These inputs lead to a deterministic value of beacon rate control and is aimed at avoiding the limit cycle which is inherent to binary control based approaches. The work establishes specific guidelines in order to implement their approach which makes its scope limited to practical applications.

3 Proposed Work

In this section, the proposed approach targeted towards optimizing the beaconing in vehicular ad-hoc networks is discussed in detail. This work proposes two approaches for adaptive beaconing, first is based on the density of one-hop neighbors, and the other incorporates speed of the vehicles. The validity of the proposed approach is established by comparing the two approaches with a static beaconing case and among each other. The following sub section discuss both the approach in details.

– Static beaconing:

In this approach, a fixed beacon rate value is taken. BSMs will be transmitted every x seconds by all the vehicles participating in the network. The static beacon frequency is selected from the following set containing 5 different values $\{0.1, 0.5, 1, 1.5, 2\}$ seconds.

– Adaptive beaconing with one-hop neighbour density:

The adaptive beaconing approach based on the one-hop neighbour density calculates its number of neighbours at any given point of time t and depending upon that decides an appropriate value using the rule-based system provided below. The density around the source vehicle is calculated by taking into account the nodes which are present in the range of 300 m. For the initial 10 s, when the vehicle joins the network, a beacon rate of 10 ms is assumed. During this interval, the vehicle records the information so as to become well aware of the network. Then the information from packets is divided and filtered to obtain the number of nodes which lie within range of the vehicle. This number is denoted as D (the density around that vehicle). This way all the vehicles keep on calculating their one hop neighbors every second. The value of D is then used to decide whether the network is sparse, dense or normal, details of which are given in Table 1. The appropriate beacon rate for the network is selected via the rule based system. The pseudo code to determine the adaptive beacon rate is given below:

Algorithm 1: Pseudocode for adaptive beacon rate

```
Start at t=0
While (t<10)
      Beacon rate = 0.1
Record information till t=10
Segregate the information as {Node ID, distance,
speed}
At t>10, for every node
      Calculate D which is the number of one-hop
      neighbours in the vicinity of the vehicle
      If D is less than 5
          BeaconRate = 20ms
      If D is between 5 and 10
          BeaconRate = 80ms
      If D is greater than 10
          BeaconRate = 1.2sec
  Else
        Do not beacon again
  Continue at t = t+1
  Exit when vehicle moves out of the network
  End
```

Table 1. Classes for the rule-based system (density)

Class	Density (D)	Beacon rate	Network type
I	D < 5	20 ms	Sparse network
II	5 < D < 10	80 ms	Normal network
III	D > 10	1.2 s	Dense network

This approach is implemented in the Veins framework, as discussed in the next section. Number of nodes participating are {800, 1100, 1400, 1800}. Going beyond this number was not possible as the computations grew much heavier due to an increased exchange of packets.

– Probability-based adaptive beaconing with speed and neighbor density:

The proposed adaptive beaconing approach is based on the speed and one hop neighbor density of the vehicles present in the network. When the speed of the source vehicle and the neighboring vehicles is high, then the network is assumed to be sparse or less dense. When the speed of the source vehicles and the neighboring vehicles is less, then we assume that the network is dense, thereby leading to an overall reduced speed in the network.

Two key parameters come into play, one is the density of vehicles in the network on a given road segment, and the other is the average speed of vehicles in that segment. Both of these parameters are considered to get a better adaptive beaconing rate. Based on the average speed of the vehicles and their neighbors within less than 300-m distance, the probability is calculated. Based on this probability, the decision needs to be made on whether beaconing is required or not and if it is required what should be the frequency for this.

When a vehicle receives a beacon, it records, in particular, the node ID, location and speed of the vehicle. The beacons are cumulatively stored in a table until the first 10 s of the introduction of the vehicle into the network. This time is needed to collect data based on which beacon rate will be adjusted. In these initial 10 s, the beaconing frequency is set to 0.1 s. After 10 s, the vehicle is ready to set and adapt its beacon rate as per the proposed approach. The vehicle calculates the number of one hop neighbors i.e. D. The speed of these vehicles within a range of 300 m is calculated and its average sum is taken as α. Using α, the β value is calculated by dividing it with the maximum speed attainable and by the vehicles in the network. The work fixes the max speed of the vehicle to 40 in the simulation environment. This assures that the value of β turns out to be less than 1, further the β is used to find out the Adaptive Beaconing Probability or ABP by subtracting it from 1. ABP is used as a catalyst to make the beacon rate more adaptive. This value when added to a pre-defined set of beacon rates gives a more adaptive and better result as it changes with respect to the change in the environment of the vehicle.

β cannot approach the value of 1 as it is practically impossible. All the vehicles cannot drive at their maximum speed in the network. Therefore, the value of 0.1 is selected as threshold, this value signifies that the vehicle speed in the network is high. On the other hand, value of ABP greater than 0.6 signifies that the network has becomes dense, and hence the increase the beacon interval is done. Similarly, as this value approaches 0.9, it signifies that the vehicle is about to come to a halt thereby inducing a stagnant state. And hence the values are chosen after much thought and trial demonstrations within the simulation. The values are chosen based on which were best suited. Based on the trial and run the resulting classification of the network is provided in the Table 2, that describe the selection criteria of the beacon rate.

The working of the proposed approach is explained in the form of pseudo code as:

Algorithm 2: Pseudocode for proposed approach

```
Start at t=0
While (t<10)
     Beacon rate = 0.1
Record information till t=10
Segregate the information as {Node
ID, distance, speed}
At t>10, for every node
     Discard Node ID with dis-
     tance>300m
     Calculate D= nodes < 300 m
     distance from the source node
```

$$\alpha = \frac{\sum_0^D speedVID}{D}$$

$$\beta = \frac{\alpha}{40}$$

```
     Close
ABP = [1-β]
If (ABP  is between 0.1 and 0.3)
     BeaconRate = 0.5+ABP
ElseIf (ABP  is between 0.31 and
0.59)
     BeaconRate = 1+ABP
ElseIf (ABP  is between 0.6 and
0.89)
     BeaconRate = 1.3+ABP
ElseIf (ABP  <= 0.9)
     BeaconRate = 2+ABP
Else
     Do not beacon again
Continue at every t=t+1
Exit when vehicle moves out of the
network
End
```

Table 2. Classes for a rule-based system

Class	Probability (ABP)	Beacon rate	Network type
I	0.1–0.3	0.5 + ABP	Sparse network
II	0.31–0.59	1 + ABP	Normal network
III	0.6–0.89	1.3 + ABP	Dense network
IV	>0.9	2 + ABP	Stagnant state

The realistic scenario from VEINS [30] framework has been taken for simulation in SUMO [31, 32] and VEINS. The numbers of vehicles were taken to be {800, 1100, 1400, 1800}. Having a large number of nodes in the network ensures the heterogeneity across the network and makes it more realistic where one vehicle can meet any particular vehicle multiple times in the same simulation. The following table shows some of the simulation parameters used for the testing (Table 3).

The following image shows the running simulation on the veins framework, where nodes are transmitting messages. These nodes are moving randomly in the network, entering from one end and leaving from another. The random mobility model is generated through the SUMO [31] (Fig. 1).

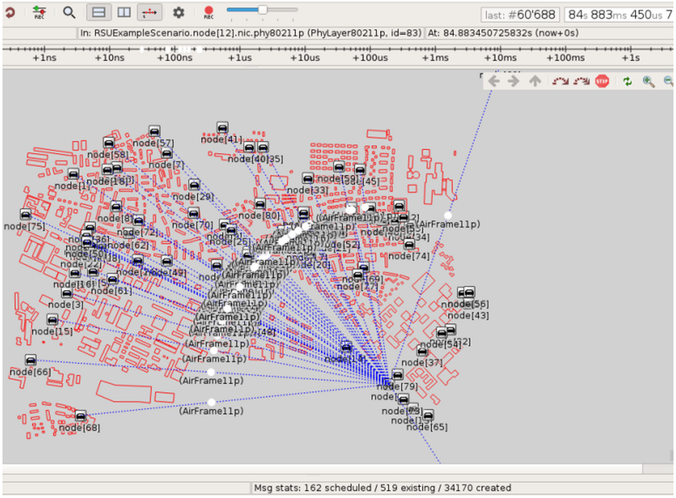

Fig. 1. Running simulation on Veins framework

Table 3. Simulation parameters

Parameter	Value
Playgroundsizex	3500 m
Playgroundsizey	3500 m
Playgroundsizez	50 m
Scalar-recording	True
Vector-recording	True
Sim-time-limit	1800
Accel	{2.6, 3.2, 4.1}
Decel	{3.7, 4.5, 5.7}
Mingap	2.5
Maxspeed	40
Random trips	trips.trips.xml

4 Implementation

This section describes the selected tools for the proposed work, as evaluating any of the proposed work in vehicular ad-hoc networking is a big challenge on its own. Real-world experimentation is extremely difficult to achieve because it requires rigorous labor and enormous hardware. The evaluation and implementation of any VANETs based approach requires majorly three tools the simulator, the mobility model and the framework. The network simulators allow us to test run the work in multiple scenarios like using random maps or custom generated maps, modifying the routes, beacon structure, applying a different set of algorithms for routing and so much more. To test the validity of the work, a combination of simulators and mobility model is used. The network simulator is OMNet++ [33, 34] is used and the proposed adaptive beaconing approach is deployed on the application layer of the IEEE 802.11p communication standard. The framework used on the simulator is VEINS[30].

The second tool is the mobility manager SUMO or Simulation for Urban Mobility [31, 35, 36] is an open-source, portable, microscopic road traffic mobility generator which is used mostly along with a network simulator. Its role is to populate the network with vehicles as entities whose properties and behavior can be custom-defined. The map, routes, type of vehicles, routes taken, intersection etc. all can be customized according to user demands, and it also works on real traffic data thereby making it more realistic in testing scenarios. The version which is used on top of the network simulator OMNet++ is SUMO 0.30.0 which is compatible with both the network simulator and VANET framework.

The final tool used is the framework for VANETs [37], the VANETs comprise of different property as compared to other network technologies. The network based customization can be done through the combination of the OMNet++ and SUMO. To incorporate specific VANET based environment, the VEINS framework [30] is selected, which already contains most of the common property required for a successful VANET such as a module specifically for the IEEE 802.11p standard. The proposed work utilizes the underlying VEINS framework to implement the customized beaconing and adaptive mode in the application layer.

5 Results

The proposed work is implemented in the Veins framework setup on top of OMNet++ 5.4.1 and SUMO 0.30.0. The number of generated BSMs, received BSMs and total packet loss are recorded in the scalar and vector files. The output files are further converted to csv files only containing the filtered data to be used for evaluation. Veins provide the ability to generate and segregate data allowing the creation of different graphs and other visualizing images, which can make analysis far better. The generated BSMs and received BSMs from the scalar application file are taken for each scenario. For calculating the total packet loss, the data from the vector file is taken. Total lost packets encompass of two types of packets, i.e. RxTx lost packets, and SNIR lost packets.

Figure 2 shows the number of generated packets vs number of nodes among different approaches. This parameter is crucial from the network load perspective. Higher the number of packet generated will result in the higher network load.

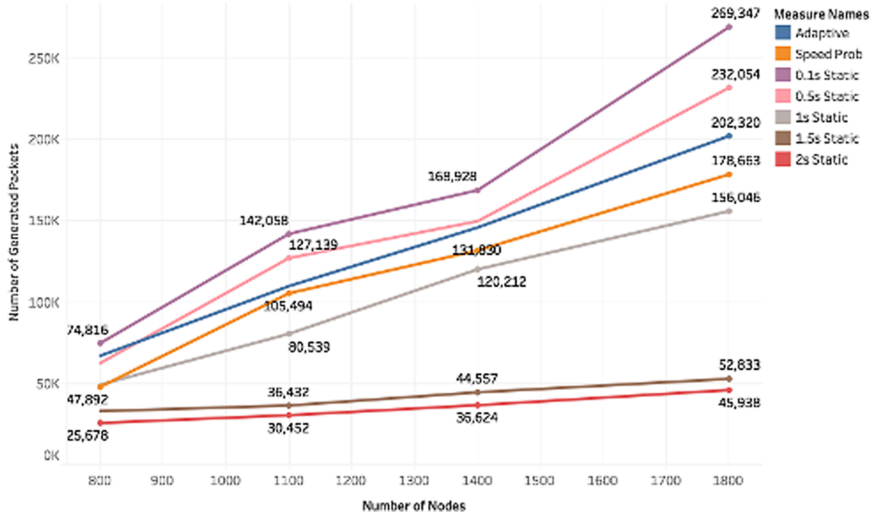

Fig. 2. Generated BSMs

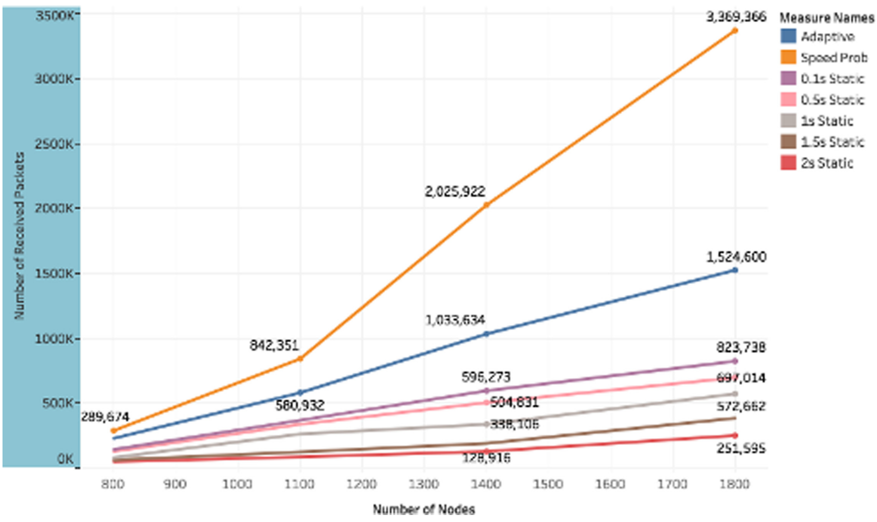

Fig. 3. Received packets

Similarly, in Fig. 3 the number of cumulative messages received on each nodes vs the number of vehicles is plotted. It is clear from the graph that the speed probabilistic is receiving higher messages as compared to all other nodes.

Figure 4 shows the lost packet on individual nodes vs the number of nodes, the lost packet is the parameter that is crucial in terms of the real-time application of VANETs. Higher the lost packet higher the chances of unreliable VANETs.

This can be observed from the graphs that the proposed approach works very optimally in all three aspects of the message generation, reception and loss.

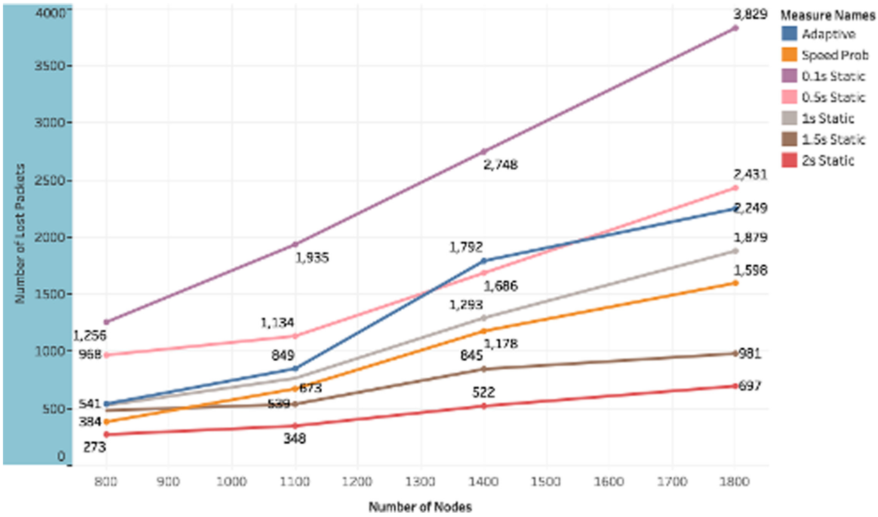

Fig. 4. Lost packets

6 Discussion

The number of generated BSMs is most significant in the case of static beaconing, where the beacon rate is 10ms and maximum is 2 s. This leads to constant generation and transmission of beacons by the vehicles in static beaconing cases. The result is channel congestion, bandwidth wastage and maybe refusal of transmission of critical information since the network is too crowded already. In the case of adaptive beaconing, however, the generated BSMs are comparatively lesser and fall within the range of 0.5 s to 1 s, which clearly demonstrates that adaptive beaconing is better than the static one in case of the number of generated BSMs. And, finally the speed based probabilistic approach where beacon rate is decided by considering the speed of the vehicles moving within the network. The number of generated BSMs is even lesser than adaptive beaconing, which means that the channel utilization has been optimized and there is less congestion in the network. Also, beacons are transmitted by the vehicles as determined by the procedure where the beacon rate is adapted concerning network state. This demonstrates that better coverage of the network is achieved. The decision to beacon or not also plays a major role in deciding whether to beacon recurrently or not, thereby leading to an optimized number of generated BSMs.

In case of several received BSMs, the static beaconing results show a lesser number of received beacons which mean there was unnecessary transmission by one end where no one was able to receive the messages at the other end. In case of adaptive beaconing based on mere density, the number of received BSMs is higher in comparison to all the static beaconing cases which yet again shows that adaptive beaconing is a better approach than the static one and has a better reach in practicality. Lastly, the adaptive approach based on speed and density has done well then both the adaptive and static beaconing. The number of received beacons gain momentum as the number of nodes increases in the network clearly representing that the performance is improving as the network becomes more complex and realistic.

Lastly, in terms of the number of packets lost, it can be observed that the packet loss is highest in the cases of static beaconing where beacon interval is less than 1 s. The corresponding number of generated BSMs is also high in static beaconing, and the number of received BSMs is less. Both of these factors reason out well with the highest number of packet loss in static beaconing. However, in the case of adaptive beaconing in both the scenarios, the number of lost packets is less due to the ability to adapt concerning changing environmental conditions in the network.

From the given graphs and charts, it can be observed that the adaptive beaconing approach outperforms static beaconing approach and also the one based solely on density. The speed-based probabilistic approach takes into account the density as well, though in a different manner, but the overall results have come out to be really promising.

7 Conclusion

Beaconing in Vehicular ad-hoc networks is used to generate cooperativeness in the network, which primarily helps in information dissemination when needed. This work have proposed a speed and density-based adaptive beaconing approach, which can be used to reduce network congestion and increased utilization of resources. Veins framework is used to implement the proposed technique, and the results are compared with density-based adaptive beaconing and static beaconing as is practiced in many standard works undergoing in VANETs. The results demonstrate that the proposed adaptive beaconing approach performs well as compared to static beaconing as to density-based adaptive beaconing as well. In future, the work can be extended by incorporating other parameters into the adaptive beaconing approach to make it more wholesome and optimized concerning the consumption of resources. The adaptive technique can also employ machine learning model, this work is identified for extension of this work.

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