Reproducing and Extending Real Testbed Evaluation of GeoNetworking Implementation in Simulated Networks

Ye Tao
The University of Tokyo
tydus@hongo.wide.ad.jp

Manabu Tsukada
The University of Tokyo
tsukada@hongo.wide.ad.jp

Xin Li
Beijing University of Posts and Telecommunication
leexin@bupt.edu.cn

Masatoshi Kakiuchi
Nara Institute of Science and Technology
masato@itc.naist.jp

Hiroshi Esaki
The University of Tokyo
hiroshi@wide.ad.jp

ABSTRACT

Vehicular Ad-hoc Network (VANET) is a type of Mobile Ad-hoc Network (MANET) which is specialized for vehicle communication. GeoNetworking is a new standardized network layer protocol for VANET which employs geolocation based routing. However, conducting large scale experiments in GeoNetworking softwares is extremely difficult, since it requires many extra factors such as vehicles, stuff, place, terrain, etc. In this paper, we propose a method to reproduce realistic results in simulation with the same software implementation. The key idea of the method is to calibrate simulator with the results of real world testbed experiments. After the simulator was calibrated, some extended experiments were carried out. Through these experiments, the fundamental functions of the GeoNetworking implementation (BTP, Greedy Forwarding, etc.) are verified, while an issue in algorithm was discovered and analyzed.

1. INTRODUCTION

Intelligent Transportation Systems (ITS) aim at optimization of the road traffic by realizing safe, efficient and comfortable transportation. Within a number of research fields in ITS, Cooperative ITS and vehicular communications became essential for the cooperation of multiple entities in the road traffic (*i.e.* vehicles, roadside infrastructure, traffic control centers) in order to achieve shared objectives (safety, efficiency, and comfort).

In order to connect among vehicles and roadside units, GeoNetworking [1] is employed as one of the network protocols in the ITS Station architecture [2] as shown in Figure 1, because the geolocation based routing shows the strength in the network with dynamic topology compared with topology based routing.

In the literature, the evaluation of GeoNetworking can be performed in flexible and large scale simulated network with low cost. However mere simulations cannot provide realistic evaluation results for a specific implementation of GeoNetworking. In contrast, the experimental evaluation using the implementation in a field operational testbed gives real results in the deployment phase of GeoNetworking. Though in practice, it requires heavy cost to conduct the experiments in terms of time, manpower, space and expense. In order to take the benefits of real field test and simulation, we reproduce the results of the field experimental evaluation in the simulated network with the same implementation.

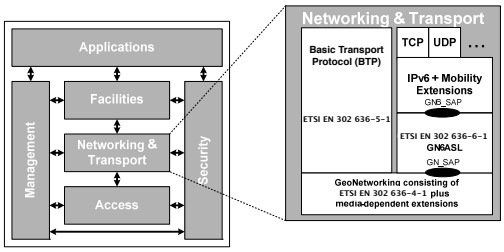


Figure 1: GeoNetworking in ITS Station Architecture

The rest of the paper is organized as follows. Section 2 highlights the related works. In Section 3, we describe our objectives in the paper. In Section 4, the experimental evaluation in the real testbed is shown. Section 5 shows the work for the reproduction of the experimentation result in the simulated networks. Section 6 extends the reproduction to the various scenarios in the simulation. Finally, section 7 concludes the paper by summarizing the main results and addressing future works.

2. RELATED WORKS

2.1 GeoNetworking and the Implementation

Vehicular ad-hoc network (VANET) is a particular case of Mobile Ad-hoc Network (MANET), which is not restricted by the battery consumption of the communication nodes and are also characterized by the high speed movement of nodes, the availability of GPS information, and a regular distribution and predictable movements.

GeoNetworking [1] is standardized by ETSI as a network

layer protocol as in Figure 1, integrating several geo-aware strategies including Greedy Forwarding (GF) [3] to route packets better in vehicular networks. Above the GeoNetworking, there are two different layers. One is *Basic Transport Protocol (BTP)* [4] which provides basic functions of the Transport layer to GeoNetworking, the other is *GeoNetworking to IPv6 Adaptation Sub-Layer (GN6ASL)* [5] in order to enable standard IPv6 over GeoNetworking.

All the GeoNetworking nodes send beacons in a specific interval and the neighbor nodes maintain its latest geographical location in the *location table (LocT)* from the received beacons. Other GeoNetworking packets delivered in the network contain the location of *source (SO)*, *sender (SE)* and *destination (DE)*; in the case that the location information in the packet is newer than the one in the location table, the location table is updated. Each *location table entry (LocTE)* has a lifetime counter, and the entry is removed when it is reduced to 0. When the source node does not have location of the designation in its location table, the node triggers the *Location Service (LS)* request message in order to obtain the location of the destination. ETSI defines the flooding based request-reply location service to get the destination location.

The CarGeo6 project[1] provides GeoNetworking implementation in open source [6]. The GeoNetworking function and the BTP function are implemented as daemons called `itsnet` and `btpecho`, respectively in the CarGeo6 implementation as in the Figure 2. In source node, `btpecho` (client mode) sends a BTP packet via inter-process communication to `itsnet`. If the destination location is in LocT, `itsnet` forwards the packet to next hop selected by GF, otherwise it triggers an LS request. Finally, when the BTP echo request is forwarded to the destination, `itsnet` send the packet to `btpecho`. On the other hand, `btpecho` (reflector mode) in the destination node sends a BTP echo reply back to the source once it received a request. The echo reply is forwarded by GF too, thus the reply packet may be delivered via a different route from the request packet.

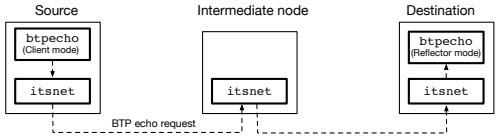


Figure 2: Overview of CarGeo6 programs

2.2 Experimentation and Simulation

The evaluation of GeoNetworking is performed a number of times in the simulations [7, 8] because it is costly to make the experimentation in a field testbed with real vehicle integrations. There are a few experimental evaluations with real vehicles, however the number of vehicles is limited. For example, [9, 10, 11] described a field experimental evaluation performed with up to four vehicles.

Network Simulator 3 (ns-3) is an open source programmable network simulator with many capabilities. Direct Code Execution (NS3-DCE, or DCE) is a module for ns-3 to provide the ability to run Linux programs directly in its simulation environment. It enables users to do experiments with their programs in the simulated network environment without doing major source code modifications. DCE supports several types of network software infrastructures, specifically, network protocol stacks Linux. One of them is the DCE-linux protocol stack, which adapts the protocol stack of real-world Linux kernel into DCE. To explain in a technical way, DCE runs several Library Linux Operating Systems [12, 13] in a single process, and connect its networking and timing backend to ns-3 facilities. The user programs can be executed in the simulated library OS efficiently.

[1] `http://www.cargeo6.org/`

3. OBJECTIVE AND APPROACH

Our objective is to investigate realistic behavior of GeoNetworking by simulation in various scenarios. To realize the objective, we take the benefits of both experimentation in real testbed and simulation in the following approach as in Figure 3. In this paper, we combine experimentation in real testbed and simulation. Firstly, we conduct experimentations in real testbed using an open source GeoNetworking implementation (Section 4). Secondly, we reproduce the experimental evaluation result of GeoNetworking in the simulated network using the same implementation (Section 5). Finally, we extend the simulation to a large scale network with various scenarios (Section 6).

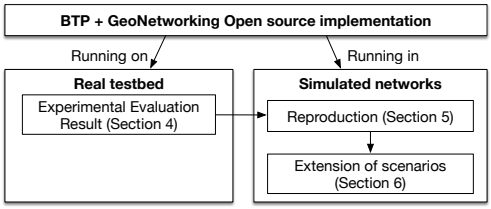


Figure 3: Our approach

The method developed in the paper has three aims. First, the developers of the GeoNetworking implementation can understand the realistic behavior of the software in large scale networks under various scenarios. Second, by understanding the behavior of the implementation, it eases the debugging and the performance improvement of the implementation. Last, it facilitates the development of ITS applications working on the GeoNetworking implementation.

4. EXPERIMENTAL EVALUATION IN REAL TESTBED

We performed an experimental evaluation using CarGeo6 version 0.9.9 on the real hardware where the specifications are listed in Table 1. The configuration of the network is similar to the topology as shown in Figure 2, with up to four nodes in order to obtain maximum 3 hops topology.

Table 1: System configuration

Item	Specification
CPU	Dual Core ARM11 600MHz SoC
Memory	128 MB RAM
Storage	16 MB Flash
Kernel	Linux kernel 2.6.35.13
MAC protocol	IEEE 802.11p (ETSI G5)
Wireless Interface	Unex DCMA-86P2

The round-trip times (RTTs) are measured between the source and the destination in the case from single hop to 3 hops with various packet sizes (varying from 20 bytes to 1500 bytes by increasing the size by 20 bytes). The `btpecho` (client mode) sent the BTP echo request 100 times to the `btpecho` (reflector mode) in each test. There is no traffic besides the echo request, echo reply and the beacons during the tests.

Figure 5(a) shows the result of average RTT in the experimental evaluation (In order to save the space of the paper, the figure also shows the uncalibrated simulation results which is explained in Section 5).

The RTT increases along with the packet size in all tests (from single hop to 3 hops). When the packet size is 20 bytes, RTT on 2 hop and RTT on 3 hop have 1.5 ms and 3.4 ms greater than the one in single hop, respectively; when packet size is 1380 bytes, they are 5.3 ms and 10.5 ms greater. BTP GeoNetworking does not process the packet bigger than the MTU because the fragmentation is not defined in the specification. Therefore all the packets bigger than 1380 bytes were lost in the experiments.

5. REPRODUCTION OF REAL TESTBED RESULT IN SIMULATED NETWORKS

In the last section, we described how the experiments are done in the real testbed. Nevertheless, the real testbed has limitations: high cost, limited scale, inflexible in configuration, etc. In order to overcome these limitations, a realistic simulation environment called Direct Code Execution was employed. With minor and trivial modifications to the CarGeo6 source code as well as some parameter calibrations, we successfully reproduced the real testbed results in the simulation environment. In this section, we describe the successful reproduction of the real testbed results in the simulation environment.

5.1 Simulation configuration

Ns-3 and DCE has many parameters which can be tuned to reproduce the real testbed environment. In order to tune and calibrate the simulator, we use a simple linear topology which is shown in the Figure 4: all nodes are configured with the same Wi-Fi parameters, and kept in a same Ad-Hoc cell; each node are in a line with 300m distance to adjacent node. With a negative Receiver Antenna Gain, the wireless radio range is adjusted to 300-400 meters. That means nearly all packets in 300m range can be delivered, yet nearly all packets from 400m away were lost. The configuration ensured each node can and can only reach the adjacent nodes. The detailed configuration in DCE is shown in Table 2.

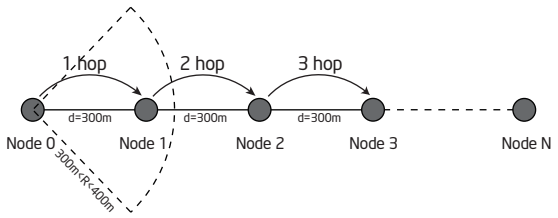


Figure 4: Topology of 300m distance

Table 2: DCE network configuration

Item	Specification
Wi-Fi Standard	IEEE 802.11g
Wi-Fi Phy	ERP-OFDM, 6Mbps
Wi-Fi Mac	Ad-Hoc
Receiver Gain	-10dBi
Propagation Delay	Constant
Propagation Loss	Friis
Node Mobility Model	Static

5.2 Processing Delay in DCE

In networking, processing delay means the time for a device to process a packet, which can affect the result of experiment. In Linux kernel, the cause of processing delay is rather complicated and can be affected by many factors including task scheduling, interrupt handling, Wi-Fi antenna delay, etc. That means, fully modeling processing delay in DCE is impossible.

The result of CarGeo6 simulation was greatly impacted by it. An approach must be carried out to calibrate it. DCE has some facilities to model the processing delay of each simulated operating system through the task scheduling. We simplified the model by aggregating other factors into task schedule delay.

5.2.1 Detection and Analysis

The processing delay issue was first detected in preliminary experiments, when we were trying to reproduce the real testbed results in simulation environment. With the same hardware parameters, simulation produced fairly realistic results, shown in Figure 5(a). However, a constant difference was observed between real and simulation results.

In the figure, we noted that the delay is approximately in proportion to the number of nodes invoked. By this evidence, the possibility of propagation delay can be ruled out since it is related to number of hop. To classify, there are two types of nodes in these experiments which should be considered separately, as in Figure 2:

Intermediate node only executes `itsnet` program and in charge of packet routing and forwarding.

Terminal node invokes `itsnet` and `btpecho`, has evidently more work than **intermediate node**.

Define D_n as the total observed delay in n-hop case ($n+1$ nodes in total), D_T, D_I as the proportion of observed value from **terminal node** and **intermediate node** respectively, while P_T, P_I for the parameters of internel task scheduling delay in DCE.

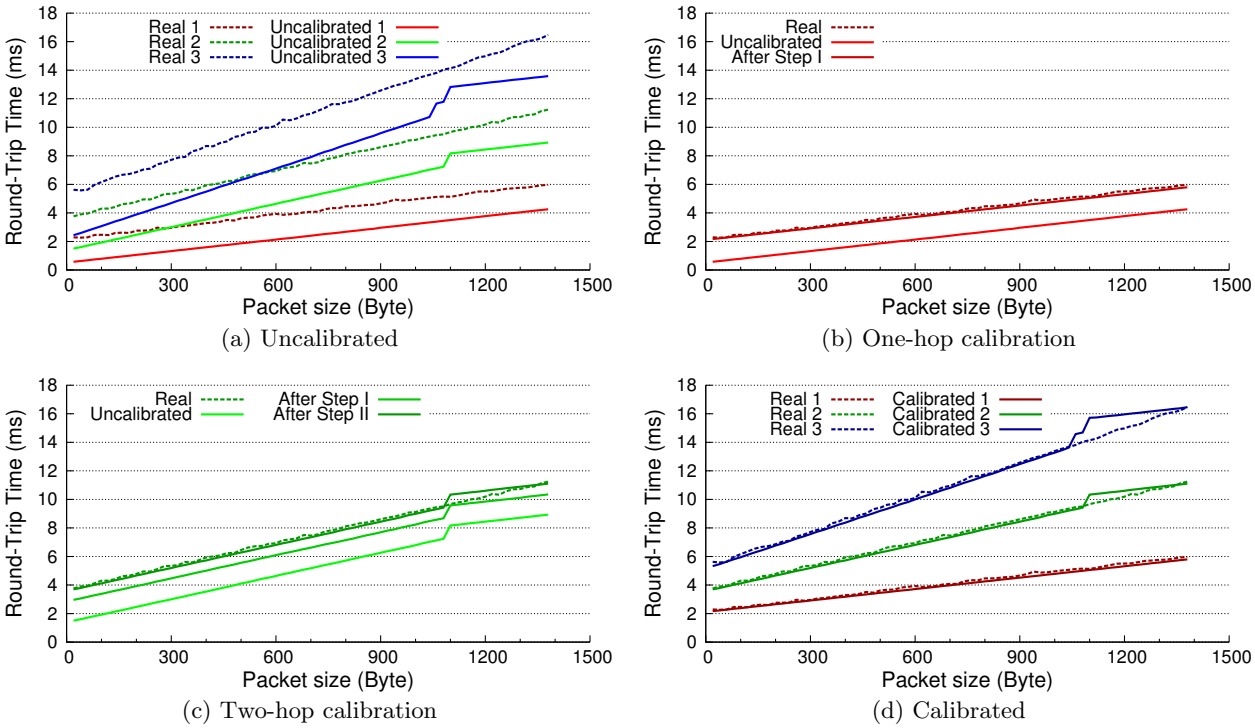
In the configuration of in Figure 4, the relationship among D_n, D_T and D_I should follow equation 1:

$$D_n = 2 \times D_T + (n-1) \times D_I \quad (1)$$

5.2.2 Calibration

Several steps are taken carefully to calibrate the processing delay in the nodes:

Pre-calibration Calculation Before calibration, we did a refined measurement and calculation on the observed



(a) Uncalibrated

(b) One-hop calibration

(c) Two-hop calibration

(d) Calibrated

Figure 5: Processing Delay Calibration Steps

difference in each experiment, which is shown in Figure 5(a). The result was slightly different from proportional expectation: $D_1 = 1600$ us, $D_1 = 2350$ us, $D_1 = 3100$ us. Thus $D_T = 800$ us, $D_I = 750$ us. With a preliminary test, we found there were no clear relationship between P_T and D_T, nor P_I and D_I.

Step I: Calibration of terminal node Calibrate the P_T on single-hop configuration. We did a binary search for the P_T, and evaluate the difference between simulation and testbed results. Optimal value were found at **190 microseconds**: in Figure 5(b), the simulation line overlaps with the testbed one.

Step II: Calibration of intermediate node After Step II, the shift distance of the simulation result of two-hop configuration is the same as one hop, as shown in Figure 5(c). Calibrate the P_I on two-hop configuration, with $P_T = 190$ us. Another binary search was carried out to find the optimal value: **480 microseconds**.

Post-Calibration Verification Verify the three-hop result with $P_T = 190$ us and $P_I = 480$ us, as shown in Figure 5(d). The simulation line is close to the testbed one, which verifies our conjecture. The fact that $P_T << P_I$ while $D_T > D_I$ is reasonable: the **terminal nodes** have heavier load than **intermediate nodes**, the Kernel scheduling was done more time, thus the delay should be lower.

After proper calibration, the results practically overlap the real ones, with maximum absolute error of 60 microseconds. The results suggest that our simulation with calibration is credible, thus it can be extended to large scale network simulations.

6. EVALUATION IN LARGE SCALE AND FLEXIBLE SIMULATED NETWORKS

In this Section, we provide preliminary evaluation results regarding the performance of the implementation from the point of RTTs with varied node distances, packet sizes and number of hops. We define Node distance (ND) as the distance between adjacent nodes, Terminal Distance (TD) as distance between destination and source nodes.

With the calibration made in Section 5, we conducted several experiments. First, experimentations with customized number of hops were conducted to evaluate the Greedy Forwarding algorithm, which shows that the algorithm successfully to choose a multi-hop route to forward packets up to 9 hops. Then, ND and TD are modified to examine their impact on the network, and we found there could be a extremely high packet loss under certain conditions.

6.1 Extended scenarios

We successfully extended the experimentation in NS3-DCE, with any desired number of nodes, and varied NDs which is difficult under real experimentation with limited manpower and resources. Thus we can examine how Packet size and Number of hops affect the results in Simulation, and whether the implementation can be properly functional with varied NDs and TDs. Therefore, the prediction of realistic behavior of the implementation is viable.

We first measured the network delay perceived by the `bt-`

`pecho` initiator with packet size range from 20 bytes to 1380 bytes in a single hop. Then, extend to 2, 3 and finally 9 hops, and repeat the first experimentation. Finally, compare and analyse the data obtained in simulation to find out how packet size and number of hops impact the network delay. For all delay measurements we measured 1000 BTP Echo Request RTTs between the two terminal nodes with interval time of 0.5 seconds.

6.1.1 More hops

RTTs of different hops and packet sizes were obtained from simulation, as depicted in Figure 6. The RTT increases as the packet size increase as we have in the previous sections. However the constant increase ends when packet size is 1080 bytes in 2 hops scenario, and it is observed from smaller packet size in more hops. With the packet size of 20 bytes, the RTT increases by 1.87ms each hop increase. When the packet size comes to 1380 bytes, the increment of RTT is 5.54ms each hop.

6.1.2 Different node distances

We select some data with some specific *NDs* and fixed packet size of 80 bytes, but with varied *TDs*, as depicted in Figure 7. The impact of *ND* and *TD* on realistic behavior of the implementation can be predicted through the data.

We use the same linear topology but the *ND* of 10m; observed that RTTs are constant regardless of *TD*. It indicates the *GF* algorithm selected the terminal node directly.

With the 100m *ND*, when *TD* rises, notable steps can be observed, which indicates that the *GF* algorithm worked in the simulation to forward the packets via a multi-hop route. With the 300m *ND*, a tendency can be observed that, the network delay presents a perfect linear rise, with the growth of *TD*, which can be considered as the number of hops with such large enough *ND*. It indicates that, the Nodal delay (the sum of all latency delays of a node) of an intermediate node is constant in a fixed packet size.

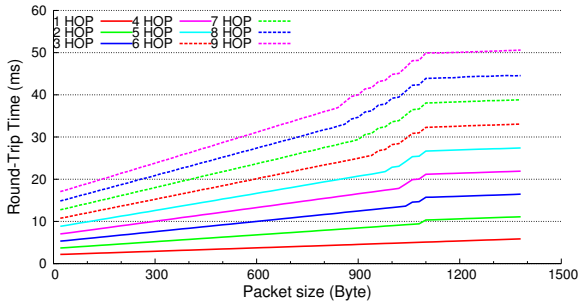


Figure 6: Average RTT in Simulation

6.2 Packet loss issue in Greedy Forwarding algorithm

During experiments, a packet loss was detected when *Node 0* try to send BTP Echo Request to *Node 4*, same is the *Node 0* try to response, with a particular scenario that 4 nodes in a line, *ND* is 100m and *TD* is 400m. In this Section, we discuss the cause of the packet loss, and how to quantify it.

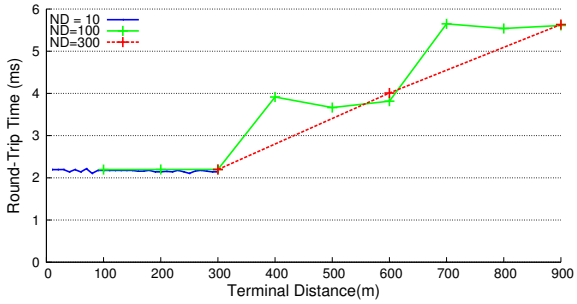


Figure 7: RTT-Distance

6.2.1 Low PDR in long distance

As described in Section 5, Friis Propagation Loss Model is employed in the simulation, making the communication channel unstable; this is the scenario we've never realized in the real testbed. In this simulation, the maximum stable transmitting radius of a node is in the range from 300m to 400m. Thus *Node 4* is at the edge of the transmitting radius of *Node 0*, which means the communication channel between them is unstable. With an extremely unstable channel, beacon messages from *Node 4* to *Node 0* are unexpected. An unexpected beacon makes a location table entry that can hardly be reached as in Figure 8.

6.2.2 Analysis

As depicted in Figure 8. Consider the following scenario:

Alice(Node 0) wants to communicate with *Bob*(Node 4), the channel between them is unstable due to the distance or obstacle. But *Carol*(An intermediate Node) has good communication channels with *Alice* and *Bob* without message loss. The three repeatedly broadcast beacon message to inform each other their existence. However *Alice* still can receive some beacon messages from *Bob* randomly with a deliver ratio of PDR_B. When *Alice* gets any message (usually a beacon message) directly sent from *Bob*, she will instantly label *Bob* as her Neighbour in her LocT as an Entry with a default lifetime(T(LocTE)) of 20s. And then, *Alice* will directly send messages to *Bob*; the packet could hit *Bob*, with a possibility of PDR_P. Otherwise, in order to reach *Bob*, *Alice* will deliver her message to *Carol*, letting her to forward the message to *Bob*, with no loss.

In the particular simulation, *Alice* received 41 out of 3254 unexpected beacon messages from *Bob*, which is founded in the log file. 4 among the 41 total beacon messages from *Bob* is encountered during the BTP Echo operation. Remember, PDR_P is the deliver ratio of BTP Echo packet, which is supposed to be smaller than PDR_B due to different packet length. To simplify, assume that $P = 0$, and the unexpected beacon message effective periods(20s) on both sides do not collide or overlap with each other. With the BTP Echo interval of 0.5s, there is supposed to be 40 packet losses every unexpected beacon message encounter. Thus, there is supposed to be $4 \times (20 \div 0.5) = 160$ packet losses in the experimentation, and it is in accordance with the result. With N as the total number of beacons from a sender (SE), N_d as the number of delivered beacons from sender (SE).

Then, do an preliminary calculation on the beacon packet lost ratio in equation 2:

$$PDR_B = N_d \div N \quad (2)$$

With $N_d = 41$, $N = 3254$, we get a deliver ratio of 1.3%.

In a statistics point of view, assume f_B as the frequency of beacon message, T as the lifetime of LocTE, then we have the expectation of loss ratio in total:

$$total\ loss = (1 - PDR_P) \times (1 - (1 - PDR_B))^{(T \times f_B)} \quad (3)$$

To simplify again, assume $PDR_P = 0$ when PDR_B is close to 0. Hence the loss ratio is only connected with f_B, PDR_B and T. According to the GeoNetworking implementation, each node broadcasts a beacon message every a little bit longer than 3 seconds. With $f_B = 1/3$ Hz, $PDR_B = 0.013$, $T = 20$ s, then we have the loss ratio P_l of 8.35%. Recall the simplification we made, the observed value may be slightly different. The observed value of 7.3% in the simulation proved this point. According to the Equation 3, the packet loss could be extremely high under certain condition as depicted in Figure 8. Another simulation proved it, and it will be discussed in further research.

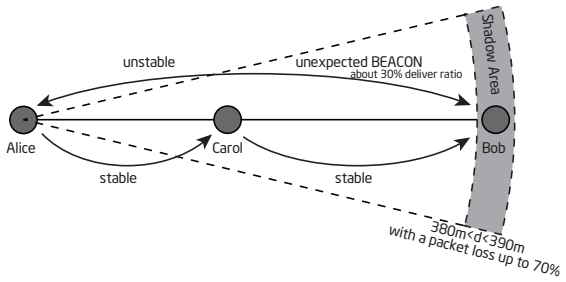


Figure 8: Unexpected Beacon loss

7. CONCLUSIONS AND FUTURE WORKS

In this paper, we have successfully reproduced real testbed experiments in simulated network environment using NS3-DCE. With the proper wireless configuration and the calibrations, the simulator produced realistic results, which can be used to predict the behavior of GeoNetworking implementation in real world. Based on the fact, several extended simulations of the GeoNetworking was conducted with NS3-DCE. The results indicate that, the implementation succeeded in delivering packets up to 9 hops with any desired number of nodes; meanwhile the *GF* algorithm functions properly; yet a packet loss is observed in configurations of a critical communication distance. Finally we quantified the packet loss, and found it is only related to 4 factors: beacon frequency, lifetime of *LocTE* and PDR of beacon and BTP; moreover, it could be extremely high under some certain conditions.

As a future work, we consider the followings: First, more factors should be introduced to the simulation *E.g.*, a moving mobility model, a complicated 2D distribution of nodes, other communications modes. Second, IPv6 over GeoNetwork should be ported to NS3-DCE for more extended experiments. Last, more efficient routing strategy can be evaluated in the simulated networks, to solve the packet loss issue discovered in the extended simulation.

8. REFERENCES

[1] Intelligent Transport Systems (ITS); Vehicular Communications; GeoNetworking; Part 4: Geographical addressing and forwarding for point-to-point and point-to-multipoint communications; Sub-part 1: Media-Independent Functionality, July 2014.

[2] ISO 21217:2010 Intelligent transport systems – Communications access for land mobiles (CALM) – Architecture, April 2010.

[3] Brad Karp and H. T. Kung. Gpsr: Greedy perimeter stateless routing for wireless networks. In *MobiCom'00*, pages 243–254. ACM / IEEE, August 2000.

[4] Intelligent Transport Systems (ITS); Vehicular Communications; GeoNetworking; Part 5: Transport Protocols; Sub-part 1: Basic Transport Protocol, August 2014.

[5] Intelligent Transport Systems (ITS); Vehicular Communications; GeoNetworking; Part 6: Internet Integration; Sub-part 1: Transmission of IPv6 Packets over GeoNetworking Protocols, May 2014.

[6] Thouraya Toukabri et al. Experimental evaluation of an open source implementation of IPv6 GeoNetworking in VANETs. In *ITST'11*, Saint-Petersburg, Russia, August 2011.

[7] ZiyaCihan Taysi et al. Etsi compliant geonetworking protocol layer implementation for ivc simulations. *Human-centric Computing and Information Sciences*, 3(1), 2013.

[8] Victor Sandonis et al. Vehicle to internet communications using the etsi its geonetworking protocol. *Transactions on Emerging Telecommunications Technologies*, 2014.

[9] J.J. Anaya et al. Geonetworking based v2v mesh communications over wsn. In *ITSC'13*, pages 2421–2426, Oct 2013.

[10] Manabu Tsukada et al. AnaVANET: an experiment and visualization tool for vehicular networks. In *TRIDENTCOM'14*, Guangzhou, China, May 2014.

[11] Manabu Tsukada et al. On the experimental evaluation of vehicular networks: Issues, requirements and methodology applied to a real use case. *EAI Endorsed Transactions on Industrial Networks and Intelligent Systems*, 14(1), 12 2014.

[12] D. Camara et al. DCe: Test the real code of your protocols and applications over simulated networks. 52(3):104–110, 2014.

[13] Hajime Tazaki et al. Direct code execution: Revisiting library os architecture for reproducible network experiments. In *CoNEXT'13*, pages 217–228, New York, NY, USA, 2013. ACM.