RPD: Reusable Pseudo-id Distribution for a Secure and Privacy Preserving VANET

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ABSTRACT

In any VANET, security and privacy are the two fundamental issues. Obtaining efficient security in vehicular communication is essential without compromising privacy preserving mechanisms. Designing a suitable protocol for VANET by having these two issues in mind is challenging because efficiency, unlinkablity and traceability are the three qualities having contradictions between them. In this paper, we introduce an efficient Reusable Pseudo-id Distribution (RPD) scheme. The proposed protocol is characterized by the Trusted Authority (TA) designating the Road Side Units (RSUs) to generate *n* reusable pseudo ids and distribute them to the On Board Units (OBUs) on request. RSUs issue the aggregated hashes of all its valid pseudo-ids along with a symmetric shared key and a particular pseudo-id to each vehicle that enters into its coverage range. Through this the signatures and certificates attached to the messages can be eliminated and thus resulting in a significantly reduced packet size. The same anonymous keys can then be re-distributed by the RSUs episodically to other vehicles. We analyze the proposed protocol extensively to demonstrate its merits and efficiency.

Keywords: VANET, privacy, security, unlinkability, traceability, pseudonyms.

1. INTRODUCTION

Vehicular communication (VC) systems are developed as a means to enhance road safety, traffic management and infotainment facilities for drivers and passengers. In vehicular ad hoc networks each vehicle is equipped with a communication device known as On Board Units (OBUs) that facilitate them to communicate with other vehicles, RSUs located on the road at different points and the TA (trusted authority) as well. In general, OBUs frequently broadcasts routine traffic related messages [1] with information about its position, current time, direction, speed, acceleration/deceleration, traffic events, etc. This helps the vehicle to be warned with critical situations such as accidents, traffic jams and so on, in addition with predicting the movements of the nearby vehicles.

Though this communication helps the driver community, it has a critical side effect of privacy. An attacker can easily track the physical location of a vehicle using these messages just by eavesdropping the communication. Tracking the movements of a vehicle such as "Big brother syndrome" is another case. One approach to solve this problem is that the vehicles broadcast their messages under pseudonyms that they change with some frequency [2]. The pseudonym based approach that has been proposed by [3, 4] is an idea to help the vehicles exchange their communications without revealing their real identity. Many studies have contributed for this approach. One of them is Baseline Pseudonyms (BP) approach that stores a huge number of pseudonyms in the OBU [5, 4]. Other is the Hybrid approach (HP) which is the combination of BP and Group Signature (GS) approaches [6] that generates pseudonyms on board and uses it for sending messages by attaching a group certificate.

In all the pseudonym based approaches that are previously discussed, pseudonyms generated are discarded soon after their life time. This cause the pseudonym providers to generate pseudonyms every now and then upon the request from the vehicles. Though generation of pseudonyms by the TA or RSUs is not an issue with their high computation and storage capacity, the computation cost of OBUs on signature and certificate generation and verification grows linearly with the traffic density, since every message comprises of a public key, a signature using its private key and a certificate on the public key essentially. In order to address this problem we propose a reusable anonymous key distribution scheme in which the pseudo-ids are generated in bulk by the RSUs and issued to the OBUs in its coverage zone by attaching a token with it. This token contains a hashed value of the given pseudo-id sealed with the long term public key of the vehicle that receives the pseudo-id. RSU also disclose the aggregated hashes of all its valid pseudo-ids generated by it to the vehicles in its range in order to facilitate them knowing the authentication of the pseudo-ids the messages are sent from. Session keys are generated by the RSUs to communicate with vehicles to share this information. Therefore, the proposed scheme avoids the attachment of signature and certificate with every message and by this way cuts down the cost of message generation and verification.

On the other hand, the token provided along with the pseudo-id will be attached by the vehicles while sending safety messages. This token is embedded with messages merely for future traceability.

2. OUR APPROACH

2.1 System Model

Prior to the network deployment, the TA generates a set of basic cryptographic materials for each OBUs and RSUs such as q, G, G_T, ê, P_1, P_2. TA randomly selects a master secret key $s \in Z_q$ and computes $U_1 = sP_1$ and $U_2 = sP_2$ as its public keys. TA also chooses a cryptographic hash functions H: $(0, 1)^* \rightarrow G$. Each RSU and vehicle are preloaded with the public parameters q, G, G_T, ê, P_1, P_2, U_2, H.

Notation	Description
s	TA's master secret key
U_1, U_2	TA's public keys
V_i	the i-th vehicle
R	the RSU
RID_v	real ID of the vehicle
RID_R	real ID of the RSU
PK_{vi}	long term public key of V_i
sk_{vi}	corresponding private key of PK_{vi}
T_{exp}	time expiry
WR_{PKvi}	warrant on the public key of V_i
$Cert_{TA}[PK_{vi}]$	TA's certificate on the public key of V_i
LOC_R	Location of RSU
LID_R	Location ID of RSU
SID_i	i^{th} short term multipliable pseudo-id
PID	pseudo-id
WR_{SIDi}	warrant on SID_i
PK_R	delegated public key of RSU
sk_R	delegated private key of RSU,
K_s	shared session key between V and RSU
E_x	encryption using the key x
D_x	decryption using the key x
T_{issue}	issue time
T_{return}	return time
τ	token
$ack_{termination}$	acknowledgement message for termination request
$h(.)$	a one way hash function such that SHA-1[24]

Table 1: Notations

The proposed protocol could be explained in five stages: registration and anonymous key generation, distribution of aggregated hashes, message generation, message validation and id traceability and revocation list. The key generation and mutual authentication between RSUs and vehicles of this protocol is based on [21]. For easy understanding the notations used throughout this paper are listed in table1.

2.2. Registration and Anonymous key generation

a) Key generation by TA:

All the vehicles and RSUs must register themselves with the TA before they join in the VANET. Each vehicle is assigned with a real identity $RID_{vi} \in G$. We assume that the TA is in-charge of checking the vehicle's identity, generating a long term public/private key pair for each vehicle and loading it into its OBU. TA chooses a random private key $sk_{vi} \in Z_q$ for the vehicle and computes $PK_{vi} = sk_{vi}P_1$ as its long term public key. TA also sets a warrant WR_{PKvi} for the issued public key to denote the expiry of the key. It stores RID_v, PK_{vi}, sk_{vi} and WR_{PKvi} in its database for future traceability and returns PK_{vi} , sk_{vi} ,WR_{PKvi}, $Cert_{TA}[PK_{vi}]$ to the vehicle.

The registration of RSUs with TA is very similar to that of vehicle registration. Firstly, the RSU sends its real-id RID_R and its location information LOC_R to the TA. TA selects $SID_i = LID_R \oplus H(a.U_1)$ for the RSU as its short term multipliable pseudo-id by choosing 'a' as a random nonce and sets a warrant WR_{SIDi} for SID_i by including its time expiry. It also computes a delegated key pair (PK_R, sk_R) where the public key $PK_R = H(RID_R)P_2 + rP_2 \in G$ and the private key $sk_R = -sH(PK_R) - r \in Z_q$ in order to prove itself as a trusted RSU to the vehicles. TA stores LID_R, SID_i, WR_{SIDi}, PK_R, sk_R in its database and returns SID, LID_R, WR_{SID}, PK_R, sk_R to the RSU. This SID can be periodically altered by the RSU (may be once in a day) by making a request to the TA.

b) Key generation by RSUs:

In this phase, the RSU is responsible for generating 'n' number of pseudo-ids PID_{i1}, PID_{i2}….. PID_{in} based on the short term pseudo-id SID_i of RSU acquired from the TA. The PID is encrypted here using ElGamal encryption algorithm [22] over the Elliptic curve Cryptography [23]. Each pseudo id $PID_{ik} = SID_i \oplus H(b.U_2)$, where $k = \{1 \ldots n\}$, 'b' is a random nonce and is changed each time to guarantee a distinct PID.

3.3. Distribution of token and aggregated hashes of pseudo-ids

The proposed RPD protocol comprises of four phases: pre-authentication phase, mutual authentication phase, key distribution phase and token return phase as illustrated in figure 3. The detailed explanation of the proposed protocol is as follows:

Pre-Authentication Phase:

In this phase, the RSU generates 'n' pseudo-ids and stores them in its pseudo-id table as shown in table2. It also computes the hash values of all the pseudo-ids generated by it and aggregates all the hashes, i.e., $h_{aggr} = h(PID_1) \| h(PID_2) \ldots\ldots \| h(PID_n)$.

pseudo_id	T_{gen}	SID	Status
PID_{i1}	t_1	SID_i	1
PID_{i2}	t_1	SID_i	0
⋮	⋮	⋮	⋮
PID_{in}	t_1	SID_i	

Table 2: pseudo-id table

Authentication Phase:

At regular intervals, RSU broadcasts a *hello* message M, its real id RID_R and its delegated public key PK_R by signing them using its delegated private key sk_R. R computes its signature σ_R using (ω, Q) on the *hello* message M as follows.

$Q = nP_2$, $n \in Z_q$

$\omega = sk_R - nH(Q) \in Z_q$

$msg_1 = (RID_R, PK_R, M, \sigma_R(M), Q, \omega, T_s)$

When the vehicle V_i enters into the communication range of the RSU R, it detects the public key PK_R of R through this message. Note that V_i uses this message only at the first time to obtain the symmetric key with R, other vehicles that are already inside the RSU range ignores the message. V_i verifies the location information attached by default with the RSU message by matching the location information of R through GPS. If both are matching then,V_i checks the public key of R for its trustworthiness.

Once the RSU is authenticated by V_i , V_i generates a random number $r_1 \in Z_q$ and computes $r_1P_1 \in G$ as its share for the session key K_s , $H(msg_1)sk_{vi}$ as its signature σ_{vi} and forms a request for the session key and pseudo-id, signs them using its private key. V_i then submits its credentials that includes its long term public key obtained from the TA and its request to R after encrypting them using the public key PK_R of R.

$$msg_2 = E_{PK_R}(V_{id} \| N \| T_s)$$

where, $N = (r_1P_1, req_1, \sigma_{vi}(r_1P_1 \| req_1))$, $r_1 \in Z_q$ and V_{id} is the vehicle's credential (see phase II of RPD protocol) and req_1 is the pseudo-id request.

The authentication on the other hand is as follows: RSU R scans the revocation list each time a new vehicle tries to associate with it. Thus, on the reception of msg_2 from V_i, R decrypts msg_2 using its delegate private key sk_R and checks V_i's public key in the revocation list and the freshness of the timestamp attached with the message. If the public key is not revoked and its warrant is valid, R checks whether the signature σ_{vi} of V_i is legitimate.

Key Distribution Phase:
After authenticating V_i , R randomly picks a pseudo-id (whose status is 0) from the pseudo-id table, and chooses r_2 for the selection of session key K_s. R then computes a token $\tau = H(PID_i \| PK_{vi} \| T_{issue})$ to bind the long term public key of V_i with the pseudo-id PID_i temporarily. R stores the token, pseudo-id, V_i's public key along with the token issue time as shown in the first four columns of table3. Note that, the records of the token table are wiped out after a certain period of time (may be once in a week or two) in order to avoid the table growing linearly. Then R encrypts the pseudo-id, token and the aggregated hashes of all its pseudo-ids by using the shared session key and sends to V_i. Once V_i receives the message from R it calculates the session key K_s and decrypts the message using it. Vehicle V_i now holds the pseudo-id and uses it for sending messages to other vehicles.

Token	**pseudo id**	**V's public key**	T_{issue}	T_{return}
τ_1	PID_{i1}	PK_{vi}	t_1	t_1+t
τ_2	PID_{i2}	PK_{vj}	t_2	t_2+t
⋮	⋮	⋮	⋮	⋮
τ_n	PID_{in}	PK_{vn}	t_n	t_n+t

Table 3: token table

Token return Phase:

Since the long term public key of the vehicle is bound with the pseudo-id it is provided, vehicle V_i must return the token to the RSU after its usage. In this phase a vehicle may pass two types of request to the RSU. *req1* is a request for new pseudo-id, which must be sent to the RSU when V_i wants to change its pseudo-id. In such case the RSU extracts the vehicles's public key from the old pseudo-id and rebinds the public key with another pseudo-id to construct a new token and issues the new id along with its token to the vehicle by encrypting it using the shared session key. *req2* is another type of request the vehicle sends to RSU when it goes out of the range of the RSU or when it receives a *hello* message from another RSU. This request can be called as a handover request to make itself free from bonds with that RSU. In either case, the RSU will respond by giving a new pseudo-id or a handover acknowledgement message based on the type of the request it received.
Key Reusability is the main advantage of the proposed scheme when compared to other studies as the RSU's burden on continuous pseudo-id generation is considerably reduced because of reusing the same key for many vehicles. Upon receiving *req1,* the RSU uses the token to extract the public key of the vehicle, resets the status of the corresponding pseudo-id of token (i.e status= 0 for the corresponding pseudo-id in table 2). This pseudo-id can then be reused by being bound with another vehicle's public key upon request.

I. Pre-Authentication Phase:
R : computes PID_{ij} where j={1…n}
R : computes $h_{aggr} = h(PID_1) \| h(PID_2) \ldots \| h(PID_n)$

II. Mutual Authentication Phase:
R : computes $Q = nP_2$, $n \in Z_q$
R : computes $\omega = sk_R - nH(Q) \in Z_q$
R : computes σ_R as (Q, ω)
R : broadcasts $msg_1 = (M, PK_R, \sigma_R(M \| PK_R), Q, \omega, T_s)$
V_i : checks σ_R to authenticate R

V_i : computes $V_{id} = (PK_{vi} \| WR_{PKvi} \| Cert_{TA}[PK_{vi}])$
V_i : computes σ_{vi} as $H(msg_1)sk_{vi}$
V_i : computes $N = (r_1P_1, req_1, \sigma_{vi}(r_1P_1 \| req_1))$, $r_1 \in Z_q$
V_i : computes $msg_2 = E_{PK_R}(V_{id} \| N \| T_s)$
$V_i \rightarrow R$: msg_2
R : $D_{skR}(msg_2)$
R : verifies PK_{vi} and authenticates V_i

III. Key Distribution Phase:
R : computes session key $K_S = r_1r_2P_1$
R : picks PID_{ik} from pseudo-id table
(where, $1 \le k \le n$ and status(PID_{ik})=0)
R : sets status(PID_{ik})=1
R : computes $O = (PID_{ik}, T_{issue}, r_2)$
R : sets $\tau = h(PID_{ik} \| PK_{vi} \| T_{issue})$ where $k \in j$
R : computes $msg_3 = E_{Ks}(O, \tau, h_{aggr})$
$R \rightarrow V_i$: msg_3 , r_2
V_i : computes $K_s = r_1r_2P_1$
V_i : computes $D_{Ks}(msg_3)$
V_i : holds PID_{ik} and h_{aggr}

IV. Token return Phase:
V_i : computes $msg_4 = E_{Ks}(req_i, \tau)$
$V_i \rightarrow R$: (PID_{ik}, msg_4)
R : if $req_i = req_1$ then
map τ in table 3 and set status(PID_{ik})=in table 2 for the corresponding τ
sets a new $\tau = h(PID_{il} \| PK_{vi} \| T_{issue})$ for V_i , where $l \in j$
$msg_5 = E_{Ks}(PID_{il}, \tau)$
else if $req_i = req_2$ then
map τ in table 3 and set status(PID_{ik})=0 in table 2 for the corresponding τ
$msg_5 = ack_{termination}$
$R \rightarrow V_i$: msg_5
(note: req_1 = new pseudo-id request ; req_2 = termination request)
Figure 1: Reusable Pseudo-id Distribution (RPD) Protocol

3. RELATED WORK

The IEEE 802.11p task group is working on the Dedicated Short Range Communications (DSRC) standards, which aims to enhance the 802.11 protocol to support wireless data communications for vehicles and road side infrastructure [7]. Many studies have been reported on the security and privacy-preservation issues for VANETs [3, 4, 8-12]. The privacy and security issues for VANET can mainly be classified into three categories.

First is based on a huge number of pseudo-anonymous key based (HAB) protocols [3, 4, 8]. Though this is a simple and straight forward solution, there found three main disadvantages [12] in HAB: (a) each OBU has to take large storage space to store a number of anonymous key pairs; (b) very time consuming for the authority to track for any problematic certificate due to the long revocation list; (c) once some OBUs' anonymous keys are revoked, it takes a long time for each OBU to update the certificate revocation list.

The second one is based on group signature (GSB) which was first introduced in [14] which allows a group member to sign messages anonymously on behalf of the group. The identity of a signer can still be revealed by the group manager in case of a dispute. Although the group signature can achieve anonymity on conditional privacy preservation, the time for message verification grows linearly with the number of revoked vehicles [15]. Worse, the unrevoked have to update their private keys and group public keys with the group manager when the number of revoked vehicles surpasses some predefined threshold. In [16], application of the short group signatures is suggested. Authors in [8] propose an efficient security protocol called GSIS which is based on the group signature scheme. With this protocol only a private key and group public key are stored in the vehicle, and the messages are signed according to the group signature scheme without revealing any identity information to the public. However the verification of each group signature requires at least two pairing operations which might not be scalable when the density of traffic is increased. Finally, a hybrid pseudonym based approach [5] has been proposed by combining the baseline pseudonym scheme [3] and the group signature scheme [8] together. However this approach is also categorized as GSB, since it suffers with the same drawbacks.

The third one employs the RSUs to assist with message authentication [12, 13]. Authors in [17] propose an authentication algorithm called Group-ID Tree. In this protocol the vehicle is able to connect the RSU after proving its membership in a group. However, this leads to additional overhead in managing group membership. The protocol proposed by the authors of [18] elects a group leader who then communicates with the RSU on behalf of the group. This protocol also suffers with the disadvantage of the overhead associated with the Revocation List (RL) management required to authenticate group membership. ECPP (Efficient Conditional Privacy Preservation) [12] protocol was proposed to solve the storage requirements by using the RSU to manage the vehicle's certificate. In this protocol the RSU issues only an ephemeral certificate for valid vehicles at the time of authentication to eliminate the need for the vehicles to manage the certificates and the RL. In [13] the authors introduced a RSU aided message authentication scheme called RAISE. RAISE is responsible for verifying the authenticity of the messages sent from the vehicles and for notifying the results back to the vehicles. They also adopted *k-anonymity* [19] to protect user identity privacy where the RSUs assign a common pseudo id to *k*-vehicles. Our work complements the RAISE and ECPP works by providing another protocol to furnish a conditional privacy preserving and a secure VANET environment.

4. EVALUATION

In this section, we use the ns-2 simulator 2.34 to evaluate the performance of our RPD protocol. Since the proposed protocol focuses on the signing and verification overhead, we are more concerned in the system performance of RPD in terms of throughput, message loss ratio and average end to end 1message delay. We simulate a traffic scenario with high vehicle density of 30-180 vehicles. The ECDSA and the group signature verification delays are 3.87ms and 11 ms respectively [25]. The simulation script is written in TCL using DSDV protocol. The traces are recorded and analyzed using *awk* utility in Linux (Fedora 14).

Simulation Setup	
Physical and MAC model	IEEE 802.11a standard
Nominal bit rate	2Mbps
Transmission Range	300m
Number of nodes	30-180nodes
Simulation duration	1000 seconds
Simulation area	1500m x 300m
Traffic Type	CBR
Routing Protocol	DSDV
Packet Size for OBU message	166

Table 4: NS-2 Simulation Parameters

a) Throughput

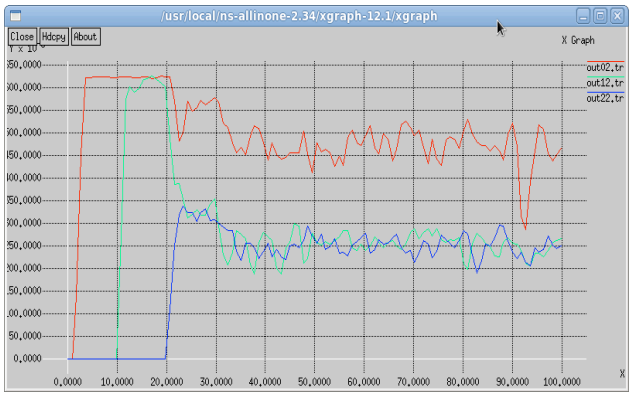
Throughput is the average rate of successful message delivery over a communication channel. Throughput is usually measured in bits/sec or data packets/sec. The throughput of a protocol varies based on the cryptographic operations involved in securing the message and the transmission overhead. The additional overload caused by security is mainly by the length of the authority certificate on the public key and the digital signature attached to every signed message. In ECDSA [20] which is accepted as the most appropriate candidate for VANET in terms of packet overload and verification delay, the total length of a signed packet is around 281 bytes, in which the additional overhead for each message is 181 bytes due to the cryptographic operations. With the group signature based scheme GSIS [8] the additional communication overhead is 184 bytes [26]. According to IBV scheme [9] a short length pseudo-id $PID_{ij} = PID_{ij}^1 + PID_{ij}^2$ posses a total length of 42 bytes. With RPD the total message length is calculated as follows:

$$L_{msg} = L_M + L_{PID} + L_{\tau} + L_{TS}$$
$$= 100 + 42 + 20 + 4$$
$$= 166 \text{ bytes}$$

According to [1], the message M occupies 100 bytes. Therefore, the additional overhead is only 42+20 bytes, which is very low for the OBU. In addition, RPD does not require the revocation list stored in OBUs, which makes the protocol free from increase in its storage overhead with the increase in number of revoked public keys. On the other hand, the additional transmission overhead on RSU is $(20*n)/m$ bytes along with the parameters for mutual authentication, where 20 B is the length of a $h(PID_{ij})$ sent by the RSU which is multiplied by n for n aggregated PIDs. This $20*n$ are shared by m messages, because in RPD the n pseudo-ids are hashed and sent as an aggregated hash (h_{aggr}) only once for an RSU range during the symmetric key establishment and thus it is considered as negligibly small.

Figure 2 shows the throughputs of Group based, PKI and RPD schemes over a period of 100 sec with a traffic density of 50 vehicles. We can see that when compared to the traditional PKI based ECDSA scheme and the group signature based scheme, RPD has very high throughput. This is because, the signature and the certificate attached dominates the length of the overhead and thus

reduces the throughput. The advantage gained by the proposed scheme is obvious, since no signature or certificate is attached with the message. (*x-axis: Time in seconds, y-axis: Data Packets in bits)*



out02.tr=RPD Scheme
out12.tr=PKI Based Scheme
out22.tr=Group Based Scheme

Figure 2: Protocol throughputs of Group Based, PKI and RPD schemes(100secs)

b) Message Loss ratio

One among the main performance metrics considered is the average message loss ratio which is to be denoted as MSG_{L_ratio}. A message is lost only if the queue of messages is full when the message verification rate is much lower than the message arrival rate. As defined in [25] the MSG_{L_ratio} can be expressed as,

$$MSG_{Lratio} = \frac{1}{N}\sum_{n=1}^{N}\frac{M_{cons}^{i}}{M_{recv}^{i}}$$

Where N_s represents the total number of vehicles in the simulation and N_c represents the number of vehicles in one hop communication range of the vehicle *i*. M_{recv}^{i} represents the total number of messages received by the vehicle *i* in the medium access control layer, M_{cons}^{i} represents the total number of messages received by the vehicle *i* in the application layer. Here, we only consider the message loss incurred by the security protocol rather than the loss caused by the wireless communication between the RSU and vehicles.

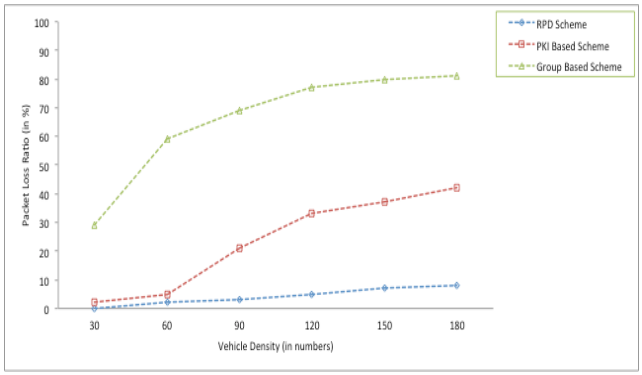


Figure 3: Message Loss Ratio vs Vehicle Density

Figure 3 shows the relationship between the PLratio and the number of vehicles, which is represented for the traffic load. We can observe that the message loss ratio of the three schemes increases as the traffic load increases. The group signature based scheme has the highest PLratio, the PKI based scheme grades the second place, whereas RPD has the lowest PLratio. This is because, the message verification rate is absolutely based on the h_{aggr} comparison computation cost is neglected when compared to the PKI based signature scheme [3].

c) Average end to end message delay

The average end to end message delay which we denote MSG_{delay} as can be defined as the difference between the time V_i sends the m^{th} message and the time V_j receives it. Considering N as the total number of vehicles in the simulation, M as the number of messages sent by the vehicle, and J as the number of adjacent vehicles within the communication range of vehicle V_i. If $T_{send}^{i\_j\_m}$ represents the time instant V_i in the application layer sends the m^{th} message to V_j and $T_{recv}^{i\_j\_m}$ represents the instant V_j in the application layer receives the m^{th} message then, according to [8], the average message delay is expressed as follows:

$$MSG_{delay} = \frac{1}{(N.M_n.J_n)}\sum_{j=0}^{J_n}\sum_{m=1}^{M_n}\times\left(T_{sign}^{i\_j\_m} + T_{transmission}^{i\_j\_m} + T_{verify}^{i\_j\_m}\right)\times\left(L_{i\_j\_m}+1\right)$$

Where $T_{sign}^{i\_j\_m}$, $T_{transmission}^{i\_j\_m}$ and $T_{verify}^{i\_j\_m}$ denotes, the time taken by the i^{th} vehicle to sign the m^{th} message, the time taken for the m^{th} message to get transmitted from i^{th} vehicle to j^{th} vehicle and the time taken by j^{th} vehicle to verify m^{th} message respectively. M_n is the number of messages sent by V_i and J_n is the number of vehicles within the one hop communication range of V_i. Since RPD does not require the message to be signed and the verification can be neglected as the h_{aggr} comparison computation is very fast, the message end to end delay is exclusively depends on the transmission delay which does not vary a lot with the increase of traffic load such like for a city scenario of 20 to 150 vehicles the message end to end delay is around 22ms[8] which is smaller than the maximum allowable message end to end transmission latency of 100ms[7]. $L_{i\_j\_m}$ (denotes the queue length in V_j when *m* from V_i is received) is neglected in RPD as well, for the above said reason. Therefore, the message delay for RPD can be reformulated as follows:

$$MSG_{delay} = \frac{1}{(N.M_n.J_n)}\sum_{j=0}^{J_n}\sum_{m=1}^{M_n}\times\left(T_{transmission}^{i\_j\_m}\right)$$

$$= \frac{1}{(N.M_n.J_n)}\sum_{j=0}^{J_n}\sum_{m=1}^{M_n}\times\left(T_{receive}^{i\_j\_m} - T_{send}^{i\_j\_m}\right)$$

Figure 4 shows the relationship between the MSG_{delay} and the traffic load. We can see that group signature scheme has the

highest MSG_{Lratio} due to the high verification delay whereas RPD yields the minimum MSG_{delay}. This demonstrates the effectiveness of the proposed protocol.

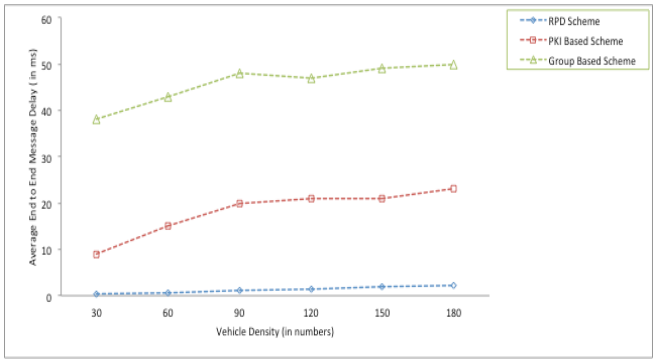


Figure 4: Average End-End Message Delay vs Vehicle Density

5. CONCLUSION

In this paper, a novel reusable pseudo-id distribution (RPD) scheme has been proposed. With RPD, RSUs are responsible to generate the anonymous ids in bulk and issue them one at a time to the requesting vehicles. The token which binds the long term public key of the vehicle with the given pseudo-id facilitates traceability. Also this makes the vehicle accountable for messages from the pseudo-id and insists the token return to get a new pseudo-id. The RPD protocol has many advantages because of the cost cut down of signing and verifying messages. Extensive simulation has been conducted to demonstrate the quite low transmission delay, message loss ratio and the message end-to-end delay. For future research, we will contribute to reduce the signature verification cost for vehicle to vehicle communication when the fixed infrastructures such as RSUs are absent in the network.

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