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Certificating Vehicle Public Key with Vehicle Attributes

A (periodical) Licensing Routine, Against Man-in-the-Middle Attacks and Beyond

(Invited Paper, Preliminary Version)

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Abstract. Vehicular networks are used to coordinate actions among vehicles in traffic by the use of wireless transceivers. Unfortunately, the wireless communication among vehicles is vulnerable to security threats that may lead to very serious safety hazards. In this work we propose a viable solution for coping with Man-in-the-Middle attacks. To the best of our knowledge, this is the first work that propose to certify both the public key and out-of-band sense-able attributes to enable mutual authentication of the communicating vehicles. Vehicle owners are bound to preprocess (periodically) a certificate for both a public key and a list of fixed unchangeable attributes of the vehicle.

Keywords: Man-in-the-Middle attack, security, vehicular network.

1 Introduction

Security is a major concern in vehicular network where on one hand the wireless, ad-hoc and mobile communication imply security threats, and on the other hand requires perfectly reliable communication, as errors have immediate hazardous implications [43]. While vehicles move in a predictable road topology, maneuvering among the vehicles is somewhat unpredictable. For example, the vehicle ordering is changed dynamically along the road.

Applications for vehicular networks: Gaining on road safety and efficient traffic management are two prime goals in the use of vehicular networks. Smart vehicles may exchange information concerning road scenario with each other to help manage the traffic and to address safety concerns [21]. For example, a notification on the occurrence of an accident or a traffic jam ahead may assist the approaching vehicles to optimize their time and energy resources. In the very near future, vehicle will interact with several other vehicles on a daily trip to coordinate actions [23].

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Recently, several major projects [1] such as Car2Car-Communication Consortium [2], Cartalk [3], Network on Wheels [4], Vehicle Infrastructure Integration [5], Partners for Advanced Transportation Technology [6], Secure Vehicular Communication [7], E-safety Vehicle Intrusion protected Applications [8] were conducted in order to initiate, develop and standardize the vehicle networks operation. These projects were funded by national governments and accomplished by a joint venture of automobile companies, universities and research organizations.

Customized standard and hardware for vehicles: Modern vehicles are equipped with Electronic Control Units (ECU), sensors, actuators [25] and wireless transceiver that supports the DSRC (Dedicated Short Range Communication) standard [15,9] thus, enabling the creation of vehicle networks. ECU's are interlinked to trigger a collaborative decision on some safety critical event. Vehicles are equipped with local in-vehicle network and a wireless gateway to interface the in-vehicle network with the outside communication devices. In-vehicle network can be divided into controller area network (CAN), local interconnect network (LIN), and media oriented system (MOST) [28]. These embedded devices enable facilities such as automatic door locking, collision warning, automatic brake system, reporting road condition, rain and dark detection and communication with the surrounding road infrastructure.

Registration and identity certification: Currently, every vehicle is periodically registered with its national or regional transportation authority, which allocates a unique identifier to the vehicle with an expiration date which is the next required inspection date. In some regions of the US and the EU, registration authorities have made substantial progress toward electronically identifying vehicles and machine readable driving license. Moreover, these registration authorities assign a private/public key pair to the inspected vehicles.

Man-in-the-Middle (MitM) attack in vehicle networks: Identifying a vehicle is crucially important in the scope of establishing secure communication with passing by vehicles. In particular, when using public key infrastructure to establish a private key among vehicle pairs in order to communicate on the road. One disadvantage of the public key infrastructure is the need to cope with MitM attacks. The following scenario demonstrates a typical MitM attack.

The scenario starts when a vehicle v_1 tries to securely communicate with v_2 , requesting for the public key. Vehicle v_3 pretends to be v_2 and answers v_1 with v_3 public key instead of v_2 . Then v_3 concurrently asks v_2 for its public key. Vehicle v_1 is fooled to establish a private key with v_3 instead of v_2 , and v_2 is fooled to establish a private key with v_3 instead of v_1 . Vehicle v_3 conveys messages from v_1 to v_2 and back decrypting and re-encrypting with the appropriate established keys. In this way v_3 can find the appropriate moment to change information and cause hazardous actions to v_1 and v_2 .

For example, consider three vehicles v_1 , v_2 and v_3 with different brands and license numbers. Vehicle v_1 wants to establish a key with v_2 , a Mercedes-Benz with license number l_2 , and send a request for a public key, specifying that it would like to set a secret session key with the Mercedes-Benz that carries the license number l_2 . At this point v_3 which is a Toyota with license number l_3 intercepts and sends its public key as if it belongs to the Mercedes-Benz that carries the license number l_2 . Now, v_1 can

verify that the received public key (of v_3 pretending to be v_2) has been legally produced by the CA, and may be fooled to establish a secret session key with v_3 . Thus, v_1 confirms the public key authenticity but cannot be sure whether it just verified a Mercedes-Benz with license number l_2 or a Toyota that pretends to be a Mercedes-Benz with license number l_2 . To avoid such a design that is sensitive to MitM attacks we suggest to certify both the public key and the attribute together in a monolithic fashion. This is possible by having the certified linked fixed attributes together with the public key.

Public key infrastructure has a severe disadvantage when coping with MitM attacks not only in the scope of vehicle networks. Even when the certificate authority (CA) signs the public key, the public key owner should be identified by out-of-band means to cope with signed certificate thefts [34]. We propose a solution that employs vehicle fixed attribute based certification mechanism to correctly identify the neighboring vehicles. The periodic licensing routine can serve as an important ingredient of our scheme. Our method has the benefit of interacting with the CA only during preprocessing stages, rather than during the real-time secret session key establishment procedure. The certified attributes may be visually verified by a camera, microphone, wireless transceiver fingerprint identification [19], and/or other sensing devices which will feed the received data to, say, machine learning based classifier that will approve that indeed the attributes in the certificate match the sensed attributes of the vehicle. Visual identification may imply a better authentication of the transmission source in comparison with noise and/or transceiver fingerprint. Therefore, the trust level in the information communicated by a neighbor, and the type of actions taken according to the information received from the neighbor, may depend on the current set of attributes verified by out-of-band means.

Our solution relies on the CA approval that the public key was originated by the CA, and that the public key belongs to the vehicle with the coupled signed attributes. Given such certified public key and vehicle attributes, we are able to establish a secret session key with neighboring authenticated vehicle using only two communication rounds. Once the session key is established vehicles can securely exchange messages.

The paper is organized into four sections. Next, subsection highlights the related work regarding security threats, mitigating man-in-the-middle attacks, entity authentication and out-of-band channel authentication. In Section 2 a detailed description of the proposed work has been given. Section 3 highlights the transport layer security handshake with certified attributes. Section 4 concludes the discussion on the proposed scheme.

Related Work. In what follows, we describe in more details the related work, concerning vehicle networks threats, the state of art for mitigating MitM attacks. Then we describe existing entity authentication schemes, and in particular, the use of group coordination and distance maintenance.

Vehicle networks threats: Autonomous wireless connection among vehicles imposes serious security threats such as eavesdropping [41], identity spoofing [17, 40], sybil attack [29], wormhole attack [33], replay attack [49], message content tempering [16], impersonation [13], denial of service attack (DoS) [12] and man-in-the-middle attack [26].

Mitigating Man-in-the-Middle attacks: Global System for Mobile Communication (GSM) is one of the most popular standards. Unfortunately, it uses only one sided authentication between the mobile station and the coupled base station [10]. Universal Mobile Telecommunication Standard (UMTS) improves over the security loopholes in GSM. It includes a mutual authentication and integrity protection mechanism but is still vulnerable to MitM attacks [47].

MitM and DoS attack analysis for Session Initiation Protocol (SIP) is shown in [18], using a triangle communication model between SIP user agent and server. This work presents an analysis on the attack possibility, but does not offer any solution to the problem in hand. The interconnection between 3G and wireless LAN is vulnerable to MitM attacks by influencing the gateway nodes [50]. According to [27] mobile host and base station shares a secret cryptographic functions and mutually raises a challenge-response string, prior to employing the original Diffie-Hellman key exchange scheme [20]. Thus, mobile host replies with a cryptographic response and Subscriber Station Identifier (SSI) to base station, but it does not verify any of the unchangeable attributes of the intended subscriber. This way a base station, capable of verifying a unique SSI connection, may not confirm the authentic owner of the SSI connection.

Entity authentication: There has been a great research activity in the scope of cryptographic solutions [35] for entity authentication. A security scheme for sensor networks, called TESLA has been proposed in [36]. TESLA is based on delayed authentication with self-authenticating key chains. TESLA yields a time consuming authentication mechanism (as the messages received on a timeline, can be authenticated, only after receiving the immediate next message over the same timeline). Although, chances are less but still a man-in-the-middle can intercept through weak hash collisions and fake delayed key. An improvement TESLA++ has been suggested in [46], as an adapted variation of delayed authentication. A combination of TESLA++ and digital signature provides Denial of Service (DoS) attack resilience and non-repudiation respectively. The drawback with this approach is that message digest and corresponding message (with self-authenticating key) is transmitted separately to the receiver. Thus, man-in-the-middle may step in, as it does not follow the fixed attribute based verification.

Raya and Haubaux [38, 39] proposed that each vehicle contains a set of anonymous public/private key pairs, while these public keys have been certified by CA. The certificates are short lived and therefore needs to be confirmed with a Certificate Revocation List (CRL) before the use. The drawback with this approach is that road-side infrastructure is required to provide the most updated CRL. A man-in-the-middle attack resistant key agreement technique for peer to peer wireless networks appears in [14] where primary mutual authentication is done before the original Diffie-Hellman key exchange. This primary authentication step could be secret digest comparison, e.g., through visual or verbal contact, distance bounding or integrity codes. A man-in-the-middle can intercept because the proximity awareness, visual and verbal signals are computed by the device and verified by the user; while in our case it is already verified by CA and then user verifies it again. The secure communication scheme in [48] is enhancement over the Raya and Haubaux scheme, in that certified public key is exchanged and further used to setup a secret session key as well as group

key. Here, the attacker can pretend to be some other vehicle, by replaying the certificates and there exists no other means to verify that this vehicle is not the actual owner of the certificate.

Out-of-band channel authentication: There have been great efforts to utilize various auxiliary out-of-band channels for entity authentication. The notion of pre shared secret over a limited contact channel has been raised in [45]. A method shown in [24, 31] suggests that a common movement pattern can help mutually authenticate two individual wireless devices driven by single user. In [44] a pre-authentication phase is required before the original public key is exchanged and confirmed over the insecure wireless channel. Pre-authentication channel is a limited scope channel to share limited information, still it inherits the same vulnerability as wireless channel have. In this scheme there may be cases when a vehicle is not sure that it received data from whom it should receive. In our scheme we do it in reverse first wireless channel authentication and then verification over out-of-band channel, and that too certified by CA during preprocessing.

Another work in [32] presents a visual out-of-band channel. A device can display a two dimensional barcode that encodes commitment data, hence, a camera equipped device can receive and confirm this commitment data with the public key. Unfortunately the adversary can still capture and/or fabricate the visible commitment data, as it is not certified with the public key. The approach in [22] is based on acoustic signals, using audio-visual and audio-audio channels to verify the commitment data. In the former a digest of the public key is exchanged by vocalizing the sentence and comparing with a display on the other device, while the later compares vocalized sentences on both devices. In a recent work [42], Light Emitting Diode (LED) blinks and the time gap between those blinks has been used to convey the digest on the public key. Also, a combination of audio-visual out-of-band channel has been proposed in [37], that uses beeps and LED blinks in a combination to convey the commitment data. The proposed method is less effective because the public key and the out-of-band information are not certified and therefore man-in-the-middle can learn the out-of-band information and replay it. The approach in [30] suggests the use of spatial reference authentication, which is dynamic and can be manipulated by the man-in-the-middle. Also, the visual laser authentication can be ambiguous due to the equipment and the foggy weather condition unlike our scheme that relies on static sense-able attributes coupled with the public key.

2 Out-of-band Sense-able Certified Attributes for Mitigating Man-in-the Middle Attacks

We suggest mitigating man-in-the-middle attacks by coupling out-of-(the wireless)-band verifiable attributes. Vehicles are authenticated using digitally signed certificates and out-of-band verifiable attributes. For example, these attributes may include visual information that can be verified by input from a camera when there exists line-of-sight, including the identification of the driving license number, brand, color and texture, and even the driver faces if the owner wants to restrict the drivers

1. Sender S sends the certificate $Cert_S = Attribute_S + Public\ key_S || E_{SK_{CA}}(Attribute_S + Public\ key_S)$ to a neighbor R .
2. Receiver R confirms the certificate $Cert_S$ authenticity as described in 2.(a) and then responds as detailed in 2.(b):
 - (a) R decrypts the digital signature using the CA public key PK_{CA} , namely, $D_{PK_{CA}}[E_{SK_{CA}}(Attribute_S + Public\ key_S)]$ and checks that indeed the result is a function of the attached $Attribute_S$ and $Public\ key_S$, and then verifies $Attribute_S$ using out-of-band channels.
 - (b) R responds with the certificate $Cert_R = Attribute_R + Public\ key_R || E_{SK_{CA}}(Attribute_R + Public\ key_R)$ along with a random string key_r encrypted with $Public\ key_S$ and digitally signed by R , i.e. $E_{Public\ key_S}(key_r) || E_{SK_R}(E_{Public\ key_S}(key_r))$.
3. Sender S confirms the certificate $Cert_R$ authenticity as described in 3.(a) and then responds as detailed in 3.(b):
 - (a) S decrypts the digital signature using the CA public key PK_{CA} , namely, $D_{PK_{CA}}[E_{SK_{CA}}(Attribute_R + Public\ key_R)]$ and checks that indeed the result is a function of the attached $Attribute_R$ and $Public\ key_R$, and then verifies $Attribute_R$ using out-of-band channels.
 - (b) S decrypts the secret session key concatenated with the digital signature by using own secret key SK_S , i.e. $D_{SK_S}[E_{Public\ key_S}(key_r)]$. Also the digital signature of R can be verified using PK_R and SK_S respectively, i.e. $D_{SK_S}(D_{PK_R}(key_r))$.
4. Sender and receiver exchange encrypted messages using key_r as a shared secret key for S and R .

Figure 1: Establishing session key through mutual authentication

that may drive the vehicle. Other attributes may be verified by other sensing devices, such as microphone for noise.

Our approach does not require any communication with the certificate authority or the road side units, while actually authenticating vehicles on the move. The only interaction with the CA is during a preprocessing stage, which is mandatory to possess a certificate. The certificate holds a public-key and unchangeable (or rarely changeable) attributes of the vehicle signed by the CA. These out-of-band sense-able vehicular attributes should be sensed by other vehicles and checked in real-time. Note that the procedure to check these vehicular attributes may be given as part of the certified information. Our scheme is a viable solution to combat the man-in-the-middle attacks, as it utilizes a separate sense-able out-of-band channel to authenticate the unchanged vehicular attributes. The certificate can be updated and restored on each periodical inspection or in the rare case of attribute change. Thus, saving time and communication overhead in the authentication process, as well as avoiding a CA communication bottleneck, obtaining a scheme suitable for emergency and safety critical applications. Detailed description of the solution appears in the next section.

In the proposed scheme vehicles carry digitally signed certificate $Cert$ from CA, see Figure 2 for a possible structure of such a certificate. The pseudo-code description

World Manufacturer Identifier: <i>Geographic Area, Country, Plant Code</i>
Vehicle Descriptor Section: <i>Model Year, Brand Logo, Body Style, Original Color and Texture, Color Repairs, Roof Racks, Foot Step, Mud Flap, Front and Rear Guard</i>
Vehicle Indicator Section: <i>Engine Number, Engine Type, License Number, Chassis Number</i>
GPS Device Identification
Wireless Device Fingerprint
Procedures to Execute for Verifying the Attributes
Certificate Sequence Number
Certificate Expiration Date
Public Key
Digital Signature

Figure 2: Certificate structure

of the secret key establishment procedure appears in Figure 1. In the procedure we use PK to denote the public key, SK to denote the private key, key_r is the obtained shared secret session key, $+$ denotes the combined processing and $||$ denotes the appended string value. We assume that the CA established a certificate in the form of $Attribute_S + Publickeys || E_{SK_{CA}}(Attribute_S + Publickeys)$ for each party. These certificates are used to establish a (randomly chosen) shared key, key_r . The shared key key_r can then be used to communicate encrypted information from the sender to the receiver and back. One way to do this is to use key_r as a seed for producing the same pseudo-random sequence by both the sender and the receiver. Then XOR-ing the actual sensitive information to be communicated with the bits of the obtained pseudo-random sequence. Next, we describe in detail the involved entities, and their part in the procedure for establishing a session key.

Certificate Authority: The list of CAs with their public keys PK_{CA} may be supplied as an integral part of the transceiver system of the vehicle, similar to the way browsers are equipped with a list of CAs public keys. Only registered vehicles are allowed to communicate on the road. Digital signatures $E_{SK_{CA}}(Attribute_{sender} + Public\ key_{sender})$ represent the public key and attributes encrypted with the CA secret key SK_{CA} . The digital certificate works as an approval over the public key and the out-of-band verifiable attributes of the vehicle. The CA can update or renew a certificate, upon a need, or when the current certificate expires.

Vehicular Attributes: Vehicles incorporate various sensors to capture useful primitive from the neighborhood. Each vehicle is bound to a set of primitives yielding a unique identity to that vehicle. Vehicles identity encloses a tuple comprised of attributes such as license number, public key, distinct visual attributes and other out-of-band sense-able attributes, extending the basic set of attributes required according to ISO 3779 and 3780 standard [11]. These out-of-band sense-able attributes are captured through customized device connections such as camera, microphone, cellular communication and satellite (GPS system). In addition, we suggest to identify the wireless communication itself, rather than the contents sent by the wireless communication, this is done by the certified transceiver fingerprints. Thus, the transceiver must be removed from the original vehicle

and possibly be reinstalled in attacker's vehicle to launch the attack. Verifying each of the attributes by out-of-band channel implies certain trust level in the identity of the communicating party, which in turn implies the possible actions taken based on the received information from the partially or fully authenticated communicating party. Thus, a vehicle can perceive the surroundings from driver's perspective using vision with a sense of texture, acoustic signals, and the digital certificate. A combination of these primitives is different for every vehicle, the unique license number observed by the camera, the outlook of the vehicle including specific equipment, or specific visual marks such as specific color repair marks, unique license number, outlook of the vehicle, manufacturer's logo, engine acoustics classification signals. During the communication vehicles continuously exchange the geographic coordinates that can be certified as being received from the certified GPS device, according to the device unchangeable identification number. Here the attacker has to physically remove the GPS device from the original vehicle in order to act on its behalf. Therefore, a certified GPS device number attached with the current GPS location, velocity and direction justifies high certainty, together with other cross-verified attributes, such as the visual attributes, on the vehicle identity.

We next outline the arguments for the safety assurance implied by our scheme. The proposed approach is resistant to man-in-the-middle attack. The CA public key is conveyed to vehicles in secure settings. CA receives the request for the certificate deliverance and only the intended recipient will get the certificate $Cert$ from CA. An attempt to manipulate the certificate $Cert_S$ contents, in order to replace the attributes to fit the attacker vehicle attributes or the public key, will be detected as the digital signature $E_{PK_{CA}}(Attributes + Public\ key_S)$ yields an impossibility to modify a certificate or to produce a totally new one. Receiver R decrypts the digital signature using the CA public key PK_{CA} and confirms the validity. Thus, any verifiable certificate has been originated by the CA and therefore the attributes coupled with a certain public key uniquely characterize the vehicle.

After the mutual authentication is done through a signed public key verification, coupled with the fixed sense-able attributes, a session key is to be established. A random string key_r is generated at the receiver R and is sent along with the certificate $Cert_R$, in response to sender S request for certificate $Cert_R$. As the key_r can be replaced by a MitM, S needs to authenticate the origin of key_r . Moreover, an attacker can manipulate the random string in between thus it requires to ensure the integrity. First, R encrypts the key_r using S public key $Public\ key_S$ i.e. $E_{Public\ key_S}(key_r)$ so that only S can decrypt the random string using corresponding secret key SK_S . Thus the confidentiality is ensured as only intended receiver can decrypt the key_r as $D_{SK_S}[E_{Public\ key_S}(key_r)]$. Second, a digital signature i.e. $E_{SK_R}(E_{Public\ key_S}(key_r))$ is attached with the encrypted random string $E_{Public\ key_S}(key_r)$. Thus integrity is maintained as only R can generate these signature and similarly, only S can verify the signature using secret key SK_S as $D_{SK_S}(D_{PK_R}(key_r))$. Note that the signed and encrypted key_r can be used as part of a replay attack, however, such usage will be detected by the sender and the receiver as the actual value of key_r is not revealed to the attacker. The use of synchronized date-time and signed association of the date-time can avoid even such unsuccessful attack attempts.

3 Transport Layer Security Handshake with Certified Attributes

The scheme presented in the previous section is based on Transport Layer Security (TLS) scheme augmented with the signed coupled public key and attributes. TLS handshake is based on a pre-defined sequence of phases such as mutual authentication, random secret exchange and session key establishment. Handshake between the sender S and receiver R starts by invoking the opposite party and sending the supported range of cryptographic standards called as *Hello* message. Mutual authentication is accomplished through the *CA* signed certificates called as *Certificate Exchange* message. At first, S forwards the certificate $Cert_S$ to R which then verifies the *CA* signature on $Cert_S$ and the out-of-band sense-able fixed attributes $Attribute_S$. Similarly, S also verifies the *CA* signature on $Cert_R$ and the out-of-band sense-able fixed attributes $Attribute_R$.

Once the sender and receiver have exchanged and verified the respective certificates $Cert_S$, $Cert_R$ and attributes $Attribute_S$, $Attribute_R$; a session key key_r needs to be established on both sides. For that, R generates a random string key_r and shares it with S to derive a common session key between them. The random string is encrypted $E_{Public\ key_S}(key_r)$ by using the public key $Public\ key_S$ and is concatenated with a digital signature $E_{SK_R}(E_{Public\ key_S}(key_r))$. This way a MitM attacker can no longer fabricate the session key key_r . S can now decrypt the random string key_r using SK_S and also the digital signature by using $Public\ key_R$, SK_S respectively.

This completes the discussion on mutual authentication and session key establishment. Now, S and R switch to the symmetric encryption. The recently established session key key_r is used on both sides to encrypt and decrypt the message.

4 Conclusion

The proposed work provides man-in-the-middle attack resistance and mutual authentication using certified public key and out-of-band sense-able attributes. As the *CA* pre-processes every vehicles public key and unchangeable attributes, there is no way that man-in-the-middle can fake the public key or the unchangeable attributes. Also, the out-of-band attributes are sense-able and can be confirmed, while moving on the road. There is no need to communicate with the *CA* during the real-time session key establishment of a secret key based on the mutual authentication of vehicles. The proposed approach is simple, efficient and ready to be employed in current and future vehicular networks.

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