Secure data Discovery and dissemination based on short-length public key scheme in Wireless sensor networks

Yan Wang
East China Normal University
No.3663,Zhongshanbei Road
Putuo District,Shanghai,China
boliangzai@foxmail.com

Daojing He
East China Normal University
No.3663,Zhongshanbei Road
Putuo District,Shanghai,China
djhe@sei.ecnu.edu.cn

ABSTRACT

In Wireless Sensor Networks, WSNs, dissemination is typically used to query nodes, send commands, and reconfigure the network. In fact, WSNs are always deployed in harsh and open environment, it is important to judge messages as if they are from trusted source. Authentication can be satisfied by Public Key Cryptography (PKC). But PKC operations are expensive in terms of bandwidth, computing and storage consumption. To reduce costs, we propose a lightweight and Dos-resilient broadcast authentication mechanism using short-length public/private keys and presents its application in securing Drip protocol, an open source message dissemination protocol. We compare our mechanism with traditional 160-bit ECC public-key schemes, and show that our scheme can achieve a significant improvement on energy consumptions. Besides, we believe that our mechanism fulfills the broadcast authentication requirements of WSNs.

CCS Concepts

•**Computer systems organization** → **WSNs;** • **Cryptography** → *Public key;*

Keywords

Public key; message dissemination, Dos resilience

1. INTRODUCTION

Wireless sensor networks are being used in a wide variety of applications, such as military sensing and tracking, industrial control. Sensor networks are composed of one or more base stations and a number of sensor nodes. Obviously, wireless industrial control sensor networks are broadcast networks and channels are shared among all users in the network.

ASIA CCS '17 Abu Dhabi, UAE

DOI: 10.475/123_4

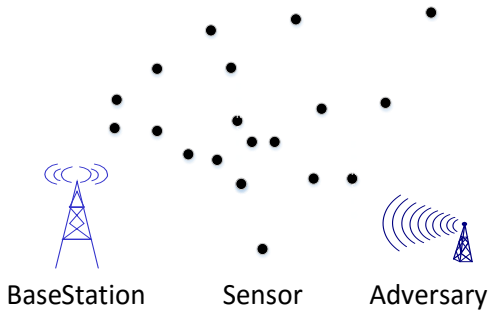

Figure 1: Attack scenario

As shown in Fig.1, when deployed in hostile environments, sensor networks are susceptible to a variety of attacks. For example, adversaries are able to easily intercept the messages between base stations and sensor nodes, impersonate the base stations to deceive sensor nodes.

Many countermeasures such as PKC, have been developed to prevent adversaries from impersonating base stations. But these countermeasures make sensor networks an easy target of Dos attacks. We provide an example to illustrate this problem.

First, as shown in Fig.1, sensors are measuring temperature, the control center may want sensors to measure humidity of the atmosphere instead. In this case, control center need broadcast values to reconfigure the whole network. In mentioned network, communications are based on IEEE 802.11.4 standard. Adversaries can broadcast a large number of bogus messages, exhausting resources of sensor nodes.

In order to secure message broadcast in industry control sensor networks. This paper has the following major contributions:

1 First, We study the specific requirements needed to secure a WSNs protocol. According to security weaknesses and efficiency problem, we review existing broadcast authentication mechanisms.

2 We propose a secure, lightweight, robust, Dos-resilient authentication mechanism. It is a secure extension of Drip and has advantages over traditional broadcast authentication protocol.

3 We conduct extensive experiments with many telosb platforms. And experimental data in chart shows that our mechanism can achieve high efficiency and performance.

Organization The organization of our paper is as follows: Section II, we discuss the related work as the context of our work, and Section III describes the network model, security requirements and assumption. In Section IV, We present our scheme in detail. Section V analyses the security and efficiency properties of our protocol. Section VI describes the implementation and experimental results of the proposed protocol via real sensor platforms. Finally, Section VII concludes this paper.

2. RELATED WORK

2.1 Existing Work on Broadcast Authentication

There are many challenges of information security in Wireless Sensor Networks. The primary one is the limited computing, communication and storage capabilities of a sensor node. Based on this factor, a number of broadcast authentication schemes, including symmetric key scheme and asymmetric key schemes, have been proposed, .

A MAC algorithm, sometimes called a keyed hash function, outputs a tag derived by accepting a secret key and an arbitrary-length message as input [1]. By allowing verifiers who also possess the secret key to detect any changes to the message content, the MAC value protects both a message's data integrity as well as its authenticity.

But it is not desirable for broadcast authentication. Since key is shared among senders and receivers, any one of receivers can impersonate sender and forge messages.

Along with the development of related technology, asymmetric key schemes become more and more practical in wireless sensor network.

Public key cryptography, or asymmetric cryptography, is a cryptographic system that uses pairs of keys: public keys which may be disseminated widely, and private keys which are known only to the owner. This typically achieve authentication function when the public key is used to verify identity of the message sender. Because of high computation costs and large signature size, public key cryptography in WSNs is susceptible to Dos attack. That is, the adversary may flood a large number of illegal signature messages to exhaust receivers' resources and render them less capable of serving legitimate users.

In order to solve above problems, some researchers proposed TESLA [2] and its various extensions [3] to authenticate broadcast packets in a network.

TESLA is an example protocol in which authentication information is sent post the broadcast message. It employs symmetric cryptographic technique with delayed key disclosure, i.e., the key used to authenticate a message is disclosed in next message. However, time synchronization is required between sender and receiver. [2] has used a direct time synchronization between sender and receiver, making WSNs susceptible to Dos attack.

On the other hand, if adversary sends a huge number of useless packets, it will take sensor nodes large memory space to store these packets until sensor nodes receive authentication key.

Other authentication schemes use one-time signature [4], [5]. Verification and authentication based on one time signature is very fast. Unfortunately, such schemes suffer from large key sizes and a limited number of uses per key.

To reduce cost, authors in [6] use a single signature to authenticate multiple data packets. In [6], sender have already known messages in advance and applied hash function to the last message and output a hash value. Then sender attach this value to the previous message. This process is continued until the first message. Then sender just sign the first message using private key. Thus sender get a signature on all messages to be disseminated. After the first message is verified, the hash value of next message is also verified. We just use this hash value to authenticate next message. And recursively, the last message will be verified through its previous packet. Obviously, this protocol does not adapt to the changing environment, WSNs needs administrator to configure the network frequently, we cannot predict the next message to be sent.

Another approach has been adopted by some researchers [7] , who use a Merkle tree instead of recursive hashing for packet authentication. This approach requires to include many extra hash value in a packet, increasing bandwidth consumption.

Also, hash chain approach [8] is an energy-efficient method to do packet verification. But its high performance requires network not too noisy. Once wireless network is affected severely and packets containing key information is lost, the authentication process behind the lost packets stops.

2.2 Review on Message Dissemination

Drip is one of the most popular message dissemination protocol in sensor networks based on TinyOS [9] . In Drip, each message is expressed as a 3-tuple (key, seqno, data), where key uniquely identifies the variable to be updated, data denotes the disseminated data item (e.g., parameter, command or query), and seqno indicates if the data item is old or new, new data has the greater seqno number. In the Drip implementation, key and seqno are 2 bytes and 4 bytes respectively. In Drip, a separate instance of Trickle algorithm [10] is for a disseminated data item. Once new data are injected to a receiver by the sender, they will be disseminated by Trickle quickly. And the whole Network will converge on this data through Trickle algorithm.

With Trickle algorithm, the problem of packet loss are greatly improved. Since the goal of a dissemination protocol is to reliably deliver a piece of data to every node in the network.

Although we have used Drip for our reference implementation, our mechanism can be extended to other popular broadcast protocols, with the assumptions listed in Section III.III. In the rest of this paper, unless otherwise specified, we assume that Drip is used as the message dissemination protocol

3. PROBLEM DEFINITION

3.1 Network Model

Fig.2 demonstrates what a conventional WSNs consists of. Basestation (Sender, S) is trying to communicate with these sensors (Receiver, R_i), exchanging data. These data may tell sensor nodes what to do next, or just ensure communication channel is under normal state.

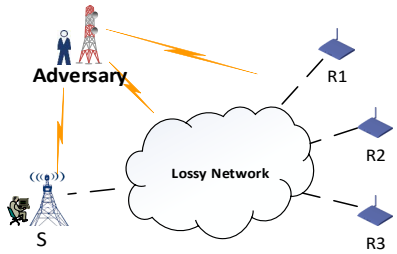

Figure 2: Network Model

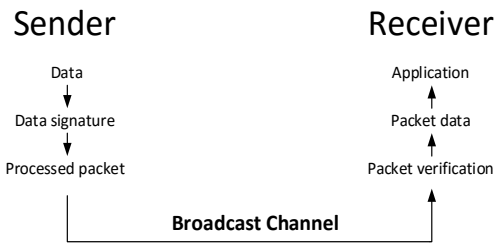

Figure 3: DataFlow

The adversary is different from both basestation and sensor nodes. Actually, the adversary is able to destroy the network in many ways, including eavedropping for sensitive information, injecting malicious information, replaying previously intercepted messages, or impersonating valid sensor nodes.

When adversary combines these methods together, it will get a large amount of valuable information about WSNs. From disseminated packets and distributed sensors, key materials will be compromised as adversary intercepts packet, reads data from sensors' memory.

3.2 Requirement

An efficient and secure broadcast authentication scheme comes with many requirements, not only just using asymmetric key schemes.

1 Independent authentication: The information included in received packet can be used for verifying itself without depending on other packets. Otherwise packet-loss will put an end up to whole process of dissemination.

2 Robust to packet loss: A general wireless sensor network may suffer from packet-loss, which is a problem to most wireless sensor network. But the concrete protocol we discuss, Drip, is typically designed to make network reliable. Its timing algorithm, Trickle, converges every node on the same data by frequently exchanging data.

3 WSNs usually are deployed in military or industrial control fields and draw instant information from environment constantly. Using a signature to verify multiple messages seems impractical, since it hard to predict next message to be sent next.

4 Low computation cost: Broadcast authentication scheme should works to secure network communication without increasing computation cost and energy consumption.

5 Receiver compromise tolerance: Even a large number sensor nodes is compromised, the protocol should ensure no valuable information be extracted from sensor nodes. Thus the key material used to do verification must be specially handled.

6 Low communication overhead: Small is the number of bytes per pakcet, while communication consumes most of the power resources on sensors.

7 DoS attacks resistance: The functions of the Wireless network should not be disrupted by DoS attacks.

8 Freshness: A receiver should be able to differentiate whether an incoming message is the newest version.

9 Scalability: The protocol should allow recipients temporarily offline and new entrants to connect the network again through simple verification process.

10 Low storage requirement: The storage space for key material such as signature should be limited to make sensors perform more function.

No matter what method a protocol use, it still cost bandwidth, energy, memory to make the WSNs function safely. In practice, dedicate tradeoff between energy consumption and efficiency needs to be found.

3.3 Assumption

Our protocol makes the following assumption.

- The legitimacy of valid sender can not be questioned, that is the basestation has no intention to destroy WSNs.
- Sensors are able to perform a number of verification operations, such as ECDSA verification and hash function.

4. THE PROPOSED PROTOCOL

Before giving the detailed description of the proposed protocol, we first provide an overview of our protocol.

4.1 Overview of Our Protocol

Elliptic curve cryptography is an outstanding approach to public-key cryptography in terms of security strength. However, as practical as they may become, the cost of public key operations may dominate the cost of transmitting packets in sensor network. Since broadcast authentication requires sensors to conduct a large number of PKC operations, using PKC in the traditional way is still impractical. It is desirable if we can significantly reduce the cost of PKC operations by optimizing the broadcast authentication protocols.

We propose ShortPK approach, i.e. short-length public key. For example, if we reduce an ECC public key from 160bits to 80 bits, the computation cost for signature is reduced to roughly one eighth and the length of signatures is reduced to half [11]. While short-length public key is easy

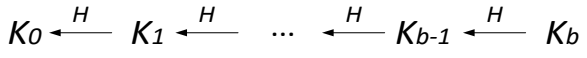

Figure 4: Hash Chain

Notation	Description
$SIG_k(M)$	the signature on message M with key k
$E_k(M)$	encryption message M with a symmetric key k
, or ||	concatenation operator of the two bit streams
$H(.)$	public one-way cryptographic hash function (e.g., SHA-1)
$H(M)$	the hash value of message M

Table 1: NOTATIONS

to break, we need a more safe way to distribute short-length public keys.

With enough memory, we can load public keys into sensor′s memories before sensor deployment. But the public keys must be encrypted, otherwise one sensor is compromised, the public keys will be compromised and private keys will be derived from public key using ECC-oriented CPU. We can use AES for the symmetric-key encryption, therefore nobody, including sensor nodes, knows public keys before the arrival of decryption key included in broadcast packet.

Meanwhile, we denote encryption key as K_i, subscript i means the *i-th* dissemination. It is important that sensor nodes are able to verify legitimacy of K_i in each broadcast packet, otherwise the broadcasting is not secure using the following attacks:

If the adversary randomly chooses a key K_i' and a public key PK_i' , encrypts PK_i' into $(PK_i')K_i'$ using K_i'. Both PK_i' and K_i' are invalid. While receiving packet, sensors do not verify K_i, then will get a gibberish PK_i'. They will use PK_i' as the public key to conduct signature verification. Even though the verification is not successful, sensors spend a lot of energy and time verifying the signature.

Therefore, sensors need to verify whether the received K_i' is from the basestation. It can be achieved by one-way hash chain:

As illustrated in Fig.4, the sender randomly chooses a number K_b, and then generates a one-way hash chain. A hash chain is based upon a public function H that is easy to compute, but computationally difficult to invert – thus, the term, one-way hash chain. A hash chain of length b is generated by repeatedly applying the hash function H to the last element, say, K_b, in the chain, to generate a sequence of hashes such that $K_j = H(K_{j+1})$. The head of the chain, K_0, serves as a commitment to the entire hash chain. The hash chain is generated in the order K_b,K_{b-1}, ..., K_1, K_0 and revealed in the reverse order. Here b is the maximum number of message disseminations permitted in the lifetime of the WSNs. The keys K_0, K_1, ...,K_b are referred to as puzzle keys, and K_j is used for the *j-th* disseminated messages, where $j > 0$.

But as illustrated in Fig.2, adversaries can intercept the communication channel between base station and sensor nodes. The encryption key broadcasted in open channel is exposed to adversaries. By compromising sensor nodes, the cipher text of PK_i' is also obtained by adversary. Based on mentioned information, using intercepted key to decrypt cipher text stored on sensors, adversary is able to get public key.

After getting public key and spending a large amount of time deriving private keys from public key, adversary is able to forge a malicious packet containing malicious information. That packet contains $(data')$, $signature'$. where $signature'$ is produced by deduced private keys and $data'$ means to destroy the WSNs.

Obviously, it take adversary time to listen to communication in channel and forge a malicious packet. We must prolong the time for adversary to produce an invalid packet. Here we can use message specific puzzle, make the packet hard to produce. That is, without solving a message specific puzzle first, adversary cannot send a malicious packet. Specific puzzle is a relatively weak authentication method and easy to implement. It requires arithmetic results of packets to follow a certain rule, such as to equal to 0. Following these design consideration, our protocol is made up of three phases: system initialization, packet pre-processing, and packet verification. The system initialization is carried out before network deployment. The framework and algorithm for security is established in this phase. Besides, private keys, public keys and encryption material of public keys should be loaded on sensors. Then before disseminating data, the basestation executes packet pre-processing phase in which disseminated packets and their specific puzzle are constructed. Finally, in the packet verification phase, a node verifies every received packet. If the result is positive, it updates the data item included in the received packet. In the following, each phase is described in detail. The notations used in the description are listed in Table I. 1

4.2 System Initialization Phase

In this stage, the sender sets up an ECC and generate a private key SK and public parameters PK,Q, p, q,H(.) by performing the following operations. It selects an elliptic curve E over GF(p), where p is a big prime number. Here Q denotes the base point of E while q is also a big prime number and represents the order of Q. It then picks the private key SK $\in$ GF(q) and generates the public key PK = SK·Q. As an illustrative example, for 160-bit ECC, both PK and Q are 320 bits long, and both p and q are 160 bits long.

Using a node of one-way hash chain as security key, strong encryption is achieved through the use of a 128-bit AES algorithm. The cipher text is loaded on every sensor nodes, thus adversary is not able to squeeze any key information out from cipher text. On the basis of AES algorithm, we can use short-length public key and short-length signature to keep our protocol cost-effective.

If the public keys are not encrypted, adversaries can immediately get all the public keys, and will have much longer enough time to find the corresponding private keys.

In this stage, sender transforms public keys into ciphertext, $(PK_i)K_i$. The encryption keys, denoted as K_1 ... K_N, are the elements of hash chain in Fig.1. K_i is the *i-th* key in the one-way key chain.

The committed value of this hash chain (i.e., K_0) and ciphertext of public keys $(PK_i)K_i$ are preloaded on each receiver of the network before deployment, together with the public parameters PK, Q, p, q,H(.) of the sender. Any of the reported secure key pre-distribution schemes (e.g., [12]) may be used for this purpose. The hash chain is called the

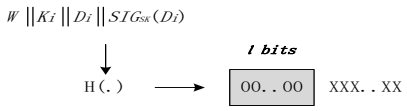

Figure 5: specific puzzle

version chain as its elements correspond to update versions of the message. The *j-th* element of this hash chain stored in the sensor receiver is called *j-th* version key.

4.3 Pakcet Pre-processing Phase

After system initialization, if the sender wants to disseminate a message, say the i-th message $D_i = \{key, seqno, data\}$, where $i > 0$, as shown in Fig.5, it uses concatenation-hashing encryption and specific puzzle to construct the packet of the message as follows.

Firstly, sender signs D_i using digital signature algorithm, ECDSA, and obtains signature, $SIG_{SK}(D_i)$. Secondly, signature, hash chain K_i, data item D_i will be concatenated together to construct a message specific puzzle. A weak authenticator called message specific puzzle is constructed by finding fixed-size segment(W) which satisfies the first l bits of $H(W \| K_i \| D_i \| SIG_{SK}(D_i))$ equls to 0.

Finally, the sender then broadcasts the packet with the payload $(W \| K_i \| D_i \| SIG_{SK}(D_i))$.

4.4 packet verification phase

Upon receiving a broadcast packet, each receiver first verifies the packet using specific puzzle. If the Hash result of the whole packet is invalid, the receiver will simply drop this packet.

Else, then receiver verifies the puzzle key K_i included in the packet, i.e., whether the hash result of K_i equals to K_{i-1} or not. In practice, K_{i-1} is pre-loaded on sensors.

If the puzzle key K_i is authentic, we can use it to decrypt the public keys ciphertext stored in receiver nodes. After that, signature included in packet will be verified by decrypted public keys.

Then, receiver accept the data item included in packet.

5. SECURITY AND EFFICIENCY ANALYSIS

5.1 Security Analysis

Integrity of Data Items In our protocol, the base station is trustworthy. It signs every message with the generated private key. Since private key is only known to base station, receivers are able to authenticate the identity of message's sender. On the basis of signature, receiver can verify the data upon receiving them.

Resistance to Dos Attacks Dos attacks was launched by exploiting authentication delays or exploiting expensive signature verification.

Due to the use of message specific puzzle, upon receiving a packet, each node can verify it immediately through performing efficient hash function. Further, because of short-length public key, the verification does not take a long time and energy.

Efficiency Analysis Only if the verification of the puzzle included in the signature packet is successful will each node execute the signature verification operation. While being transmitted, short-length signature consumes little bandwidth. It is fast hash function that verifies a specific puzzle. Hash function is fast and efficient on sensor node. Thus our protocol requires little computing overhead . Also sensor nodes spend only a little amount of memory to store public keys.

6. IMPLEMENTATION AND PERFORMANCE EVALUATION

We evaluate our protocol by implementing all its components in an experimental test-bed. Also, we choose Drip for performance comparison.

6.1 Implementation and Experimental Setup

Our implementation has the base station and sensor node side programs. The base station side programs are C programs using OpenSSL. All programs and application on base station side is running on virtual machine, VMware Workstation, which is a distinguished software. Besides, the sensor node side programs are written in nesC, an event-driven programming language. NesC is running on resource-limited sensor motes, Telsob. The Telosb mote has an 8-MHz CPU, 10-kB RAM, 48-kB ROM, 1MB of flash memory, and an 802.15.4/Zigbee radio. Telosb, nesC, is specially designed for TinyOS, an open source operating system designed for wireless devices. The key size of ECC is set to 128 bits. Without additional specification, we repeated one million times (resp., one thousand times) for each measurement in order to obtain a objective accurate results.

To implement our protocol, we add the following functionalities in the C tools on the base station side: construction of specific puzzles.

In the implementation of Drip, when a packet with a new version number is received, a node stores the packet and then resets the Trickle timer. In our protocol, when a packet with a new version number is received, a node stores the packet and then authenticates it. If the result is positive, the node resets Trickle timer; otherwise, the node simply discards the packet. In an improved protocol, the packet additionally contains a specific puzzle, the result is different.

Following the design of our protocol described above, we employ the ECDSA and SHA-1 hash operations of TinyECC 2.0 library to add the verification function of signature packet into the Drip nesC library. In our implementation, the base station (i.e. a laptop PC) first sends the signature and data packets through a serial port to a particular sensor node which is referred to as disseminator. Then, the disseminator disseminates these packets by Drip protocol.

6.2 Evaluation Results

The charts in Fig.6 show the average times for each operation phase in TinyECC. This charts shows that ECC with secp128r1 has no obvious advantage over that with secp160r1 in speed. It has the similar time consumption with secp160r1. But shortness is a virtue we appreciate in packet broadcast, since packet transmission consumes major bandwidth and energy of sensor nodes. Besides, in initiation phase, secp128r1 is the fastest. It will help quick deployment of WSNs under some exceptional circumstances.

The charts in Fig.5 show that the computing time grows exponentially.

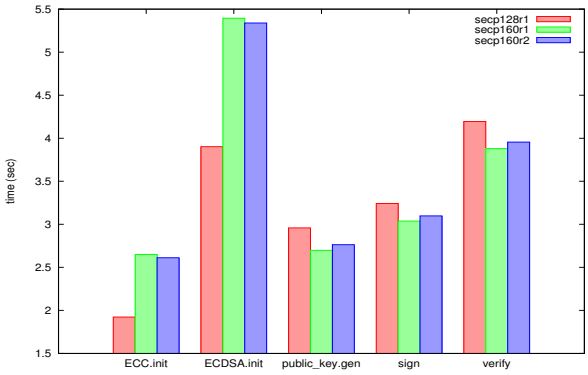

Figure 6: DataFigure

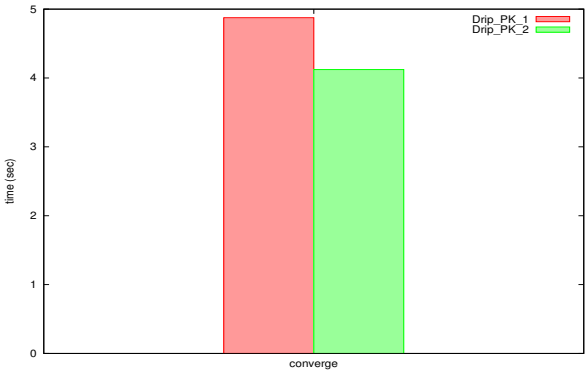

Figure 8: DataFigure

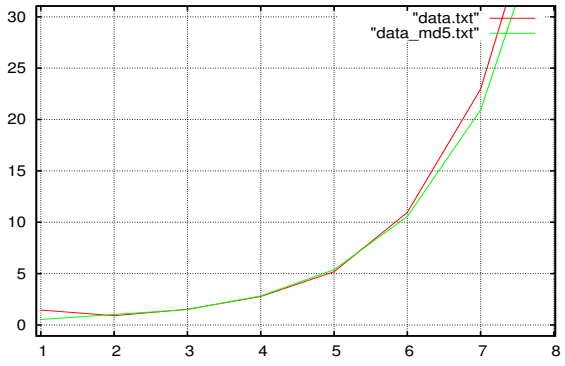

Figure 7: DataFigure

7. CONCLUSIONS

In this paper, we have identified the security vulnerabilities in data discovery and dissemination of WSNs. We then developed a lightweight protocol to allow efficient authentication of the disseminated data items by taking advantage of short-length public key. Our protocol is designed to work within the computation memory and energy limits of inexpensive sensor motes. In addition to analyzing the security of Our protocol, this paper has also reported the evaluation results of Our protocol in an experimental network of resource-limited sensor nodes, which show that our protocol is efficient and feasible in practice.

8. ACKNOWLEDGMENTS

APPENDIX

A. REFERENCES

[1] Karlof C, Sastry N, Wagner D. TinySec: a link layer security architecture for wireless sensor networks[C]//Proceedings of the 2nd international conference on Embedded networked sensor systems. ACM, 2004: 162-175.

[2] Perrig A, Canetti R, Tygar J D, et al. The TESLA broadcast authentication protocol[J]. RSA CryptoBytes, 2005, 5.

[3] Liu D, Ning P. Multilevel ÎijTESLA: Broadcast authentication for distributed sensor networks[J]. ACM Transactions on Embedded Computing Systems (TECS), 2004, 3(4): 800-836.

[4] Perrig A.: The BiBa one-time signature and broadcast authentication protocol[C]//Proceedings of the 8th ACM conference on Computer and Communications Security. ACM, 2001: 28-37.

[5] Lee J, Kim S, Cho Y, et al. HORSIC: An efficient one-time signature scheme for wireless sensor networks[J]. Information Processing Letters, 2012, 112(20): 783-787.

[6] He D, Chan S C, Guizani M.: Small data dissemination for wireless sensor networks: The security aspect[J]. Wireless Communications, IEEE, 2014, 21(3): 110-116.

[7] He D, Chan S, Tang S, et al. Secure data discovery and dissemination based on hash tree for wireless sensor networks[J]. IEEE transactions on wireless communications, 2013, 12(9): 4638-4646.

[8] Eldefrawy M H, Khan M K, Alghathbar K, et al. Broadcast authentication for wireless sensor networks using nested hashing and the Chinese remainder theorem[J]. Sensors, 2010, 10(9): 8683-8695.

[9] http://www.tinyos.net/

[10] Patel N, Culler D, Shenker S.: Trickle: A self regulating algorithm for code propagation and maintenance in wireless sensor networks[M]. Computer Science Division, University of California, 2003.

[11] Wang R, Du W, Liu X, et al. ShortPK: A short-term public key scheme for broadcast authentication in sensor networks[J]. Acm Transactions on Sensor Networks, 2009, 6(1):2939-2965.

[12] Gandino, F., B. Montrucchio, and M. Rebaudengo. "Key Management for Static Wireless Sensor Networks With Node Adding." IEEE Transactions on Industrial Informatics 10.2(2014):1133-1143.