ID-Based Authentication for Mobile Conference Call

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Abstract

In this paper a secure conference call set-up protocol is proposed for a mobile communication system. The proposed scheme uses ID-based concept and enables a mobile unit and a base station to authenticate each other. It has an additional feature of providing mobile subscribers with location privacy. Reauthentication in the course of handoff is also discussed.

Keywords

ID-based cryptosystem, privacy, secure protocol, mobile communication

1. INTRODUCTION

Wireless has recently become a widely discussed research topic. Many people have already experienced and enjoyed the convenience provided by mobile phone services. With the inclusion of mobile data services in the foreseeable future, we shall march into a new era of personal multimedia mobile communication services.

Technically speaking, wireless research involves many key issues such as RF technology, propagation, access technique, handoff and channel assignment. Security is also a very important but far less addressed issue in mobile communications.

In wireless communications, signal transmission is done through radio channels and is vulnerable to attacks from intruders. These attacks include avoiding to pay for the use of the system and attempting to gain access to information. These attacks are apparently due to the exposure of the radio link to outsiders. Security has become a great concern of cellular subscribers. To prevent these attacks, tight security measures must be adopted. Authentication is a mechanism designed to expel these illegal attempts. New generation of digital cellular mobile communication such as GSM has made the security improved many orders of magnitude over the analog systems, e.g. Haug (1994).

New generation of wireless system is planned to support a good variety of services such as speech, data, e-mail, fax and etc. According to the technical report, e.g. T1P1.3/93-044R1 (1993), the design objectives of security measures should include: privacy of speech and data, privacy of user location, privacy of call setup information, protection against fraud, protection against disclosure of information, and protection against unauthorized access to subscriber data.

In this paper we concentrate on the construction of an efficient authentication protocol for a mobile communication system. Location privacy is one of our design objectives. Our scheme as a matter of fact provides an additional feature of two-way authentication in the sense that we also allow a subscriber/mobile unit to verify whether a base station is genuine.

The authentication protocol proposed in this paper is also operable in the course of hand-off. What is meant is that during each handoff the base station will be reauthenticated by the original mobile unit, since the base station is changed during handoff in such a way the base station is easily impersonated. In principle, a handoffed mobile needs also to be reauthenticated. In this paper we only propose protocol to reauthenticate a base station. The reauthentication of a mobile station remains to be completed.

In order to meet these requirements, cryptographic techniques should also be carefully chosen. Prior works on security issues in mobile communication systems can be found in Tatebayashi et al. (1990), Hwang (1993), Coomaraswamy and Kumar (1993), Beller et al. (1993), Ashar and Diffie (1994), Lin and Harn (1993) and Molva et al. (1994). Most of these works are done for point-to-point communications. Recently, Hwang and Yang (1995) proposed a public-key-based conference key distribution protocol in which the conference key is shared by all conferees and the authentication is only executed during call set-up.

In this paper, we propose a secure conference call set-up scheme among a group of mobile units via ID-based concept. ID-based cryptoschemes have the convenience of allowing users to communicate secretly using only their identifications. This cryptographic technique has recently received considerable attention from researchers, e.g. Shamir (1985), Okamoto and Tanaka (1989) and Tsujii and Itoh (1989). In this paper two authentication protocols are constructed: one for call setup and one for handoff.

In Section II we introduce the principle of ID-based cryptosystem as a preparation. System architecture and protocol are outlined in Section III. Discussions and security analysis are done in Section IV. Conclusions are drawn in Section V.

2. ID-BASED CRYPTOSYSTEMS

The well known public key cryptosystem was first proposed by Diffie and Hellman (1976). Public key system allows each user to place his/her encryption key in a public file while keeping the decryption key secret. It has the advantage of requiring no key management. Therefore, the public-key systems are widely used in distributed environment such as a computer network. The ID-based cryptosystem has similar features. It also has an additional feature of not requiring a public file. Any user-associated information such as name, telephone number and address can be used as public key. A smart card ID-based cryptosystem was first proposed by Shamir (1985). we illustrate an ID-based signature scheme as follows. In RSA algorithm, the public keys are $n = pq$ and e while the secret key is d , where p, q are two large primes. The encryption key e and decryption key d must satisfy $ed \equiv 1 \pmod{(p-1)(q-1)}$. Shamir assumes the existence of a key generation center which generates each user U_i 's secret key K_i by $K_i = (ID_i)^d \pmod n$, where ID_i is U_i 's unique identity number, d is a system secret key. In order to sign a message M , the smart card computes a pair (t, s) as follows: $t = r^e \pmod n$ and $s = K_i r^{f(t, M)} \pmod n$, where r is a random number and f is a one-way function. The pair (t, s) is the signature of M which is to be sent to anyone who is the intended recipient of M . For legitimate receivers, the signature of M can be easily verified by performing the comparison s^e and $ID_i t^{f(t, M)}$ in modulo n .

In order to realize authentication, the signature scheme is usually used when the communicating parties do not trust each other, e.g. Tanenbaum (1988). In our proposed scheme each mobile unit is equipped with a unique ID. i.e. $ID_{\text{mobile-unit}}$. Each base station is also associated with a unique ID, $ID_{\text{base-station}}$. Then the authentication is done by validating the

received signature message.

3. SYSTEM ARCHITECTURE AND PROTOCOLS

A cellular mobile communication system consists of three basic parts: subscriber/mobile units (MUs), base stations (BSs) and mobile switching center (MSC). A MU communicates with BS via the radio link and each BS is connected to the MSC through the wireline link. To authenticate calls an authentication center (AC) is needed and is assumed to be a part of MSC. The AC of MSC is assumed to have a powerful processor together with a database. Compare to the AC, a BS has rather limited computing power, but it still has a processor to perform high-speed computation. A call setup procedure involves handshakings between a BS and the MSC. The handshaking is done through wireline link which is assumed to be safely guarded. In other words we are assuming that wireline communication links are secure. We shall concentrate only on the security of radio links.

In this paper, we propose two authentication protocols: one for call setup and one for handoff. Our protocols allow a MU and a BS to verify each other. It also offers an additional feature of providing MUs with location privacy. Featuring two-way authentication and location privacy are particularly desired in a mobile communication network. There are in general two kinds of authentication scheme: one-way and two-way. One-way authentication is only suitable when sender completely trusts the receiver, whereas in mobile environment, MUs and BSs do not know each other (i.e. the two parties do not each other completely trust). Location privacy is a protection against tracing the location of a mobile unit by listening to the signalling exchanged on the radio link. The protection is normally done by the use of random number. In our scheme a random number is generated each time a new call is established. A random number was given and stored into a mobile unit when it registered with MSC.

For the convenience of describing our work, we first define the following set of symbols:

1. MU_i : The i th mobile unit.
2. BS_i : The i th base station.
3. RC : A random check number, different RC 's are used in different call setups. RC is chosen randomly by MSC at each call setup and given to MU_i .
4. K_c : The conference key used by MU_i . The regular messages including voice and data are encrypted by K_c after a conference call is correctly built.
5. K_s : The session key generated by MU_i . It is chosen by MU_i at each call setup and used to participate in the construction of K_c .
6. PKC : Public key cryptosystem. In our protocol we use low exponent RSA as our basic cryptosystem of which public keys are $n = pq$ and e , the secret key is d , where p, q are two large primes. Encryption key e and decryption key d must satisfy $ed \equiv 1 \pmod{(p-1)(q-1)}$. MSC first chooses a primitive root g which falls in both $GF(p)$ and $GF(q)$ and makes it public. In order to satisfy the low-circuit complexity and fast computation requirement desired for a mobile unit, the encryption exponent e is chosen to be a small integer. Here, we let $e = 3$ and both p and q be about 256 bits long. d is obtained by satisfying the relation $3 \times d \equiv 1 \pmod{(p-1)(q-1)}$.
7. $h(\bullet)$: one-way hash function.
8. $a||b$: a concatenation operation for a and b .

3.1 Call Setup Authentication Protocol

This protocol is executed each time a call setup request is launched. The protocol is sketched in Fig. 1 and described as follows.

- Step 1. MU_i encrypts $(ID_{MU_i} || RC || K_s)$ by using PKC of MSC and computes $C_{MU_i} = (ID_{MU_i} || RC || K_s)^3 \bmod n$, then sends C_{MU_i} to BS_i via the radio link.
- Step 2. After receiving C_{MU_i} , BS_i forwards the received C_{MU_i} , and his identity ID_{BS_i} to MSC .
- Step 3. MSC receives ID_{BS_i} , decrypts C_{MU_i} and gets $(ID_{MU_i} || RC || K_s)$. MSC searches the identity of MU_i , if ID_{MU_i} does exist in the database, MSC further compares the RC sent from MU_i to see if it is identical to RC prestored in the database. If the comparison is correct, MU_i is accepted as a legal subscriber and go to the next step; otherwise, MSC terminates the call setup procedure.
- Step 4. MSC selects randomly a new random check number RC' for MU_i to use during the next call setup. MSC then computes a number $NR = RC \oplus RC'$, where " $\oplus$ " is an invertible operator.
- Step 5. MSC generates a secret key $S_{BS_i}^{(0)}$ for BS_i as $S_{BS_i}^{(0)} = (h(ID_{BS_i}) \times RC)^d \bmod n$ sends $\{S_{BS_i}^{(0)}, NR\}$ to the BS_i of MU_i .
- Step 6. BS_i chooses a random number r_i , generates

$$X_{BS_i} = g^{-3r_i} \bmod n, \quad (1)$$

$$Y_{BS_i} = S_{BS_i}^{(0)} \times g^{r_i} \bmod n, \quad (2)$$

and sends $\{ID_{BS_i}, X_{BS_i}, Y_{BS_i}, NR\}$ to MU_i .

- Step 7. After receiving $\{ID_{BS_i}, X_{BS_i}, Y_{BS_i}, NR\}$ from BS_i , MU_i computes

$$\frac{Y_{BS_i}^3 \times X_{BS_i}}{RC} \bmod n \quad (3)$$

to see if it is equal to $h(ID_{BS_i})$, where ID_{BS_i} is sent from BS_i and RC is a random number prestored in MU_i . If they do match then BS_i is treated legal and go to the next step; otherwise MU_i hangs up the call.

- Step 8. MS_i sends an acknowledgement to BS_i and BS_i tells MSC the acknowledgement via the wireline network.

- Step 9. MU_i replaces RC with RC' for the next call setup and assigns a number $V_{BS_i}^{(0)} = h(ID_{BS_i})$ for use in handoff.

- Step 10. After receiving the acknowledgement from MU_i , MSC replaces RC in the database with RC' and stores $S_{BS_i}^{(0)}$ for use in handoff, the two-way authentication procedure is now completed. $\square$

3.2 Secure Conference Call Construction

In this section we present a secure conference call for mobile communications. We assume that there are $m+1$ mobile units $MS_0, MS_1, MS_2, \dots, MS_m$ in the system. Let MS_0 be the chairperson who initiates the electronic conference with any k of the other m mobiles, where $1 \leq k \leq m$. Let $G = \{MU_{i_1}, MU_{i_2}, \dots, MU_{i_k}\}$ be the set of conferees to whom MU_0 wishes to establish connection. The conference call protocol is sketched in Fig. 2 and summarized as follows.

- Step 1. MU_0 computes $(ID_{MU_0} || RC_0 || K_{s_0})^3 \bmod n$ and $(ID_{MS_{i_1}} || ID_{MS_{i_2}} || \dots || ID_{MS_{i_k}})^3 \bmod n$ and sends them to MSC via BS_0 .
- Step 2. MS_0 and MSC authenticate each other using our authentication protocol for call setup. If the authentication is successfully completed, then MSC calls the other $MU_{i_j}, j = 1, 2, \dots, k$ in G .
- Step 3. After receiving the call signal, each MU_{i_j} computes and sends $(ID_{MU_{i_j}} || RC_{i_j} || K_{s_{i_j}})^3$ to MSC via BS_{i_j} .
- Step 4. Both MS_{i_j} and BS_{i_j} authenticate each other using our call setup authentication protocol. After the authentication between MS_{i_j} and BS_{i_j} is completed, then MU_{i_j} now shares a common session key $K_{s_{i_j}}$ with MSC.
- Step 5. MSC collects the coordinate points (ID_{MU_0}, K_{s_0}) and $(ID_{MU_{i_j}}, K_{s_{i_j}}), j = 1, 2, \dots, k$ and then constructs an interpolating polynomial $f(z)$ of degree k over $GF(n)$ passing through these coordinate points.
- Step 6. MSC generates a number $K_c = f(0)$ as the common encryption key in the conference, regular messages including voice and data are encrypted by K_c during the conference.
- Step 7. MSC selects k distinct coordinate points $(a_j, b_j), j = 1, 2, \dots, k$ from the polynomial $f(z)$.
- Step 8. MSC broadcasts $(a_j, b_j), j = 1, 2, \dots, k$ to the participating mobile units of the conference.
- Step 9. Each participating mobile unit in the conference individually reconstructs the interpolating polynomial $f(z)$ of degree k over $GF(n)$ via the k known coordinate points $(a_j, b_j), j = 1, 2, \dots, k$ and his own coordinate pair (ID_{MU}, K_s) . K_c is thus obtained by substituting $z = 0$ into $f(z)$. $\square$

Fig. 1 Call setup authentication protocol

Fig. 2 Conference call construction

3.3 Handoff Authentication Protocol

When MU_i moves across the cell boundary, it needs to switch from the old base station, BS_i , to the new base station, BS_{i-new} . This procedure is known as handoff. During handoff, it is possible that an intruder pretends to be a genuine base station. In the following we propose an authentication protocol against such attack during handoff. Suppose that initially MU_i is communicating with BS_i via the radio channel. When the first handoff occurs BS_{i-new} sends a new secret key $S_{BS_i}^{(1)}$ to MU_i , MU_i reauthenticates the new base station BS_{i-new} . The protocol is sketched in Fig. 3 and described as follows.

Step 1. MSC chooses a new basebase BS_{i-new} , computes $S_{BS_i}^{(1)} = (h(ID_{BS_{i-new}}))^d \times S_{BS_i}^{(0)}$, where $ID_{BS_{i-new}}$ is the identity of BS_{i-new} , $S_{BS_i}^{(1)}$ is next sent to BS_{i-new} .

Step 2. After receiving $S_{BS_i}^{(1)}$, BS_{i-new} chooses a random number r'_i , generates

$$X_{BS_{i-new}} = g^{-3r'_i} \mod n, \quad (4)$$

$$Y_{BS_{i-new}} = S_{BS_i}^{(1)} \times g^{r'_i} \mod n. \quad (5)$$

and sends $\{ID_{BS_{i-new}}, X_{BS_{i-new}}, Y_{BS_{i-new}}\}$ to MU_i

Step 3. After receiving $\{ID_{BS_{i-new}}, X_{BS_{i-new}}, Y_{BS_{i-new}}\}$ from BS_{i-new} , MU_i computes $\frac{Y_{BS_{i-new}}^2 \times X_{BS_{i-new}}}{RC} \mod n$ to see if it is equal to $V_{BS_i}^{(0)} \times h(ID_{BS_{i-new}})$, where $V_{BS_i}^{(0)}$ is prestored in MU_i , $ID_{BS_{i-new}}$ is sent from BS_{i-new} and RC is a random number prestored in MU_i . If they do match then BS_{i-new} is accepted by MU_i as a legal base station.

Step 4. After completing the handoff procedure, MU_i stores $V_{BS_i}^{(1)} = V_{BS_i}^{(0)} \times h(ID_{BS_{i-new}})$ and MSC stores $S_{BS_i}^{(1)}$. $\square$

Due to the new base station and the previous base station are connected with MSC through wireline links, and the wireline links are made secure in our assumption so that a legal signature of new base station must be relative to previous one. Therefore, if the handoff procedure is executed l times for a MU_i after the conference call is built, the secret key $S_{BS_i}^{(l)}$ of new base station BS_{i-new} is then computed as $S_{BS_i}^{(l)} = (h(ID_{BS_{i-new}}))^d \times S_{BS_i}^{(l-1)}$ and $V_{BS_i}^{(l)} = V_{BS_i}^{(l-1)} \times h(ID_{BS_{i-new}})$, $l \geq 1$.

Fig. 3 Handoff authentication protocol

4. DISCUSSIONS AND SECURITY ANALYSIS

Our scheme offers the following attractive features.

1. **Message confidentiality:** The sensitive information is well protected from outsiders during the handshaking between a subscriber and a BS via the radio link. After the conference call is correctly built, the regular messages including voice and data can also be well protected from outsiders by using the common conference key K_c . K_c is reconstructable by all the authorized mobiles' session keys K_s 's, and K_s 's are secure under the use of RSA scheme, Rivest et al. (1978).
2. **Location privacy:** Users such as wealthy people or high ranking government officials may desire to keep their location secret since location is a critical portion of safety. Location privacy is achieved through the use of random check in our protocol.
3. **Two-way confirmation:** The first generation cellular mobile systems, such as AMPS, provides only voice service so that only the invasion from an illegal subscriber is concerned.

But in the second or third generation of cellular mobile systems which will provide data and other types of service, the impersonation of a subscriber or a genuine BS is possible. Thus two-way authentication becomes necessary and important. Our protocol obviously can provide two-way authentication during call setup. The security of our authentication scheme relies on the difficulty of forging signatures X_{BS} and Y_{BS} which satisfy (1) and (2), since the system secret key d must be first evaluated, it seems intractable as in the well-known RSA.

4. Authentication during handoff: In handoff, the communication link from a subscriber to the old BS is first terminated and switched to a new link to the new BS. During this transition period, it is possible for an illegal BS to personate a new genuine base station. Our protocol indeed prevents this from happening. Since the signature message of new BS is computed from the secret key S_{BS} of old BS and S_{BS} is transmitted by MSC via secure wireline.
5. Security of the conference key: During the conference, in order to achieve secrecy, the message has to be encrypted under K_c before sending out through the radio channel. For K_c , it can only be constructed by the authorized mobiles who participate in the conference. Consider a polynomial $f(z)$ of degree k which is constructed by interpolating $k+1$ distinct coordinate points (ID_{MU_0}, K_{s_0}) and $(ID_{MU_i}, K_{s_i}), j = 1, 2, \dots, k$. MSC chooses other k distinct coordinate points $(a_j, b_j), j = 1, 2, \dots, k$ from the loci of $f(z)$. Each MU interpolates the k coordinate points (a_j, b_j) s with his own coordinate point (ID_{MU}, K_s) to obtain a polynomial $\hat{f}(z)$, then $\hat{f}(z)$ is identical to $f(z)$. Owing to K_s is only known by an authorized MU in the conference, K_c can be obtained from $f(z)$ with $z = 0$. But other unauthorized MUs have no way of getting K_c . Therefore, K_c is secure from revealing by outsiders.
6. Free of replay: Replay is a serious problem in authentication protocol. An easy solution is to embed a time stamp into the message, while time synchronization is needed for the time stamp strategy. In our scheme, because random number RC , signature pair (X_{BS}, Y_{BS}) are randomly changed in each authentication procedure, the attack of replay can thus be avoided.
7. Low computation complexity: Due to the requirements of low circuit complexity and low power consumption in handset, a subscriber has only limited computing power. The computation complexity of exponent encryption in our scheme would be lower when a small exponent (e.g. $e = 3$) is to be chosen and n is a 512-bit composite number. Using the addition chain method in Knuth (1981), only two modulo multiplications are required. In an 8-bit microcontroller, handset or low-circuit complexity terminals, for example, the computation time in a single 512 modulo multiplication takes about 0.1s so that our handset only requires about 0.2s processing time in performing the public key encryption. Using RSA scheme, approximately 20s is needed for an 8-bit microcontroller. On the other hand, the construction of K_c in each MU needs $O(k \log^2 k)$ operations using methods discussed in Knuth (1981), where k is the total number of participating mobile units in the conference call. It is believed that a mobile can perform such computation in a reasonable time.
8. Defend the intrusion from BS: In a cellular mobile system, there are many widespread BSs. These BSs are unprotected and may be intruded. Anyone trying to steal the secret information from subscribers can be done by intruding a BS. So it is insecure to place permanent and secret information in BS. A MSC is usually more well protected to have better protection of permanent and secret information. In our protocol there is no permanent and secret information stored in BS. What placed in the BS, are temporary messages. Even when an intruder can collect all the information of a specific user in BS, he still can

not determine the secret d of MSC since breaking the system is the same as challenging the RAS algorithm.

One concern of our work is that the MSC needs to maintain a database of all the home subscribers' relative information which may be vulnerable to attacks. But this can be prevented by storing these information in ciphertext form.

5. CONCLUSIONS

In this paper we have proposed an ID-based two-way authentication scheme suitable for digital cellular mobile radio system in terms of hardware complexity, time complexity and power consumption. The proposed scheme is initially finished through two-way authentication, and further extended to multi-mobile unit in order to hold a conference call. In particular, the secret information appearing in BSs is randomly changed to prevent the intruder from penetrating BSs to steal the information. Although the computation in MSC is more complex, our assumption that MSC has powerful computing capability to compute the secret key of BS in the manner that a subscriber and a BS can authenticate each other within a reasonable time is not too unrealistic.

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