Trustworthy Device Pairing for Opportunistic Device-to-Device Communications in Mobile Crowdsourcing Systems

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ABSTRACT

Mobile Crowdsourcing System is an emerging service paradigm base on numerous personal smart devices, where the Device-to-Device communication among opportunistically encountered participating devices is an indispensable part of task allocation, file transmission and data collaboration. Considering that participating devices are privately held and opportunistically encountered, we design the Trustworthy Device Pairing (TDP) scheme that realizes user-transparent sharing secret key negotiation and reliable peer device determination for trustworthy spontaneous D2D transactions. TDP is demonstrated to be effective based on our proof-of-concept implementation, and a further evaluation on efficiency will be conducted.

1. INTRODUCTION

Mobile devices with enriched sensing capabilities stimulate the proliferation of mobile crowdsourcing systems (MCSs), an ubiquitous, heterogeneous and smart service paradigm that aims to provide data collecting, processing and computing services, by exploiting the capacities of ubiquitous personal mobile devices in a collaborative way [1].

The emerging Device-to-Device (D2D) communication techniques [2] such as WiFi Direct, Bluetooth Smart, and LTE direct have a great potential to provide cost-effective solutions to collaborative interactions among mobile devices for mobile crowdsourcing [3, 4]. However, since participating devices are private and temporarily hired, there is no prior trust relationship between devices opportunistically encountered. The initial trust establishment, or Device Pairing, cannot rely on physical interactions between unfamiliar device holders. Furthermore, considering the high device density, there is no reference to determinate a proper peer device among multiple available candidates.

In this paper, we propose a mechanism, TDP, for opportunistically encountered devices in MCSs to autonomously establish a secure D2D connection transparently to device holders. Moreover, trustworthy peer device is determined based on the device trust value reflecting the reliability on fulfilling different types of D2D transactions. Specifically:

- TDP realizes user-transparent device pairing that is not supported by off-the-shelf protocols [5, 6] and rapid device pairing that is faster than state-of-art non-interactive device pairing schemes [7–9], and device trustworthy is novelly adopted for the determination of the most reliable D2D peer device.
- TDP guarantees a comparable security intensity as off-the-shelf device pairing protocols [5, 6] while taking account of traffic oriented attacks, like the Trust Forging Attack and the Collusive Attack manipulating D2D traffic, that are exclusive for D2D communications in MCSs.

2. SYSTEM ARCHITECTURE

An MCS, see Fig.1(a), is generally composed of a Backend Server (BS) and numerous participating devices (A, B, ..., N). Specifically, BS formulates service campaigns, publishes crowdsourcing applications, outsources computing and sensing tasks, manages feedback and maintains device profiles. On the other hand, any personal smart device that has installed the crowdsourcing application and registered at BS becomes a potential contributor to crowdsourcing tasks. Devices communicate with BS through wireless access of the Internet, like WiFi or cellular access points, meanwhile they communicate with each other in a D2D manner through outband wireless channels, like Bluetooth or WiFi Direct connections.

Based on the crowdsourcing application installed on participating devices, BS outsources crowdcomputing tasks intending to offload computing or processing intensities and crowdsensing tasks intending to spontaneously collect environmental or social status data. Accepting allocated tasks, participating devices need to establish D2D connections with opportunistically encountered peers to recruit collaborators, exchange intermediate processing results, or forward sensing data packets.

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Figure 1: Architecture of TDP

3. TRUSTWORTHY DEVICE PAIRING

Considering issues discussed in Section 1, we design the Trustworthy Device Pairing (TDP) scheme to realize opportunistic D2D communications and the D2D trust management in MCSs. Specifically, it has three major components: Device Registration, Device Pairing, and Device Trustvalue Management, whose general procedure is illustrated in Fig.1

3.1 Device Registration

In our design, device pairing credentials are generated and managed within a Certificateless Public Key Cryptography (CL-PKC) framework [10], where an authenticated key pair composed of a private key and a public key (sk, pk) is utilized for device authentication and sharing secret negotiation. Under CL-PKC settings, the Computational Diffie-Hellman Problem on the Elliptic Curves [11] is treated as an intractable mathematical problem.

For the system initialization, BS setups security parameters according to system scale, like expected user amount, server capacities, and types of provided services. An elliptic curve E and the master key pair (x, P_{pub}) of BS is generated, where E and P_{pub} are predeployed into our crowdsourcing application.

Any personal smart device, says A, that has installed the application becomes a potential crowdsourcing task contributor. To get its D2D credential, A needs to register at BS. The secret and public key pair of A (sk_a, pk_a) is cooperatively generated by A and BS, where parts of sk_a and pk_a are locally generated by A and the rest of them is generated by BS based on the received public key part of A using the master secret key x . Such a cooperative means guarantees that BS is not able to decrypt D2D traffic between any arbitrary pair of encountered devices since it does not have any entire key pair, while, generated using the master secret key x , any valid key pair itself can be treated as an authenticated certificate for mutual authentication between opportunistically encountered devices.

3.2 Device Pairing

The determination of a proper peer when there are multiple options will be explicitly discussed in the next section. Without loss of generality, when determines to conduct a D2D transaction with registered device B, registered device A will initiate the Device Pairing process in Fig.1(b).

With the public key of peer device in the probe packet, A and B will respectively generate a partial sharing secret $V_{a(b)}$ based on their own private key $sk_{a(b)}$, the other's public key $pk_{b(a)}$ and the main public key P_{pub} . Since the partial sharing secret based on one's public key can only be verified using corresponding private key, and valid public keys of registered devices can be authenticated using the main public key, A and B are able to restore the partial sharing secret of their peer device $V'_{b(a)}$.

The final sharing secret $S_{ab} = V_a \oplus V'_b = V'_a \oplus V_b$ can be authenticated using general Challenge-Response schemes. If S_{ab} is successfully established, then we say A and B are mutually authenticated, and S_{ab} is treated as the session key of the current D2D transaction.

3.3 Device Trustvalue Management

In our design, we use behaviors in previous D2D transactions to evaluate the reliability of device fulfilling future transactions, which is regarded as the criterion of the peer device determination when there are multiple D2D options.

We define such a reliability as Device Trustvalue $t(ID_a, i)$, which is an n -dimension vector with the value of each dimension representing the reliability of device A fulfilling corresponding type of D2D transaction defined by BS after its i 'th transaction. $t(ID_a, i)$ can be calculated as

$$t(ID_a, i) = \frac{2}{\pi} \arctan(\tan(\frac{\pi}{2} t(ID_a, i-1)) + \Delta t), \quad (1)$$

where Δt is defined as

$$\Delta t = S * Cre * tv, \quad (2)$$

where S is the feedback A received in its i th D2D transaction, tv is an n -dimension vector that represent the weight of such a transaction, and Cre is A's confidence level on S , which is defined as

$$Cre = \beta Div + (1 - \beta) Sim, \quad (3)$$

where Div denotes the relative diversity of devices that A and its peer have paired with before, Sim denotes the similarity of feedback that respectively from A and its peer to devices that both of them have paired with before. Both of them can be retrieved from device pairing histories that record previous feedback to those paired devices. $\beta \in (0, 1)$ is the weight adjustment coefficient. The meaning of Div and Sim is to prevent potential adversaries from forging their own trustvalues or collusively enhancing each other's trustvalue within a group to manipulate D2D traffic.

With such a definition of device trustvalue, according to Fig.1(c), a participating device, says A, will cooperatively generate a D2D transaction receipt Re with its peer device, says B, to record feedback, credibility and transaction vector for a trustvalue adjustment at BS. Such a receipt is, and only is, verifiable to A, B and BS using their private keys, while the obfuscated feedback is verifiable to the receiver without revealing its actual value.

For participating devices, the trustvalue adjustment is delay-tolerant, which is only performed when there is an

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Problems Javadoc Declaration Search Console LogCat Devices
BackEndServiceService [Java Application] C:\Program Files\Java\jre7\bin\javaw.exe (01.07.2015 20:41:08)
Connected
=====
Device Registration Requests
=====
Device ID : 1120028880846232760483695201306055846280774660886
Device P : 021D9681A81B1962C8BF7D0987A358412C9F248750
Device R : 033F3EF4636865C7CD27458D2A6386301D83172978
=====
Current Registered Devices :
Device (ID) : 1120028880846232760483695201306055846280774660886
=====
Connected
=====
Device Registration Requests
=====
Device ID : 1146135003874081429272444946334775525019883714106
Device P : 021E30E3CF43BA9E34D1D12EA6C7F727A570D8E131
Device R : 0306F8FFB07AC262BC3A8955C569FFE88242872A8E
=====
Current Registered Devices :
Device (ID) : 1146135003874081429272444946334775525019883714106
Device (ID) : 1120028880846232760483695201306055846280774660886
=====
Connection reset by the other end
Connection reset by the other end

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Figure 2: Implementation of BS

economical access to the Internet. BS is responsible for the verification of D2D receipts and the adjustment of trustvalues, after which it will generate a corresponding digital signature of the adjusted trustvalue for its future D2D pairing authentication.

4. IMPLEMENTATION

We implement a Proof-of-Concept version of device registration and pairing functionalities on a prototype consisting of a BS based on Window7 workstation and two Android smart devices (Google Nexus7 with Android L and Samsung Galaxy Note3 with Andorid 4.3 Jelly Bean) with Bluetooth V4.0 modules, where our implementation is running as a security service upon a rapid insecure Bluetooth connection [12].

With cryptography primitives introduced by [13] and ECC parameters adopted from secp160r1 [14], device registration and pairing functionalities are realized, as shown in Fig.2 and 3. D2D credentials $sk = (x, d)$, $pk = (P, R)$ are cooperatively generated by BS and the participating device. After the registration, device is able to start the crowdsourcing service that allows user-transparent pairing with other registered device encountered, and the D2D session key SK will be negotiated and authenticated based on D2D credentials.

5. CONCLUSION AND FUTURE WORK

In this paper, we presented TDP focusing on trustworthy device pairing for opportunistic D2D communications in MCSs. We realized a user-transparent device pairing scheme to establish sharing keys securing D2D transactions between encountered devices, then proposed a device trust management mechanism to evaluate the reliability of encountered devices fulfilling pending D2D transactions. Based on our implementation, TDP is demonstrated to be effective for MCSs.

In future, we will extend our pairing scheme to WiFi Direct communications for a higher bandwidth, and further evaluate the performance of our trust management mechanism with both OMNeT++ simulations and voluntary participating experiments in real campus environments. Additional factors we emphasize during the evaluation include participant mobility modeling and crowdsourcing task/D2D transaction modeling.

Figure 3: Device Registration and Pairing

6. REFERENCES

- [1] Ju Ren, Yaoxue Zhang, Kuan Zhang, and Xuemin Shen. Exploiting mobile crowdsourcing for pervasive cloud services: challenges and solutions. *IEEE Commun. Mag.*, 53(3):98–105, 2015.
- [2] A. Asadi, Qing Wang, and V. Mancuso. A survey on device-to-device communication in cellular networks. *IEEE COMMUN SURV TUT*, 16(4):1801–1819, 2014.
- [3] Shusen Yang, Usman Adeel, and Julie McCann. Selfish mules: Social profit maximization in sparse sensor networks using rationally-selfish human relays. *IEEE J. Sel. Areas Commun.*, 31(6):1124–1134, 2013.
- [4] Shusen Yang, Usman Adeel, and Julie McCann. Backpressure meets taxes: Faithful data collection in stochastic mobile phone sensing systems. In *Proc. IEEE INFOCOM*, 2015.
- [5] Wi-fi peer-to-peer (p2p) technical specification v1.5. *Wi-Fi Alliance*, 2014.
- [6] Bluetooth core specification 4.2. *Bluetooth SIG*, 2014.
- [7] Markus Miettinen, N. Asokan, Thien Duc Nguyen, Ahmad-Reza Sadeghi, and Majid Sobhani. Context-based zero-interaction pairing and key evolution for advanced personal devices. In *Proc. ACM CCS*, pages 880–891. ACM, 2014.
- [8] Hien Thi Thu Truong, Xiang Gao, Babins Shrestha, Nitesh Saxena, N Asokan, and Petteri Nurmi. Comparing and fusing different sensor modalities for relay attack resistance in zero-interaction authentication. In *Proc. IEEE PerCom*, pages 163–171. IEEE, 2014.
- [9] Jingchao Sun, Xu Chen, Jinxue Zhang, Yanchao Zhang, and Junshan Zhang. Synergy: A game-theoretical approach for cooperative key generation in wireless networks. In *Proc. IEEE INFOCOM*, pages 997–1005. IEEE, 2014.
- [10] Sattam S Al-Riyami and Kenneth G Paterson. Certificateless public key cryptography. In *Advances in Cryptology-ASIACRYPT 2003*, pages 452–473. Springer, 2003.
- [11] Antoine Joux and Kim Nguyen. Separating decision diffie-hellman from computational diffie-hellman in cryptographic groups. *Springer J CRYPTOL*, 16(4):239–247, 2003.
- [12] Android. Bluetoothadapter. <http://developer.android.com/reference/android/bluetooth/BluetoothAdapter.html>.
- [13] Bouncy Castle. The legion of the bouncy castle java cryptography apis. <http://www.bouncycastle.org/java.html>.
- [14] Certicom Research. *SEC 2: Recommended Elliptic Curve Domain Parameters*. Standards for Efficient Cryptography Version 1.0, 2000.