A Survey on Context-based Co-presence Detection Techniques

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Abstract—
The use of co-presence (or proximity) detection techniques is rapidly increasing in mobile authentication systems due to their improved usability. Specifically, a co-presence detection refers to the contactless authentication approaches which verify that a prover (or user) and a verifier (or terminal) are within specified proximity, before the verifier grant access of the system to the prover. Unfortunately, the radio channel, e.g., near-field communication (NFC) and radio frequency identification (RFID), used for communication between the prover and terminal are vulnerable to various security and privacy attacks such as eavesdropping, relay, impersonation, and distance hijacking. Thus, limits the security and usability of such communication systems.

In this paper, we present a systematic survey on the proximity verification techniques that are being used in Zero-Interaction based Co-presence Detection and Authentication (ZICDA) systems. First, we discuss the possible adversary and communication models, and the existing security attacks on ZICDA systems. Then, we review the state-of-the-art proximity verification techniques that make use of contextual information. Such techniques are commonly referred as Contextual Co-presence (COCO) protocols, which dynamically collect and use the specific contextual information to improve the security of such systems. Finally, we summarize the major challenges and suggest the possible innovation and efficient future solutions for securely detecting co-presence between devices. Based on our review, we observe that detecting co-presence between devices is not only challenging but also a significant contemporary research problem. The proximity verification techniques presented in the literature usually involve trade-offs between metrics such as efficiency, security, and usability. However, currently, there is no ideal solution which adequately addresses the trade-off between these metrics. Therefore, we trust that this review gives an insight into the strengths and shortcomings of the known research methodologies.

Index Terms—Relay attack, Zero-interaction authentication, Context-aware, Sensor modalities, Distance bounding, RFID, Proximity detection.

I. INTRODUCTION

NOWADAYS, there are many industrial applications which grant specific services and privileges based on the physical proximity of the communicating devices. For instance, we use contactless smart keys to unlock our cars, even start the engine without inserting the keys. These industrial applications use the most popular short-range communication technologies called Radio Frequency Identification (RFID) and Near Field Communication (NFC), for establishing contact between the communicating pairs. Other widely used applications that use short-range contactless smart cards based on RFID or NFC includes supply chain management, e-passport, access cards (such as building, parking, highway toll fee collection and public transports), medical implants, Point-of-Sale (PoS) systems, to name a few. Moreover, the smartcard based access control systems that require proximity verification and authentication are also being deployed in safety and security-critical infrastructures such as military research facilities and nuclear power plants, thus it is essential to secure such systems for all types of adversaries. The main reason for the popularity of contactless authentication systems when compared to contact-based smartcards is there higher overall user experience in terms of ease in manageability and usability.

By definition, RFID systems are used for uniquely identifying objects and individuals using radio waves. An RFID system usually consists of a tag, a reader, and an antenna. When a tag comes into the proximity of a reader, the reader broadcast interrogating signals using the antenna. The tags reply to the reader’s query using their unique identification number. The range of communication between tag and reader is up to 100 meters depending upon the use of active or passive tags. The NFC is considered as a future RFID technology with a communication range of few centimeters only. NFC allows mobile devices such as smartphones and tablets, to have both tag and reader functionalities. Thus, NFC device can act both as a reader and as a tag. The major technology companies and financial institutions such as Apple, Samsung, Visa and Sony, and telecommunication providers such as T-mobile and Verizon in the US are working together to provide smartcards that use the NFC technology. It is done to offer various services in fields like contactless payment systems, identification, smart homes, and business. A recent study unveils that approximately 2000 million bases of NFC-enabled phones are installed worldwide from 2013 to 2018, and transactions conducted via NFC handsets will grow from USD 45 billion in 2017 to USD 240 billion in 2021. Unfortunately, due to the inherent weaknesses in underlying wireless communication, the RFID/NFC systems are exposed to a wide variety of security and privacy attacks. Thus, it subverts the security and usability advantages offered by these
authentication systems.

In particular, the so-called relay attacks are one of the many distance hijacking attacks that exploit the radio communication technology of RFID/NFC systems [7] [8] [9]. In relay attacks, to impersonate a victim’s card within the proximity to the reader, a proxy device (or often referred to as "ghost") which emulates a contactless smartcard is placed near the reader. On the other end of the communication point, a mole (or often referred to as "leech") which acts as a reader is placed nearby the victim card [10]. Both of these malicious devices are in control of an adversary. The proxy forward all the messages to the mole which act as a fake authentic reader for the victim card. The distance between the proxy and mole can be increased as far as the communication delay is kept sufficiently short. Example instances that show the vast existence of relay attacks are demonstrated in [11], in which authors show a successful relay attack over more than 300 miles, and in [8], in which authors demonstrated relay attacks on passive keyless entry and start for over 50 meters. Furthermore, in [12], successful relay attacks over more than 110 meters are demonstrated using three NFC smartphones.

To overcome the aforementioned inherent vulnerabilities of contactless communication systems (i.e., RFID/NFC), the researchers are working towards various defense techniques. These techniques try to preserve the fundamental properties such as zero-interaction and usability of these systems while ensuring the protection from various distance hijacking attacks. The two most commonly found defense techniques in the state-of-the-art are the contextual co-presence [15] [16] and the distance bounding [14] [16] protocols. Both these protocols provide zero-interaction authentication [1, 2002], which uses a secure co-presence detection between the prover and verifier devices as an additional security measure. In particular, one device called “prover (P)” needs to prove to another device called “verifier (V)”, that P is within the proximity of V, and P is not malicious. In other words, to get access to V, not only P has to verify its co-presence to V, but it is also required that P authenticate (using some cryptographic techniques or contextual information) itself to V. In the distance bounding protocol, the system assumes that both, the prover and the verifier shares a secret in advance. Using this secret, the verifier triggers a rapid-fire round of cryptographic challenges, and the prover needs to respond quickly to these challenges. The round-trip-time (RTT) consisting the time between sending a challenge and receiving a response is then used to estimate the upper-bound on the distance between P and V.

The contextual co-presence detection protocols leverage the fact that both the devices reside within the proximity of each other will “see” (approximately) the same ambient environment (i.e., context). Thus, it ensures that only the two co-present devices could have the same contextual information from their surroundings. In this paper, the co-presence detection techniques that are based on distance bounding protocols are considered out of the scope. It is because we aim to review only the applications that make use of resource constrained and commodity devices as a prover and verifier. The distance bounding needs to be implemented at the lowest possible layer in the communication stack because even a small error in estimating processing time at the prover side can lead to significant deviations in the distance bound. Therefore implementing distance bounding on commodity devices like ordinary smartphones might be a challenge. We direct the interested readers toward the following comprehensive distance bounding related research works [17] [18].

A. Motivation

Due to technological advancements in the mobile devices and radio frequency communications, a broad array of applications such as contactless payments, keyless entry systems, proximity cards, smart posters, to name a few, are deployed rapidly for mass-market users. These applications use contactless authentication along with the proximity verification between the communicating devices for ensuring secure access control. The increased overall user experience regarding ease in manageability and usability are the main attractions of these applications. Unfortunately, the radio channel used for communication is vulnerable to various security and privacy attacks such as eavesdropping [19], relay attack [20] [21], impersonation [22], and distance hijacking [23]. Thus, it limits the usability of these application domains.

The considerable potential damage such as an unauthorized entry in a secure and sensitive facility, stealing a car, credit card frauds and skipping tolls, which could be caused by exploiting the vulnerabilities in co-presence systems require a robust security model. Over the years, researchers have proposed many solutions based on distance bounding and context-aware information protocols, which develop patches to fix these vulnerabilities. To the best of our knowledge, this is the first attempt which provides an extensive overview of the attacks and prevention techniques for Zero-Interaction based Co-presence Detection and Authentication (ZICDA) access control systems. However, efforts have been made to describe, the problem and its possible solutions within one specific protocol, like distance bounding protocols for distance based attacks [17], or within a particular communication technology like RFID [24]. The current survey does not sufficiently cover the details of all the ongoing attacks on proximity and their proposed solutions, but they only provide partial coverage of the attack vector. For example, in [25], author’s discuss the feasibility of implementation, and the corresponding security implications for various active and passive relay attacks, and in [26], authors present a brief survey on various attacks and their countermeasures using distance bounding protocols with IEEE 802.15.4a (i.e., Impulse Radio Ultra-Wideband). Additionally, [25] and [26] are outdated given the extensive research that was done in the last few years on the security of co-presence systems. It is due to the increase in the attack vector, which is caused by these systems rapid deployment in real-world scenarios. Hence, we firmly believe that a comprehensive survey is essential for an audience who are planning to initiate research in this direction. This paper does not attempt to solve any new challenge but presents an overview and discussion of the ZICDA systems security threats along with their available countermeasures.
B. Contributions

In this paper, for the first time, we provide a comprehensive survey on co-presence detection techniques, our survey includes state-of-the-art contextual security protocols for co-presence detection between devices in ZICDA access control systems. We believe that we have taken here the required initial steps that will help understand, how to make full use of the contextual information to provide flexibility, and to strength decision making in access control systems. To this end, the major contributions of our work are as follows:

- We present the current security problems that are affecting the use of contactless smartcards in ZICDA access control systems, we review security threat’s, vulnerabilities, and attacks specific to these systems, and we examine the existing security solutions that protect these systems from various risks. In particular, we survey the literature over the period 2000-2018, by focusing our attention on impact analysis of security attacks performed on ZICDA systems.
- We present a general architecture of the ZICDA system, which includes its characteristics, deployment challenges, and applications. Furthermore, we discuss the communication and adversary system models that are being used in ZICDA based access control systems. In particular, we assist interested readers in understanding existing challenges in the deployment of ZICDA systems, estimate the possible damages caused by the adversaries, and to improve the techniques for proximity detection and containment processes. Furthermore, we provide an overview, concerning feasibility, robustness, and effectiveness for the existing and potential attacks over ZICDA systems, and we examine the risks for users of these systems.
- We present a survey of the state-of-the-art security solutions for detecting co-presence using contextual information, and are known as Contextual Co-presence (COCO) protocols. We further extend our survey by including, the co-presence detection techniques that also emphasize, the importance of privacy preservation (mainly regarding user location) during the access control authentication processes in location based services. Please note that this paper do not survey the context-aware solutions that are used for improving the security and privacy of users in other application domains, such as mobile applications [27] [28], Internet of Things (IoT) [29], Industrial IoT [30], and future wireless networks [31].
- Finally, we discuss how the existing approaches ensure fundamental security requirements and protect communications in the ZICDA systems together with the open challenges and strategies for future research work in the area. This is, as far as our knowledge goes, the first survey with such goals.

To the best of our knowledge, this is the first survey in the area of co-presence detection techniques in ZICDA systems. Our survey indicates that the co-presence between devices is not only challenging but also a significant contemporary research problem. The state-of-the-art co-presence detection techniques usually involves trade-off between essential system metrics such as efficiency, security, and usability. Currently, there are no reasonably good solutions available which adequately addresses the trade-off between these metrics. Therefore, we trust that this review gives an insight into the strengths and shortcomings of the known research methodologies, and it provides a platform to the researchers and practitioners towards developing next-generation privacy preserving and secure, yet usable co-presence detection techniques for ZICDA systems.

C. Organization

The rest of the paper is organized as follows. In Section II we present the overview of ZICDA systems, which include its characteristics and applications. In the same section, we also discuss details about communication model, authentication system, and adversary model used for proximity verification between communicating devices in a ZICDA system. Furthermore, at the end of the Section II we discuss all the existing attacks and their impacts on the co-presence detection systems. In Section III we review existing solutions which are proposed for detecting the co-presence between the communicating devices. We broadly discuss the proximity detection techniques that are based on contextual co-presence protocols. In Section IV we present open issues and directions for future work. Finally, Section V concludes the attacks in co-presence systems and their existing solutions.

II. ZERO-INTERACTION BASED CO-PRESENCE DETECTION AND AUTHENTICATION

In this section, we present the overview of the functional model for Zero-Interaction based co-presence Detection and Authentication (ZICDA) access control system. First, We define the terminologies, and the standards and deployment techniques used in ZICDA systems. Then, we discuss the standard communication and adversary model for ZICDA systems. The communication model includes, type and number of devices along with their functions and interaction protocols used in ZICDA systems, while in adversary model, we discuss assumptions made and capabilities of adversary in a ZICDA system.

The ZICDA system represents a set of contactless access control systems in which the access-seeking entity (or person) will implicitly prove their location information along with the verification credentials. ZICDA systems can use Bluetooth Low Energy (BLE), Near Field Communication (NFC) and Radio Frequency Identification (RFID) technologies as a wireless communication channel between the communicating entries. For instance, Passive Keyless Entry (PKE) system which is also named as “Smartkey” system is an automobile’s electronic lock and ignition system. In PKE system, the driver carries a token (i.e., smartkey) that communicates (using RFID technology) with car’s access control system, and unlock the doors, and activate the ignition, only if, the token’s authenticity and proximity can be verified.

Verifying the proximity along with the authenticity is necessary in ZICDA systems else, these systems becomes vulnerable to various forms of Man-In-the-Middle (MIM) attacks.
such as eavesdropping, distance-hijacking, data corruption and manipulation, and relay attacks. However, proximity can be simply guaranteed through received signal strength, but an adversary can easily manipulate the signal strength through active relays. A large number of access control systems are susceptible to MIM attacks as depicted by a comprehensive study in [24]. Particularly, relay attacks are successful in ten car models from eight different vendors [8]. In addition to vehicular systems, these attacks can easily target credit/debit cards and smartphones which uses NFC technology, and contactless smartcards.

A. Terminology and Standards

A ZICDA access control system consists of various components, technologies and its functionality is driven by many factors. We use the following terminologies regarding the ZICDA systems in the rest of this paper:

- **Zero-Interaction authentication (ZIA) system**: In ZIA, a user wears a small authentication token (i.e., smartcard, tag etc.) that communicates with a verifier over a short-range, wireless link. Whenever the verifier needs decryption authority, it acquires it from the token; authority is retained only as long as necessary. In this paper, we consider "proximity based ZIA access control system", and called it ZICDA system. In ZICDA systems, the verifier not only authenticate the prover, but also verify, whether the verifier and prover devices are co-present or not.

- **co-presence detection systems**: In a co-presence detection systems, a terminal authenticates the presence of a user device in physical proximity of the terminal over a wireless communication channel. We use the terms “co-presence” and “proximity” interchangeably.

- **Smartcard**: A “contactless” smartcard is a card that can communicate with the reader without having any physical interaction. Smartcards can provide unique identification, authentication, data storage, and application processing. We use the terms “smartcard”, “proximity card”, “smartkey” and “tag” interchangeably.

- **Prover (P)**: In ZICDA systems, P is an end-user(s) holding the smartcard in order to get access for a specific service (i.e., entering in building, unlocking a car, and payment at PoS etc) by authenticating itself to the reader. We use the terms “prover” and “user” interchangeably.

- **Verifier (V)**: Verifier is a device, it performs the access control function for ZICDA systems by conducting authentication and proximity verification process for provers. Verifiers broadcast challenges to smartcards in their radio communication ranges, and smartcards send responds to get access into the system. We use the terms “verifier”, “reader”, and “terminal” interchangeably.

- **Cryptographic keys (C_key)**: $C_{key}$ represents the secret key (private/public keys or shared keys) used between the prover and verifier for authentication process, and for encryption of the communication traffic.

- **Adversary**: An adversary is a malicious entity that tries to disrupt the communication process between a prover and a verifier device in ZICDA system. We assume, the adversary has no physical control over the hardware and software’s installed in the prover and verifier devices, but it has complete control over the communication channels.

B. Communication Technologies

Among the three short-range, and low-energy sensor technologies used in ZICDA systems, including Radio Frequency Identification (RFID), Near Field Communication (NFC), and Bluetooth Low Energy (BLE), NFC is used in a large array of applications. This is because NFC combines the security of BLE with the short-range data transfer capabilities of RFID. For NFC to work, one must tap or wave his smartphone (acts as NFC reader) against a NFC tag to secure an objects context or to perform an action. For example, you could purchase chocolates just by tapping your NFC reader against the box of chocolates. NFC capable device such as smartphone can work as a reader as well as a tag. It is predicted that NFC will be used as a key technology in realizing Internet of Things (IoT) [32] paradigm due to its enhanced security features, such as a user can easily pair an NFC tag with another form of authentication on hand (like the license in your wallet) to create a two-pronged authentication system. This method is particularly relevant in the health-care world [33], and is even being mandated by the Drug Enforcement Administration (DEA) as a standard security practice.

NFC is viewed as a finely honed subset of Radio Frequency identification (RFID). NFC operates at the same frequency (i.e., 13.56 MHz) as high frequency RFID tags and performs many of the similar operations as RFID tags and readers.
NFC can operate in the following communication modes:

- **Read/Write:** In this mode, a NFC-enable reader/writer device can read information from the smart objects, and act up on the received information to improve services provided by these smart objects. By performing a simple touch of their device to the smart objects, users can perform various tasks such as end short message service (SMS) texts without typing, automatically connect to websites via a retrieved URL, and get information about various relevant offers or obtain coupons. This mode is very helpful for realizing Internet of Things (IoT) services.

- **Peer-to-Peer:** In this mode, one NFC-enable reader/writer device can communicate with other NFC-enable reader/writer device. One of the reader/writers device behaves as a tag, creating a communication link.

- **Card Emulation:** Working in this mode, a NFC-enable reader/writer device can replace a contactless smartcard, enabling NFC devices to be used within the existing smartcard infrastructure for services such as making payments at PoS, access control at building entrance or for a vehicle, tollgates, and medical implants.

As NFC being subset of RFID, the standards and protocols for NFC are based on RFID standards outlined in FeliCa, ISO/IEC 14443 [34], and some are parts of ISO/IEC 18092. The use of proximity cards using RFID technology is governed by these standards.

C. Communication and Adversary Models

In this section, we discuss the standard communication and adversary models for the ZICDA systems. Figure 2 shows a general communication model for ZICDA systems (i.e., co-presence based authentication systems). The communication model consists of two devices, prover (P) and verifier (V). In order to get access in the system, P has to authenticate itself to V, and also prove that P is close to V. The authentication process between the devices i.e., P and V triggers automatically when both devices are in close proximity (or communication range) to each other. The communication traffic between P and V is encrypted using a pre-shared secret key which is generated using either shared-key or private/public key model. P encrypt its authentication information using her secret key before transmitting it to V. Depending upon the application and system implementation, a “credential verification” function make the authentication decision for P at V either locally or remotely as shown in Figure 2. For example, in a PoS application, a user (i.e., P) performs the contactless payment using her NFC-enabled smartphone at a PoS terminal (i.e., V). In this specific application, the “credential verification” function will be stored at the web server of bank whose credit card is used for the payment at PoS terminal. Other applications such as locking/unlocking a car using a smartkey, or mobile phone) acts as P and the terminal (i.e., a desktop computer, wall-mounted device or car) plays the role of V.

The adversary model for ZICDA systems is shown in Figure 3. We assume that an adversary possesses following standard Dolev-Yao [35] features and capabilities: a) adversary (A) has complete control over the communication channel used for authentication process between P and V, and b) A has no physical access or possession of P and V, nor does A can compromise the functionality of P and V devices. Therefore, none of the benign entities in the communication protocol of ZICDA system can be tampered with or compromised. However, A is allowed to stay in close proximity of V and P. The main aim of A is to fool V into concluding that P is in close proximity, and thus acquires access to V despite the fact that P is not co-present to V, and P is not intending to authenticate to V.

As it can be seen from Figure 3 that A is allowed to stay in the close proximity of P and V, thus it can perform the various forms of distance hijacking (i.e., distance-reduction or distance-enlargement) attacks on the wireless communication channel between P and V. First, A can intelligently place one device called mole (A_v) in the close proximity to P, without P knowing about it. A_v acts a legitimate reader is placed nearby the victim’s card (i.e., P). Then, A places another device called proxy (A_p) close to V, and A_p emulates a contactless smartcard which is placed near the V. Both A_v and A_p communicates using a high bandwidth channel. In this way, A takes the form of a “mole-and-proxy” (or often called “ghost-and-leech”) duo (A_v, A_p), and relays messages to and forth between V and P. Thus, leading V to conclude
D. Attacks vector for ZICDA Systems

In this section, we discuss various attacks reported in literature that have been launched by adversaries upon exploiting the vulnerabilities of inherently insecure communication channel in ZICDA systems. In principal, ZICDA systems must ensure security against various man-in-the-middle (MIM) attacks along with attacks caused by a malicious prover or verifier. To provide security against all types of attacks in ZICDA systems is a challenging task, therefore the existing authentication protocols for ZICDA systems consider addressing a subset of these attacks. In particular, a ZICDA system should be protected against the following attacks:

- **Mafia fraud:** Mafia fraud attacks, also called relay or wormhole attack, are first introduced by [37] and [38]. In this attack, the $V$ and $P$ are honest and far apart, and an adversary tries to shorten the physical distance between them. The adversary uses a similar attack scenario as described in Figure 3, the attacker places a proxy verifier ($V'$) near $P$ and a proxy prover ($P'$) near $V$. These proxies simply create an extended high bandwidth communication link between $V$ and $P$ by relaying all the communication messages between them. In this way, $P'$ and $V'$ makes $V$ and $P$ to falsely conclude that both are in close proximity. Traditional cryptographic based security techniques cannot prevent the Mafia fraud attacks as the proxies (i.e., $P'$ and $V'$) need not to perform any decryption or encryption on communication messages, nor they require to run any authentication process with $V$ and $P$. Thus, these proxies are able to create an effective transparent communication link between $V$ and $P$. The attack scenarios used to depict the functionality of Mafia fraud attacks has also been used to describe a wormhole and a relay attack. This attack has been successfully demonstrated in various ZICDA Systems in which NFC/RFID techniques are used for communication between $V$ and $P$.

- **Distance fraud:** In Distance fraud attacks [14], a sole fraudulent prover ($P''$) convinces the honest verifier ($V$) that she is at a different (usually shorter) distance than she really is. Unlike Mafia fraud attack, in Distance fraud attack, the prover itself is dishonest, and only the verifier is a victim here. Distance fraud attacks are most effective and disastrous for real-time location-based systems (RTLS). Application instances of RTLS includes manufacturing, logistics and supply chain management, where expensive components or parts of a final product are automated systems that determine the locations of assets.
and other important entities involved are being tracked throughout the whole logistic process. A practical example of how Distance fraud attacks can adversely effect the RTLS is shown in Figure 4. In this scenario, three nodes (i.e., $V_x$, $V_y$ and $V_z$) perform continuous tracking of the current location of the node $P$ using its received signal strength. As it can be seen from Figure 4, if node $P$ wants to be malicious, it could pretend to be at position $P'$ at the same time when it is at $P$. To perform this action, $P$ decreases its signal strength when communicating with node $V_z$, while increases the signal strength when communicating with $V_y$. In this case, the verifier nodes $V_y$ and $V_z$ are unable to detect the fraud of $P$ because she is a legitimate node, and authenticates herself with true credentials.

- **Terrorist fraud**: A slightly different version of Distance fraud attack in which a dishonest prover ($P'$) attacks the access control system with the help of a third party attacker ($A$) is called Terrorist fraud [39]. In Terrorist fraud attacks, $P'$ which is far apart from a honest verifier ($V$) colludes with $A$, who is in close proximity to $V$ to masquerade as the honest prover by providing $A$ with selected credentials for authentication. A real-world example, assume $A$ is a terrorist who wants to cross the border. $P'$ helps $A$ in answering the questions of the immigration officer (i.e., $V$). Another example could be one in which $A$ helps $P'$ in applications such as location forging. Assume a scenario involving electronic monitoring using an ankle bracelet. Terrorist fraud attack enables the subject (i.e., $P'$) of electronic monitoring system (i.e., $V$) to leave her residence with the help of $A$ who stays in close proximity to $V$.

- **Distance-hijacking**: A Distance-hijacking attack [24] is an attack in which a dishonest far-away prover ($P'$) exploits one or more honest close-by provers’ $\{P_1, P_2, \cdots , P_n\}$ to provide a verifier $V$ with false information about the distance between $P'$ and $V$. Consider a real-world scenario as shown in Figure 5 in which several employees (i.e., $\{P_1, P_2, \cdots , P_n\}$) work in a secure building. A mainframe system (i.e., $V$) containing sensitive information is located inside the building. Any authorized employee can get access to $V$ wirelessly using their contactless smartcard. To complete authorization process with $V$, an employee needs to be in the building along with her valid credentials. Now, assume that an adversary ($P''$), which has a (stolen) smartcard is sitting outside the building along with a powerful antenna. In order to access $V$, $P''$ already has the valid security credentials, but $P''$ also need to prove that she is inside the building. For this purpose, $P''$ performs eavesdropping over the communication channel of the distance bounding protocol, which is running between the employee $P_1$ and $V$ in order to $P_1$ to get access to $V$. Distance bounding works in two phases, in first phase the $P$ needs to prove to $V$ that both are in close proximity to each other. After successful completion of first phase, in second phase $P$ authenticates itself to $V$ using valid credentials. To perform distance-hijacking attack, $P''$ jams the communication link between $P_1$ and $V$ as soon as the first phase of the distance bounding is completed. Then $P''$ will complete the second phase on behalf of $P_1$ using her (stolen) credentials. In this way, $V$ now believes that the $P''$ is in the building with valid credentials, and she is granted wireless access.

- **Location cheating [40]**: It is a colluding attack in which a close-by helper and a far-away dishonest prover ($P''$) collude in order to prove that $P''$ is in close proximity to verifier ($V$). Location-based services (LBS) led by foursquare[5], GasBuddy[4], GyPSii[6], Loopt[5] and Dark Sky[6] has attracted a lot of attention in recent years. The LBS use the geographical position of a user to enrich user experiences in a variety of contexts such as location-based searching and location-based mobile advertising. To attract more users, the location-based mobile social networking services provide real-world rewards or offers to the user, when a user checks in at a certain venue or location. This gives incentives for users to engage in location-cheating for their personal benefits. Dishonest provers may obtain undeserving benefits at specific venues (i.e., places like coffee shops, restaurants, shopping malls, to name a few) by making multiple false location check-ins at different times. For example, Foursquare connect users to local businesses like shops or restaurants using their current location information. A number of business owners offer concrete benefits such as free vouchers, special offers, and even cash reward to the most active registrants visiting their shops or restaurants. In such a scenario, a $P''$ can perform location-cheating attack by taking help from her friend sitting in or near a restaurant. The close-by helper of $P''$ will use the credentials of $P''$, and prove her presence along with the authentication to trick the $V$. As a large array of LSB services uses GPS location

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2http://www.foursquare.com
3https://www.gasbuddy.com/
4http://www.gyPSii.com
5http://www.loopt.com
6https://darksky.net/app/
obtained from smartphone a user. In such services a user perform location-cheating [41] by exploring the open source operating systems for smartphones (e.g., Android) to modify global-positioning-system-(GPS)-related application programming interfaces (APIs). Once this is done, a user is able to cheat on her location using falsified GPS information.

- **Impersonation [42]**: In Impersonation attack, a close-by adversary tries to impersonate a honest prover in her absence in order to get access from verifier. Impersonating adversary can launch this attack in form of device cloning, address spoofing, unauthorized access, rogue base station (or rogue access point) and replay.

All the above mentioned attacks are possible and successful on ZICDA systems, because the verifier has no concrete way to verify the correct physical distance between the prover and itself (i.e., a verifier is unable to authenticate the presence of a legitimate prover in its physical proximity). In some attacks, such as mafia fraud and impersonation, an external attacker performs the attack, and get the false access into the system by fooling the verifier, thus causing harm to both the prover and the verifier. While, in attacks such as distance fraud, distance-hijacking and location-cheating, the prover itself or though some external adversary gets access in the system illegally, in order to perform malicious activities.

**III. CONTEXT-AWARE CO-PRESENCE DETECTION TECHNIQUES**

In this section, we present a comprehensive survey on existing context-based co-presence detection techniques that addresses one or more security threats discussed in section II.D. The basis of provisioning contextual security in ZICDA systems is the fact that all devices residing in the same physical and ambient environment (i.e., availability of suitable context). With the recent advancements in mobile devices’ hardware, these devices are now equipped with one or more inbuilt “sensors” such as microphones (for audio), wireless networking interfaces (for WiFi connectivity), global positioning system (for location), Bluetooth (for short range communications), and other physical environment sensors (humidity, gas, temperature and pressure/altitude). The data collected using these sensors can be used as supplemental information to improve security decisions in ZICDA systems, and it can be done dynamically at the time the decisions are made. In particular, during the authentication process in ZICDA systems, two honest communicating devices can exchange and compare the dynamically gathered supplemental information to determine their co-presence towards each other.

**A. System Model for Context-based Access Control in ZICDA Systems**

Figure 6 depicts the system model for ZICDA systems that are based on contextual co-presence detection techniques. The main aim of a context-based ZICDA system is to provide security against relay attacks. As can be seen that from Figure 6 that the $P$ and $V$ will “see” (almost) the same ambient environment, if they lies in close proximity. When either one of them leaves their common ambient environment the context gathered by $P$ and $V$ will not match during the co-presence detection process, thus access to the system will be denied for an adversary (please refer Figure 6).

The general working methodology of the ZICDA system models is represented in Figure 6. It works in two phases, in the first phase, when a $P$ enters in the transmission range (or close proximity) of a $V$, $P$ sends a trigger to $V$. Once triggered, $V$ start the authentication process with $P$ by sending one (or more) challenge(s) ($ch$) to $P$, upon reception of $ch$, $P$ generate (using her private key) a response ($rsp$), and send the $rsp$ back to $V$. After successful authentication, in the second phase $V$ and $P$ initiate a context sensing process for a pre-defined set of contexts for a fixed duration $t$. The context information collected by $P$ within duration $t$ can be represented by a vector ($\rho$) such that $\rho = \{\rho_1, \rho_2, \rho_3, \ldots, \rho_n\}$, where $n$ is the number of sensor modalities used to form the context information. Similarly, $\nu = \{\nu_1, \nu_2, \nu_3, \ldots, \nu_n\}$, is the corresponding vector of $n$ sensor modalities collected by $V$. Based on the similarity index calculated using vectors $\rho$ and $\nu$ at $V$, the access of $P$ for the system is either allowed or denied. The effectiveness and correctness of the calculations for similarity index at $V$ depends upon the feature extraction, classification and machine learning methods used in the process. Therefore, the use of contextual security in the authentication process not only improves the security of the system, but it also gives flexibility in access control decisions.

A point worth mentioning here is the “initial delay” in authentication process incurred due to the use of contextual security. Due to this, a trade-off arises between system access delay and its usability i.e., higher the delay leads to the lower usability and vice-verse. This initial delay can be minimized to some extent using the following approaches: (i) reduce the number of context during the context-aware authentication,
but as the number of context decreases, the security level in the system also decreases, and (ii) $V$ can perform the credential and contextual authentication processes for $P$ in parallel, but in this process if $P$ uses a low battery power device for authentication than this method posses a high energy consumption, and $P$ needs to perform frequent recharges, thus reduces the usability of the system.

B. Context-based Co-presence Detection Framework

In this section, we present the working methodology of a generic contextual information based co-presence detection framework, which is usually employed to enhance the security in access control applications at ZICDA systems. In particular, we will discuss the functionalities and interactions of the major components involved in the framework.

In any access control system, three basic requirements that must be met to achieve contextual security are availability of contextual information, efficient integration of contextual information in run time, and the instant availability to the contextual information to security analysts. In practice, a typical major obstacle to incorporating context into a security monitoring program is the availability of the contextual information in a format that supports integration with log and alert data. Additionally, the contextual information needs to be validated to ensure that it is accurate and has integrity. The ideal platform integrates the data and information in real or near real-time to allow not just the linkage of the data and information efficiently and effectively, but also enables rules and complex event processing to occur using the contextual information. Finally, the platform must have the capability to make the integrated information quickly and easily available to security analysts in order to present a “scenario” (as discussed in the earlier contactless smartcard examples) that provides all of the information required to validate, respond to and mitigate incidents.

Figure 7 shows, the interaction between the major components involved in a general Contextual co-presence Security Framework (CCSF). Existing proximity detection techniques either uses the whole or part of the CCSF in order to verify the co-presence between the communicating devices. The CCSF apply context profiling and machine learning algorithms on real-world reference dataset collected in an un-controlled environment, and it evaluates the effectiveness of automatic and adaptive context classification for detecting co-presence. For an access control system the CCSF architecture is used for training the classifier using the ground truth data. The trained classifier will then used as a context comparator to compare the received contextual data from a prover and verifier at run time. The CCSF can be instantiate depending upon the requirements and applications of the underlying access control system. As it can be seen from Figure 7, the CCSF mainly consists of three major components:

- **Context data acquisition**: The CCSF architecture is driven by the contextual information collected by this component, and the accuracy of the assessment of co-presence detection depends highly on the data collection and aggregation process used. The contextual security refers to the use of additional information (i.e., context) to improve the security at the time when security decisions are made. Therefore, the context data sensing is done dynamically at the time when a decision must be made for an access control system. Depending upon the type of the application, the communicating entities involved in the context-aware authentication process needs to gather a set of predefined contextual data types using their corresponding inbuilt sensors. The sensed data by the verifier and the prover devices is then compared in order to verify the co-presence between them. The comparator must be trained, in advance, using the ground truth data (or reference data) to provide precise interpretation, analysis and decision making. The task of collecting the ground truth data is the main aim of the context data acquisition component of CCSF. Once collected, the reference data is passed to the next component of CCSF called context management and feature classification for training the classifier.

To gather contextual data, one can install an easy-to-use and secure application on a large number of user devices. The user devices involved in the data collection process could be the smartphones, tablets or a specific purpose device such as [43]. Data collection is the most important phase of the framework because the number and quality of the ground truth data collection have high impact on the accuracy of the assessment of co-presence detection.

Data collection is a time-consuming, expensive and cumbersome process. In order to collect the reference data an on-site resources deployment is required. The data collection could be done using the dedicated users (employees or suppliers), or an approach such as crowdsourcing where data collection is done by soliciting contributions from a large group of people (self-selected volunteers or part-time workers). In both cases, the users will be carrying the data collection device with required sensing capabilities (hardware or software). The former approach is expensive and the collected data set will be of small size, but the data will be trustworthy and of high quality. While, the latter will collect data which is in-expensive and it will have higher data quantity, but it will be less secure and of low quality. In particular, to build a robust and accurate CCSF, the collected reference data should have characteristics such as high quality and quantity, accuracy, timeliness and variability. Furthermore, their are strict government issued guidelines (to support user or information privacy) that needs to be followed during the process of data acquisition. Collecting real-world reference data to train the classifiers and update them periodically is one of the biggest challenge in context-aware access control systems. Once the training phase is complete and CCSF is ready to use, it is deployed in the corresponding real-world application. After CCSF system deployment, the data collection component will collect sensor data dynamically, only at the time when a prover asks access for the access control system.

- **Context management and feature classification**: During the context-aware authentication phase the pre-
defined contextual data is collected by prover and verifier devices and sent to the context management and feature classification (CMFC) module of CCSF. The CMFC module consists of three components: data profiler, classifier and training dataset. Data profiling will help in quickly and thoroughly unveiling the true content and structure of the observed context data. The profiler will perform completeness, uniqueness, values distribution, range and pattern analysis on received data to ensure that it is of adequate quality. Once analyzed properly, the profiler identify most promising features (i.e., feature selection) to build a feature vector describing the current context of the users.

The classifier’s such as decisions trees, Support Vector Machine (SVM) and K-Nearest Neighbours can be trained under supervised learning using a reference dataset. Once the training phase is over, the classifier uses the context feature vectors, generated by profiler, to classify new observations (i.e., sensor data) with respect to the current applications context’s security and privacy-related properties. The classifier outputs, the classification estimates and its associated confidence value, and these are forwarded to the policy management module along with the received confidence value in order to enforce suitable policies on the verifier. In this way, depending upon the type of policies enforced, different users can receive variable levels of security access on the same access control system. For instance, a server can be only accessed, if the user is within its proximity, but different users have different access rights on the server. In such a scenario, proximity check is coupled with the individual users security policies, and therefore policy enforcement at the time of context-aware authorization is required.

In the next section, we will discuss the state-of-the-art context-aware co-presence detection techniques that utilizes, partially or fully, multiple components from the CCSF architecture that we have presented in this section.

C. Co-presence Detection using Sensor Modalities

In this section, we discusses the co-presence detection techniques that uses one or more sensor modalities to collect context information during the proximity verification process. In recent years, the use of mobile devices for spontaneous communications increases significantly in various applications. Therefore, securing these communications from various attacks such as relay attack, eavesdropping, and impersonation becomes an important precondition. For instance, an attacker can read, relay, and modify messages between communicating peers without either peer suspecting that the communication between them has been tempered. The use of contextual security as an additional layer on top of the traditional security can help preventing such malicious third party attacks, as obviously no user want their private information being leaked or tampered. The main motivation
| Proposals | Communication channel | Sensor modalities | Privacy preservation support | Application specific | Description |
|-----------|-----------------------|------------------|-------------------------------|----------------------|-------------|
| [44]     | RFID                  | magnetometers, accelerometer, GPS | No | No | design context-aware selective unlocking mechanisms and secure transaction verification |
| [45], [46] | RFID/NFC              | audio, ambient light | No | No | determine the proximity by correlating certain sensor data extracted from the two devices |
| [47]     | RFID                  | GPS              | Yes | PoS | location-aware secure transaction verification scheme |
| [48] [49] | RFID                  | audio            | No | PKES | sound-based proximity-detection method |
| [50]     | RFID/NFC              | WiFi (radio waves) | No | No | authenticate co-located devices based on their shared radio environment |
| [51] [52] | RFID/NFC              | temperature, single-bit round-trip | N/A | No | elliptic curve-based mutual authentication protocol |
| [53]     | bluetooth /RFID/NFC   | audio, WiFi, and GPS | No | No | comparing and fusing different sensor modalities in ZIA systems |
| [54] [55] | bluetooth /NFC        | ambient noise and luminosity | No | IoT domains | secure ZIA pairing suitable for IoT and wearable devices |
| [56]     | N/A                   | GPS, WiFi        | Yes | mobile applications | detection against device misuse and sensory malware |
| [57]     | N/A                   | audio and luminosity | N/A | proofs-of-presence (PoPs) | solutions against context guessing attacks in LBS |
| [58] [59] | RFID/NFC              | accelerometer, gyroscope | N/A | access control systems | authorized reference trajectories on Transparent Authentication (TA) schemes |
| [60]     | WiFi                  | trajectory through a road network (gyroscope signal, and GPS) | Yes | VANETs | technique to verify the ongoing co-presence of vehicles in an urban environment |
| [61]     | RFID/NFC              | WiFi, bluetooth, GPS, and audio | No | No | investigate the performance of different sensor modalities for co-presence detection |
| Proosals   | Communication channel | Sensor modalities                                                                 | Privacy preservation support | Application specific | Description                                                                                           |
|-----------|-----------------------|----------------------------------------------------------------------------------|-------------------------------|----------------------|--------------------------------------------------------------------------------------------------------|
| 62 63 64 65 | bluetooth/RFID/NFC    | artificial ambient environments (infrared light, sound, etc)                    | N/A                           | time-restricted      | evaluated the effectiveness of 17 ambient sensors                                                      |
| 66       | N/A                   | bidirectional sensing and comparing button presses and releases behaviour       | N/A                           | EMV                  | detection based on sensing button presses on the user’s smartphone by both transaction devices       |
| 67       | bluetooth             | magnetometer                                                                     | N/A                           | device pairing       | pairing smartphones by exploiting correlated magnetometer readings                                  |
| 68 69 70 | NFC                   | accelerometer                                                                     | No                            | Yes                  | PoS and context-based technique to prevent mafia attack in mobile NFC payment                         |
| 71       | NFC                   | audio and light                                                                   | Yes                           | payment cards        | secure proximity detection techniques                                                                |
| 72       | N/A                   | electromagnetic signals                                                           | yes                           | LBS                  | privacy-preserving proximity testing                                                                 |
| 73       | RFID/NFC              | ambient temperature, precision gas, humidity, and altitude                       | No                            | PoS                  | use of purely ambient physical sensing capabilities in authentication systems                         |
| 74       | RFID/NFC              | Features-fusion and decisions-fusion                                              | No                            | No                   | systematic assessment of co-presence detection in the presence of context-manipulating attacker       |
| 75       | RFID/NFC              | speech recognition, and location sensing/ classification                          | Yes                           | payment systems      | defend against unauthorized reading and relay attacks                                               |
| 76       | RFID                  | features-fusion and decisions-fusion based on majority voting                    | Yes                           | ETC systems          | unauthorized reading and relay attacks detection in RFID ETC systems                                 |
| 65       | WiFi, bluetooth, infra-red | accelerometer                                                                    | No                            | smartcard            | continuous two-factor authentication                                                                |
| 13 77    | bluetooth             | audio                                                                            | No                            | online banking       | a usable and deployable two-factor authentication                                                     |
for the researchers to develop context-aware solutions is the rapidly ongoing technological and hardware advancements that enables many RFID/NFC tags to be equipped with many low-cost sensing capabilities. Over the recent years, sensors with various sensing capabilities have been incorporated in RFID tags [73] [79]. For instance, Intel’s Wireless Identification and Sensing Platform (WISP) [80] [81] has developed tag with various sensing capabilities, this extends the use of RFID beyond simple identification. With the help of these advanced RFID devices, one can efficiently provide numerous promising applications for pervasive sensing and computation. It also pave the way towards providing improved security and privacy services by leveraging contextual information from existing physical environment. Tables I and I depicts the state-of-the-art context-aware co-presence detection techniques along with their short description and some other related information such as the sensor modalities used for content gathering, the communication channel(s) considered between the prover and verifier, and are the proposed approach provides support for specific application or it supports the user privacy (where applicable).

The use of contextual information to improve the security of access control applications is not a new technique. For example, from years the banking authentication systems are using time and location as contextual information to provide additional security layer in online transactions. In this scenario, assume a customer wants to transfer all his funds to a third-party account. The transaction appears genuine, i.e., the customer has authenticated itself properly to the bank; she is accessing an account for which she is authorized, and the third-party bank account appears valid too. However, the access location or time of the transaction looks suspicious, e.g., the account has been accessed from a location which is far from the home location of customer or the activation time of the transaction is not consistent with the previous transactions timestamp pattern of the customer. Therefore, without the additional context, the bank is unable to determine if the activity is fraudulent or not. The use of contextual information to improve the security of the access control system is rapidly increased in recent years, it is mainly due to the advancements in the mobile device and communication techniques, which makes the availability of the content easier to the system.

In [82], authors propose an approach that provides additional security using context in role-based access control (RBAC) systems. In particular, the main aim is to combine contextual security (by using location and time as context), and role-based access control to retail business processes, which use the RFID technology. Furthermore, in [83], authors propose a context-aware security architecture for emerging applications, and in [84] a context-aware remote security control for mobile communication devices. In both the works, the contextual information such as location, time, and network access points (such as WiFi) is used to improve the security by dynamically setting the security polices for individuals based on their current threat levels.

In [47] and [76], authors propose context-based security techniques that uses on-board tag sensors to collect contextual information (location and speed). The proposed techniques minimize the likelihood of unauthorized reading and relay attacks in RFID electronic toll collection and banking investment access control systems. In [76], the sensed context data using GPS sensors is used to develop a context-aware selective unlocking technique for tags at ETC such that they can selectively respond to reader challenges, and thus minimizes the risk of being attacked.

In [50], authors propose a proximity-based authentication technique called “Amigo”. To authenticate co-present mobile devices, Amigo uses knowledge of their shared radio environment as proof of physical proximity. The key advantages of Amigo includes following: it do not require any additional hardware, it does not require user involvement in the authentication process, and it is not vulnerable to eavesdropping. The main idea is that the co-present devices will simultaneously monitor a common set of ambient radio sources (WiFi access points or cell phone base stations) to perceive a similar radio environment. An evaluation conducted using WiFi-enabled laptops shows that Amigo is robust against a range of passive and active attacks. To further strengthen the fact that copresent devices will see the common radio environment, fluctuations in the signal strength of existing ambient radio sources are considered in [85]. It minimizes the false positives and false negatives in the system.

In [56], authors present a system called NearMe. NearMe discovers what is already nearby and to augment context for ubiquitous computing. For this purpose, NearMe server determines proximity by comparing lists of WiFi access points and signal strengths called “WiFi signatures” from clients. To use NearMe, each client has to perform the following three functions: 1) register with proximity server, 2) report recent WiFi signature, and 3) query nearby places and peoples. A similar proximity testing system which uses WiFi access points and bluetooth signals to generate “location tags” is introduced in [72]. The system was implemented and evaluated on android platform. Along with security, it also guarantees the privacy preservation for the clients involved in it.

Based on the audio and light data collected from the ambient sensors available in NFC enabled smartphones, a secure proximity technique is presented in [71]. The main aim of the proposed technique is to prevent relay attacks in point of sale (PoS) systems, where just bringing the NFC enabled smartphone close to PoS is sufficient to complete a transaction. In particular, author’s propose a transaction verification mechanism that can determine the proximity (or lack thereof) between honest verifier and prover by comparing certain sensor data (audio or light), which is extracted from the communicating devices. In [49], a secure radio channel between communicating devices based on similar audio patterns has been proposed in order to develop an unobtrusive but cryptographically strong security mechanism. Furthermore, in [75], authors use ambient audio for secure device pairing on android mobile phones. In this work, audio is used as a metric to generate a secure cryptographic key that establishes communication between mobile distributed devices.

The use of Secret Handshakes as context information rapidly increases in large an array of applications that uses RFID or contactless cards for access control purposes. The intuition
We argue that with the increase in the number of sensor modalities, the time required to authenticate a prover, and the complexity of context-aware algorithms deployment increases, thus it decreases the usability and feasibility of the access control system. In [61], to make the proximity detection techniques more robust and versatile, authors motivate the need for a stronger adversarial model, in which the adversary can compromise the integrity of context sensing mechanisms. For instance, an attacker can create fake wifi access points, add random noise, and it can modify the purely ambient physical sensing capabilities [73] such as ambient temperature, precision gas, humidity, pressure, and altitude.

One of the most comprehensive work towards analyzing, extending, and systematizing state-of-the-art works on context-aware proximity detection under a stronger, but realistic adversarial model is presented in [74]. In this work, authors present a systematic assessment of proximity detection in the face of context-manipulating adversaries. It has been shown that not only the content manipulation is possible, but an attacker can consistently control and stabilize the values of multiple, heterogeneous (e.g., acoustic and ambient physical environment) sensors using low-cost, off-the-shelf equipment. Thus, an attacker who is able to manipulate the context gains a significant advantage in defeating access control systems that are based on contextual security techniques.

Authors in [13] propose a representative approach called Sound-Proof, a usable two factor authentication that leverages ambient sound to detect co-presence between the phone (used as a second authentication factor) and the browser (a login terminal such as a banking website) running on a different mobile device. Sound-Proof claims to found an optimal trade-off between the usability (i.e., it does not require an interaction between the user and her phone) and security (i.e., safe login on browser in presence of remote attackers). In particular, Sound-Proof uses the audio signatures collected from the microphones of the two devices, i.e., phone and the device such as laptop, which is running the login browser. Sound-Proof provides a usable security enhancement on top of the traditional password-only authentication technique that are commonly used to perform online banking transactions. The only essential requirement in Sound-Proof is that the user should keep her phone near to the computer while doing the login tasks, thus it increases the usability while securing the login process. However, a weakness of the Sound-Proof is identified by authors in [77]. In [77], authors show that to perform an attack, the remote attacker does not have to predict the ambient sounds near the phone as assumed in the Sound-Proof, instead, it can deliberately make or wait for the phone to perform an attack, the remote attacker does not have to predict the ambient sounds near the phone as assumed in the Sound-Proof, instead, it can deliberately make or wait for the phone to produce predictable or previously known sounds (e.g., ringer, notification or alarm sounds). Therefore, exploiting the above mentioned weakness, a full attack system can be launched to successfully compromise the security of Sound-Proof.

Authors in [87] also aims to authenticate messages in VANETs through physical context comparison. The physical context consists of the surface of the road that includes road conditions such as bumps and potholes that can be measured using accelerometer. Later, the context is used to derive a secret key, which is shared between the co-present
vehicles. However, the entropy of the context to generate the secret key, and the effect of different road surfaces remains unexplored, thus making the security guarantees of the system unclear. Recently, authors in [60] propose an approach to verify the ongoing co-presence between two vehicles in an urban environment. The approach exploits the characteristics of a trajectory (using gyroscope signals, GPS, etc) through a road network. The aim is to allow authentication checks for safety critical applications. The approach requires a vehicle to share the same route as a leading vehicle in order to become a verified following vehicle. Co-present vehicles gain knowledge of verified neighbors, and thus the capability to authenticate their VANET messages. The construction only reveals a driver’s trajectory to other co-present vehicles and hence protects passengers privacy against an eavesdropping attacker.

The proposed approach operates transparent to pseudonym schemes and thus cannot be exploited to attribute different messages to the same sender. The proposal has been implemented as an Android application to evaluate its performance in experiments involving two cars.

D. Co-presence Detection in Location Based Services

One of the major goals of pervasive computing is to build service applications that are sensitive to the user’s current context information. For example, location-based applications such as Swarm, Foursquare, Glympse and Google-now, which uses the user’s location as a context to dynamically provide various services, like information of nearby places, friends, and shops. One way to provide such services is to determine proximity by measuring absolute locations and compute distances. However, computing absolute location threatens user privacy, and it is also not necessarily easy to calculate, especially indoors, where GPS on user device does not work well which is usually a place where people spend most of their time. These Location Based Services (LBS) uses the approximate geographical position to enrich user’s quality of experience (QoE) concerning various contexts such as location based searching and location based mobile advertising. In order to attract more users, the service providers give real-world rewards to the user, when a user do a check-in at a certain venue or location. These reward points motivate users to cheat on their real locations. In particular, LBS can be defined as an array of services available with mobile devices (e.g., smartphones, tablets, and smart-watch), tailoring their functionality to current positions or trajectories of users or vehicles [88].

In [89], authors investigate vulnerabilities leading to possible location cheating attacks in LBS applications, and discuss possible countermeasures for the same. By using Foursquare as a use-case scenario, a novel location cheating attack is proposed, which can easily cheat the current location verification techniques. The paper shows that if an attacker carefully studies the open-source operating systems for mobile devices such as Android in order to modify GPS-related application programming interfaces (APIs), the attacker is able to cheat their location by modifying the GPS information. While LBSs offer great opportunities for a large array of customer-oriented services, but at the same time it also present significant privacy threats to the users. To strengthen the mechanisms for preventing location-cheating in LBS, authors in [57] propose Proofs of Presence (PoP) based resilient techniques against malicious users. The paper presents facts indicating that the use of context-aware PoPs for verification of users’ location claims are vulnerable to context guessing attacks. Furthermore, it proposes two countermeasures to mitigate context-guessing attacks. The first countermeasure called “surprisal filtering”, which is based on profiling and estimating the entropy associated with individual PoPs. The second countermeasure suggests the use of longitudinal observations of ambient physical properties of the context. In [89], authors investigate and discuss, the trade-off issues between users’ location privacy protection and their quality of service (QoS) for the LBSs.

The basis of LBS comes from spatial and temporal big data, which is provided by an enormous amount of mobile devices through GPS and various communication networks (e.g., cellular networks and WiFi). Using LBS to perform co-presence detection poses significant threat to user privacy. To address this issue, various privacy preservation LSB schemes has been proposed in recent literature. For example, authors in [88] first investigates the privacy issues in LSBs concerning possibilities of sensitive data leakage in a system, and then proposes an approach that preserves the query data with the aim of providing accurate LBS answers with zero-server-knowledge on query data. In most of the state-of-the-art schemes for privacy preservation in LSB, a single trusted anonymizer is placed between the users and the location service provider (LSP), thus limits privacy guarantees and incurs high communication overhead when used in continuous LSBs. It is because once the anonymizer is compromised, it may put the user data at risk. Authors in [90] proposes a dual privacy preserving technique for continuous LSBs to protect the users’ trajectory and query content privacy. In this approach, multiple anonymizers are placed between users and LSP which are combined with Shamir threshold mechanism, dynamic pseudonym mechanism, and K-anonymity technique. Similarly, to achieve an adequate balance among user privacy, usability, and efficiency in LSBs, authors in [91] proposes SPOIL, which is a practical location privacy approach for LSBs. In particular, the idea is that a client (i.e., mobile device) shifts user-intended point-of-interests (POIs) to some neighboring POIs instead, and query the mapping server using the shifted POIs.

IV. OPEN ISSUES AND DIRECTIONS FOR FUTURE WORK

In this section, we present the lessons learned from our survey that includes an array of security threats to the ZICDA systems, and the state-of-the-art context-based co-presence detection techniques that has been proposed to improve the security and privacy of various applications which uses these systems. Additionally, we discuss open issues and directions for future work that could lead to possible enhancement in securing the ZICDA access control systems.

Based on our survey, the context-aware co-presence detection is emerged as a very promising approach for defense
against the relay attacks, which is considered as a major threat to ZICDA systems. In context-based co-presence detection techniques contextual information is gathered from the surrounding environments, which mainly includes audio-radio environment (e.g., ambient audio, WiFi, Bluetooth, infrared, and GPS, and combinations thereof) and physical environment (temperature, pressure, humidity, gas and altitude, and combinations thereof). Apart from contextual information based techniques, the distance bounding (DB) protocols have also shown significant potential in resisting various distance-hijacking attacks \[92\] \[93\]. However, the use of distance bounding protocols in resource constrained devices such as sensors, low-end smartphones, and smartcards are not suitable \[94\]. It is due to the multitude of hardware components and the multi-process architecture that is being used to implement the distance bounding techniques, which leads to unpredictable performance behaviour. In particular, these protocols interacts at the physical layer, hence dedicated hardware is mandatory for practical implementation. Therefore, widespread deployment of DB protocols must await manufacturer endorsement.

In the state-of-the-art, various types of context information that could be extracted from different sensor modalities such as magnetometers, accelerometer, GPS, and gyroscope, is used as contextual information to discover the co-presence between prover and verifier. Researchers use single or a set of sensor modalities to generate some sort of contextual signature that when matched upto a given threshold, the prover and verifier are considered within each others close proximity. It can be deduced from the surveyed techniques that the use of multiple modalities provide more resistance to relay attacks and higher accuracy (i.e., lower false positives and false negatives), but as the number of modalities increases in the contextual set, the usability of the system decreases and the cost of the deployment increases. Additionally, the availability of the multiple sensor modalities depends on the device capabilities and the surrounding environment where the co-presence is being checked.

Despite of the availability of large array of context-aware co-presence detection techniques, the various types of distance-hijacking attacks threatens the secure and efficient deployment of various emerging applications, e.g., secure message exchange in VANETs \[87\], two-factor authentication for user identification \[95\], and secure device pairing and service creation in IoT \[96\]. \[97\]. The correct implementation and functionality of these applications are based on the concept of contextual co-presence. Below, we discuss the challenges and future research directions that requires significant research attention, to improve the security of ZICDA systems and the privacy of its users.

- **Integration of proximity proofs:** To integrate context-based co-presence schemes in a target system, the first requirement is the availability of the adequate context. Having context availability alone is not sufficient, it should be in the correct format or mechanism, and it should to be validated to ensure that it is accurate and has integrity. Once the contextual information is available in an accurate, up-to-date, and validated format, it needs to be integrated based on key values, and a platform is needed that enables the log. Additionally, alert data to be linked together with the contextual information is required to enable efficient integration of contextual information in real-time. Finally, the system must have the capability to make the integrated information quickly and easily available to security analysts in order to present a “scenario” that provides all of the information required to validate, respond to, and mitigate possible security related incidents. Performing integration is easy if the system components (e.g., prover and verifier) only needs software updates, but in cases where hardware updates are required, then a development of the appropriate infrastructure is needed. In particular, how to deploy contextual co-presence detection solutions in a cost-effective and efficient manner remains a research problem to address for future researchers.

- **Usable solutions:** As mentioned before that the use of multiple sensor modalities for context gathering not only increases the cost of deployment, but it also decreases the usability of the system, which directly effects the quality-of-service (QoS) perceived by the end-users. Therefore, selecting an optimal yet minimal set of sensor modalities, which effectively considers the tradeoff between the security, cost, and usability of the system remains an open issue.

- **Resistance against context manipulations:** Most of the state-of-the-art co-presence detection or relay attack resistance mechanisms considers the simplest adversary model (i.e., Dolev-Yao systems), hence these mechanisms might not be able to defend the system in presence of a strong adversary (i.e., context manipulating attackers). The existing research shows that it is trivial to modify, consistently control and stabilize the context data gathered from different (single or multiple) audio-radio and physical environments using low-cost, off-the-shelf equipment \[74\]. Therefore, extensive research is required to ensure the robustness of the access control systems against distance hijacking attacks. For instance, the classifier and machine learning algorithms that are being used to train the system should consider, the possibility of a strong adversary during the training phase. Also, the size of the training data set should be large, and it should exhibit the characteristics of the real-world data.

- **Privacy preserving proximity detection:** In most of the available co-presence detection approaches, the context information consists of sensitive user data such as location, audio, and behavioural patterns. Therefore, it is essential to ensure the use of such contextual information in a privacy preserving manner. However, it is hard to ensure privacy in co-presence systems due to the need of precise information that these systems requires to perform the co-presence evaluation. For instance, it is hard to use the partial GPS information \[98\] and still do an accurate evaluation for co-presence. Hence, novel solutions are required to ensure the privacy preservation during the proximity detection.
V. CONCLUSIONS

When a user tries to access the system, one can simplify the security decisions by basing it on binary decisions (Yes/No). However, the rapidly increasing threats against logging credentials that are caused by the human or the system related errors, such binary decisions are not enough to protect the system. Therefore, if the verifier can base the security decisions on the who, when, where, when, what, and why behind the user’s access request, it can develop usable security and privacy solutions for users without sacrificing the level of protection. This paper examines several ways that make use of a context-aware model (a new and adaptive security model), which feeds additional information to the security analytics engine (SAE) to make efficient and flexible security decisions. In this paper, we start with the discussion on various real world applications (e.g., Passive keyless entry (PKE) systems, contactless smartcard based access control systems, contactless payment systems, inventory managements, medical implants, and e-passport) and security threats (relay attack, terrorist fraud, location cheating, and impersonation) with respect to the Zero-Interaction based co-presence Detection and Authentication (ZICDA) access control systems. We provided a comprehensive survey that include all the state-of-the-art context-based co-presence detection techniques along with their merits and limitations. With the set of future research directions and challenges that we have discussed, we hope that our work will motivate fledgling researchers towards tackling the security, usability, and privacy issues of ZICDA systems.

REFERENCES

[1] K. Finkenzeller, “Rfid handbook: Fundamentals and applications in contactless smart cards and identification,” John Wiley and Sons, Inc., New York, NY, USA, 2 edition.

[2] “Iso/iec 18092 (ecma-340), information technology telecommunications and information exchange between systems near field communication interface and protocol (nfc-ip),” Available: https://www.iso.org/ 2004.

[3] “International civil aviation organization (icao), document 9303 machine readable travel documents (mrdt), part i: Machine readable passports,” 2005.

[4] “London transport oystercard,” Available: http://www.oystercard.com

[5] “Mastercard paypass,” Available: http://www.paypass.com

[6] N. Akinyokun and V. Teague, “Security and privacy implications of nfc-enabled contactless payment systems,” in Proceedings of the 12th International Conference on Availability, Reliability and Security, ser. ARES ’17. ACM, 2017, pp. 47:1–47:10. [Online]. Available: http://doi.acm.org/10.1145/3098954.3103161

[7] S. Drimer and S. J. Murdock, “Keep your enemies close: Distance bounding against smartcard relay attacks,” pp. 7:1–7:16, 2007.

[8] A. Francillon, B. Danet, and S. Capkun, “Relay attacks on passive keyless entry and start systems in modern cars,” 2010, http://eprint.iacr.org/2010/332.

[9] L. Francis, G. Hancke, K. Mayes, and K. Markantonakis, “Practical nfc peer-to-peer relay attack using mobile phones,” pp. 35–49, 2010.

[10] Z. Krif and A. Wool, “Picking virtual pockets using relay attacks on contactless smartcard,” pp. 47–58, 2005.

[11] L. Spriettoli and A. Ciardulli, “Long distance relay attack,” pp. 69–85, 2013.

[12] T. Korak and M. Hutter, “On the power of active relay attacks using custom-made proxies,” pp. 126–133, April 2014.

[13] N. Karapanos, C. Marfiorio, C. Soriente, and S. Capkun, “Sound-proof: Usable two-factor authentication based on ambient sound,” in Proceedings of the 24th USENIX Conference on Security Symposium, ser. SEC’15. Berkeley, CA, USA: USENIX Association, 2015, pp. 483–498. [Online]. Available: http://dl.acm.org/citation.cfm?id=2831143.2831174

[14] S. Brands and D. Chaum, Distance-Bounding Protocols. Springer Berlin Heidelberg, 1994, pp. 344–359.

[15] S. Bengio, G. Brassard, Y. G. Desmedt, C. Goutier, and J.-J. Quisquater, “Secure implementation of identification systems,” Journal of Cryptology, vol. 4, pp. 175–183, Jan 1991.

[16] D. Beth and Y. Desmedt, Identification Tokens — or: Solving The Chess Grandmaster Problem. Springer Berlin Heidelberg, 1991, pp. 169–176.

[17] A. Brehurut, D. Gerault, and P. Lafourcade, “Survey of distance bounding protocols and threats,” in Foundations and Practice of Security. Cham: Springer International Publishing, 2016, pp. 29–49.

[18] G. Avocrine, M. A. Bingl, I. Bourreau, S. apkun, G. Hancke, S. Karda, C. H. Kim, C. Lauradoux, B. Martin, J. Munilla, A. Peinado, K. Rasmussen, D. Singele, A. Tchamkerten, R. Trujillo-Rasua, and S. Vaudenay, “Security of distance-bounding: A survey,” ACM Computing Surveys, vol. 4, 2017.

[19] G. P. Hancke, “Practical eavesdropping and skimming attacks on high-frequency rfid tokens,” J. Comput. Secur., vol. 19, no. 2, pp. 259–288, 2011.

[20] G. Hancke, “A practical relay attack on iso 14443 proximity cards,” Tech. Rep.

[21] D. Cavadar and E. Tomur, “A practical nfc relay attack on mobile devices using card emulation mode,” in 2015 38th International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO), May 2015, pp. 1308–1312.

[22] G. Avocrine and A. Tchamkerten, An Efficient Distance Bounding RFID Authentication Protocol: Balancing False-Acceptance Rate and Memory Requirement. Springer Berlin Heidelberg, 2009, pp. 250–261.

[23] C. Cremers, K. B. Rasmussen, B. Schmidt, and S. Capkun, “Distance hijacking attacks on distance bounding protocols,” in 2012 IEEE Symposium on Security and Privacy, May 2012, pp. 113–127.

[24] H. Jannati, “Analysis of relay, terrorist fraud and distance fraud attacks on rfid systems,” Int. J. Crit. Infrastruct. Prot., vol. 11, pp. 51–61, Dec. 2015.

[25] G. P. Hancke, K. E. Mayes, and K. Markantonakis, “Confidence in smart card proximity: Relay attacks revisited,” Comput. Secur., vol. 28, no. 7, pp. 615–627, Oct. 2009.

[26] P. Poturalski, M. Frity, P. Papadimitratos, J. P. Hubaux, and J. Y. L. Boudec, “Distance bounding with ieee 802.15.4a: Attacks and countermeasures,” IEEE Transactions on Wireless Communications, vol. 10, no. 4, pp. 1334–1344, April 2011.

[27] Y. Zhauniarovich, G. Russello, M. Conti, B. Crispo, and E. Fernandes, “Moses: Supporting and enforcing security profiles on smartphones,” IEEE Transactions on Dependable and Secure Computing, vol. 11, no. 3, pp. 211–223, May 2014.

[28] A. K. Sikder, H. Aksu, and A. S. Uluagac, “6thsense: A context-aware sensor-based attack detector for smart devices,” in 26th USENIX Security Symposium (USENIX Security ’17). Vancouver, BC: USENIX Association, 2017, pp. 397–414. [Online]. Available: https://www.usenix.org/conference/usenixsecurity17/technical-sessions/presentation/sikder

[29] O. B. Sezer, E. Dogdu, and A. M. Ozbayoglu, “Context-aware computing, learning, and big data in internet of things: A survey,” IEEE Internet of Things Journal, vol. 5, no. 1, pp. 1–27, Feb 2018.

[30] I. Bisio, C. Garibotto, A. Grattarola, F. Lavagetto, and A. Sciaronne, “Exploiting context-aware capabilities over the internet of things for industry 4.0 applications,” IEEE Network, vol. 32, no. 3, pp. 101–107, May 2018.

[31] Q. N. Nguyen, M. Arifuzzaman, K. Yu, and T. Sato, “A context-aware green information-centric networking model for future wireless communications.” IEEE Access, vol. 6, pp. 22 804–22 816, 2018.

[32] R. Parada and J. Melia-Segui, “Gesture detection using passive rfid tags to enable people-centric iot applications,” IEEE Communications Magazine, vol. 55, no. 2, pp. 65–70, February 2017.

[33] M. Wazid, A. K. Das, M. K. Khan, A. A. D. Al-Ghaibeh, N. Kumar, and A. Vasilakos, “Secure authentication scheme for medicine anti-counterfeiting system in iot environment,” IEEE Internet of Things Journal, vol. PP, no. 99, pp. 1–13, 2017.

[34] W. Issovits and M. Hutter, “Weaknesses of the iso/iec 14443 protocol regarding relay attacks,” in 2011 IEEE International Conference on RFID-Technologies and Applications, Sept 2011, pp. 335–342.

[35] D. Dolev and A. C. Yao, “On the security of public key protocols,” in Proceedings of the 22Nd Annual Symposium on Foundations of Computer Science, ser. FOCS ’81. IEEE Computer Society, 1981, pp. 350–357.

[36] O. Bos, U. Mitrokotsa, and S. Vaudenay, Practical and Provably Secure Distance-Bounding. Springer International Publishing, 2015, pp. 248–258.

[37] C. JH, “On numbers and games,” Academic Press, 1976.
ambient audio,” in Proceedings of the 2016 ACM SIGSAC Conference on Computer and Communications Security, ser. CCS ’16. New York, NY, USA: ACM, 2016, pp. 908–919. [Online]. Available: http://doi.acm.org/10.1145/2976749.2978328

[78] D. J. Yager, J. Holleman, R. Prasad, J. R. Smith, and B. P. Otis, “Neuralwisp: A wirelessly powered neural interface with 1-m range,” IEEE Transactions on Biomedical Circuits and Systems, vol. 3, no. 6, pp. 379–387, Dec 2009.

[79] A. P. Sample, D. J. Yager, and J. R. Smith, “A capacitive touch interface for passive rfid tags,” in 2009 IEEE International Conference on RFID, April 2009, pp. 103–109.

[80] A. P. Sample, D. J. Yager, P. S. Powledge, and J. R. Smith, “Design of a passively-powered, programmable sensing platform for uhf rfid systems,” in 2007 IEEE International Conference on RFID, March 2007, pp. 149–156.

[81] J. R. Smith, A. P. Sample, P. S. Powledge, S. Roy, and A. Manishev, “A wirelessly-powered platform for sensing and computation,” in Proceedings of the 8th International Conference on Ubiquitous Computing, ser. Ubicomp’06, 2006, pp. 495–506.

[82] M. Y. Wu, C. K. Ke, and W. L. Tzeng, “Applying context-aware rbac to rfid security management for application in retail business,” in 2008 IEEE Asia-Pacific Services Computing Conference, Dec 2008, pp. 1208–1212.

[83] M. J. Covington, P. Fogla, Z. Zhan, and M. Ahamad, “A context-aware security architecture for emerging applications,” in 18th Annual Computer Security Applications Conference, 2002: Proceedings., 2002, pp. 249–258.

[84] G. An, D. Seo, J. Kim, K. Kim, and D. Seo, “Context-based remote security control for mobile communication device,” in 2010 10th International Symposium on Communications and Information Technologies, Oct 2010, pp. 815–820.

[85] A. Varshavsky, A. LaMarca, and E. de Lara, “Enabling secure and spontaneous communication between mobile devices using common radio environment,” in Eighth IEEE Workshop on Mobile Computing Systems and Applications, March 2007, pp. 9–13.

[86] J. Krumm and K. Hinckley, “The nearme wireless proximity server,” in UbiComp 2004: Ubiquitous Computing, N. Davies, E. D. Mynatt, and I. Sito, Eds. Berlin, Heidelberg: Springer Berlin Heidelberg, 2004, pp. 283–300.

[87] J. Han, M. Harishankar, X. Wang, A. J. Chung, and P. Tague, “Convoy: Physical context verification for vehicle platoon admission,” in Proceedings of the 18th International Workshop on Mobile Computing Systems and Applications, ser. HotMobile ’17. New York, NY, USA: ACM, 2017, pp. 73–78. [Online]. Available: http://doi.acm.org/10.1145/3032970.3032987

[88] S. Wang, Q. Hu, Y. Sun, and J. Huang, “Privacy preservation in location-based services,” IEEE Communications Magazine, vol. 56, no. 3, pp. 134–140, March 2018.

[89] K. G. Shin, X. Ju, Z. Chen, and X. Hu, “Privacy protection for users of location-based services,” IEEE Wireless Communications, vol. 19, no. 1, pp. 30–39, February 2012.

[90] S. Zhang, G. Wang, and Q. Liu, “A dual privacy preserving scheme in continuous location-based services,” in 2017 IEEE Trustcom/BigDataSE/ICCESS, Aug 2017, pp. 402–408.

[91] C. Di, S. Xiaodong, G. Hailong, L. Hao, and Z. Shilei, “Spoil: Practical location privacy for location based services,” in 2017 IEEE 17th International Conference on Communication Technology (ICCT), Oct 2017, pp. 574–578.

[92] C. Dimitrakakis and A. Mitrokotsa, “Distance-bounding protocols: Are you close enough?” IEEE Security Privacy, vol. 13, no. 4, pp. 47–51, July 2015.

[93] A. Yang, E. Pagnin, A. Mitrokotsa, G. P. Hancke, and D. S. Wong, “Two-hop distance-bounding protocols: Keep your friends close,” IEEE Transactions on Mobile Computing, vol. 17, no. 7, pp. 1723–1736, July 2018.

[94] I. Boureanu and S. Vaudenay, “Challenges in distance bounding,” IEEE Security Privacy, vol. 13, no. 1, pp. 41–48, Jan 2015.

[95] A. Basu, R. Xu, M. S. Rahman, and S. Kiyomoto, “User-in-a-context: A blueprint for context-aware identification,” in 2016 14th Annual Conference on Privacy, Security and Trust (PST), Dec 2016, pp. 329–334.

[96] M. Miettinnen, N. Asokan, T. D. Nguyen, A.-R. Sadeghi, and M. Sobhani, “Context-based zero-interaction pairing and key evolution for advanced personal devices,” in Proceedings of the 2014 ACM SIGSAC Conference on Computer and Communications Security, ser. CCS ’14, 2014, pp. 880–891.

[97] E. de Matos, L. A. Amaral, R. T. Tiburski, M. C. Schenfeld, D. F. G. de Azevedo, and F. Hessel, “A sensing-as-a-service context-aware system for internet of things environments,” in 2017 14th IEEE Annual Consumer Communications Networking Conference (CCNC), Jan 2017, pp. 724–727.

[98] L. Heng, A. R. Kumar, and G. Gao, “Private proximity detection using partial gps information,” IEEE Transactions on Aerospace and Electronic Systems, vol. 52, no. 6, pp. 2873–2885, December 2016.