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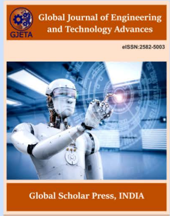

(REVIEW ARTICLE)

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Secure signaling and traffic exchanges in smart cities: A critical review of the current trends

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Abstract

The need to enhance convenience, transparency and reduce costs has led to the adoption of smart cities in most countries. In this environment, a myriad of internet of things devices such as sensors and actuators exchange large volumes of highly sensitive and private data. There is therefore need to develop security frameworks, protocols and architectures to offer the much required protection to the exchanged data. To this end, numerous schemes have been put forward by various researchers over the recent past. In this paper, a broad review is provided of the security, privacy and performance issues of these schemes in a smart city environment. Based on the obtained results, it is evident that the attainment of ideal security and privacy for the data exchanged over open wireless channels is an uphill task. Therefore, some recommendations are given on how best the security solutions should be tailored to bridge this gap.

Keywords: Smart city; Security; Privacy; Attacks; Performance; Private

1. Introduction

The Internet of Things (IoT) network offers ubiquitous connection of smart sensors, smart devices and other daily living physical objects, giving rise to smart cities. As such, smart cities provide a platform through which governments deliver real-time unique data to the citizens based on their requirements. Basically, a smart government is the implementation of a set of business processes and enabling information technology that facilitate seamless flow of information across government agencies [1]. The goal is to dispense services in an efficient, cost-effective and transparent manner so as to attain global competitiveness. As explained by Malik et al.[2], the IoT technology in smart cities offer tracking, communication, identification, monitoring, sensing and control functionalities among the numerous physically distributed devices. In addition, the ICT based E-governance has facilitated interactive internet enabled smart delivery of services to the citizens [3]. This delivery is made possible by a range of smart devices which can be implantable or embedded. They may include smart watches, roadside units and smart phones among others [4], [5], [6]. This technology helps alleviate challenges faced by cities such as decreasing state aid, budget declines as well as increased budgetary uncertainty [7], [8].Therefore, smart cities must offer high-quality smart services to the citizens. These services may include environment monitoring, social contact, entertainment, healthcare and transportation. As explained by Zeng et al. [9], the objective of smart systems and services such as smart home, smart appliances, healthcare and monitoring, security and surveillance applications is to enhance convenience in the life of people. In general, smart environments have numerous applications domains such as smart homes [10], smart health care [11], smart grids [12], smart transportation and smart cities [13] as shown in Fig.1.

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The recent advances in mobile and wireless technologies have enabled citizens to obtain real-time access to data and services, especially in technologically advanced countries [14], [15], [16], [17]. Therefore, smart cities play critical roles in education, economy, tourism and government. To accomplish this, a myriad of electronic gadgets such as cameras, sensors and actuators are deployed [18]. For instance, sensors in smart health systems are capable of measuring blood pressure [19], cardiovascular parameters [20], [21] and respiration variables [22], [23], [24]. On the other hand, sensors and actuators in intelligent transportation improve road safety through the provisioning of more convenient driving experience using dedicated or crowd sensing technologies [25], [26], [27]. For instance, smart parking services facilitate the finding of a suitable vacant parking spot in busy cities [28]. In addition, closed-circuit television camera (CCTV) can be incorporated with IoT to act as smart sensors for enhanced safety and security [18]. In smart homes [29], the smart appliances offer convenience, improve energy consumption through smart heating, ventilation and air conditioning [30]. As explained in [31], the utilization of Cyber Physical Systems (CPSs) in smart cities enhances transportation services, healthcare, utilities, environmental health, utilities and safety. For instance, smart driving employs various technologies to evaluate and assess road status and hence help drivers prevent accidents. Therefore, it contributes to improved drivers and passengers safety [32]. In addition, other intelligent transport systems within the smart city enhance public transportation in addition to offering citywide services that guarantee the smooth flow of traffic [33]. Further, it can help law enforcement officers in addressing traffic incident disputes [34]. In spite of the numerous benefits that accrue from the utilization of smart cities, a number of integrity, authenticity, privacy and security issues [35] are yet to be solved. For instance, although CCTV is a significant element of smart cities [36], they raise a number of integrity issues. This is because of the capabilities of attackers modifying reality so as to spread false information [37]. The many IoT devices supported in smart cities has also been identified in [31] as being the source of vulnerabilities and risks. The increased competition among smart city application developers to introduce novel and innovative products has seen the treatment of security and privacy requirements as afterthoughts [38]. The developers need to meet strict deadlines and therefore they leave security and privacy requirements as elements that can be incorporated later on as system features.

Figure 1 Smart City Elements

Therefore, these immature smart city IoT devices fall short of security and privacy requirements which are critical constituents [39], [40], [41]. Due to the prevalence of many vulnerabilities and attacks in smart city IoT devices, there is a sense of mistrust among the communicating entities [42]. Another serious challenge in these smart cities is the resource-constrained nature of the IoT devices which limits the applicability of strong and enhanced cryptographic techniques [43], [44], [45], [46]. As these IoT systems are being attached to the physical infrastructure systems, there is need to uphold confidentiality, availability and integrity [47]. Unfortunately, the physical layer is the weakest link in these smart city systems as demonstrated by Arias et al. [38], who were able to exploit hardware vulnerabilities to hijack smart home products. Indeed the authors in [48] explain that cryptographic approaches provide only software security and are unable to protect against side-channel and hardware attacks. Particularly, the servers in cloud-based smart city applications have been noted to be vulnerable to attacks such as data leakage [40], malicious data injection, denial of service (DoS) [49] and spoofing. Although techniques such as access control, anonymous communication and encryption can be deployed to protect against these attacks [40], the intrinsic IoT features raise manifold challenges in deploying these off-the-shelf techniques.

Considering smart vehicles, the threats against them can be classified as physical or interception depending on their vulnerabilities [50]. Whereas physical threats target the electronic control unit of vehicles so as to gain unauthorized access to data or sabotage the operation of the vehicle, interception threats aims to capture the exchanged data. Since each vehicle transmits messages containing unique ID and location-related information, eavesdropping attacks can yield critical information about the vehicle and its driver [51]. Similarly, smart grid applications are highly depended on information communication technologies for power line communication, Bluetooth, ZigBee and IEEE 802.11 h [52], [53]. However, making the grid intelligent and integrating it with the cyber world exposes them to numerous vulnerabilities and cyber attacks that can compromise its privacy, integrity and availability [54]. Considering smart homes, security and privacy challenges have been identified in [55] as being major hindrances. As explained by Jose and Malekian [56], smart homes share the weaknesses of wireless local area network protocols. Therefore, they are susceptible to routing and wormhole attacks. In addition, the IoT devices in smart homes are shipped with simple default passwords that users rarely change. Even though strong passwords are deployed, other threats such as firmware and spoofing attacks can still be utilized to compromise the network [57]. By monitoring the IP addresses of the IoT devices or using machine learning techniques, it becomes easy for attackers to trace data packets to their source devices. It is also possible to eavesdrop the communication channel and hence compromise user privacy. Therefore, smart devices should be made anonymous and techniques for preempting unauthorized data fusion should be incorporated [58].

Based on the discussion above, it is clear that IoT nodes in smart cities can be compromised and hence endanger public safety. Any successful attack can have devastating impact due to the high number of devices involved. As such, security smart cities safety is important. Unfortunately, IoT-based smart cities are vulnerable to unauthorized access [59], [60]. Technologies such as artificial intelligence, virtual reality, botnets and smart vehicles render smart city security assurance extremely challenging [61]. Therefore, upholding privacy and security for data at rest and in transit over smart cities is a challenging task [3], [62], [67], [64], [65], [66]. To curb the threats, strong authentication techniques are needed [67]. For instance, when mobile users request for data services from some remote service providers, the authenticity of each party should be verified [68], [69], [70].

The rest of this paper is organized as follows: Section 2 gives the motivation behind this review, while Section 3 presents the contribution of this study. On the other hand, Section 4 discuses related work, while Section 5 presents the results. Towards the end of this article, Section 6 concludes the paper.

2. Motivation

Large volumes of personal data such as photos, contact details, call logs and bank account details are generated and stored in mobile gadgets such smartphones. Since these smartphones are connected to the smart city IoT communication, the potential threats to the stored information increase exponentially. This is worsened by the fact that smartphones are easily stolen, lost or accessed by non-owners. In addition, in most of the smart city communications, wireless transmission medium is utilized, which is more insecure compared to wired communication channels. Clearly, user privacy is at risk and the entire network is susceptible to attacks such as eavesdropping and forgery. There is therefore a need for proper security solutions.

3. Contributions

The major contributions of this article include the following:

- A broad review of security, privacy and performance issues in smart cities is provided.
- The state-of-the-art security solutions presented in literature are identified.
- The operational shortfalls, security and privacy gaps of the state-of-the-art security solutions are discussed.
- Recommendations geared towards enhanced security and privacy posture in smart cities are provided.

4. Related work

The need to preserve confidentiality, integrity and availability in smart cities has seen the development of many security solutions based on a number of technologies. For instance, user authentication techniques based on passwords and personal identification numbers (PINs) have been presented in literature. Although simple passwords are easy to remember, they are vulnerable to guessing attacks [71], [72]. On the other hand, sophisticated and long passwords are more secure but extremely cumbersome for users to remember [73]. PINs are easily remembered than passwords but are generally less secure and hence can be easily and quickly guessed [74], [75]. Over the recent past, the blockchain technology has been utilized to secure IoT devices in smart cities. For instance, authors in [18], [76], [77], [78] and [79]. Although these schemes enhance trust and prevent forgery attacks, the blockchain technology has high storage and computation costs [80]. To address this challenge, other privacy-preserving authentication (PPA) protocols have been presented in [81], [82], [83], [84], [85] and [86]. Unfortunately, these protocols generally do not provide perfect forward secrecy [87]. To prevent data manipulation over the communication channels and boost trust [88], Intrusion Detection Systems (IDS) have been deployed. This is particularly important in smart transportation where falsified data can mislead drivers resulting in accidents. Game theoretic solutions have also been proposed in distributed architectures such as smart cities [89]. However, their performance depends on various assumptions, such as the rules of the game and whether or not the adversaries are cooperative. Although the scheme in [90] can solve this challenge, it is vulnerable to server impersonation attacks [91], [92]. In addition, the adversary can easily obtain the user's genuine identity.

Hybrid machine learning based techniques have also been instrumental in smart city security, more so in anomaly detection [93]. However, the efficacy of these algorithms relies on feature extraction, which present some challenges. For instance, salient features extraction is a complicated task. In addition, adversaries can learn the relevant features and engineer their attacks accordingly [94]. Since deep learning (DL) techniques operate on raw data, they can be deployed to solve this problem. In addition, DL based IDS have been shown to be resilient against zero-day attacks owing to their tolerance to small changes in data compared to other machine learning algorithms [95]. Unfortunately, DL algorithms call for large and high-quality training datasets [96]. Biometric technology presents another significant method for enhancing smart city security. For instance, a biometrics-based authentication and key agreement protocol has been presented by Yoon and Yoo [97]. However, this scheme is susceptible to user impersonation attacks [98], [99]. Similarly, authors in [100] have identified some flaws in the scheme developed by He and Wang [101]. In addition, the protocols in [100] and [101] require the registration center (RC) to be always online to facilitate mutual authentication. Therefore, these approaches cannot scale well and incur high costs in establishing and maintaining an always online RC.

In smart transportation, location based services are critical for the provision of context-sensitive information. However, this raises privacy concerns especially when adversaries access the location data. Most of the existing user location preserving solutions have high computation and communication. Although pseudonyms are widely deployed for location privacy protection, their management is centralized. This raises concerns about scalability and communication latencies as the number of devices surge. To address this problem, there is need for distributed pseudonym management systems that employ edge computing [102]. To prevent video forgery in smart cities CCTV, a scheme employing recurrent neural networks is proposed in [103]. On the other hand, a scheme using bilinear paring operation during the authentication phase is introduced in [91]. However, these pairing operations are time consuming [104]. Similarly, digital videos trustworthiness identification model is presented in [105], while a video authentication technique is presented in [106]. To enhance integrity of stored sensor logs, a verification technique is introduced in [107]. However, the efficacy of this approach is depended on the deployed instrument. This challenge is addressed by the schemes in [108] and [109]. Standard cryptographic approaches such as transport layer security (TLS) and secure socket layer (SSL) can also be utilized to enhance privacy and security in smart cities. However, these approaches are quite expensive for resource-constrained IoT devices [110]. This challenge can be addressed by lightweight key-establishment mechanisms based on symmetric encryption in [111].

To increase integrity, a verification strategy is presented in [112]. Unfortunately, the authors failed to discuss the spectrum and implementation details of this approach. To detect irregular energy consumption, ML and DL have been deployed in [113]. Although this scheme has impressive accuracy, it requires high-quality training data. Artificial immune systems can also be deployed here, but their applicability to real-world scenarios is not completely known [114]. A watermark based CCTV video authentication method is presented in [115]. However, this technique cannot protect against forgery. Further, new nodes and participants additions as well as their verification procedures [116] are not discussed. These issues can be addressed by the scheme in [117]. However, this approach fails to offer forward secrecy [118], [119]. On the other hand, Trusted Platform Module (TPM) based hardware and software security implementations have high power and cost overheads [120]. There is therefore need to develop IoT-optimized integrity attestation schemes that do not rely on TPM [121]. For instance, the schemes in [122] and [123] do not require TPM. However, the scheme in [122] is not robust against password guessing and smart card loss attacks. Similarly, the scheme in [124] is vulnerable to password guessing attacks [125]. Therefore, improved schemes are presented in [126] and [127].

The physically unclonable functions (PUFs) present another technology that can be utilized to secure smart city IoT devices against physical attacks. However, the challenge-response pairs can sometimes be inconsistent, raising stability issues [128], [129]. To curb this, the biometric authentication scheme in [130] can be deployed. Encryption algorithms can also help in securing smart cities through authenticity validation and spoofing detection [131]. Unfortunately, these algorithms can never defend against side-channel attacks. In addition, most of these encryption techniques have high computation overheads [132]. Although the scheme in [125] can alleviate side-channeling attacks, it cannot defend against user impersonation and password guessing attacks [133]. To address password guessing and impersonation attacks [134], physiological and behavioral biometric authentication schemes have been presented in [135], [136], [137], [138], [139], [140], [141], [142], [143]. However, physiological biometrics based authentications using iris recognition, face locks and fingerprint scans can be duplicated and changed. For instance, hand geometry and fingerprints can be recreated in plastic, while scars and bruises can alter the fingerprints. In addition, diverse face poses can confuse face recognition systems. Further, physiological biometric techniques using fingerprint and iris recognition call for additional hardware for input. These challenges can be addressed by behavioral biometric authentication schemes such as the one developed in [139]. Moreover, the protocol developed in [144] can also mitigate some of these issues. However, this method does not offer forward key secrecy and is vulnerable to smart card loss attacks [145], [146].

Fully homomorphic encryption techniques such as the ones in [147] and [148] can enable servers apply algorithms to encrypted data without first requiring them to be decrypted. However, current homomorphic algorithms have significant performance penalty that render them unsuitable for many smart city applications. In addition, these schemes cannot protect against hardware and side-channel threats such as cache, timing and power analysis attacks [48]. Therefore, improved schemes based on Elliptic Curve Cryptography (ECC) and pseudonyms are proposed in [149] and [131] respectively. However, the ECC in [149] increases the size of the exchanged messages. On the other hand, pseudonyms [150] may make it difficult to identify malicious users in the networks. This problem can be solved using identity based protocols in [151] and [152]. However, identity-based schemes have key escrow issues [153]. Therefore, an improved scheme is presented in [154], which is shown to resist key exposure attacks.

Attribute based encryption (ABE) algorithms are effective in the provision of diverse access control privileges. This renders them applicable in cloud-based smart cities. However, ABE has high computation complexity [155] which is unsuitable for IoT devices. In addition, both ABE and identity-based protocols require central servers, which limit their applicability in distributed implementations. To solve this challenge, Certificateless Signcryption (SLSC) technique has been introduced in [156]. In these techniques, the service provider only dispenses partial keys, eliminating the need for a completely trustful server. Similarly, smart card based remote user authentication scheme in [157] incurs low computational costs and hence can address the issues in ABE based schemes. Blockchain technology based schemes have been deployed to uphold non-repudiation and eliminate central server requirements [158], [159], [160], [161]. However, these blockchain based protocols are vulnerable to 51% attacks. In addition, they have high storage and computation complexities [162]. These complexities result in high latencies which cause inconvenience for users [163]. Since blockchain enables the tracking of user transactions, their visiting patterns can be revealed, compromising their privacy.

5. Results and discussion

The extensive literature review carried out has yielded many security solutions tailored for the smart cities. These security solutions are based on techniques such as blockchain, identity, attributes, biometrics, PUFs, watermarking, smart cards, TPM, fully homomorphic, ECC, game theory, machine learning, passwords and PINs. Table 1 presents the observed weaknesses of these techniques.

Table 1 Smart Cities Security Techniques Challenges

Technique	Challenges
Passwords and PINs	Vulnerable to guessing attacks; cumbersome for users to remembers
Blockchain	Susceptible to 51% attacks; high storage and computation costs
Game theory	Performance depends on various assumptions, such as the rules of the game and whether or not the adversaries are cooperative
Machine learning	Salient features extraction is a complicated task; adversaries can learn the relevant features and engineer their attacks accordingly

Biometric	Can be duplicated and changed; fingerprints can be recreated in plastic
TLS, SSL	Expensive for resource-constrained IoT devices
Watermarking	Cannot protect against forgery
TPM	High power and cost overheads
PUF	Have stability issues
Fully homomorphic	Have significant performance penalty
ECC	High bandwidth requirements
Identities	Have key escrow issues
ABE	High computation complexity; inapplicable in distributed implementations
Smart card	Prone to smart card loss and side-channel attacks

As shown in Table 1, all these technologies have either security or privacy issues. There is therefore need to explore novel technologies that can sufficiently protect smart cities. Table 2 presents the challenges of the specific smart cities security approaches.

Table 2 Challenges of Smart Cities Security Schemes

Scheme	Weaknesses
Gipp et al. [76], Khan et al. [18] Kim et al. [77], Javaid et al. [78], Hang et al. [79]	High storage and computation costs
Sood et al. [81], Lee et al. [82], Tsaur et al. [83], Mishra et al. [84], Li et al. [85], Xue et al. [86]	Lack perfect forward secrecy
Tsai and Lo [90]	Vulnerable to server impersonation attacks; adversary can easily obtain the user's real identity
Aloqaily et al. [93]	Salient features extraction is a complicated task; adversaries can learn the relevant features and engineer their attacks accordingly
Yoon and Yoo [97]	Susceptible to user impersonation attacks
Odelu et al.[100] , He and Wang [101]	Require an online RC; has scalability issues; incur high costs
He et al. [91]	Time consuming
Ghimire et al. [112]	Spectrum and implementation details are not discussed
Yip et al. [113]	Requires high-quality training data
Kerr et al. [115]	Cannot protect against forgery
Chen et al. [117]	Fails to offer forward secrecy
Kumari et al. [122]	Susceptible to password guessing and smart card loss attacks

Chen et al. [124]	Vulnerable to password guessing attacks
Jiang et al. [125]	Defenseless against user impersonation and password guessing attacks
Dhillon and Kalra [135], Frank et al. [136], Trojahn et al. [137], Chaturvedi et al. [138], Zheng et al. [139], Ferrero et al. [141], Nickel et al. [142], [Buthpitiya et al. [143]	Deployed features can be duplicated and altered
Shunmuganathan et al. [144]	Cannot offer forward key secrecy; is vulnerable to smart card loss attacks
Honan et al. [147], Page et al. [148]	Have significant performance penalty; cannot protect against hardware and side-channel threats
Kalra and Sood [149]	High bandwidth requirement; difficult to identify malicious users in the network
Chaudhry et al. [151], [Zhong et al. [152]	Have key escrow issues
Hammi et al. [158], [Rathee et al. [159], [Ouaddah et al. [160], [Rashid et al. [161]	Vulnerable to 51% attacks; can compromise user privacy

As shown in Table 2, all these schemes have security issues that can potentially impede their applicability in smart cities. Therefore, the recommendations in Section 6 are deemed necessary in addressing some of these challenges.

Recommendations

From the foregoing discussions, it is obvious that smart cities face numerous security challenges. Although a good number of schemes have been presented in literature, perfect security at low complexities remains a mirage. For instance, three-factor authentication using biometrics, passwords and smart cards has been shown to be effective [164], [165]. However, this authentication is complicated and hence prohibitive for some smart city users such as the elderly and disabled. In addition, continuous authentications cannot be provided by these three-factor based schemes. There is therefore need for non-invasive and user-friendly authentication approaches for every communication channel as shown in Fig.2. To accomplish this, information collected by radio frequency sensors, cameras and radio frequency identification systems [166] can be deployed.

Most of the conventional smart city security solutions involve public and private key pairs. Consequently, they require an additional copy of data for every data access request [48]. Therefore, for smart city application scenario such as smart healthcare with complicated data access patterns, these solutions can become prohibitively sophisticated. There is therefore need for less sophisticated authentication schemes that provide the same level of protection.

To address the resource-constrained nature of smart city IoT devices, many lightweight key-establishment techniques based on symmetric encryption have been presented. Unfortunately, most of these approaches rely on trusted centralized authorities which are assumed to be tamper-proof. However, this assumption does not hold in most smart city application domains. In addition, encryption can potentially complicate data query and data processing [167]. Therefore, a need arises for innovative approaches of making data query and processing efficient in the face of symmetric encryption.

Figure 2 Proposed Smart City Secure Message Exchanges

6. Conclusion

This paper has discussed the privacy, security and performance of the current schemes developed for securing the smart city environment. It has been shown that most of the current security solutions have numerous security gaps that require immediate attention. In addition, performance is another major hindrance for the utilization of majority of these schemes in resource-constrained IoT environments such as smart cities. Based on the identified gaps, a number of recommendations are given which are thought to be necessary for the attainment of perfect security in smart cities. Future work will include the practical implementations of these recommendations so that their effect on security and performance can be empirically analyzed.

Compliance with ethical standards

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