Smart City IoT System Network Level Routing Analysis and Blockchain Security Based Implementation

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Abstract
This paper demonstrates, network-level performance analysis and implementation of smart city Internet of Things (IoT) system with Infrastructure as a Service (IaaS) level cloud computing architecture. The smart city IoT network topology performance is analyzed at the simulation level using the NS3 simulator by extracting most of the performance-deciding parameters. The performance-enhanced smart city topology is practically implemented in IaaS level architecture. The intended smart city IoT system can monitor the principal parameters like video surveillance with a thermal camera (to identify the virus-like COVID-19 infected people), transport, water quality, solar radiation, sound pollution, air quality (O3, NO2, CO, Particles), parking zones, iconic places, E-suggestions, PRO information over low power wide area network in 61.88 km × 61.88 km range. Primarily we have addressed the IoT network-level routing and quality of service (QoS) challenges and implementation level security challenges. The simulation level network topology analysis is performed to improve the routing and QoS. Blockchain technology-based decentralization is adopted to enrich the IoT system performance in terms of security.

Keywords IoT technology · Smart applications · Network simulation · Blockchain technology

1 Introduction
Because of its impressive performance and great potential, the IoT technology's role in the design of smart systems is thrived in many fields like smart cities [1–3], medical [4–6], aquaculture [7–9], industry [10–12], and smart home [13]. Industry 4.0 is aimed at mass customization and cyber-physical cognitive systems, in that IoT technology proved its ability and significance. When compared with RFID and smart device technology IoT plays a vital role in exploring smart applications [14].

The IoT device users count is growing rapidly as shown in Fig. 1, and this is the major motivating point for many kinds of researchers to choose IoT as a major domain of research [15]. However, the major research challenges in the implementation of IoT systems are maintaining high throughput, less delay, low power consumption, low path loss, good packet receive rate, quality of service (QoS), congestion control, reliability, heterogeneity, scalability, high security, and best network routing [16, 17]. The network-level IoT topology simulation helps to make the implementation cost-effective and the incorporation of blockchain technology in IoT will make the system more secure and sturdy [18].

The present-day civil people are using more and more IoT devices and there is a significant demand for smart IoT systems like the design of smart transport, smart building, smart home, smart business [19], and smart grids [20]. However, the development of smart city applications using IoT is one of the potential research areas. Nowadays IoT systems for smart cities monitor viruses (like COVID-19) spread which is very essential. The vital smart city parameters are video surveillance, transport, water quality, solar radiation, sound pollution, air quality (O3, NO2, CO, Particles), parking zones, iconic places, E-suggestions, and public relational officer (PRO) information as shown in Fig. 2.

The sensor, network, and implementation level challenges of a smart city-based IoT system as listed in Table 1. Identifying the best IoT routing topology for a smart city with good quality of services (QoS) is one of the network-level potential research challenges. Before the implementation,
doing network level simulation analysis by extracting the parameters like throughput, delay, path loss, packets received, the distance between the mobile nodes and station nodes to access points ratio helps to improve the quality of service (QoS) [21–23]. Maintaining the exact distance between the nodes helps to improve the throughput of the system [24–27]. Security and reliability are the two major challenges in IoT system implementation. Blockchain technology is useful to resolve the security challenges in IoT [28].

Blockchain technology enables the decentralization of the database over a peer-to-peer network of nodes, each of which stores a copy of the whole database [29]. IoT devices produce massive volumes of data that must be stored and analyzed. Incorporation of blockchain technology with IoT helps to detect unofficial actions on stored IoT data with this the overall system security improves, is cost-effective, and speeds up the data transmission Process. The presented IoT system can majorly monitor atmospheric, traffic conditions, and identification of virus-infected people in the city [30].

This paper is described: in Sect. 2, we holistically investigate research gaps and possible solutions related to IoT-based smart city. Section 3 describes the simulation of network routing and parametric extraction to address the network quality of service. Smart city data collection and monitoring system implementation by incorporating distributive blockchain technology which offers high security is discussed in Sect. 4 and followed by Conclusions in Sect. 5.

2 Literature Survey

The smart city with the IoT paradigm is the most widely discussed area by both industry people and researchers. In this paper, we have primarily demonstrated network routing, quality of service, and security aspects in the smart city data monitoring IoT system. Monitoring the smart city parameters with IoT is considerably explored by many researchers, but still, we can find potential research gaps like defining the best network routing, improving quality of service (QoS), achieving high reliability or lifetime, getting the best scalability and providing high security as listed in Table 2. The smart city network simulation performance indices are listed in Table 3.

Different technologies involved in the design of IoT systems are listed in Table 4. The mathematical expressions for the topology performance analysis are listed in Table 5. IoT technology is emerged in many fields because of its great potential and unique ability to adapt to new technologies [64, 65]. Now there is a huge demand for the IoT in a wide area network, but in wide range offering reliability, scalability, proper network routing, congestion control, security, and quality of service (QoS) is a challenging task [66–68]. In this paper, we have addressed three potential research challenges in smart city IoT wide area networks i.e., network routing, QoS, and security. The blockchains are primarily classified as permissionless (public) and permission (private). Any type of blockchain incorporation in IoT enables decentralization which makes the network more secure and scalable.
### Table 1  Network and implementation level IoT challenges

| Level                  | Challenges                                                                 | Solution                        |
|------------------------|----------------------------------------------------------------------------|---------------------------------|
| Sensor Node            | Node capturing, false data injection, eavesdropping and interference, malicious code injection, side-channel attacks, booting attacks, sleep deprivation attacks | Encryption, digital signature    |
| Network                | Routing, patch loss, congestion control, reliability, scalability, and quality of service (QoS) | Network level simulation analysis |
| Implementation         | Sensing of physical parameter accurately, Privacy, security, storage, data analysis and visualization | Blockchain, ICN, SDN             |

### Table 2  Comprehensive study of smart city IoT related work

| Refs. | Topic discussed related to smart city | Strength | Simulation used (tool) | Routing topology | Protocols |
|-------|--------------------------------------|----------|------------------------|------------------|-----------|
| [31]  | Smart energy management system       | Context life cycle for IoT-based smart cities | Yes (FIWARE)     | –                | MQTT      |
| [32]  | Traffic Classification               | Network security and quality of service       | No               | Random           | COAP      |
| [33]  | Generic IoT Networks                 | Hierarchical IoT network (HIoTN)              | No               | –                | Authentication Protocol (UAKMP) |
| [34]  | IoT with Blockchain                  | IoT interface with blockchain                 | No               | –                | MQTT      |
| [35]  | Key oriented verification style for IoT devices using blockchain | Blockchain with authentication | Yes (ns-3)      | –                | MQTT      |
| [36]  | Bloom filters, to make compact names from node reports; data broadcast policies | Distributed NAMing Service (DINAS) | Yes (contiki/cooja) | –                | MAC, IPv6, RPL |
| [37]  | ICN, Named Data Networking           | Lightweight Authentication and Secured Routing | Yes (ns-3)       | Hierarchical routing | Information centric networking (ICN) |
| [38]  | Waste management using IoT           | IoT architecture for waste management in smart city | No               | –                | CoAP, HTTPS, and MQTT |
| [39]  | Stable IoT Networks enabled by Confirmation | Suggest an attestation-enabled protocol for stable and scalable routing | Yes (cooja)      | –                | CoAP, HTTPS, and MQTT |
| [40]  | Objective BF-ETX Feature for RPL Routing Protocol | Adaptation and implementation of the objective function in routing protocol RPL | Yes (cooja)      | Random           | –         |
| [41]  | Effect of the Reliability            | Narrowband of Internet of Thing (NB-IoT)     | Yes (ns-3)       | –                | MQTT      |
| [42]  | Multi-tier Fog Computing             | ad-hoc fogs and dedicated fogs               | No               | –                | DSDV      |
| [43]  | Transmission manager style in heterogeneous WSNs | Optimum transmission manager (OptTM) approach in WSNs where there are many implementations | Yes (ns-3)       | Random           | DSDV      |
| [44]  | Fog Flow                             | Cloud & Edge computing role in Smart Cities  | No               | Random           | COAP      |
| [45]  | The Smart Cities Full Lifecycle Technology Management System | NB-IoT   | No               | –                | COAP      |
| [46]  | ICN-IoT                              | IoT Smart Applications                       | ndnSIM an ns-3 extension | –                | CoAP, HTTPS, and MQTT |
### Table 3 Basic smart city and network topology parameters

| Refs. | Topic discussed                                                                 | Simulation Parameters | Simulation Parameters |
|-------|--------------------------------------------------------------------------------|-----------------------|-----------------------|
| [47]  | Models to incorporate networks of wireless sensors into the Internet of Things | Network area: 100×100 m², Number of nodes: 100–500, Transmit data rate: 250 kbps, Node placement: Random | Simulation tool: –, Simulation time: 1000 s, Other: physical and media access control model = IEEE 802.15.4, packet size = 96 bits, electronic energy (Eelec) = 50 nJ/bit, transmission range R = 75 m; |
| [48]  | Formal Human-Assisted Smart City Emergency Response Research                    | City size (nxn regions) = 5×5 to 30×30, road types = MW,OR,IR; probability of volatility ($p_v$) = 0.1–0.9; probability of congestion ($p_c$) = 0.1–0.9; probability of workload (low/high) ($p_w$) = 0.5; | |
| [49]  | Optimal positioning of Cloudlets in SDN based Internet of Things Networks for connectivity latency minimization | Number of cloudlets = [1, 4]; Number of APs = [10, 40]; Number of IoT devices = [200, 1000]; Average transmission data rate of each AP = 1.0 Gbps | Average request size = [20, 100] KB; Failure probability of APs = [0.05, 0.08]; Failure probability of network links = [0.02, 0.08]; Attachment rate = 2; |
| [50]  | Safe and trustworthy policy-based Sensing for the Internet of Things in Smart Cities | Network area: 600 m × 600 m, Number of nodes: 50, 100, 200, Transmisison range: 120 m; Num. of malicious nodes = 5, 10, 20; Node Motion Speed = 5 m/s, 10 m/s, 20 m/s; | |

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The table above outlines various parameters for different smart city and network topology simulations, including network area, number of nodes, transmit data rate, node placement, simulation tool, simulation time, and additional simulation parameters such as the physical and media access control model, packet size, electronic energy, transmission range, and additional network and node parameters.
| Refs. | Topic discussed                                                                 | Simulation Parameters                                                                 |
|-------|---------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|
| [51]  | Energy and Congestion-Aware Routing Metric in Smart City for Smart Grid AMI Networks | 300 × 300 m² Number of nodes = 20, 40, 60, 80, 100; Random Cooja Contiki 3.0 2 h (7200 s) |
|       |                                                                                  | Radio Medium = UDGM; TX Ratio = 100%; TX Range = 50 m; INT Range = 60 m; RX Ratio = 20%, 40%, 60%, 80%, 100%; Energy Model = Energest; Initial Energy = 10 J; Energy Consumption (TX) = 0.0017944 mJ; Energy Consumption (RX) = 0.00199 mJ; |
| [52]  | An Authentic-Based Smart e-Healthcare Services Privacy Preservation Protocol in IoT | 80 × 80 m² Communication nodes = 3–9, Sensor nodes = 160 NS 3.28 1800s                  |
|       |                                                                                  | Network platform = ubuntu 14.04, Routing protocol = Optimized link state routing (OLSR), Traffic type = UDP/TCP, Mobility = 2 to 50 m/s |
### Table 4 Comprehensive study on technologies involved in different layers of Internet of Things

| Refs. | Perception layer | Network layer | Middleware | Data processing | Cloud platforms | Application layer |
|-------|------------------|---------------|------------|-----------------|-----------------|-------------------|
|       | Boards/ controllers | Things | Network Interface | protocols | Data storage | Software and APIs | Architecture | Application |
| [53–59] | Arduino, Raspberry-pi, Intel Gelineo Gen, Intel Edison, Beaglebone Black, Broadcom, Netduino, Intel Edison, Flutter, Marvell, Tessel 2, Particle, Node mcu ko, Smart things, etc., | Sensors, actuators, RDID/NFC tags, Identification (EPC, uCode; QR.), touch screen display, onboard software, etc., | 3GPP, IEEE 802.15.6, Z-Wave, IEEE 802.3, RFID, NFC, UWB, i/faDA, PLC, CAN, LPAW(low-LTE-M), cellular(2G, 3G), UWB(Lora, NB-IoT, SigFox), LTE-M, cellular(2G, 3G), 802.11, Bluetooth 4.2, Bluetooth 4.1, Zigbee (IEEE 802.15.4), BLE, Zigbee (802.15.4), RF1/2NFC, WPAN (IEEE 802.15.4), etc., etc., | Application (CoAP, MQTT, AMQP, XMPP, DDS, Websocket, Transport (TCP, UDP), Network (IPv4, IPv6), Routing (RPL), Service Discovery (mDNS, DNS-SD, SSAPD, SLP), LEACH-C, FCMCP, etc., | Storage infrastructure (public, private, hybrid), DB (MongoDB, cassandra, Hadoop, CouchDB, Redis, etc., storage architecture, etc., | Data mining, Big Query, Cloud DataLab, Apache Hadoop, Kafka, Storm, RapidMQ, Scribe, SPARQL, SciDB, Semantic technologies (JSON, W3C, OWL, RDF, EXI, WSDL, etc.,), etc., | OpenIoT, Amazon, Google Cloud, BM Watson, FIWARE, Arkessa, One platform, SensorCloud, Smartthings, ThinkWorks, Oracle IoT, Platly, Nimbits, ThinkSpeak, Xively, etc., | OS (LiteOS, Android, RIoT OS, RangOS, Cantiki, FreeRTOS), APIs (JML, Web GL, RAML), Embedded and custom apps built using a things data |
13 Network Simulation Analysis of Smart City IoT Topology

Embedded systems that communicate with transducers and involve wireless communication are composed of IoT devices. In Ubuntu 18.0, we first compared compound TCP over Wi-Fi output with NS-3 simulator experiments. The smart city IoT system protocol stack is as in Fig. 3. It is made up of wireless equipment, a PC router on which a dummy net is mounted, a connection point, and a server. The Gateway and the А 22 Mbps Ethernet links to the server. We used the slandered IEEE 802.11a. There are systems with a Wi-Fi internal 802.11b card.

The smart city network scenario is framed by considering Vijayawada city located in Andhra Pradesh state, India. Here, we performed the simulation level analysis on network performance by varying the number of sensor nodes (МхN), the number of gateways (К), and the number of user counts (G). It is beneficial to build low-cost nodes to promote their large deployment, taking into account that the IoT system can monitor smart city parameters. This means saving money on the majority of the IoT architecture. The designed network parameters are listed in Table 6. The smart city model network topology is shown in Fig. 4. The smart city IoT scenario is virtually simulated in the ns-3 environment for 8000 s, it is offering a throughput of 22Mbps, Average power consumption of 2.6 mW, Delay of 80 ms, and Packet delivery ratio of 0.85%, and latency is 7.8. The network performance indices are as shown in Fig. 5.

### Table 5 Basic IoT system network level mathematics [60–63]

| Parameter               | Mathematical equation               | Variables                                                                 |
|-------------------------|-------------------------------------|----------------------------------------------------------------------------|
| Power consumption       | \( \frac{\text{PACKET}}{\text{P}} = \frac{n}{n-1} \) \( P_{\text{RX}} + nP_{\text{TX}} + \) \( 2P_{\text{idle}} + P_{\text{amp}} + P_{\text{deep}} + 2P_{\text{startup}} \) | \( P_{\text{RX}} \) is the receiver power, \( P_{\text{TX}} \) is the transmitter power, \( P_{\text{idle}} \) is the idle power, \( P_{\text{amp}} \) is the power for the startup RF, \( P_{\text{deep}} \) amplifier power in communication module |
| Path loss               | \( P_{\text{L}}(d_l) + 20\xi \log_{10}(d_l) \) for \( d_l < 8\text{m} \), \( l = 1, 2, ..., n \) | \( d_l \) is the distance of the length \( l \) |
| Delay                   | \( D_{\text{cont}} + D_{\text{prc}} + D_{\text{swt}} + D_{\text{prop}} + D_{\text{trans}} + D_{\text{queue}} + D_{\text{rec}} \) | Contention, propagation, switching, processing, transmission, queuing delays. Software defined networks are preferable in IoT to minimize access delay |
| Throughput              | \( N(1 - \pi_m(t)) \) \( P_s \)                | \( N \) is the number of nodes in the network, \( S \) is the packet size, \( T \) is the length of the cycle, \( P_s \) is the window size, \( \pi_m(t) \) is the probability of successful DATA packet transmission |
| Sensor network life time| \( \frac{E_{\text{initial}}}{E_{\text{total}}} \) | \( E_{\text{initial}} \) is initial energy of a SN and \( E_{\text{total}} \) is total energy dissipated during data transmission and reception |

### Table 6 Network Parameters

| Parameter               | Value                     |
|-------------------------|---------------------------|
| Sensing model           | IEEE 802.11a              |
| Area                    | 1000 x 1000 m²            |
| Number of IoT nodes     | 10–30                     |
| Packet size             | 96 bits                   |
| Simulation time         | 8000 s                    |
| Transmission data rate  | 22 Mbps                   |
| Throughput              | 18–22 Mbps                |
| Average power consumption| 2–2.6 mW                 |
| Delay                   | 80 ms                     |
| Packet delivery ratio   | 0.85–0.74%                |
| Latency                 | 7.8                       |

Fig. 3 Smart city IoT system protocol stack

4 Practical Realization Aspects

Monitoring the smart city parameters as air quality, sound pollution, parking zones, solar radiation, water quality, waste management, transportation, iconic places, e-suggestions, public relations officer (PRO) information, video surveillance, human flow, and emergency services really help the
civil people in the process of decision making [69–71]. In this paper, we have presented a smart city IoT system that can monitor the overall 13 parameters as illustrated in Fig. 6 related to the smart city. Primarily the air quality will depend on the levels of carbon monoxide (CO), ammonia (NH3), nitrogen dioxide (NO2), ozone (O3), sulphur dioxide (SO2), and particle matter 2.5, (PM2.5), particle matter 10 (PM10). The commercially available sensor to monitor the smart city parameters are listed in Table 7.

### 4.1 Blockchain for Smart City IoT

The purpose of incorporating blockchain technology with smart city IoT is, which enables the decentralization of storage and server as shown in Fig. 7, with this the system security improves and makes it more sturdy. The smart city IoT system performance is significantly improved with blockchain. The role of blockchain in presented smart city IoT is, that at the sensor level, the data was encrypted with the public key. The IoT device maker stores the associated public key in a blockchain block [75–77]. A network node sends a random challenge message to an IoT device, to which the IoT device responds with a signature. At the network level, other than centralized cloud, here we used decentralization of cloud services. With this, the system speed increased and the system is more scalable.

The smart city IoT application was designed by considering Vijayawada city in Andhra Pradesh state in India. Deployed multiple internet-enabled sensor nodes all over the city, those are capable to send the sensors data to the pre-defined destination API location. Eventually, an application for the smart city for better monitoring and analysis of the data as shown in Fig. 8 was designed with blockchain security.

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Fig. 4 Network topology for Vijayawada city, Andhra Pradesh, India
Fig. 5 Network simulation parameters, a Throughput (MBPs), b Average Power Consumption (mW), c Delay(ms), d Packet Delivery Ratio, e Latency
The designed smart city application specifications are listed in Table 8. The sensor nodes are designed with Raspberry pi-3 and all the sensors related to smart city parameters are interfaced. The node is connected with an LTE access point for the internet. MongoDB and WinNMP are used as databases and servers respectively. MQTT IoT protocol was incorporated into the user access side. An application program interface (API) connector mechanism was used which enables highly secure data transmission to the destination. Overall the smart city IoT system was implemented with infrastructure as a service (IaaS) architecture.

5 Conclusion

This article presented a smart city IoT system that helps to monitor essential parameters like video surveillance using a thermal camera, air quality, water quality, sound pollution, weather, solar radiation, waste management, parking zones, E-suggestions, and Iconic Places. Prior virtual simulation is performed on the smart city IoT network scenario using NS-3. Eventually, the IoT system is implemented with good quality of service and security. The incorporation of blockchain with the smart city makes the system more secure, highly scalable, and cost-effective.
Table 7 List of sensors incorporated with specifications [72–74]

| Smart city parameters | Sub category | Standard range | Effects | Commercial available sensor/actuator |
|-----------------------|--------------|----------------|---------|--------------------------------------|
| Air quality           | CO           | 2.0 µg/m³ for 8 h | Headache, dizziness and fatigue | MQ-7 | 20–2000 ppm |
|                       | NH₃          | 400 µg/m³ for 24 h | Liver, kidney and spleen problems | MQ-135 | 10–300 ppm |
|                       | NO₂          | 80 µg/m³ for 24 h | Respiratory problems | MiCS-2714 | 0.5 to 5 ppm |
|                       | O₃           | 100 µg/m³ for 8 h | Chest pain, coughing, throat irritation and airway inflammation | MQ-131 | 10–1000 ppm |
|                       | SO₂          | 80 µg/m³ for 24 h | Coughing, wheezing, shortness of breath | 2SH12 | 10–100 ppm |
|                       | Small particles (PM2.5) | 60 µg/m³ for 24 h | Respiratory problems | nova pm sensor sds011 | 0.0–999.9 µg/m³ |
|                       | Big Particles (PM10) | 100 µg/m³ for 24 h | They can get deep into your lungs | nova pm sensor sds011 | 0.0–999.9 µg/m³ |
| Waste management      | Bin level    | Semi full        | Dustbin overflow leads to spilling along the roads which attracts animals | IR Sensor | 850 nm |
| Water quality         | PH           | 6.5–8.5          | Cancer | PH meter v1.0 | 0–14 |
|                       | Nitrite      | 0.1 mg/l         | blue baby syndrome | NO₃ probe | 1.4 to 2200 ppm |
| Weather               | Relative humidity | 30–60%             | The risk of cold, flu and other infections is substantially increased | DHT11 | 20%-90% |
|                       | Temperature  | 32–40°C          | Dehydration, Headache | DS18B20 | – 55–125 °C |
|                       | Sound        | 0 –70 dB          | Sounds between 120 and 140 dB causing pain | MAX4466 | 0 dB –70 dB |
|                       | Solar radiation | solar radiation | 100 and 1 mm | Solar panel | Solar panel |
|                       | Traffic      | spectrum          | More traffic leads to air and sound pollution | Ultrasonic Sensor | 100 nm and 1 mm |
|                       | Parking zones | –                | Without proper parking zones in a smart city may leads to traffic congestion | Ultrasonic Sensor | 1–100 cm |
| Video surveillance    | Bike, LWM (car), HWM (Lorry) | –               | – | – |
| with thermal camera   | Trace the human flow | –              | Identifying and controlling the human flow is not possible. Now a days, there is a threat with the virus (covid-19) spread through human interaction | AMG8833 Thermal Camera | – |
|                       | To identify the viral infected people | –             | – | – |
Fig. 7  Smart city. a IoT system with centralized server, b Blockchain enabled IoT system with distributed server
Fig. 8  Smart city IoT application, a home page, b location based information monitoring
Table 8 Smart city IoT system implementation parameters

| Parameter          | Details |
|--------------------|---------|
| Sensor node device | Raspberry pi-3 |
| Network connection | Wi-Fi    |
| Access point       | LTE      |
| Database           | Mango DB |
| Server             | WinNMP   |
| IoT protocol       | MQTT     |
| Framework          | LAREVEL  |
| Security from      | Cross Script Attack |
| Connector          | API      |

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