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Research Article

Real-Time Monitoring in Smart Cities: Sensor Networks and Communication Protocols

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ABSTRACT

Real-time monitoring plays a crucial role in developing smart cities, leveraging sensor networks and communication protocols to gather and analyze data for efficient urban management. This paper examines the integration of sensor networks and communication protocols in enabling real-time monitoring systems within smart cities. It explores the deployment of sensor nodes across urban areas to collect diverse data streams related to environmental quality, traffic flow, energy consumption, and infrastructure health. Communication protocols, such as those based on IoT technologies and wireless sensor networks, facilitate seamless data transmission and integration, ensuring the timely and accurate delivery of information to city authorities and stakeholders. The paper also addresses scalability, interoperability, and concerns related to data privacy and security. Insights drawn from case studies and technological advancements highlight the transformative impact of real-time monitoring on urban sustainability and citizen well-being.

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1. Introduction

A smart city is a municipality that uses information and communication technologies (ICT) to enhance operational efficiency, share information with the public, and improve government services and citizen welfare. The city's success depends on its ability to form a strong relationship between the government and the private sector, as most work in creating and maintaining a digital, data-driven environment occurs outside of the government.

Smart city technology encompasses Internet of Things (IoT) devices, software solutions, user interfaces (UIs), and communication networks. IoT devices often have edge computing capabilities, ensuring only relevant information is communicated over the communication network. Firewalls are essential for protecting, monitoring, and controlling network traffic within a smart city network. Other technologies include APIs, artificial intelligence (AI), cloud computing, dashboards, machine learning (ML), machine-to-machine (M2M), and mesh networks. Emerging trends, including automation, machine learning, and the Internet of Things (IoT), are driving the adoption of smart cities. Smart city initiatives can encompass various areas of city management, including smart parking meters, transportation, intelligent traffic management, and smart public transit. Energy conservation and efficiency are major focuses, with smart sensors and grid technology improving operations and monitoring energy outages. Smart city initiatives also aim to address environmental concerns, waste management, and sanitation using smart technology. Fig. 1 shows components of a smart city.

Fig. 1. Components of smart city.

The increasing number of vehicles in cities has led to an imbalance in daily mobility, prompting the development of parking services to reduce unnecessary driving. This has caused additional carbon dioxide emissions and

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traffic congestion, causing accidents. However, the Internet of Things (IoT) and new technologies provide modern solutions to create smart cities, optimizing urban operations and services. Smart cities are used in various areas, including medical facilities, industry, hospitals, offices, transport, and parking lots (Definition, Smart City). Fig. 2 shows a structural smart city.

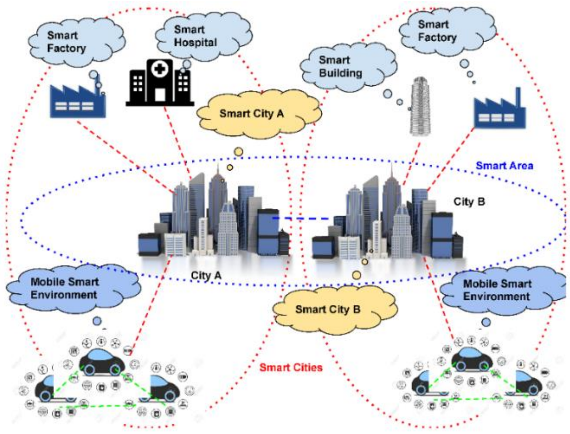

Fig. 2. Structural smart city (Jawhar et al., 2017).

The increasing number of vehicles has caused traffic jams, accidents, and illnesses due to poor road traffic management and unnecessary movement of drivers. This article presents an intelligent and connected system based on wireless sensor networks (WSNs) at road intersections and car parks to make roads and cities smarter (Giuseppe Tricomi, 2024). This innovative system connects citizens to roads and parking spaces remotely and in real-time using only one mobile application, addressing the issues caused by poor traffic management and excessive movement of drivers. Fig. 3 shows smart automated traffic control.

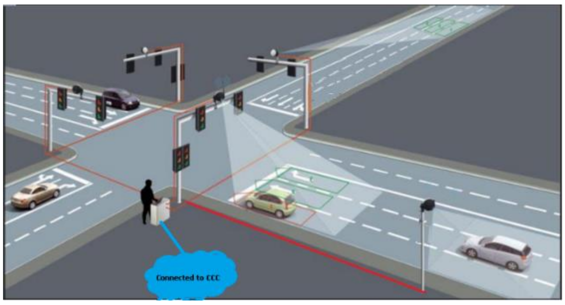

Fig. 3. Smart automated traffic control.

This work aims to discuss the overall architecture of the proposed intelligent traffic control system, our system's presentation, a self-organization protocol suggestion, and our intelligent system's algorithm. Along with the Android Smart Traffic mobile application, the simulation and assessment of the performances in terms of energy usage, WSN lifetime, etc., are also provided.

2. Literature review

The first urban big data project, "A Cluster Analysis of Los Angeles," was developed in Los Angeles in the 1970s, marking the beginning of the journey toward smart cities. When a virtual digital city was established in Amsterdam in 1994, it was maybe the first smart city. Then, when IBM and Cisco initiated their projects in the mid-2000s, things began to pick up speed. The first-ever Smart City Expo World Congress was held in Barcelona in 2011 and has since evolved into an annual event that tracks the advancement of smart cities.

A paper proposes a fast, fault-tolerant, and low-energy leader election algorithm for smart cities. It uses the WBS (Wait Before Starting) technique, where each node waits for a time before sending the first message. The leader is the node with the smallest x-coordinate, and the total of sent and received messages represents global consumption. The algorithm is well-balanced in energy consumption, efficient, and adapts well to network growth, making it suitable for smart cities (Ala' Khalifeh, 2021). Another paper proposes an IoT-based Urban Traffic Light Control architecture (IoT-UTLC) to interconnect roads and traffic lights through an IoT platform. The architecture uses Message Queuing Telemetry Transport (MQTT) protocol to manage Quality of Service (QoS), enabling lights to adapt remotely and interrupt traffic light's classic cycles. Experimental results show MQTT is efficient when packet rates exceed 35% of traffic flow and reduces traffic delay up to 0.05s at 90% congestion. The system has been prototyped and tested with different QoS levels (Kadjouh Nabil, 2019).

A recent study shows that the increasing number of vehicles has led to traffic jams and accidents in smart cities. To address these issues, engineers propose an intelligent traffic management system using wireless sensor networks (WSNs), surveillance cameras, and IoT. The system collects data on road traffic and available parking spaces, allowing drivers to view traffic rates and parking availability remotely using an Android mobile application. This system integrates three smart subsystems, enhancing connectivity between citizens and a smart city (Rafik Zitouni, 2019). Another study proposed that Urban planning is being revolutionized by communication technology, which makes it possible to schedule, aggregate, and process data efficiently. Smart city services including transport planning, energy conservation, water management, waste management, environmental monitoring, public safety, healthcare, education, and entertainment are made possible by this method, which combines sensor/device networks and cloud computing. By achieving lower latency and data processing time than standard cloud-based techniques, the suggested multi-layer network architecture improves service quality and urban governance (Adil Hilmani, 2020).

3. Design for the Intelligent Traffic Management System

The proposed system consists of three parts: parking space management center, traffic light management center, and global information and management center. The parking space management center uses WSNs to consolidate availability states in parking spaces, which are then transferred to the global information and management center. Hybrid sensors, such as presence sensors and RFID readers, detect vehicle presence and identify them based on their RFID tags. Fig. 4 shows a smart traffic light management system.

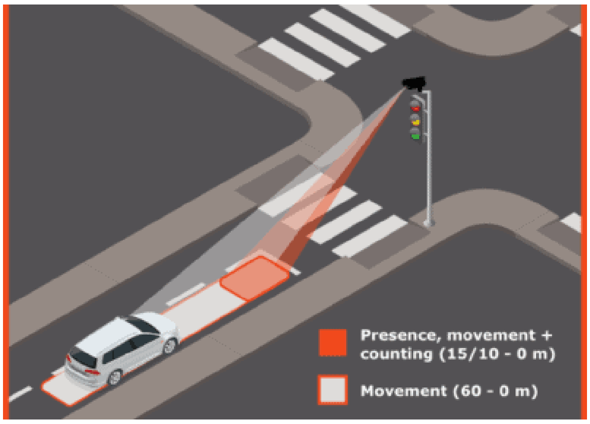

Fig. 4. Smart traffic light management system.

The traffic light management center manages and controls traffic lights at intersections to minimize traffic jams and ensure traffic flow. It collects the density and number of cars circulating in each road forming crossroads, estimating the maximum duration for traffic lights to remain green. The global information and management center provides a database of information collected from sensors installed in the city, managing parking spaces and traffic lights to increase traffic flow. An Android mobile application helps drivers find free parking spaces and real-time traffic rates, avoiding unnecessary trips and congestion.

4. System management

Sensors, wireless connectivity, network topology, data transmission, and other components make up system management.

4.2.1. Sensors management:

The management center utilizes various sensors, including magnetic sensors, to detect the presence of vehicles. These sensors, installed in the ground, measure the magnetic fields generated by vehicles, allowing for precise detection of their presence. The system transmits these detection states to the corresponding gateway, transmitting them to the global information and management center.

4.2.2. Wireless connectivity:

Traffic control in cities relies on wireless communication technologies like Bluetooth and ZigBee for efficient and reliable data exchange between sensors and gateways. Bluetooth simplifies communication, allowing low-speed data transfer, but its energy consumption is a concern. ZigBee, on the other hand, offers energy-saving characteristics, high reliability, and low-cost pricing, making it a suitable choice for sensor networks that require long-lasting battery-powered sensors. Fig. 5 shows wireless communication.

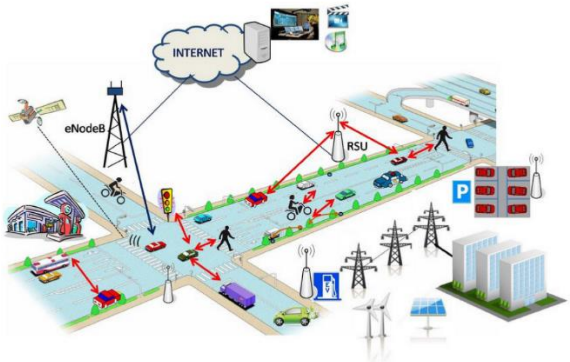

Fig. 5. Wireless communication.

4.2.3. Network topology:

Wireless sensor networks utilize small sensor nodes with limited energy resources and low communication power to collect and transfer information. These decentralized nodes self-organize to form a network topology for communication and data transfer. To overcome power consumption issues, hierarchical clustering approaches are used, grouped into clusters with a cluster head responsible for data aggregation and transmission. The protocol consists of three phases: node position collection, cluster head selection, and data collection and transmission. This hierarchical approach ensures efficient communication and data transfer in wireless sensor networks. Fig. 6 shows wireless communication with mash network tropology.

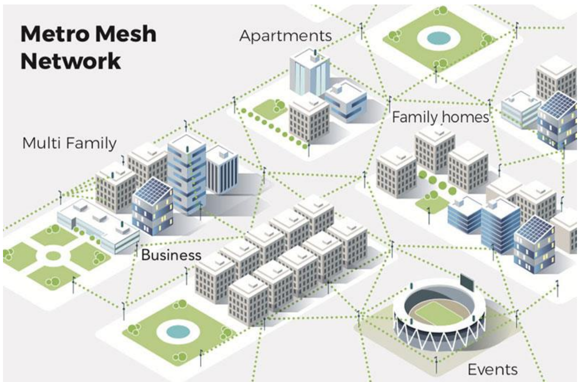

Fig. 6. Wireless communication with mash network tropology.

4.2.4. Data transmission:

The TDMA protocol is used to transmit data between cluster nodes and their respective CHs, based on location level. The CHs aggregate collected data and transmit it to the intermediate CH node or the base station. To maximize energy levels, an energy-efficient multi-hop communication is designed. For the first level, single-hop communication is used to reduce energy consumption. The next level selects new CHs independently, sending a next-hop, Cluster Head, MSG broadcast message containing residual energy, CH-Id, location, and cluster Cluster-Id. CHi nodes modify their neighborhood table based on location level and Cluster-Id to select the best route to the base station.

4.2.5. Parking Space Management Center:

The parking space management center detects free spaces on city roads by receiving filtered data from global information centers. It uses an integrated RFID reader to read driver data and merge it with seat status. This data is used for parking time payments and incident checks. If cars are not tagged, officials send messages to manage parking spaces, ensuring payment of parking fees.

4.2.6. Global Information and Management Centre:

The parking management center collects real-time traffic data from the traffic light management center and the global information and management center, storing it in a MySQL database server. This information is then used to connect drivers and citizens via an Android mobile application, ensuring efficient traffic management.

5. Conclusion

This paper provided an intelligent traffic control system built on the integration of many cutting-edge Internet of Things technologies, including mobile applications, WSN, and RFID. Based on IEEE 802.15.4, the system manages a network of hybrid RFID and WSN sensors that may be swiftly installed in any place outside of the city. To optimize WSN performance and extend its lifetime and resilience, our system uses a powerful and practical cluster tree self-organization technique. Both the number of parking spots available and the city's traffic density are continuously and real-time monitored by a central server that uses sophisticated database management techniques. Furthermore, a distinct smartphone app helps drivers locate available parking spots near their location and provides them with alternate routes to prevent circling and becoming caught in traffic.

In subsequent work, we will refine our suggested system to better meet the demands of our customers by incorporating cutting-edge features like online parking fee payments, remote parking reservations, and NFC, all while enhancing our car algorithm. We suggested a self-organizing algorithm to enhance energy efficiency and prolong the lifespan of the wireless sensor network.

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