Dependable Messaging In Wireless Sensor Networks Architecture And Protocols
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In this section we discuss some of the work presented in these papers. Zanella et al. In addition, the authors presented and discussed a proof-of-concept implementation of IoT in the city of Padova, Italy. There are generally two common approaches to offer data access to things in IoT. The first is using multi-hop mesh networks with short-range communication in the unlicensed spectrum among the network nodes. The second is using long-range cellular technologies in the licensed frequency band. From its name, this communication technology can provide low-rate, long-range transmission in the unlicensed frequency bands using star topology.

These features can be very useful for some smart city applications. Leccese et al. Sanchez et al. Some work more related to our contribution in this paper is investigating network architectures for smart cities. Wan et al. The authors also conducted a case study using this architecture for vehicular applications.

Gaur et al. This architecture is mainly for wireless sensor networks applications in a smart city. Jin et al. The last paper [17] is the closest to our contributions in the paper, thus we will elaborate on it. The autonomous network architecture is usually not directly linked to public networks such as the Internet.

It can be connected through gateways if this link is needed. This network architecture is suitable for some smart city applications such as automatic parking management in which most of the network connections are mainly to support the application. The QoS requirements in this network architecture are mainly dependent on the requirements of the application. In the ubiquitous network architecture, smart objects including the sensors and actuators are part of the Internet.

Information from these smart objects can be obtained by authorized users and applications through the Internet directly or through intermediate servers which serve as sinks that gather data from the connected smart objects. The smart objects can be connected to the Internet through multirier and multiradio.
The QoS of such network architecture can be challenging due to the level of heterogenous network components used. The application layer of the architecture is suitable for large scale networks with a large number of distributed nodes. These nodes can be logically structured in clusters with cluster heads that can run in-network data processing task to reduce network traffics.

One application of this network architecture is using a wireless sensor network WSN for environmental monitoring. The QoS for applications suitable for such architecture is generally tolerable to some level. The service-oriented network architecture is based on an innovative network architecture, called Information Driven Architecture IDRA [18].

In this architecture different network functions such as addressing, naming, forwarding, and routing are provided as network services. These network services can be utilized to provide different network configurations to suit different applications. Although, this approach can be very useful, flexible and can provide advanced network features, it requires new network components technology. The participatory sensing network architecture is considered a special case and a new model of IoT.

In this model, residents through their consumer devices collect, analyze, and share sensor data. Some possible applications of this architecture are environmental monitoring, intelligent transportation, and healthcare. QoS in such network can be challenging as humans are the main source of data and humans can be lazy, privacy-worried, error-prone, and misbehaving.

Unlike other related work, our contributions in this paper is mainly in investigating networking architectures focusing on the communication characteristics and requirements of the main smart city applications including smart buildings, smart grids, gas and oil pipeline monitoring and control, smart water network, intelligent transportation, manufacturing control and monitoring, and unmanned aerial vehicle applications for smart cities.

The works we studied usually focus on a single attribute or characteristic such as quality of service in [17]. We considered several communication characteristics and requirements including bandwidth, delay tolerance, power consumption, reliability, security, heterogeneous network support, network type, and mobility support.

In addition, we studied the suitability of different networking protocols for different smart city applications. These protocols are IEEE With this, we are providing a comprehensive study in networking architectures and protocols for smart city systems. Development and operation of smart city applications can face many challenges.

To identify and understand these challenges, we discuss some important smart city applications used or proposed for different domains. We highlight their benefits as well as their development and operational challenges. This will help us identify the type of support needed by the networking platforms designed for smart city applications. In the energy domain, smart city applications are used to add values such as efficiency, reliability, and sustainability of the production and distribution of electric power in smart grids [19].

A smart grid is a renovated electrical grid system that uses information and communication technology ICT to collect and act on available information about the behavior of suppliers and consumers in an automated fashion. A smart grid uses CPS to provide self-monitoring and advanced control mechanisms for power productions and consumer needs to increase grid efficiency and reliability. In addition, CPS systems are used to control the processes of generating renewable energy from hydropower plants [20] and wind power plants [21].

Furthermore, some applications are used to monitor and control energy consumptions in smart buildings [3]. Smart building systems are usually equipped with different types of sensor nodes that monitor the current energy usage and environmental conditions. These sensors report their observations and measurements to a centralized monitoring and control system.

The control system implements intelligent algorithms to control the sub-systems used in the buildings to optimize energy usage based on the sensed observations and current operational and environmental conditions.

In the transportation domain, an important smart city application area that recently received high attention is intelligent transportation. Vehicular safety applications constitute one of the most important classes of such applications. There are many safety applications for vehicles including lane change warning messages, emergency breaking, collision avoidance mechanisms, and blind spot monitoring. These applications provide fully automatic or semi-automatic actions to enhance driving safety.

The most important features of such applications are the real-time and reliability support in detection and response. All aspects of vehicular safety applications including threat observations, decision making, communication, and actions must be reliable and able to run in real-time.

This imposes a serious restriction on how the software is designed and how well it supports high levels of integration across all the devices involved to ensure real-time and reliable responses. In addition, self-driving cars are considered as important smart city applications [22].

Since they practically integrate all the mentioned features in addition to vision and monitoring components to allow the vehicle to navigate the roads based on sensed data and intelligent software that interprets and responds to this data in real-time. Another intelligent transportation application include intelligent traffic light controls, which include monitoring devices across multiple locations to accurately predict traffic patterns and adjust traffic lights to optimize flow.

One example of such domain is discussed in [23]. In addition, smart city systems can be used to protect water networks and to make them smarter, more efficient, more reliable, and more sustainable.

CPS systems can be embedded within water networks to provide some monitoring and control mechanisms and to add smart features to the operations of water distribution [24].
One of these functions is to provide early warning mechanisms to identify problems in water networks. For examples, leaks and pipe bursts can be easily detected while fast and temporary solutions can be applied to reduce water waste and to minimize further risks or damages to the network.

Other smart city applications include greenhouse monitoring that aims to provide efficient control for suitable climate, soil, lighting, and water level in greenhouses [25]. In addition, some applications involve autonomous operation of unmanned vehicles using CPS systems.

Such systems provide networks that connect the payloads on the unmanned vehicles like sensors, actuators, cameras, storage, communication devices, and microcontrollers [26]. Additional smart city systems are also used to automate, control, monitor, and enhance manufacturing processes [27]. Finally, monitoring and controlling oil, and gas pipelines is another one of the applications for smart cities. We discuss the corresponding architecture and features of this and other important applications in the section illustrating selected smart city systems later in this paper.

In this section, we investigate the different networking and communication requirements of the various smart city applications, as well as the protocols that can be used to connect the components used to support such applications. As shown in the table, applications with short range communication such as smart buildings, and smart water networks can use protocols from the personal area network PAN class such as IEEE 802.15.4. These protocols are generally characterized by lower bandwidth, low energy consumption, and short range.

Applications requiring longer ranges such as intelligent transportation, and manufacturing and control use protocols, which are in the local area network LAN class, such as IEEE 802.3. All of these protocols have provisions to support asynchronous and synchronous data connections. The former can be used with smart city applications with best effort traffic, which can tolerate delay, while the latter can be used with applications that generate traffic requiring more stringent quality of service QoS requirements such as larger bandwidth and limited delay.

Such applications involve real-time and multimedia communication. In addition, these protocols have reliability and security services. However, most of the security features require more processing, and can cause added delay and energy consumption.

Consequently, these considerations should be taken into account when enabling such features. Also, the table shows that certain applications, such as intelligent transportation, have low bandwidth requirements. Others, such as smart buildings, gas and oil pipeline monitoring, and UAVs require more bandwidth. However, even inside the same type of applications, the bandwidth requirements can range from low to medium or even high, depending on the type of data that is generated.

For example, telemetric and control data such as UAV ground-to-air control commands only require small bandwidth, while UAVs taking images and videos, and transmitting them to ground base units require considerably larger bandwidth. In addition, it is shown that some applications have low tolerance for end-to-end delay. Such applications include intelligent transportation.

This is the case, since the data that is being transmitted needs to arrive within microseconds in order to allow the control systems to react within an acceptable time frame to avoid car imminent danger or life-threatening collisions. On the other hand, other smart city applications have higher tolerance for delay.

These applications include ones that rely on the collection of information and monitoring data for later analysis. Examples of such applications include UAVs taking images for later processing. Power consumption is also an important requirement for smart city applications.

However, as shown in the table, some applications that have local high energy sources such as smart grid systems, can tolerate protocols with higher power consumption levels.

Other applications, which have energy sources with limited capacities have medium power requirements. Other applications have very limited energy sources and require protocols with low or very low energy consumption characteristics. Such applications include gas and oil pipeline monitoring, smart water networks, and UAVs. Reliability is another important parameter in smart city applications, and the table shows that most applications either have medium reliability requirements such as smart water networks, while others have high reliability requirements such as smart grid, and intelligent transportation.

With respect to security, most applications require medium to high security. For example, applications such as manufacturing control and monitoring require medium security, while others such as smart grid have high security requirements due to the sensitivity of the data and criticality of the functions that are performed. Most smart city systems include networking protocols, which connect the various components within the system. Examples of such systems include include smart buildings, and intelligent transportation.

In such cases, these protocols must be able to co-exist without interfering with each other. In addition, appropriate mapping of the various control information inside the headers at the various layers of the networking stack of the different heterogeneous protocols and networks must be done to ensure seamless and efficient operation.

The table also shows that some smart city applications such as gas and oil pipeline monitoring, and UAVs mostly involve wireless communication. Others, such as smart buildings and intelligent transportation involve both wired as well as wireless communication. In such cases, communication within a particular physical system can use wired networking e.

Finally, mobility is another important characteristic of smart city applications. The table shows that some systems have low or medium mobility such as smart grid, gas and oil pipeline monitoring, and smart water networks.

Other systems have high mobility such as intelligent transportation, and UAVs. Consequently, the networking protocols that are used to connect medium to high mobility smart city systems must be robust and adapt well to node mobility without consuming too much bandwidth on control
messages and related processing to readjust to changes in the network topology. In addition to the requirements and characterization of the links between nodes in smart city systems, we identify the following additional issues and challenges, which must be considered.

Smart city systems rely on various heterogeneous networking protocols at the physical and data link layers, which use different medium access control MAC strategies. Interoperability between these protocols is important in order to provide seamless integration of the underlying technologies.

The IEEE Development of similar protocols to expand the support mechanism for smart city systems is a good area for future research. Software and hardware availability are essential components of smart city systems due to the criticality and real-time nature of a lot of the related applications. Software availability can be achieved by ensuring that the various services are available to the corresponding applications.

On the other hand, hardware availability is obtained by ensuring that the various devices that are needed to provide networking contestability and efficient performance are readily available anytime and anywhere. One way to accomplish these objectives is through redundancy of both software and hardware components and systems. This was already considered and studied for IoT devices [29, 30]. Furthermore, considerations to attain availability need to be incorporated as a part of the design objectives of networking and communication protocols for smart city systems.

Performance is always an important consideration for any type of architecture, and this is also the case for smart city systems. In order to achieve this essential objective, more evaluation needs to be done for the various networking protocols at the various layers of the architecture, especially at the data link, network and transport layers.

These three layers are critical components in order to support traffic of various QoS requirements. In addition, the middleware layer can be used to provide proper interface and convergence services between these layers and the application layer.

Another important aspect of smart city system networking is management of the thousands or even millions of devices that are involved in many applications.

For example, to achieve energy management in smart buildings, thousands of sensor and actor devices can be deployed in each building. Efficient protocols are needed to provide effective management of fault, configuration, accounting, performance, and security PCAPS aspects of these devices.

Similar efforts are encouraged for smart city systems in order to offer standard mechanisms and services to efficiently manage and control the communication of devices at the various levels of the architecture. It is important for smart city systems to be able to accommodate new devices without appreciable loss in the quality of the provided services and associated network traffic flows.

This can be accomplished through virtualization and extensibility in the platforms and their operations. An extensible IoT architecture was proposed in [33], which consists of three layers: Virtual object, Composite virtual object, and Service layer.

The design must have objectives of automation, intelligence, and zero-configuration for objects and related devices in order to achieve scalability and interoperability. More research is desirable in order to extend this strategy to smart city systems. Huge amounts of data is collected by smart city systems and the corresponding IoT devices that are spread out over a considerably larger geographic area.

Analyzing and extracting useful information from this data can provide considerable advantages for businesses and government institutions. In addition, communication and collection of a very large number of messages in a timely fashion according to their priority, delay-tolerance, and size is vital to the efficient operation of smart city systems.

In order to reduce the amount of exchanged traffic, local processing, compression, and aggregation of the generated messages need to be done at the lower and intermediate levels of the node hierarchy and geographic areas. Consequently, more research is needed to provide proper convergence and mapping of the networking parameters between the various layers of the networking stack at the data-generating nodes.

Cloud computing is an important component of any smart city as it can provide scalable processing power and data storage for different smart city applications [34]. Cloud computing has powerful processing capabilities, large and scalable data storage, and advanced software services that can be utilized to build different support services to provision diverse smart city applications.

Cloud computing can be used as the main control and management platform used to execute smart city applications. As the collected data from a smart city can also become big data as huge amounts of data are collected throughout the city.

Cloud computing can provide the necessary powerful platforms for storing and processing this big data to enhance operations and planning. The communication between city sensors and actuators and cloud computing can involve different communication requirements to smoothly support smart city applications. These requirements should be supported by the network architectures deployed in the smart city.

Smart applications rely on the integration between sensors and actuators on one side and the cloud on the other and cannot performed well unless there is a good network that provides good communication services connecting both sides. Another issue that arises when using cloud computing for a smart city is that the cloud services are either offered at a centralized location or across multiple distributed platform in various locations.

The distributed cloud computing approach can provide better quality and reliability support for different cloud applications [35]. However, there is usually a need to provide good communication links among the distributed cloud computing facilities available in different places. Another issue arising when using the cloud is the reliability and performance of the networks connecting all components on both sides. With the Internet in the mix, there are problems with delays, lost packets and unstable connections.
Careful planning and management of network resources and communication models in addition to the design and architecture of the smart city application is necessary to account for these issues. Yet, there are some unavoidable aspects such as the transmission delays.

While cloud computing can provide many advanced and beneficial services for smart city applications, it cannot provide good provisions for distributed applications that need real-time, mobility, low-latency, data streaming, synchronization, coordination, and interaction support services. This is mainly due to the transmission delays imposed by the large distances to be covered between the smart city sensors and devices and the cloud platforms.

In addition, it is difficult for cloud computing to manage and deal with a large number of heterogeneous sensors, actuators, and other devices distributed over a large area.

Fog computing was lately introduced to offer more localized, low latency, and mobility services. Fog computing allows to move some functionalities from the cloud closer to the devices [36]. This approach aims to enable different IoT applications through distributed fog nodes that provide localized services to support these IoT applications.

In a smart city, fog computing can complement cloud computing to support smart city applications [37]. While cloud computing can provide powerful and scalable services for smart city applications, fog computing can provide more localized, fast-response, mobility, and data streaming services for smart city applications.

Furthermore, integrating IoT, fog computing, and cloud computing as shown in Fig. This integrated platform needs good networking and communication support to efficiently handle the communication between all these components. This also includes a good network security support to avoid any threat vulnerability issues in the integration and in supporting smart city applications. An illustration of the integration of IoT, fog computing, and cloud computing to support smart city applications.

An hierarchical representation showing the integration of IoT, fog computing, and cloud computing to support smart city applications. The table shows their main characteristics, the physical and data link layer specifications, their data rates, and transmission range. We can see that the applications requiring short range such as smart buildings, smart grid and smart water, generally can use the IEEE It is intended to allow these devices to last up to several years using the same battery.

In addition, the IEEE It is a WPAN protocol, which uses the 2. It allows best effort operation using the distributed coordination function DCF as well as reservation-based operation using the point coordination function PCF.

The latter service is useful for multimedia audio, video, and real-time data traffic, which require QoS guarantees of certain parameters such as bandwidth, delay and delay jitter.

It supports data rates from 15 to Mbps, and has a communication range up to 25 m. The cellular 3G and 4G protocols can be used with applications such as smart grid, smart water, UAVs and pipeline monitoring. They use packet switching for data communication and optional packet or circuit switching for voice communication.

The data rates that are supported are Mbps to 1 Gbps. The geographic area that is covered is the entire city or country without roaming, and it has world-wide coverage if roaming is used.

Satellite communication can also be used with applications such as UAVs, pipeline monitoring, and intelligent transportation. They typically use frequencies in the range of 1. The data rate is between 10 Mbps download and 1 Gbps upload. Geographically, satellite communication covers the entire earth since handoff between satellites can be used to achieve such continuous coverage. In this section, five selected smart city systems are briefly presented in order to illustrate some possible networking and communication models that are used.

These protocols use dissimilar mechanisms for loss recognition and loss recovery. The transport layer is exactly needed when a system is planned to contact other networks. Providing a reliable loss recovery is more energy efficient and that is one of the main reasons why TCP is not fit for WSN.

In general, Transport layers can be separated into Packet driven, Event driven. The simple idea of the routing protocol is to explain a reliable lane and redundant lanes, according to a convinced scale called metric, which varies from protocol to protocol. IEEE There are several versions of IEEE Wireless sensor networks may comprise of numerous different types of sensors like low sampling rate, seismic, magnetic, thermal, visual, infrared, radar, and acoustic, which are clever to monitor a wide range of ambient situations.

Thus, this is all about what is a wireless sensor network, WSN architecture, characteristics, and applications. We hope that you have got a better understanding of this concept. Furthermore, any queries or to know about wireless sensor network project ideas, please give your valuable suggestions by commenting in the comment section below. Here is a question for you, what are the different types of wireless sensor networks?

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