UAV-BASED SMART SURVEILLANCE SYSTEM OVER A WIRELESS SENSOR NETWORK

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ABSTRACT

Wireless Sensor Networks (WSN) is a revolutionary networking technology of the last years that has led to the establishment of expandable networks like the Internet of Things (IoT) and services like smart surveillance using sophisticated tools such as IP cameras, drones, etc. In this paper, we present a UAV-based smart surveillance system that can be used in a WSN for data gathering. Moreover, Energy Harvesting (EH) techniques can also be used in parallel to offer Energy Efficiency (EE) and extend network lifetime.

Index Terms — Energy Efficiency, Energy Harvesting, Smart Surveillance, UAV, Wireless Sensor Networks.

INTRODUCTION

Unmanned Aerial Vehicles (UAVs) have many applications today, such as civilian, commercial, military, etc. In Computer Science and especially in wireless networking, UAVs can be used to gather data from wireless sensors of the ground or power and charge them with the necessary energy to provide them the ability to continue successfully their operation.

In this paper, we focus on these two operations of UAVs to overcome the problem of energy-hole. As it is known, wireless sensors or wireless sensor nodes are small devices that are responsible to control specific areas collecting useful information depending on their use. The main concern with these wireless devices is that since they operate using built-in batteries, they can be dangerously discharged due to their work overload or other applied features like security mechanisms. Therefore, an external power supply unit is needed to make the nodes stay alive. For this reason, we demonstrate the ways for a UAV to improve the network lifetime in a Wireless Sensor Network (WSN) and speed up the process of data gathering and data sending.

The rest of this paper is structured as follows: In Section "Related Work", we present the latest research studies on UAV-based WSNs; in Section "Problem Definition", we highlight the problems that arise during WSN-based surveillance; in Section "A Proposed Approach", we describe our proposed approach for better management of a WSN with the use of UAVs; and finally in Section "Conclusion", we conclude our research study and give some possible future directions.

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RELATED WORK

A lot of research studies face the crucial challenge of Energy Efficiency (EE), and thus, prolong the network lifetime in WSN and the expandable Internet of Things (IoT). According to the literature, clustering is mentioned as a method where wireless sensor nodes are properly deployed with specific closeness amongst each other. Especially in a WSN, clustering is regarded as an effective method that provides less energy consumption in the sensor nodes and improves the operation of routing algorithms [1]. Therefore, clustering can also enhance the network lifetime.

Moreover, sink nodes can have mobility for enhanced data gathering from the surrounding sensor nodes. Many research studies [2-4] have proven that the mobility of sink nodes improves the overall performance in the WSN, prolongs the network lifetime, and overcomes the constraint of energy consumption.

Green energy can also play a vital role in WSN. Some sensor nodes can harvest ambient energy from renewable sources, e.g. the sun, and convert it to necessary electrical energy to complete their tasks. L. Guntupalli et al. [5] demonstrate a novel On-demand Energy Requesting (OER) model that presents significant enhancement in terms of delay performance, even in low traffic and energy harvesting conditions.

UAVs or commonly "drones" have already been used in WSNs. Specifically, a UAV can settle Line-of-Sight (LoS) link for ground-to-air communication using on-board wireless transceivers and a Magneto-Resistive (MR) sensor which is used to transmit the data in a short distance, using a low powered radio. UAV can fly close to sensor nodes to achieve a better channel quality, and collect data from a large area effectively [6].

In many research works UAVs have been proposed to power the sensor nodes in a WSN or collect the sensed data from them. B. Liu and H. Zhu in [7] propose the deployment

of a UAV-aided WSN where a UAV plays a second role of data collector for delay-tolerant sensed data. Experimental results demonstrate that this scheme can be used to achieve significant energy savings compared to other conventional approaches.

Other schemes, which use UAV for data gathering from ground sensor nodes, promise EE using advanced heuristic algorithms [8-9]. Moreover, C. Zhan and G. Yao propose an efficient algorithm for WSN using UAV for minimization of the total energy consumption in the sensor nodes compared to related schemes [10].

Problem Definition

Although there are many different research studies upon smart surveillance over WSNs with the use of UAVs, some problems related to energy efficiency and resource allocation arise due to the lack of an integrated system that will combine the most-known state-of-the-art technologies to provide better overall performance and solve potential network instability.

First of all, a typical WSN is composed of many sensor nodes that are responsible for data gathering from the surrounding area in which they are densely deployed. These sensor nodes have limited resources, because of their small size. Moreover, in the case that the nodes are used for serious purposes, such as military bases, increased surveillance areas, or restricted-access areas, they should be equipped with advanced security mechanisms that may be powerful enough and hence, high energy-consuming.

On the other hand, wireless sensor nodes are devices that operate with built-in batteries that need frequent maintenance and replacement that is not always possible. For example, battery replacement is not easy in cases that sensor nodes are deployed in inaccessible environments like glaciers, even rugged forests, and mountains.

The problem occurs when the sensor nodes are near to the node that operates as a data collector, and hence their batteries are depleted quicker than the other sensor nodes. This fact is also known as the “energy-hole problem”. As it is obvious, the EE is a vital factor for IoT, especially for IoT-based devices with constrained power resources.

It is notable that if a sensor node is being fully discharged, the WSN will present instability and may cause and send false-negative information to the network administrator. For instance, fire occurrence may not create an alarm in the case of an out-of-order sensor node.

Besides, wireless sensor nodes have limited resources in terms of memory, Central Processing Unit (CPU), and energy. For this reason, such devices can only run weak encryption algorithms that make them vulnerable to hackers for Distributed-Denial-of-Service (DDoS) attacks and other threats. Thus, an attacker can gain unauthorized access to such wireless devices, and steal their sensed data.

A Proposed Approach

A proposed approach to address the above problems is the integration of some state-of-the-art technologies to provide better efficiency in terms of energy consumption, Quality of Service (QoS), and network lifetime. These technologies are Smart Surveillance, Wireless Sensor Networks (WSNs), Unmanned Aerial Vehicle (UAV) networks, Energy Harvesting (EH), Cloud Computing (CC), Big Data Analytics (BDA), Compressed Sensing (CS), Multimedia Compression, and Internet of Things (IoT), as it is shown in Figure 1. In addition, Table 1 summarizes the features and benefits of each technology.

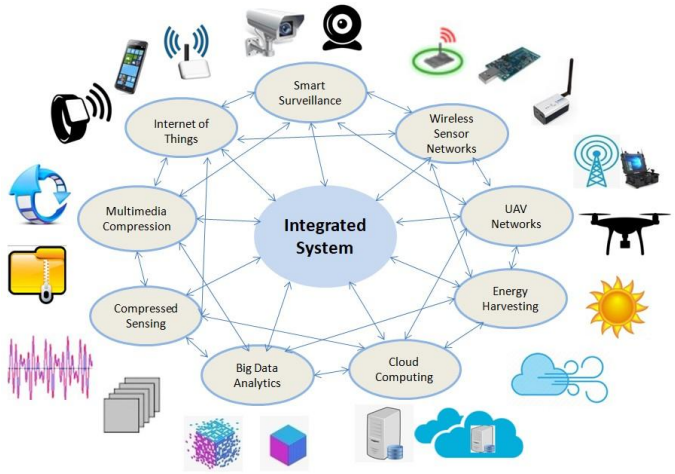

Figure 1. The involved technologies in our proposed approach.

Involved Technologies

- Smart Surveillance

Surveillance is a monitoring technique of the behavior, activities and other changing information for human influencing, managing, directing, or protecting purposes. Essentially, the term “surveillance” can refer to remote monitoring using different types of electronic devices (webcams, CCTV, etc) and stream interception using phone calls, internet bandwidth, etc.

Smart surveillance integrates all the ways of real-time image and video analysis into the surveillance systems. Using the image and video compression standards, multimedia surveillance systems multiplex or store efficiently images and videos from a wide range of cameras into mass storage media, such as discs, videotapes, etc. Smart surveillance systems can analyze and convert in real-time multimedia surveillance to information at much greater quality, improving the Quality of Experience (QoE) of the end-users, satisfying their needs.

- Wireless Sensor Networks (WSNs)

WSNs are deployed in various environments, such as glaciers, forests, and mountains in order to collect vital information about the environment for long-term periods, e.g. temperature, atmospheric density, moisture, etc. As a consequence, sensor nodes can act as smart surveillance systems to catch and collect all important information from the surrounding area in which they are located. WSNs can be separated into many groups of sensor nodes, known as “clusters”.

TABLE 1. Involved technologies and advantages.

Technologies	Components	Advantages
Smart Surveillance	+ IP web-cameras + Wireless sensor nodes	✓ Remote monitoring ✓ Real-time image and video analyzing
Wireless Sensor Networks (WSNs)	+ Routing protocols + Clustering + Sensor nodes + Mobile sink nodes	✓ Monitor environmental phenomena ✓ Faster feedback in real-time ✓ Flexible ✓ Save costs
UAV Networks	+ Drone + Onboard wireless transceivers + MR sensor + GCS + Satellite	✓ Reduce energy consumption ✓ Improve accuracy ✓ Improve time of data acquisition ✓ Network lifetime improvement ✓ Portability and versatility ✓ Better management ✓ Balance and optimize the overall workload ✓ Support data communication and synchronization services
Energy Harvesting (EH)	+ Sun (solar / photovoltaic energy) + Wind energy + Thermal - thermoelectric energy + Vibrational / kinetic energy + Salinity gradient energy	✓ Environmental friendly ✓ Eliminates reliance of sensor nodes on battery power ✓ Reduces maintenance costs ✓ Prolongs network lifetime ✓ Reliability
Cloud Computing (CC)	+ Cloud Servers	✓ Storage over the Internet ✓ Service over the Internet ✓ Applications over the Internet ✓ Energy efficiency (EE) ✓ Computationally capable ✓ Resource savings
Big Data Analytics (BDA)	+ BDA algorithms + BDA tools	✓ Data classification ✓ Uncover useful information
Compressed Sensing (CS)	+ CS algorithms + CS tools	✓ Enables real-time data transmission ✓ Reduce local computation ✓ Reduce sensor data volume
Multimedia Compression	+ H.265/MPEG-H (HEVC) + H.266/MPEG-I Part 3 (VVC) + MPEG-5 Part 1 (EVC) + MPEG-5 Part 2 LCEVC + VP9 + AV1 + XVC	✓ Higher quality ✓ Less bandwidth consumption ✓ Data encryption ✓ Protection against attacks
Internet of Things (IoT)	+IoT-based devices (computer systems, laptops, smartwatches, tablets, mobile phones, etc.)	✓ QoE improvement ✓ QoL improvement

As it is mentioned above, clustering is an Energy Efficient (EE) method that reduces the energy consumption of the sensor nodes in a WSN. Moreover, clustering conserves the available bandwidth since it restricts the range of interactions between inter-clusters and cluster-heads. Clustering can also be used to routing algorithms to enhance their operation and thus, improve the lifetime of the WSN. Therefore, the optimal approach is to divide the whole WSN into many clusters of nodes where each of them has a Cluster Head (CH) which operates as a data sink for its cluster.

- UAV Networks

A UAV can be used in a WSN either/both as a mobile sink to gather the sensed data from the surrounding sensor nodes, or/and as a power transmitter to the ground sensors wirelessly to prolong the lifetime of them. Practically, a UAV has a mass of more than 25Kgs (55 lbs) and its name varies. UAV is commonly referred to as “drone” (French term), while in the United States (US) and United Kingdom (UK) it is called UAS (Unmanned Aircraft System), and RPAS (Remotely Piloted Aircraft System) by the International and other National Aviation Agencies.

Thus, UAVs have been incorporated in many networks such as in WSN, thanks to smart antennas, sensors, and wireless networking technologies. Specifically, with onboard wireless transceivers, UAV is more possible to settle Line-of-Sight (LoS) link for ground-to-air communication and is capable of

flying close to sensor node to achieve better channel quality, and hence gathering data from a wider area with UAV can be more energy-efficient [6]. The sink node can transfer all the data that it has collected to the UAV while it is being charged. Plus, the Magnetoresistive (MR) sensor only needs to transmit the data in a short distance, allowing it to use a low powered radio.

The role of UAV as a mobile data sink makes it more effective and faster in information gathering. UAV is responsible for data collection from the ground sink nodes to forward them via the internet to the IoT-based device of the end-user. Furthermore, many research studies demonstrate that UAVs as mobile sinks enhance the WSN lifetime and overcome the limitation of energy consumption into it.

UAVs as mobile sinks minimize network overhead caused by procedures like discovery, connectivity, and conservation of UAVs' routing tables, which lead to less energy consumption in the network. Besides, UAVs in WSN present efficiency in terms of energy, accuracy, and data acquisition time [11].

- Energy Harvesting (EH)

EH refers to the harvesting of green and renewable energy sources from the environment or other external energy sources from the surrounding to convert them into electrical energy [12]. Such green sources of energy are mainly the following:

a. Vibrational or kinetic energy: refers to exploiting mass vacillation coordinately to the environment's prevalent mechanical frequency
b. Photovoltaic energy: refers to solar energy absorbed from the sun
c. Thermal - thermoelectric energy: refers to the difference in temperature between two things
d. Wind energy: refers to electromagnetic, piezoelectric, and triboelectric energy
e. Salinity gradient energy: refers to the energy that can be utilized or produced due to the change in the salinity of seawater and freshwater

EH is very important for charging the UAVs to be able to power the sink nodes of each cluster of the WSN. Furthermore, EH can be used by mobile sinks to power the surrounding static ground sensors for a better Packet Delivery Ratio (PDR).

The sensor nodes of a WSN have constrained energy resources in their energy storage unit, and hence may be easily depleted during long-period operation. EH from external sources solves the dependence of sensor nodes for battery power, minimizes a lot of the maintenance for battery replacement, and thus significantly improves the WSN lifetime [13].

- Cloud Computing (CC)

CC provides available resources in terms of storage, computing, applications, and services over the internet, beyond the IoT-based devices. The solution of CC is recommended for IoT networks since in general, IoT-based devices have constrained storage, communication, and computation resources, which are not enough to accomplish automated procedures.

Thus, UAV can send the collected data first to a Cloud Server where the data will be analyzed before they are sent to the end user's IoT device. Cloud Servers have an ever-increasing size for data storage of the collected sensor nodes. Besides, CC provides Software-as-a-Service (SaaS) capabilities to users who can use a cloud service with their IoT-based device, saving resources.

- Big Data Analytics (BDA)

BDA is the use of advanced sophisticated methods to analyze vast and diverse datasets such as structured, semi-structured, and unstructured data, collected from different sources in order to reveal value from them. BDA can be a remarkable method that can be used by Cloud Servers to analyze stored data collected from wireless sensors.

- Compressed or Compressive Sensing (CS)

CS is referred to as the sparse sampling that is the signal process to obtain and reconstruct effectively a signal using solutions for sub-directional linear systems. This method complies with the principle in which a signal sparsity can be retrieved from much fewer samples than required through optimization with the Nyquist-Shannon sampling theorem. Thus, CS is regarded to be an effective method for high-dimensional data sampling which has an indiscreet structure.

In WSN, CS can be adopted to enable real-time data transmission by significantly minimize the local computation and sensor data volume that needs to be transmitted over wireless channels to a remote fusion center. Thus, the CS-WSN approach delivers about the same performance as conventional local data compression methods while greatly reduces the data volume and local computation [14]. Furthermore, CS can be used in Cloud Servers in parallel with BDA for the stored data, since it is an advanced method for reducing the large data volume and the local computation into them.

- Multimedia Compression

H.264/MPEG-4 or AVC is a multimedia compression standard that spans a large number of applications, such as video streaming, conferencing, and transmission through wireless and fixed networks with various types of transport protocols.

Nowadays, AVC is regarded to be outdated and H.265/MPEG-H or HEVC is its successor. HEVC standard was officially standardized by the Joint Collaborative Team on Video Coding (JCT-VC) and offers greatly better compression than AVC since it enables Ultra-High-Definition (UHD) image and video view using about half bandwidth.

However, next-generation video coding standardization recommends the launch and use of new compression standards, such as H.266/MPEG-I Part 3 known as VVC, MPEG-5 Part 1 or EVC, MPEG-5 Part 2 or Low Complexity Enhancement Video Coding (LCEVC), Google developed VP9, AV1 developed by the Alliance for Open Media (AOMedia), and eXtreme Video Codec (XVC) developed by Divideon [15].

The above new compression standards can be used for performance improvements in terms of better compression in real-time multimedia transmission among the sensor nodes

over an IoT network. Thus, the information which is reached to the end-user can be of high quality and definition. Moreover, new compression standards offer transparent encryption and protection against attacks, and hence can be used for improved security and reliability in multimedia transmission over a WSN or IoT network.

- Internet of Things (IoT)

IoT tends to become a global network in which all physical objects will be connected to the internet and ubiquitously connected amongst each other to exchange data. The advantages of using IoT are multiple since everything around us, such as computers, phones, smart wearables, buildings, etc, can have access to the internet, realizing new capabilities and thus, simplifying human lives in terms of Quality of Experience (QoE) and Quality of Life (QoL).

System Architecture

As we see above, our proposed approach is based on nine (9) technologies. Specifically, as it is shown in Figure 2, a WSN is deployed in a particular area. The WSN is composed of many sensor nodes that operate as smart surveillance devices, e.g. surveillance of an environmental phenomenon. For more effective management the WSN is divided into clusters where each of them has a mobile sink that is responsible to gather all the collected data from its surrounding nodes. The mobility of the sink offers energy consumption reduction and better PDR.

Moreover, mobile sinks can operate as power receivers from a UAV. A UAV can be used to transfer energy to the CHs of each cluster that are the mobile sinks. This energy emanates from renewable energy sources like the sun or the wind. The UAV has the ability to harvest energy from such external sources in order to power the CH or mobile sinks with the required energy for successful operation. To achieve this, the UAV has an energy harvesting module and a wireless charging module. Technically, the energy harvesting relies on Radio-Frequency (RF) signal energy extraction in which a part of the received signal is utilized for this procedure while the rest part is utilized for data gathering during the flight over a cluster of sensor nodes [11]. Based on information received from the sink nodes, the UAV can schedule properly to power

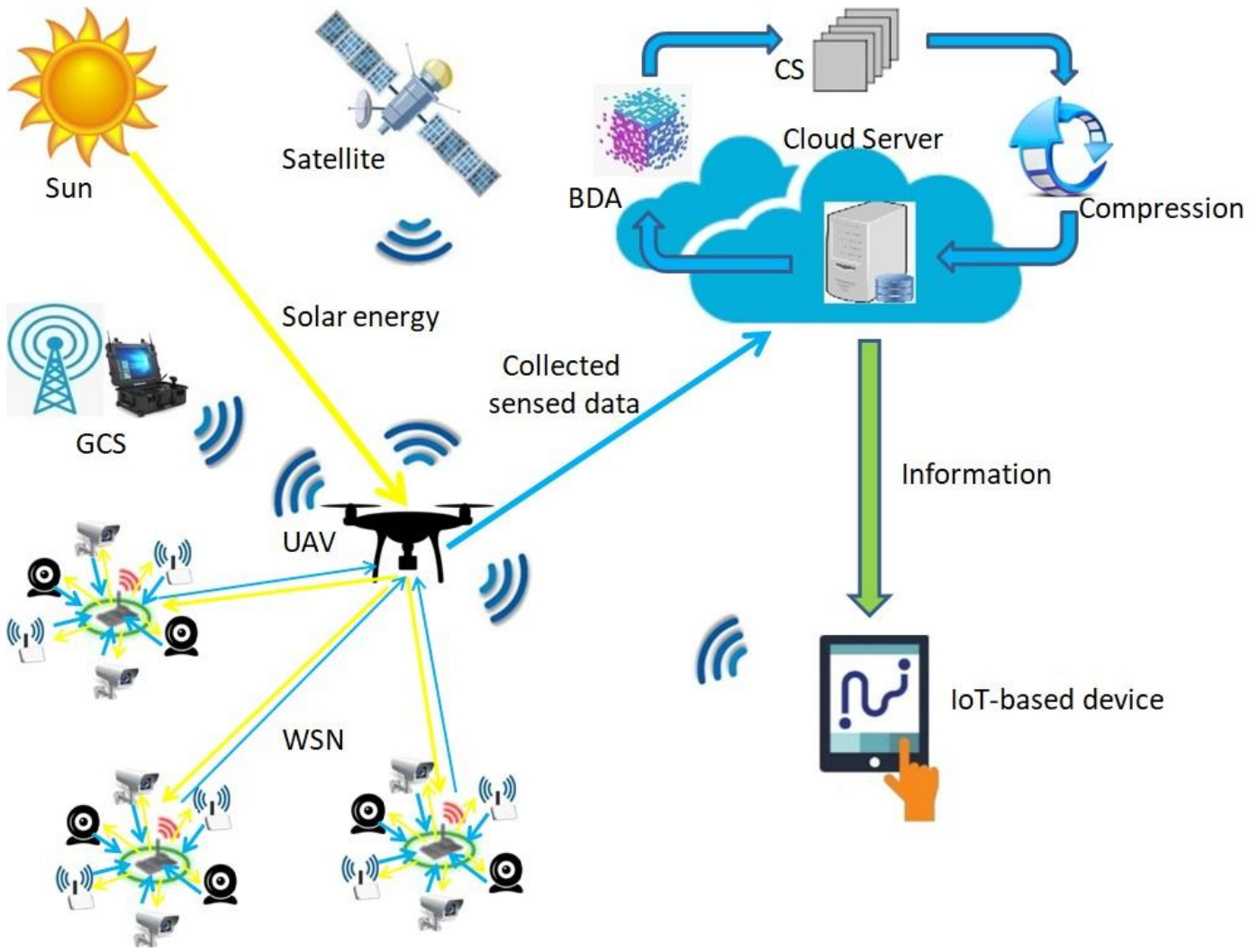

Figure 2. A proposed system architecture.

the sink nodes and receive the gathered information from them.

In addition, the UAV has an integrated direct current-to-direct current (DC/DC) which is a type of electronic circuit that can be used to convert energy came from the sun (photovoltaic energy) into electrical energy in order to increase its flight range. Also, this energy can be transferred from the UAV to each sink node of a WSN to recharge its batteries, or it can be utilized from the sink nodes to power their nearby sensor nodes of the cluster they belong to and collect their sensed data [16].

Then, the UAV sends this information to a Cloud Server for a thorough analysis of the collected data before the information is delivered to the IoT-based devices of the end-users. This procedure is necessary and important because the sensed data is actually raw and needs processing to be more readable and meaningful for the end-users. The analysis is conducted in three parts: a) big data analysis, b) compressed sensing application, and c) new compression standards in the case of images and videos. This data analysis takes part in the Cloud Server. The reason is that CC technology is capable to store a massive volume of sensed data-sets over the internet through hardware virtualization. Thus, CC can provide higher availability, scalability, and accessibility of the stored BD. Besides this, CC offers advanced statistical tools for resourceful processing and BDA.

Specifically, the BDA method uses sophisticated algorithms for the examination of huge and different data sets to classify them based on the data type, the data security, or the difficulty level. CS method can be used in parallel with the BDA in the Cloud Server to take advantage of data acquisition, reducing hugely the data volume and the local computation. Hence, a CS-based BDA to such architecture for data collection from wireless sensor nodes can offer a reduction in data collection time and energy consumption.

Moreover, for multimedia data, new compression standards such as HEVC, VVC, EVC, LCEVC, VP9, AV1, and XVC can be applied instead of AVC for better compression performance since they achieve the same or even better quality in much lower bit-rate, which means less bandwidth consumption during multimedia transmission from sensor nodes to the IoT. Besides, these new compression standards provide transparent encryption and protection against attacks like DDoS which are very popular and dangerous in WSN and IoT environments.

Finally, the necessary information is delivered to the end-user who uses an IoT-based device, such as a mobile phone, a smart-watch, etc. These smart devices support internet connectivity and interaction with other IoT-based devices over the internet and hence can share information amongst each other, improving the end-users' Quality of Experience (QoE) and the Quality of their Lifes (QoL).

It should be mentioned that a satellite can also be integrated into our proposed scheme, as it is shown in Figure 2, in order to provide localization for both UAV and WSN [11]. For the first case, each UAV is equipped with a Global Positioning System (GPS) and operates as a beacon node. For the latter case, GPS information is combined with the Received Signal Strength Indicator (RSSI) of RF communication between UAV and the sink nodes of the WSN. Beyond that, a satellite also supports data communication and synchronization among multiple UAVs [11]. For UAV-to-UAV communication (U2U), a Ground Control Station (GCS) can also be used as a relay. GCS offers portability, versatility, and better management of UAVs, while it balances and optimizes the overall workload in U2U communications.

DISCUSSION

At this point, we can conclude the advantages of our proposed architecture, both for effective data gathering from a WSN with the assistance of UAV, and the extract in real-time of the necessary meaningful information from the sensed data, after the application of advanced big data analytic methods and compression tools, in order to forward this to IoT-based users.

Such an architecture can offer an effective collection of the sensed data from a WSN even in cases of inaccessible areas, utilizing renewable green energy sources to power the UAVs and therefore the sensor nodes of the WSN. Thanks to green energy sources, wireless sensor nodes can stay alive for long periods with continuous high operation stability compared to typical sensor nodes which are battery-dependent and may cause network instability and packet loss in remote and inaccessible areas.

Big data analytic methods, compression tools, and advanced compressed sensing algorithms provide better QoS and QoE to the IoT users. Furthermore, new compression standards provide better encryption and protection level against bot attacks which is a very popular threat for WSN and IoT networks.

Finally, the specific cluster-based deployment of the sensor nodes in our approach provides better overall efficiency and improves network lifetime. Common network problems such as network instability and high latency can be addressed using such a data collection method with the assist of UAV.

CONCLUSION

In this paper, we highlight the cutting-edge technologies which can be used in a WSN to maximize the overall efficiency in terms of energy consumption and data collection. Since sensor nodes can be applied to difficult accessible environments such as glaciers and rugged mountains, UAVs can be used as a data collector mobile sink to collect all the acquired information to forward it to a Cloud Server before it will be delivered to the IoT device.

Moreover, UAVs can be equipped with a power supply unit that harvests green types of energy like solar to power the ground sensor nodes, and thus, overcome the problems of discharging the batteries of the sensor nodes, increasing the WSN lifetime. Other methods such as CS and BDA in combination with new compression standards can improve the QoS and QoE of the IoT users.

Future approaches focus on the integration of data mining technologies such as Artificial Intelligence (AI) and Machine

Learning (ML) to WSNs and Cloud Servers for optimized results. Based on the literature, ML algorithms can be used to estimate the behavior of the connectivity quality during the UAV flight to ensure the reliability of the communication between UAV and GCS [17]. Finally, the integration of Unmanned Aerial Base Stations (UABSs) into our proposed architecture can be proactively considered in case of any damage to the network infrastructure due to natural disasters or malicious attacks, improving the overall network throughput coverage [18].

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APPENDIX

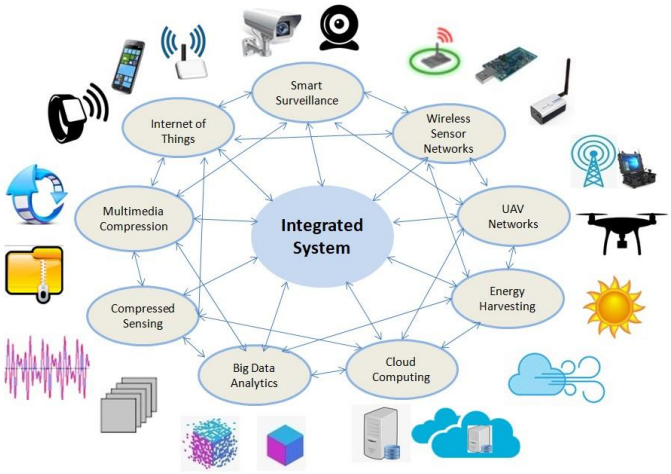

FIGURE 1. The involved technologies in our proposed approach.

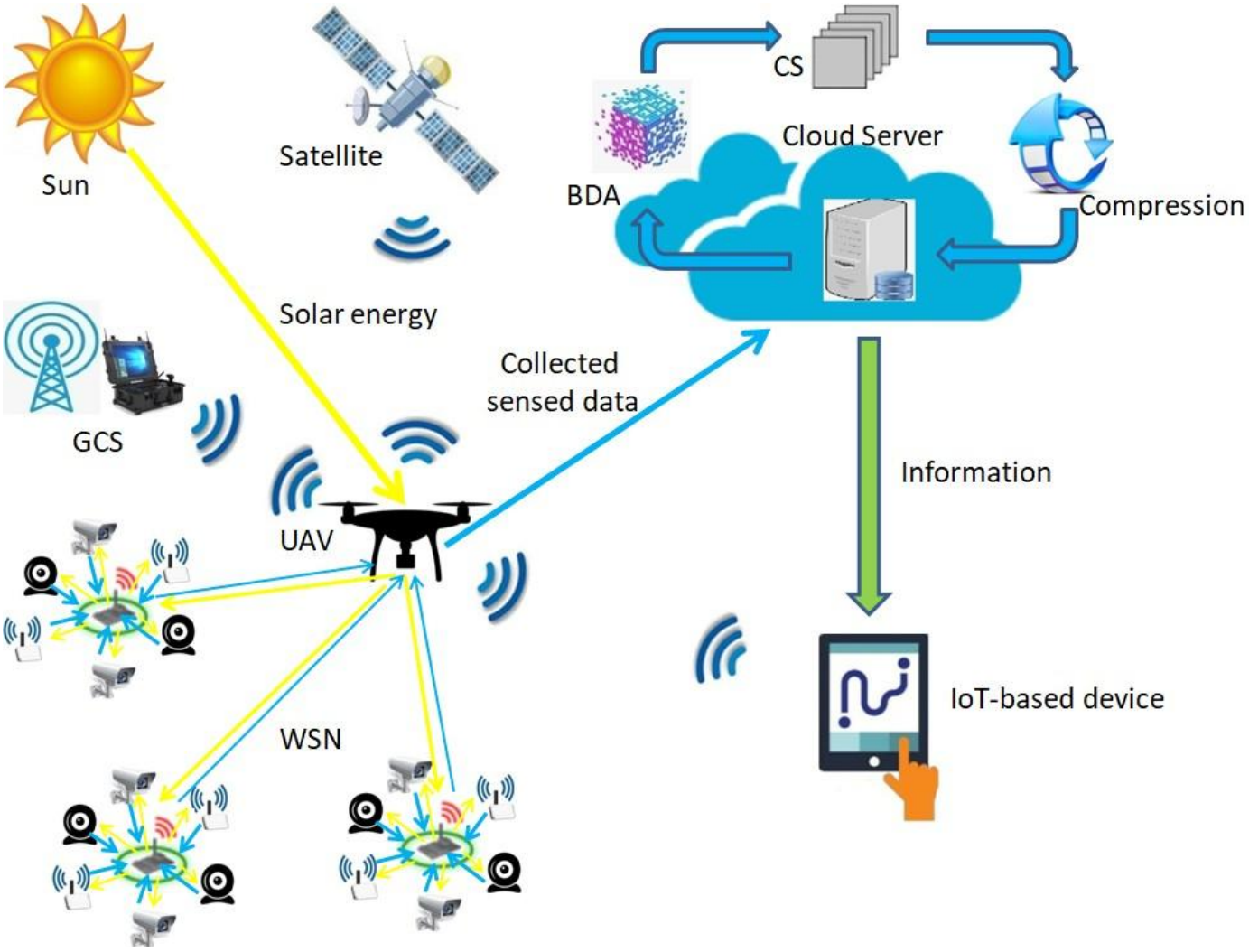

FIGURE 2. A proposed system architecture.