A Review of the state-of-the-art Ubiquitous Multimedia Sensor Networks

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Abstract - The recent rise in the demand to incorporate multimedia contents such as audio/video and still images over Wireless Sensor Networks (WSNs) has led to the development of Wireless Multimedia Sensor Networks (WMSNs). Thus several new applications have arisen such as e-Health, environmental monitoring, video surveillance, automated transport systems, traffic control, smart cities and smart grids, home automation etc. The International Telecommunications Unit (ITU) recommendation Section for Ubiquitous Sensor Network (USN) presents the requirements for a platform to numerous number of life services and applications. This envisions a system that will connect all devices on the network ubiquitously with collaborative efforts of many small wireless multimedia and scalar sensors to heterogeneously provide a smart web. This requirement has thrown several new challenges to wireless sensor networks. In this paper, we have given a comprehensive discussion of the Wireless Multimedia Sensor Network (WMSN) and Ubiquitous Sensor Networks (USN) architectures and outlined their design challenges. The paper will give the reader a clear view of the researches that are ongoing in multimedia systems ubiquitous sensor networks, and shed the light on the current challenges and future trends. We also hope it will foster discussions and new research ideas among its researchers.

1 INTRODUCTION

In recent years, there has been massive increase worldwide in the use of Wireless Sensor Networks (WSNs) for varieties of applications. This is due to rapid buildouts of Micro-Electro-Mechanical Systems (MEMS) technology and consequently the development of Smart-Sensors. Thus, the availability of Low-cost hardware such as CMOS cameras and microphones coupled with the significant progress in distributed signal processing and multimedia source coding techniques, facilitated the development of Wireless Multimedia Sensor Networks (WMSNs) (Gurses & Akan, 2005; Almalkawi et al., 2010). Wireless Multimedia Sensor Networks (WMSNs) are networks of wirelessly interconnected devices that are able to ubiquitously retrieve multimedia contents such as Video and Audio streams, still images, and scalar sensor data (Temperature, humidity, etc) from environment (Akiyildiz et al, 2002; Randhawa, 2014). Hence, Multimedia systems ubiquitous sensor networks offer distinctively an enabling technologies where billions of smart devices are interconnected with video and audio sensors to collect video and audio data. Likewise, Cities, Airports, rail stations, Car parks, smart bridges, and shopping malls are interconnected with video sensors.

This technology poses new challenge to existing WMSNs and has become and active focus area for researchers all over the world. These challenges includes Quality of Service (QoS), Bandwidth (high bandwidth requirement), power management (high energy demand), time restriction among others (Evik et al, 2015). This is because ubiquitous systems multimedia sensor Networks should be able to sense environment, retrieve, store, process, transmit and communicate scalar data and multimedia data such as still images, audio and video data (Al-Karaki & Kamal, 2004), (Stankovic et al, 2003). Wireless Multimedia Sensor Networks has found wide range of applications in both civilian and military areas such as intelligent traffic congestion control, Telemedicine for Health-care monitoring, Industrial monitoring (Rosario et al, 2013), Explosive detection systems (Okwor et al, 2016). The major contribution of this work is to review and analyze the performance of WMSNs and proffer a futuristic albeit achievable by this technology in the area of ubiquitous computing, ambient assisted living, the Internet of Thing (IoT). We shall evaluate the existing solutions and identify the potential research issues for WMSNs.

In this paper, the general architecture of WMSNs, applications and issues militating against the design of WMSNs are discussed. The remainder of this paper is structured as follows: Section 2 provides brief overview of WMSNs architecture. Section 3 current issues facing WMSNs while Section 4 gives a brief overview of Ubiquitous Sensor Networks (USNs). Lastly, Section 5 concludes the paper.

2 WIRELESS MULTIMEDIA SENSOR NETWORKS OVERVIEW

Wireless Multimedia Sensor Network (WMSN)

Akiyildiz et al (2002) is a network of wirelessly interconnected sensor nodes equipped with multimedia devices, such as cameras and microphones, and capable to retrieve video and audio streams, still images, as well as scalar sensor data. It’s is an emerging trends in sensor networks and an enhancement over the existing Wireless Sensor Networks (WSNs) of applications that is capable enabling several other new application in the field of WSNs. These new applications includes but not limited to the following:

E-Health to monitor patients’ body activities and behaviors for easy identification of the cause of illness (Denis et al, 2012), Home automation including monitoring of elderly and disabled, Storage of potentially relevant activities such as thefts, car accidents, traffic violations, and make video/audio streams or reports available for future query, multimedia surveillance sensor networks for smart cities and smart grid, wide life and ecological monitoring (Eisenberg et al, 2002).

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Telemedicine Sensor Networks (TSNs) could be used as an advanced health-care delivery when the network is integrated with 3G network to provide ubiquitous health-care service to monitor patient’s vital signs from a remote medical centers. In Deng et al (2011) and Tan et al (2009), WMSNs could also be used for environmental monitoring and disaster management, person locator for missing person, industrial process monitoring and control such as food manufacturing industries, oil and gas industries to monitor oil and gas pipelines for anomalies, water distribution companies to monitor water pipelines for defects, habitats monitoring, monitoring of ecosystems, Agricultural monitoring, monitoring of borders, etc. (Bagula et al, 2012).

2.1 Wireless Multimedia Sensor Networks Architecture

To create a WMSN (Denis et al, 2012), a wireless mote need to be equipped with audio and visual information collection modules. Moreover, WMSNs should be able to also have the ability to in real time store, process, communicate and merge correlated data obtained from heterogeneous sources. WMSNs should be able to also perform online processing of the received sensor data through the combined technologies from communication and networking, signal processing, computer vision, control and robotics. A standard WMSN comprised of various network components as summarized below (Akyildiz et al, 2007).

Standard Video and Audio Sensors: These sensors capture sound, still, or moving images of the sensed event and are typically of low resolution (in terms of pixel/inch for the video sensors and in dB for the audio sensors). They can be arranged in a single-tier network, as shown in the first cloud (Fig. 1), or in a hierarchical manner, as shown in the third cloud.

Scalar Sensors: These sensors sense scalar data and physical attributes, such as temperature, pressure, and humidity and report measured values to their cluster head. They are typically resource-constrained devices in terms of energy supply, storage capacity, and processing capability.

Multimedia Processing Hubs: These devices have comparatively large computational resources and are suitable for aggregating multimedia streams from the individual sensor nodes. They are integral to reducing both the dimensionality and the volume of data conveyed to the sink and storage devices.

Storage Hubs: Depending upon the application, the multimedia stream is desired in real time or after further processing. These storage hubs allow data-mining and feature-extraction algorithms to identify the important characteristics of the event, even before the data is sent to the end user.

Sink: The sink is responsible for packaging high level user queries to network specific directives and returning filtered portions of the multimedia stream back to the user. Multiple sinks may be required in a large or heterogeneous network.

Gateway: This serves as the last mile connectivity by bridging the sink to the Internet and is also the only IP-addressable component of the WMSN. It maintains a geographical estimate of the area covered under its sensing framework to allocate tasks to the appropriate sinks that forward sensed data through it.

Unlike scalar WSNs where sensor networks is based mainly only on a flat homogeneous architecture that has the same capabilities. This type of architecture may not be suitable in WMSNs all the times due to high traffic intensity generated by multimedia applications such as audio and video (Ang, et al, 2013). Explained below are the WMSNs architecture types.

The Single-Tier flat architecture of WMSNs is easy to manage, with sensor nodes of the same capabilities and functionalities deployed in homogeneous flat fashion (Molina et al, 2012). The processing of the sensed data is distributed among the nodes and consequently prolonged network lifetime. See the diagram below for the Single-tier flat WMSNs architecture.

The Single-tier cluster architecture is made up of combination of multimedia (video and audio) and scalar sensors within each cluster ray. Thus, heterogeneous sensors are deployed to a cluster head which has the capability of performing a more intensive data processing and has more resources (Akyildiz et al, 2008). The cluster head is wirelessly connected to sink or the gateway through other cluster head or just directly in a multi-hop fashion. The diagram below depicts the architecture of a single-tier cluster architecture of WMSNs. In this architecture, resource-constrained, low-power elements are in charge of performing simpler tasks, such as detecting scalar physical measurements, while resource rich, high-power devices take on more complex tasks.

Fig 1: Single-tier Flat Architecture of MMSN

Fig 2: Single-Tier Cluster Architecture of WMSN
In multi-tier architecture with heterogeneous sensors, the first tier is deployed with scalar sensors which perform just simple tasks such as temperature monitoring, humidity monitoring, smoke detection and motion detection (Yaghmaee et al, 2008). The second tier of multi-tier architecture is deployed with camera (video and audio) sensors which performs a more complicated tasks such as object detection and object recognition tasks. It has more processing and storage capabilities (Kulkarni et al, 2005). While the tier is deployed with high-end and more powerful resolution camera sensors which are capable of performing more complex tasks such as object tracking (Akyildiz et al, 2002). The diagram of multi-tier architecture of WMSN is shown below.

![Multi-tier Architecture of WMSN](image)

Each tier (Gu et al, 2007), may have a central hub to perform more data processing and communicate with the higher tier. The third tier is connected wirelessly with the sink or the gateway. This architecture can accomplish tasks with different needs with better balance among costs, coverage, functionality, and reliability requirements. On the other side, the use of just one node type in homogeneous flat network is not scalable enough to enclose all complexity and dynamic range of applications offered over WMSNs.

2.2 Wireless Multimedia Sensor Systems and Component Architecture

The basic components of a wireless multimedia mote includes the following: sensing unit, processing unit, the memory subsystem, the communication subsystem, the coordination subsystem and mobility subsystem. The diagram below shows the components architecture of a wireless multimedia sensor system.

![Component Architecture of a Multimedia Sensor System](image)

**The sensing unit:** Sensing units are usually composed of two subunits: sensors and analog to digital converters (ADCs) (Okwor et al, 2016). The analog signals produced by the sensors based on the observed phenomenon are converted to digital signals by the ADC, and then fed into the processing unit (Lin et al, 2009; Okwor et al, 2016).

**The processing unit:** The processing unit or the controller manages the procedures that make the multimedia sensor node collaborate with the other nodes to carry out the assigned tasks. The controller is the core of a multimedia wireless sensor node. It collects data from the sensors, processes this data, decides when and where to send it, receives data from other sensor nodes, and decides on the sensor’s behavior. It is the Central Processing Unit (CPU) of the sensor node (Sundmaeker et al, 2010).

**The communication subsystem:** The communication subsystem provides software for interaction between processing unit, memory unit and power unit. It is composed of transceiver and communication software such as localization software, sensor operating system and middleware. It contains the communication protocol stacks for interaction between the layers (physical, MAC, Network, Transport and Application layer) (Vuran et al 2005).

**The coordination subsystem:** The coordination subsystem contains the location management subunit, motion controller subunit and network synchronization subunit. These subunits help to provide operations such as network synchronization and location management (Campbell et al, 2005).

3 CURRENT ISSUES FACING WMSNS

WMSNs requires additional research support since multimedia handling demands much more than what traditional WSNs usually do, thus a more powerful system has to be built. Some of the numerous challenges and issues faced are discussed in this section:

**Time restrictions:** For applications that requires live streaming of multimedia (MM) contents, time is very vital and buffering may not be possible because of limited memory, thus a more sophisticated algorithms will be needed.

**Security and Privacy:** This is a very important and sensitive topic as far as WMSNs are concerned. It is required to safeguard the system from being attacked by ill-intentioned people.

**Human Health and Safety Issues:** Radiations from sensors or any incidences of sensor failures and explosions could ignite gases. Precautions should be made in advance.

**Qos Requirements:** Applications that require real-time streaming can, however, tolerate a few losses. Thus, normally all these requirements are application specific.
Hence, a given standard of service must be ensured depending on any given application. Ways to achieve QoS are mainly through ensuring reliability, timeliness and high quality.

**Limited Resources:** Multimedia contents imposes additional load on WMSNs in terms of following concepts: CPU performance (processing power), Memory, Battery power, data rate, among others.

Energy Consumption: WMSNs requires huge computations, lot of data processing and transmission of huge data which requires more energy/power, thus a need for energy efficient algorithms.

**Bandwidth:** There is always a limited bandwidth for wireless networks, but multimedia contents needs high bandwidth. High bandwidth with low power spectral density can be provided by Ultra-Wide Band (UWB) technology recently.

**Cross-Layer Optimization:** Most of the challenges associated with MM streaming in WSNs differ from stack layer to stack layer. Thus, a requirement for an energy-efficient cross-layer design.

**Resource Allocation:** WMSNs often has limited resources allocation method. These resources should be allocated in a way that prolong the network’s lifetime. Thus Hybrid Automated Repeat Request (HARQ), Schedulers and other functional blocks that operate seamlessly are coupled with Dynamic Resource Allocation (DRA) techniques should be a good approach to this issue.

**End-To-End Throughput:** For good performance and better QoS to be achieved, these two protocols were suggested: The Radio Link Control protocol (RLP or RLC) and Adaptive Selective Repeat protocol (ASR).

**Routing:** There is need for efficient routing algorithms for energy aware routing. A lot of research to tackle this topic has been made, but it is still an open area of research. Some of the suggested solutions will be covered later. These include; the adaptive inter spurt approach, letting the source do the transmission path selection among others, etc.

Other research issues associated with WMSNs includes: Synchronization, Field of View (Fov), Coverage, Transport, etc.

**4 Ubiquitous Sensor Network**

Ubiquitous sensor networks (USNs) envisions a system where sensors of the physical world, computing systems and information networks constitute the future network where physical objects and digital information merge to produce a new generation of smart applications such as e-Health, environmental monitoring, video surveillance, traffic control, smart cities, home automation etc. (Almalkawi et al, 2010).

**4.1 Ubiquitous Sensor Network Architecture**

Implementation of ubiquitous sensor networks (USNs) by wireless sensor networks (Nuhu et al, 2016) is very crucial and play a vital and critical role in actualization of the next generation ubiquitous networks (The Internet-of-Things). When all the devices in the network connect ubiquitously together with collaborative efforts of many small wireless multimedia and scalar sensors to measure and monitor environmental and physical conditions it’s known as Multimedia Systems Ubiquitous Sensor Networks. (ITU-T. ITU-T Y.2221, Study Group 13, 2010)

![Ubiquitous Sensor Networks Architecture](Source: Bagula et al, 2012)

The requirement for audio/Video services in wireless sensor networks have fostered the development of wireless multimedia sensors networks (WMSNs). Thus, Wireless Multimedia Systems Ubiquitous Sensor Networks will provide a more precise information to the end users and networks than just a scalar data. It will enable end users to visually verify the real impact of events for prompt decision based on the visual information obtained.

**5 Conclusion and Future Work**

This research was motivated by the need for Wireless Multimedia Sensor Network for developing countries, this paper surveyed the research carried out on Wireless Multimedia Sensor Networks (WMSNs). Architectures of WMSNs and USNs were discussed. We analyzed the major technical challenges and research issues associated with the design and deployment of multimedia systems ubiquitous sensor networks and suggested possible solutions to these challenges. As researches are ongoing in this research area, most of the available solutions still faced numerous challenges.

Our suggestions of future research in this area includes: permutation of the position of the data bits, value transformation. However, this first method does not guarantee security. The second approach we suggested here is called Value transformation with an idea to transform or reverse the data itself, and the combination of the two methods give rise to a very high security. Also, where possible, shortest path should also be used. Multi-path for MM should be used and algorithms should be very simple and reliable and not computation intensive. Using congestion control mechanism to improve Quality-of-Service (QoS) necessary. Another
vital QoS mechanism we are suggesting is congestion control communication protocol for MM in WSNs and multi-channel cross-layer architecture for MM sensor networks for a known QoS issues.

REFERENCES


