Multimedia Data Navigation in Wireless Sensor Networks

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ABSTRACT
Wireless Multimedia Sensor Networks (WMSNs) is simply a wireless sensor network supporting multimedia traffic by deployment of data sensors and multimedia sensors as the nodes. The requirements of the WMSN is much different and specific as compared to other genera wireless networks, hence requires more specific protocols designed for each layers. These layers need to support the issues that multimedia traffic brings to the sensor networks, e.g. QoS, energy, MAC layer, bandwidth, etc. However it doesn't support the cause that these protocols are being treated as independent identities, as WMSN requires a cross-layer optimization of these protocols for proper functioning. With the assumption that most of the multimedia traffic consists of real-time video sensing and transmission, several solutions have been released, proposed and still are in research.

General Terms
Wireless Sensor Networks, Survey, Data Navigation.

Keywords
Wireless Sensor Networks, Multimedia Communications, Cross-layer protocol design, Quality of service.

1. INTRODUCTION
The continually increasing demand of the modern society for cutting edge technologies providing higher throughput, reliable data transmission, stable infrastructure, etc. have increased the pressure on the current traditional network infrastructures; that are either infrastructure-based or infrastructure-less. Moreover the condition is worsened by the alleviated demands of live streaming by multimedia applications that are grasping the major portion of bandwidth in all communication standards. The existing 3G cellular networks and Wireless LANs although met these demands to an extent, their infrastructure-based functionality limited their role during network congestion or breakage, implying demand of robust infrastructure. Solutions to these issues regarded high end capital and time investment that limited its growth in field of ever demanding wireless networks.

These requirements gave a platform for an infrastructure-less networks infrastructure thus provided by ad hoc and sensor networks which utilized moving nodes to setup a network in places where there was a need of communication but no prevailing infrastructure was present. These networks that deployed low-cost, low-powered and multifunctional sensors that performed the tasks of sensing, processing data and communicating while functioning as network nodes, are called Wireless Sensor Networks (WSN) [6].

These sensor networks made by the integration of wireless communications, micro-electro-mechanical systems technology and digital electronics provide the unavailing features like reliability, accuracy, flexibility, cost-effectiveness and easy deployment. However with the ever demanding needs of users with respect to multimedia based applications brought about a new perspective on WSN and a new terminology categorized the WSN with multimedia streaming capabilities, into Wireless Multimedia Sensor Networks (WMSN) [16, 7].

WMSN comprised of a similar sensor networks as in WSN apart from deploying sensors capable of audio/video sensing and processing capabilities along with data sensor nodes. By taxonomy, it is clear that data sensor nodes are capable of sensing physical variables like sound, motion, heat or light thus providing network with the identification and the location information, while the video sensor nodes might be triggered by data sensor nodes or working independently to capture the audio/video of the target and then carry on with the processing and dissemination tasks. With the advent of cheap sensors like CMOS cameras and microphones it has become easier to retrieve multimedia content like audio/video data, still images, etc. and with the embedded microprocessors, encoding of these data have become a lucrative option.

However the idea of multimedia streaming through sensor networks immediately poses several challenges to the network in terms of bandwidth and processing delays. As known very truly, real-time multimedia streaming poses the needs of high bandwidth, end-to-end delay, and possible losses during transport along with other several unseen requirements [22]. Here we detail some of the issues to be faced while concerned about the efficient multimedia streaming in WSN. As understood, multimedia streaming would require two processes to be working in tandem:

- Multimedia Encoding at the sensor nodes, challenged by the low power and computational limitations of the nodes.
- Transport of the encoded data, challenged by the real-time requirements of bursty multimedia traffic and loss over the hops between sensor node and wireless station.

Though, two characteristics of WSN that can be utilized for meeting these challenges are:

- Base station; unlike sensor nodes have extreme power and complex processing capabilities.
- Information captured by sensor nodes is redundant as the same is being captured by other nodes simultaneously.

The issues listed below are dealt with an assumption that a sensor node that is able to encode video data can also encode audio data and henceforth all the issues are discussed with consideration of video streaming applications.

2. CHALLENGES OF MULTIMEDIA NEVIGATION IN WMSNs

2.1 Efficiency (QoS)

The biggest issue in WMSNs, Quality of Service (QoS) determines what and how the network is able to perform the multimedia streaming tasks. The efficiency of a WSN to handle the multimedia traffic is specified by its QoS that is specified at the beginning of any network design [9, 12]. All other parameters are being addressed by different layers according to the specified QoS.

QoS issues, in WMSNs, are responsible to network layer that needs to; i) provide energy efficient and stable routes, which guarantee the end-to-end QoS specifications ii) intermediate the performance parameters between application layer and MAC.

Timeliness and reliability are the approaches to achieve the desired QoS at network layer. Among several protocols targeting these requirements, MMSPEED, came the closest but lacked in handling network layer aggregation, managing energy-delay tradeoff and required lot of information to be stored at intermediate Sensor Nodes [24].

Moreover, applications in WMSNs have added requirements over those in data sensor networks, focused on data delivery, by the addition of multimedia processing and delivery. This includes triggered information in a piece of time or delivery of sustained information through streaming over longer periods of time. Thus modifications are required in terms of hardware and high-level algorithms for delivering application specific QoS requirements. Cooperative Caching Solution, Novel packet error concealment technique and Multi-user Session Control, are some of them. Measured in terms of reliability, distortion, delay, network lifetime, energy consumption, etc. these algorithms might reach into multiple domains.

2.2 Routing

Routing is another of the biggest issues when talking about multimedia streaming in WMSNs. It gets this tag of biggest issue due to large sized data packets and longer periods of logged sessions, which require extremely efficient routing algorithms in order to support streaming multimedia applications [4, 5]. The three main requirements that cause routing to be treated as a major issue are:

- Multipath Transmission, due to the fact that data packets in WMSNs are large, hence needs to be sent through multiple paths for efficient transmission.
- Hole Bypassing that requires, several nodes that are being overloaded in small area creating dynamic holes due to multimedia transmission that needs to be successfully bypassed.
- Shortest Path requires that the delay constraint in multimedia transmission is obeyed, by using the shortest path to minimize the end-to-end delay.

Routing algorithms need to supplement these requirements with least complexity and keeping the QoS requirements within specifications. Few of the most feasible algorithms for routing in WMSNs are:

- Adaptive inter-talk spurt approach, wherein, the transmission path selection and play out delay adjustment is done by source.
- Geographic Node disjoint Path Routing (GNPR) [17] routing algorithm explores the possible routing path and then optimizes the explored path using minimum number of hops.

2.3 End-to-End Throughput

Deals with efficiency of the links in WMSN and required new protocol definition aimed at improving it. Medium Contention in wireless networks affects the transport layer performance thus affecting the QoS Requirements in multi-hop wireless networks.

Link Adaptive Transport Protocol controls the data rate between two ends based on the degree of medium contention whose information is acquired from the network, based on the research fact that level of contention on the link determines the performance and the optimal protocol settings in streaming applications.

Thus two protocols were proposed that adapted to the variable bandwidth:

- Adaptive Selective Repeat (ASR) protocol, that configures the retransmission timeouts dynamically
- Radio Link Control (RLC) protocol (esp. used in UMTS networks) that doesn’t bank on retransmission timeouts.

2.4 Bandwidth Demand

Streaming in WMSN e.g. video streams need transmission bandwidth much larger than required by data sensors which requires high data rate and low power consumption-transmission techniques [23].

Ultra-wideband (UWB) provides a high data rate over short links with very low power consumption.

2.5 Resource Allocation

The sensors have their limits when we consider the power, memory, achievable data rate, processing capability [8]. Hence the resources need to be efficiently allocated for the network to be flexible. As for an example continuously logged sessions or multiple logged sessions can bring about lack of flexibility in WMSNs.

Use of Dynamic Resource Allocation (DRA) Techniques, as in IEEE802.16e system wherein flexibility is with the operators to deliver broadband traffic achieving high efficiency can cater this issue to an extent. Scheduler, Link Adaptation (LA), Resource Allocation (RA) and Hybrid Automated Repeat Request (HARQ) functional blocks that interwork seamlessly, are integrated within the DRA to accompany the procedure.

2.6 Power Consumption

Large volumes of data, high transmission rate and extensive processing in WMSNs, take a toll on the power consumption on a network consisting of battery-constrained sensors. The fact that communication functionalities dictate the energy consumption in conventional sensor networks is not true for WMSNs [2, 25].

Thus design of new protocols, network architectures and algorithms, that providing the application-specific QoS along with increased network lifetime, is desired, e.g. power aware packet scheduling algorithms.

2.7 Variable Channel Capacity

The interference level detected at the receiver determines the capacity of a wireless link in multi-hop wireless networks. Further this interference level depends on the functions like routing, power control and rate policies that are being handled by network devices in a distributive manner. Thus the channel capacity and delay that can be attained on any link are dependent on location, continuously varying and bursty in nature. Hence the provisioning of QoS is a challenging task.

Use of the above suggested routing protocols and power aware packet scheduling algorithms are some feasible solution to maintaining a stable bandwidth over the entire network.

2.8 Source Encoding/Compression

Requires techniques that are less complex, gives low output bandwidth, loss tolerant and requires least of power. These techniques use either intra-frame compression reducing the redundancy within a frame or inter-frame compression (e.g. motion estimation or predictive coding) that uses the redundancy within frames [11]. But predictive coding techniques require multifaceted encoders, dominant processing algorithms and high power requirement thus making it unsuitable for low cost multimedia sensor networks.

Solution: Use of encoding/compression techniques preferably used for still images, thus visualizing video as sequence of images thus avoiding motion estimation and compensation. Like Distributed Source coding that utilizes source decoder statistics to design a complex decoder thus keeping the encoder simple [13, 14]. Examples of Coding Paradigms: Distributed Source Coding, Individual Source Coding, etc. Examples of Compression Techniques: Single Layer, Multi-layer, Multiple Descriptions.

2.9 Coverage

WMSNs comprise of multimedia sensors that have larger radii of coverage area and are very sensitive to direction of acquisition i.e. directivity besides requiring direct LOS between it and the object under observation.

Thus the coverage design of a data sensor network won't be sufficient for multimedia sensor networks and a new model is required to accommodate the larger coverage of multimedia sensors.

2.10 Congestion Control and Reliable Transport

In general networks, transport layer is oriented towards providing end-to-end packet delivery reliability that is successful transmission of a number of packets from one node to another within specified time. However in WMSNs, end-to-end event reliability is a more suitable paradigm for transport layer that refers to delivery of specified number of packets from an event area to sink.

Congestion Control and Reliable Transport, two of the biggest responsibilities of transport layer towards providing end-to-end event based reliability, are not yet addressed by any specific protocol in WMSNs. WSN based protocols STCP and ESRT come close but doesn't address issues of supporting multipath routing protocols, data segmentation, accurate reassembling of packets [3]. In addition transport layer, in WMSNs, need to handle multiple priorities, high data rates with jitter, ably perform fast congestion control by notifying sources faster, creating and maintaining event driven sessions, and more others. Thus requires for a single optimized protocol dedicated in handling all these issues at transport layer.

2.11 MAC Layer

In addition to the usual MAC layer requirements, i.e. collision avoidance, contention resolving, power management, bandwidth provisioning, interference minimization, etc., two other requirement add in case of WMSNs. These additional responsibilities include packet latency optimization to achieve end-to-end delay specifications & providing multiple priorities to packets based on their varying service requirements. Moreover MAC protocols needs to be power/energy aware [10, 30].

Three schemes for MAC might be used referred to as

- Contention-Free Schemes, based on TDMA, FDMA, CDMA. e.g. S-MAC
- Contention-Based Schemes based on IEEE 802.11 extensions.
- Hybrid Schemes, contention phase followed by contention free phase.

Hybrid schemes offer the obvious advantage with the mechanism to support real-time traffic, and promoting energy saving and scalability at the same time. Although hybrid schemes are the most suitable, time synchronization between the nodes is a most significant issue to be dealt with. Also it doesn't consider the data redundancy reduction and trade-off in energy-delay for real-time applications.

2.12 Localization

Localization refers to process of determining the position of the sensor nodes with facilitated to a common reference, or in the perspective of the object being monitored. Reachability and coverage are two of the important considerations for efficient sharing of monitoring tasks due to limited range of operation of video and audio sensors [29]. Thus localization mechanisms aid in allocation of resources to events, finalizing sensing precision and making surety of the complete monitoring of the area under observation.

Localization Mechanisms include determining the relative 3D positions of sensor nodes using a closed form of approx. solution based on time difference of the flight and time of flight, however requiring the audio signal not interfering with the localization process. Another technique is a two-tier wherein, low resolution cameras are deployed for detection while the high resolution cameras are used for tracking purpose. Thus the location of any object is determined from the overlapping coverage of the two cameras. It assumes that the orientations of sensors relative to a global reference frame are known & and are achieved through distributed techniques.

2.13 Security

The security issues including confidentiality, authentication and integrity are pertinent in WMSN applications as they are in WSNs [18]. However the techniques to resolve these differ in both domains due to the difference in data requirements.

The public key cryptography techniques, due to their high power and computational requirements, provide less usability in WSNs leading to use of the standard symmetric encryption techniques like DES and AES. But use of these techniques for large sized multimedia data block demand for more memory and computational requirements, hence making them unsuitable for WMSNs. Privacy is another parameter under Security measures of WMSNs. It is required that the multimedia sensors do not interfere into the privacy of others and produce sensitive information related to environment other than the object under observation. Hence high end image processing algorithms are required for maintaining privacy through multimedia sensor networks. Another security issue is that of denying service or disruption of service by malicious intruders who inject false multimedia packets into the networks. These packets are routed making them traverse through the network up to the base station where they are found to be unusable.

Solutions to these security issues can be availed using either of any three encryption techniques:

- Position permutation, wherein data are encrypted using a predefined scheme. Although a fast scheme, this technique fails in providing strong security guarantee.
- Value Transformation, which transforms the data value and then reverse-transforming to obtain the real data at the receiver. This technique ensures less complex computational requirements and low h/w implementation cost.
- Combination, utilizing combination of both techniques to provide very high data security.

2.14 Cross-Layer Coupling of Functionalities

The different functionalities being practiced at different levels of communication stack are inherently and strictly interdependent on each other due to shared nature of communication channel, real-time audio-video multimedia traffic and standard data traffic [26]. So these layers need not be treated as separate when efficient solutions for QoS provisioning are sought. Instead there must be a close interaction with relation to mapping of performance parameters across the layers. As for example, application level QoS parameters to the performance parameters of the MAC layers by the networks layer owing to the fact that application layer doesn’t know about the route information while MAC layer singly focuses on one hop. Thus cross-layer coupling becomes a challenge when dealing with real time multimedia traffic.

Several approaches have been devised for cross layer optimization based on power consumption minimization, maximizing throughput, etc. However ability of these approaches is questionable due to their partially distributed or centralized approach, thus limiting the scalability.

Several approaches including; bottom-up approach, where the higher layers are being insulated from losses and channel capacity variations by the lower layers, & top-down approach, wherein the lower layer parameters are optimized by upper layers in protocol stack.

2.15 Multimedia In-network Processing

When talking about network-design, multimedia processing is taken as an isolated task. Thus the issue of content delivery did not consider source channel characteristics and focused on cross layer functioning at lower levels of protocol stack. But, the two processes of multimedia content processing and delivery are not independent and largely affect the QoS through their proper interaction [11]. Thus in-network processing algorithms are desired that delivers the raw data through the combined utilization of cross-layer optimization and in-network processing. In-network processing thus describes working through multiple views, through multiple media using multiple resolutions thus leveraging system scalability by decreasing redundant information [14]. This, however, required application independent and self-organizing architectures to fulfill the demands of multimedia streaming. However this cannot be suggested for low-end multimedia sensors as the cost would rise alarmingly.

2.16 Network Synchronization

In WMSNs, time synchronization is an important issue, difficult to achieve because of slow clock drift over time, humidity and fluctuation of temperature on clock frequencies, coordination and correction amongst deployed nodes with low messaging overhead. Synchronization is important for supporting in-network processing, prevent buffer underflows and overflows in real-time multimedia streaming [19,20], Limited Synchronization, wherein it is implemented over the chosen route and within specified time, can be used to help the in-network processing avoiding large-scale coordination. Phase Locked Loops (PLLs) can be used for supporting real-time multimedia streaming by maintaining a stabilized frequency.

2.17 Inter-media Synchronization

Multimedia sensors produce heterogeneous and correlated data, e.g. audio & video samples could be collected over the same geographical area, or still pictures may be in combination with text data containing field measurements. Thus synchronization of the flow of these two separate multimedia streams as the actual data present at the end user under a joint timing constraint is an issue. This task of coordination of such sequences is termed as multimedia synchronization.

At the physical layer, multiplexing of data over shared wireless medium is done, or storage is carried in common physical storage. At the same time, the application layer is concerned with inter-media synchronization required for presentation or playout.

Inter-media Synchronization is best measured by the average instantaneous delay variation (skew) for continuous media while for discrete events this measure is provided by the maximum and minimum delay. Dropping and duplicating frames from different media streams can mitigate the inter-media skew through play back in unison at the receiver.

Table 1. Factors affecting the multimedia data navigation in wireless sensor networks

Factors	Issues	Remarks
High Bandwidth Demand	• The transmission of their own data, sensor nodes relay the packets coming from other nodes due to the intrinsic low range, multi hop communication strategy of WSN • Stringent delay constraints	• Data transmission rates of sensor nodes need to be sufficiently high to accommodate the high Bandwidth demand • Ultra wideband (UWB) • Impulse Radio Technology • Provide high bandwidth for multimedia in WSN.
Multimedia Coding Techniques **Processing Efficiency** **Communication Efficiency**	• Bad Rate-distortion performance for signals with temporal correlation. • cliff effect problem Brust Loses	• Predictive encoding • Multiple description coding (MDC) • Wyner-Ziv Encoder [1]
Power Consumption	• High complexity • Low Compression Ratio	• Intraframe coding
Production Cost	Higher processing and memory Capacities, Costly sensing circuitry e.g., H.263, MPEG-1, H.264/AVC, MPEG-4/AVC.	low complexity encoder designs
Application Specific QOS Requirement & delay bounds	• Problem behind delay bound are • Gained Communication Latency • Computation time to compress data • Delay jitter	• Wakeup scheme • Application-specific delay bounds should also be taken into account when selecting appropriate multimedia error resilience techniques at the application layer. • Sink may handle the jitter problem

2.18 Network Management

In WMSNs, network management can be treated as a functionality of resources, tools, theories and Mechanisms for manipulating of data from different & mixed media, to extract relevant information. For WMSNs, the design of such systems would depend on two factors:

- Reduced hardware/application requirement: Devices comprise of hand-held devices, used by the network manager for conducting on-site surveys. Light weighted application environments like J2ME, AJAX, etc can be employed for dynamic reassignment based on desired QoS.
- Independence of platform/programming environment: Platform independent and general purpose monitoring tools are needed so that the integration of tools should not become an issue. Use of languages like J2ME, C++ provides these features especially for WMSNs

WMSNs by their scope need to support several independent and heterogeneous applications that have specific requirements. Hence flexible and hierarchical structures are to be developed that support the requirements by these applications within the same infrastructure.

2.19 Integration with Internet Architecture

As the world of internet growing rapid to allow each and every device to be accessible through it, there would be the stage where WMSNs are required to be accessed from Internet so that remote users from anywhere can query important data.

Thus there is an issue of importance and ability in WMSN to be interoperable with the Internet Architecture. Despite this fact, the possibility of all IP-sensor networks are ruled out due to the characteristics of WSNs, which recommend application level gateways/overlay IP networks for integrating Internet Architecture with WMSNs [31].

2.20 Integration with other wireless technologies

Use of other wireless technologies to connect several small sensor networks can result into large-scale sensor networks. However this integration of wireless technologies with WMSNs shouldn’t in any manner reduce the efficiency in operation of individual sensor networks [21].

3. CONCLUSION AND FUTURE DIRECTION

Wireless sensor networks has a broad range of possible applications which support the strongly connection with the physical phenomena to better human interaction. While enormous mainstream research studies have pointed on the applications necessitate conventional data navigations, there exist several WSN applications which involve multimedia data navigation such as disaster relief, smart homes, homeland security, target tracking and surveillance, proactive health care. In order to recognize these multimedia WSN applications, efficient communication protocols, which pose the distinctive challenges due to the WSN paradigm and multimedia navigation requirements, are compulsory. In the present state of the art on WSN, the research efforts have been pointed on addressing the challenges of conventional data navigation. In this paper, we reviewed the research problems and the present status of the literature on the multimedia data navigation in WSN. In particular, the multimedia applications of WSN, basic design challenges, existing proposed solutions in other application, and open research issues for multimedia data navigation in WSN are addressed. The main outcome of this survey reveals that there present a clear requirement for deal of research effort to attention on developing effective network and communication protocols in order to recognize multimedia WSN applications.

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